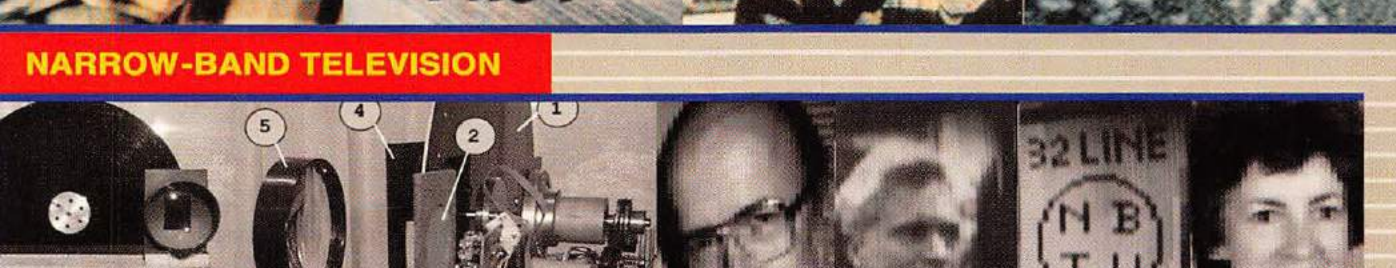
$25.95

# THE ARRL IMAGE COMMUNICATIONS HANDBOOK

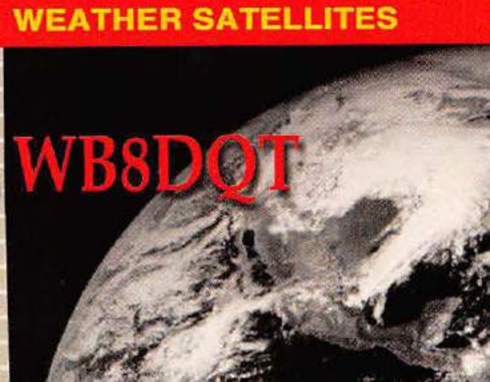
SLOW-SCAN TELEVISION

AMATEUR TELEVISION

NARROW-BAND TELEVISION



WEATHER SATELLITES



## By Dr. Ralph E. Taggart, WB8DQT

**CD-ROM INCLUDED**
With Software Utilities!

# THE ARRL IMAGE COMMUNICATIONS HANDBOOK

## RALPH TAGGART,
## WB8DQT

EDITOR:
R. Jan Carman, K5MA

PRODUCTION:
Shelly Bloom, WB1ENT
Paul Lappen
Jayne Pratt Lovelace
David Pingree, N1NAS

Cover Design:
Sue Fagan

ARRL The national association for AMATEUR RADIO
Newington, CT 06111-1494
ARRLWeb: www.arrl.org

This work is publication No. 279 of the Radio Amateur's Library, published by ARRL.

Printed in USA

ISBN: 0-87259-861-6

First Edition
First Printing

# CONTENTS

# DEDICATION

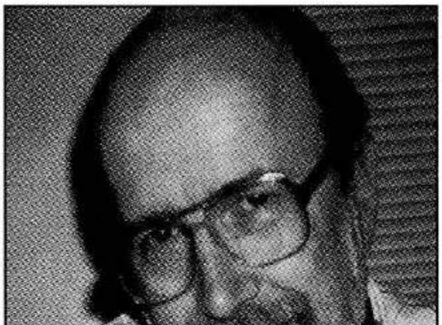
This book represents a legacy of forty years of involvement in image communications via Amateur Radio. Two fine men, Lew West (W2PMV) and Sam Milbourne (WB2INC), played key roles in igniting an interest that has yet to flag over all of these years. True to the traditions of Amateur Radio, Lew and Sam accepted a very young man as one of their own in our mutual quest to communicate via Amateur Television. The topography of northern New Jersey and the limits of the technology of the time combined to see that we never had the contacts we worked so hard to achieve; but, in the end, it didn't matter. The fellowship we enjoyed in making the attempt is what leaves the lasting memories. Both of these men are now Silent Keys; and although they are gone, they are not forgotten.

My initiation into slow-scan television was facilitated by a number of people; but Ted Cohen (W4UMF), Don Miller (W9NTP), Robert Gervenack (W7FEN), Dave Sumner (K1ZZ) and Clay Abrams (K6AEP) are particularly noteworthy. Ted helped me over the tough spots in the construction of some of my first slow-scan gear, and we later worked together to achieve the first successful techniques for transmitting color images via SSTV. It was my pleasure to work with Don in the writing of the ***Slow Scan Television Handbook*** back in 1972. If we ever have an "SSTV Hall of Fame", Don and Gervie certainly would be in the first class of inductees! Despite his protests to the contrary, Dave is worthy of note for the endless hours he spent putting W8SH, the Michigan State University Radio Club station, on SSTV in the late 1960s. It is due in no small measure to his efforts that we achieved as much as we did in a remarkably short time. Finally, Clay was the one who introduced me to the wonders of assembly language programming as part of our work in getting the RadioShack Color Computer working on both SSTV and weather satellite fax.

None of the enjoyment and accomplishments over my last thirty-three years in Amateur Radio would have been possible without the support and tolerance of my wife, Alison. Along with my three daughters (Jennifer, Heather, and Molly), she has put up with rooms filled with bizarre equipment, unusual sounds drifting through the house at all hours, and both elation and depression, depending upon how the latest project was going! I didn't always deserve her patience and consideration, but I always got it. For that I am profoundly grateful!

# ABOUT THE AUTHOR

## RALPH E. TAGGART, WB8DQT



Dr. Ralph E. Taggart was first licensed as WA2EMC in the late '50s while still in high school. He received his BA in Biology from Rutgers University, an MS in Botany from Ohio University, and his PhD in Paleobotany from Michigan State University. Ralph holds appointments as full Professor in the Department of Plant Biology, the Department of Geological Sciences, and as Curator of Fossil Plants at MSU.

Ralph's first venture into image communications involved the construction of a complete Amateur Television (ATV) station, including the TV camera, in 1963. His very first published Amateur Radio article (in the mid-60s) was a video modulator that appeared in the old ***Amateur Television Experimenter***. In 1967, when Ralph went to Michigan State to work on his doctorate, he became interested in slow-scan television (SSTV) and built a complete SSTV monitor and camera. While at MSU, Ralph did pioneering work in SSTV, including the development of an analog technique for transmitting and receiving color images. Among the more notable achievements of his work with the Michigan State Amateur Radio Club station, W8SH, was the first transmission of color SSTV images and the first two-way color SSTV contact. In 1972 Ralph co-authored, with Don Miller (W9NTP), the ***Slow Scan Television Handbook***, the first comprehensive introduction to SSTV. He then became interested in the application of SSTV display techniques to weather satellite images, leading in 1976 to the publication of his ***Weather Satellite Handbook***. The book has been continuously in print since that time and is now in its 5th Edition through the ARRL. Ralph has written a very large number of articles on ATV, SSTV, weather satellites, and other Amateur Radio projects that have appeared in ***QST***, ***73 Magazine***, and ***Ham Radio Magazine***.

Ralph operates QRP on the high frequency bands, has Worked All States on several bands and modes running QRP and earned what is probably the first Worked All Continents on QRP SSTV. He currently operates QRP on SSTV, CW, and PSK31 and all the power he can muster on ATV. His most recent projects involve experimenting with mechanical television techniques that date back to the late 1920s.

Ralph has been flying ultralight aircraft since 1981 and designed and built his own ultralight gyroplane. He combined his interests in electronics, computer programming, and flying with the design of an award-winning digital instrument pod and flight recorder for ultralight aircraft. He has been an ultralight columnist and contributor for ***Rotorcraft*** magazine and ***Kitplanes*** and is Rotorcraft Director for Aero Sports Connection, a national ultralight organization.

Ralph and his wife Alison have three daughters and two granddaughters. Ralph is an Elder in the Presbyterian Church, teaches adult Church School classes, serves on the Ethics Board for the City of Mason (Michigan), and has served a total of 24 years on local and Intermediate School Boards.

# INTRODUCTION

As a young man, growing up in a log cabin in the woods and mountains of northern New Jersey, I had the good fortune to discover Amateur Radio. My first station wasn't much — a borrowed pre-War receiver, a one-tube transmitter built from parts salvaged from junked radios, two precious war-surplus crystals, and an antenna that was just a long run of bell-wire running out through the trees. Most of my time was spent on 80 meters — the best band for the receiver I was using. Even there, the evening hours prior to midnight were simply too crowded with stations to make out much of anything. Things did calm down in the wee hours of the morning and then, laboriously tapping away on a war-surplus telegraph key, I actually made contact with other amateurs—some as far away as Ohio and Indiana! I suppose I had one of the most pitiful collections of QSL cards on the planet, but I was hooked!

If you leave out the log cabin, the story of my personal entry into Amateur Radio is probably remarkably similar to that of other young people from the mid-1950s. These days, equipment is significantly more reliable and effective; and a new amateur today, young or old, is unlikely to be building major items of station equipment. In some ways, however, the amateur experience across those many years has more in common than one might realize. Amateur Radio offers a tremendous range of operating activities once you get to the point where everything is working and you start to think about what you will be doing with all that gear! General ragchewing, simplex and repeater operation on VHF and UHF, chasing DX and/or awards, working contests, and using your computer to operate the many digital modes are some of the more obvious options. The purpose of this book is to introduce you to a whole new range of activities — using Amateur Radio for image communications.

Even the term "image communications" probably has an unfamiliar ring. After all, Amateur Radio is all about talking, be it with a microphone, Morse key, or the bits and bytes flowing from your computer keyboard. Most new operators are hardly aware of the possibilities of using Amateur Radio to see as well as talk to other amateurs. Even experienced operators may well think of such activities as experimental, difficult, or expensive — possibly all three. The fact is that amateurs have been involved in image

The author's current amateur station occupies only the top of a standard desk. However it handles all the primary image communications modes (NBTV, SSTV, ATV, and weather satellite imagery), a wide range of digital modes, and, of course, basic phone and CW. On the far left is the computer monitor with the tower case inside the desk. It is the computer and associated software that provides most of the mode flexibility. To the right of the monitor is the TV set used for ATV image display. Actually, the TV is due for retirement in the near future, since the computer is equipped with a USB interface module that lets it function as a television receiver. The small unit on top of the TV is the computer webcam that lets me dispense with the standard TV camera for ATV operations. To the right of the TV monitor is a stack of four pieces of equipment. The lower unit is a Tridon 2000 3-watt ATV transceiver for the 70 cm band. A brick-type power amplifier for 70 cm is housed under the desk. The next unit up is a parallel-port interface originally designed for the *Weather Satellite Handbook*. With respect to basic satellite image display, this unit could be retired in favor of the soundcard in the computer; but it still has some interesting capabilities that earn it a spot at the operating position. The third item in the stack is a Vanguard WEPIX 2000B synthesized VHF receiver for weather satellite reception. The very small unit on top of the receiver is a USB module that converts the VGA/SVGA video from the computer to NTSC television standards, allowing the computer to serve as an ATV video source. To the right of the stack is the ICOM IC707 HF transceiver. The two items to the left on top of the ICOM are a W9GR DSP unit, used primarily for weak-signal CW work, and a Radio Shack HTX-252 two-meter FM transceiver. The latter provides a two-meter audio link for ATV as well as SSTV on two meters. The unit on the upper right of the transceiver is a simple interface to connect the computer soundcard to the ICOM and Radio Shack transceivers as well as the Vanguard satellite receiver. The station speaker is located on the far right, topped by an indoor/outdoor thermometer, since you cannot have an HF QSO without being able to provide a local weather report. The HF and VHF hand-microphones grace the desktop, along with a working replica of the Marconi key used by the wireless operators on the ill-fated *RMS Titanic* in 1912. The author's wife, Alison, is putting a copy of this photo in the family album, as she claims this is the only time anyone has actually seen the glass surface of the desk!

communications for the past 75 years, but their numbers were few. What they were able to accomplish had relatively little impact on the mainstream of our hobby. In the context of this ***Handbook***, image communications can be subdivided into the following major activities:

**Narrow-Band Television (NBTV)** — The use of modern technology to investigate the potential of the low-resolution television systems that first became operational in the 1920s and 1930s.

**Amateur Television (ATV)** — The use of broadcast-standard cameras and receivers to provide two-way medium-resolution, full-motion television, typically in color, on the 70 cm and higher-frequency amateur bands.

**Slow-Scan Television (SSTV)** — The transmission of medium to relatively high-resolution still images, both gray-scale and color, using standard amateur voice equipment (SSB, AM, FM) on any bands (HF through microwaves) where voice transmissions are authorized.

**Facsimile (Fax)** — The transmission of very high-resolution images, typically gray scale, on amateur bands where voice operations are authorized. Fax techniques are most commonly employed to receive the extremely detailed images transmitted by both polar-orbit and geostationary weather satellites.

Not too long ago, attempting to write a book covering the spectrum of amateur image communications would have been a daunting and somewhat thankless task. Each image communications category was literally a world of its own. None of the equipment needed for a specific activity had anything to do with "standard" amateur gear; and, at least in the beginning, all of it had to be constructed from scratch. My first ATV station occupied a floor-mounted rack, and I had to build it all — including the TV camera! The transition to solid-state devices helped a lot, as did the eventual introduction of commercial equipment for some modes; but you still had to either spend a lot of money or a great deal of time building specialized equipment that wasn't particularly useful for anything else! The different areas of amateur image communications were so highly specialized that there was very little interaction between them, and it isn't surprising that the Amateur Radio mainstream didn't sit up and take notice.

Over the past decade that situation has changed dramatically. The agent of that change is the personal computer. PCs first entered most amateur stations very modestly in the 1980s. They were very useful for logging, both day-to-day and especially in contests, and they were easy to justify because they could also be used to type the children's school assignments, catalog the spouse's collections or recipes, and even do the family tax returns. Once you had capable computers in the shack, it didn't take long for inventive amateurs to create simple interfaces to enable the machines to function as Morse keyboards. Make the interface a little more complex and RTTY becomes possible, as do packet, and "new" digital modes like ASCII, AMTOR, and Clover. While all of this was going on, the computers kept getting faster with bigger disk drives and improved graphics. By the early 1990s computers were being used for SSTV and weather satellite work using external or internal interface hardware. By the mid to late 1990s, the development of computer soundcards, based on DSP technology, made it possible for computers to handle all existing digital modes as well as SSTV, NBTV, and weather satellite imaging with no additional interface hardware. You still needed to match the soundcard inputs to the station receiver(s) and the output to the transmitter, but the soundcard provided the required signal processing. By the close of the decade, the PC had become the preferred approach to implementing both digital and imaging modes.

While the computer/soundcard combination didn't impact ATV, both internal and external adapters appeared that permitted the PC to function as a receiver, replacing the TV set as a required item in a typical ATV installation. Simple scan converters also were available, permitting computer VGA/SVGA video to be converted to NTSC or PAL video formats, thus allowing the computer to function as an ATV signal source. Since webcams were also widely available, it was even possible to dispense with a standard TV camera in the ATV station!

In effect, the evolution of the IBM-compatible PC has essentially connected all of the imaging options that were once separate and distinct. Not that long ago, the transmitting and receiving equipment was what one focused on in setting up a station. As we start this new century, the PC has become the core of any multi-mode amateur station; and the transceiver is simply one of the peripherals. You may still want a power amplifier, and there will always be the need for effective antennas. However, beyond the capabilities of your microphone and key, it is the computer and its amateur software that defines the modes that you can operate. The result is that all these imaging modes, not to mention the ever widening digital mode options, are easy and inexpensive to implement.

At the same time the computer is expanding the modes available to you, the physical requirements of the typical amateur station are shrinking in terms of the number of equipment items needed, the power they consume, and the space required. As just one example, Figure 1.11 shows my slow-scan station from the early 1970s — a whole operating position dominated by the equipment to operate just SSTV. Compare that figure with the illustration of my current station, shown on the previous page. Today's gear takes up approximately a third the space of the 1970s set-up, yet it provides everything needed to operate NBTV, ATV, SSTV, weather satellite fax, and any of the current digital modes. I am as prone as any "old timer" to getting nostalgic about the so-called "good old days" of Amateur Radio, bemoaning the fact that so few amateurs are building their own equipment. In fact, if there is a Golden Age of Amateur Radio, it is always the present, for that is where the promise of new and exciting possibilities is to be found. In effect, there is just as much designing and building as there ever was, but the venue has changed. Today, amateur experimenters spend comparatively little time designing and building hardware. Instead they are writing software to make better use of those computers and improving the options available to the entire amateur community. It is that spirit, building on the accomplishments of the past, that makes it feasible to undertake this Handbook.

We will start our exploration with an examination of the history of image communications (Chapter 1), followed by some basic imaging principles and concepts (Chapter 2). With that material as a foundation, we will then look at the details, equipment, and operation of NBTV (Chapter 3), SSTV (Chapter 4 and 5), weather satellite reception and display (Chapters 6 and 7), and ATV (Chapters 8 and 9). Finally, in Chapter 10, we will examine some of the future options that can be projected, based on experiments now underway and the potential of computers as the driving force in new imaging approaches and techniques. Virtually any visualization of the future involves personal communications using both voice and pictures. Well, for Amateur Radio, that future is here and now, and you are welcome to join the fun!

## CHAPTER 1

# SEEING AT A DISTANCE

*A picture's meaning can express ten thousand words.*
Chinese Proverb

*As soon as there is general recognition of the fact that a radio receiver need no longer be blind, the acceptance of television is inevitable.*
Zworykin and Morton, 1940

*Hams should be seen as well as heard.*
Don Miller, W9NTP

## INTRODUCTION

If we are fortunate, we are born into the world with five senses — taste, smell, touch, hearing, and sight. During our first weeks of life we tend to depend upon the first four, while inside our brains a major miracle is in the making. Over time our minds begin to make sense of the flood of neural signals coming from our eyes. Handling information that would put a fast computer to shame, the brain patiently works at assembling this information into an image of the world, complete with nuances of light and dark and a rainbow of color. As if this were not enough, the tiny muscles that position the eyes are exercised and brought under control, as are the almost microscopic muscles that control the amount of light reaching the photosensitive retina. In time the two eyes will move as one, each producing a slightly different image that the brain learns to fuse into a mental three-dimensional reconstruction of the world around us. Once the miraculous gift of sight is complete, for as long as we are blessed with it, it literally becomes our chief "window on the world". As much as we may appreciate the subtle tones of a symphony or the messages delivered by our other senses, we humans are visual creatures that amass much of what we know about the world using our eyes and the magnificent neural network that makes vision a reality.

It is impossible to understate the power of visual images. Forty thousand years ago our ancestors created images on the walls of caves in France and Spain. These paintings captured the essence of mammoth, cave bears, and the herds of horses and wild cattle that were a source of food, allowing the animals themselves to be manipulated and controlled by the power of tribal magic. Drawings and paintings, followed later by writing, abolished the limits of time and space; but there was still the desire to reach beyond the limits of sight and sound here and now. The crystal balls and magic mirrors of myth and fairy tale are obvious expressions of our desire to extend our senses — particularly the sense of sight.

The barriers of time and space began to fall in earnest in the middle and late 19th Century with the invention of the telegraph, the telephone, and wireless. Each of these innovations was, in the strictest sense, the product of amateur experimenters. Samuel Morse was a painter, Alexander Graham Bell a teacher of the hearing impaired, and the young Marconi began as a dilettante experimenter attempting to send message across the family estate without the use of wires! Wireless, what today we call radio, had an almost magic allure for the technically-minded youth of the turn of the last century. For some like David Sarnoff, who received messages from the doomed liner *Titanic* in 1912, this interest would lead to the founding of the broadcast industry.

For Hiram Percy Maxim and a host of other pioneers, wireless was a fascinating pastime that captivated their attention and creative talents. The state-of-the-art in wireless made tremendous strides in the period before, during, and immediately after the Great War (1914-1918). Amateur Radio in particular achieved significant advances by ready adoption of the emerging technology of vacuum tubes, the transition from spark to CW transmitters, and a willingness to explore the then-uncharted world of "short waves" — higher frequencies the military and broadcast services initially thought of as "useless" for practical communications. The result was the genesis of Amateur Radio and the birth of the American Radio Relay League and other national societies devoted to the interests of "amateur" wireless enthusiasts. All early amateur communication was conducted on CW (code), but more sophisticated tubes and circuits to use them made it possible to modulate a carrier wave with a voice signal. The result in the early 1920s was the birth of the radio broadcast industry and early amateur experiments with voice transmissions. This was the apex of the state-of-the-art for amateur stations of the period, and few operators gave thought to the possibilities of actually sending images over the airwaves. In fact, the maturation of a number of different technologies created an environment where image communications would soon become commonplace — the culmination of over half a century of creative thinking and innovative experimentation.

Any attempt to encapsulate the history of image communications, even from an amateur perspective, into a single chapter is quite impossible. Instead, my goal is to sketch out the broad outlines of trends as they developed. Details, where appropriate, will be reserved for later chapters while we deal with the elusive "big picture"!

In many ways, the history of electronic image communications parallels the development of photographic technology. Even a casual consideration of the host of problems inherent in dealing with images would suggest that it is technically less demanding to create a still image then to create images with the illusion of motion. In the history of photography, techniques for taking and reproducing still images preceded the ability to produce motion pictures. The same trend can be seen in the electronic arena. The electronic transmission of still images over wire or radio is known as ***facsimile*** or simply ***fax***. As we shall see, quite reliable systems for facsimile transmission and reception were in place and commercially exploited by the First World War. By WW II it was possible to transmit photographs with high-resolution anywhere in the world. The advent of transistors and other solid-state technology provided for additional refinements, as did the introduction of digital techniques; but all of this development was essentially a refinement of techniques that had matured early in the 20th Century.

Transmission of moving images, now generally termed ***television***, was a tougher problem. The first limited but workable systems did not arrive until the mid-1920s, and full realization of the broadcast potential for television was not achieved until after WW II. Although the development of facsimile and television were offset in time, each followed a similar track, dictated by the problems that had to be solved in the maturation of the respective technologies. The earliest systems were capable of handling simple black and white silhouettes or line drawings. The ability to transmit a true grayscale came later, followed by improvements in resolution and system reliability. With this overview, let's take a somewhat more detailed view back into history.

## FACSIMILE — STILL PICTURES BY WIRE AND RADIO

Following the threads of any technology back into time is both difficult and frustrating. Ideas for a new technology can often be traced quite far back in time. Generating a new idea may require imagination and foresight, but often does not require that the dreamer actually accomplish what is encompassed by his vision. Actually, realizing the dream usually involves the coming together of fundamental advances in science — particularly physics and chemistry — and the maturation of engineering and an associated infrastructure to make it possible to actually build practical devices. In the case of facsimile, the first engineering realization can be traced back to Alexander Bain in 1842. Bain was a Scot working in the area of telegraphy just five years after Morse's "invention" of a workable telegraphic system. Bain outlined the basics of a device he called the ***facsimile telegraph***. In his system, a document to be transmitted would be set in metal type. The typeset "document" would then be scanned progressively by a metal stylus attached to a pendulum, causing an electrical signal to be generated each time the stylus contacted some element of the raised metal type. The entire document was slowly advanced by a clockwork mechanism so that after several minutes, the entire face of the document would have been sampled by the pendulum-mounted stylus. At the receiving end of the system, an identical pendulum would advance over a sheet of chemically treated paper, driven by a clockwork mechanism identical to that employed at the transmitter. When an electrical contact was made with the stylus and type at the transmitter end, a current would pass through the paper from the receiving stylus, creating a dark mark on the paper induced by the current through the paper. Bain was granted a British patent for his device in 1843. While it was unwieldy in the extreme, it did introduce two concepts that were inherent in every image transmission system that was to follow:

- **Scanning**. Bain realized that it was impractical to transmit any image in its entirely. Instead, the image had to be sampled in small units in a sequential fashion. The status of each of these small units would then be transmitted in sequence. At the receiving end the same sequential process would be used to reconstruct the entire image, one unit at a time. This process, that we now call ***scanning***, was accomplished by the linear swing of the pendulums at each end, combined with the movement of the entire document at each end by means of the clockwork mechanism. Scanning is essential for both the transmission and reception of an electronic image and will be discussed in Chapter 2. The scanning sequence at the transmitting and receiving ends of the circuit must be identical if the image is to be properly reproduced. If the scanning units are large relative to the size of the image, the resulting replica at the receiving end will be coarse and lacking in detail. If the scanning is performed in very small increments, a more detailed reproduction of the image is possible. Scanning is thus related to the ***spatial resolution*** of the image — also discussed in Chapter 2.

- **Synchronization**. Using identical scanning systems at either end of a circuit is one requirement to successfully transmit an image but there are two other requirements. First, the ***rate*** at which the image data are transmitted must be matched at the receiving end. If the receiver scanning is slower or faster than that at the transmitting end, a hopeless pattern of light and dark is all that may be seen when an attempt is made to reproduce the picture. Bain's use of identical pendulums at each end of the circuit assured that the rate image transmission matched the rate at which the image was reproduced at the other end of the circuit. A second factor, besides rate, is that the timing of the start of the image at the transmitter end must match the point where the image reconstruction is initiated at the receiving end. Image ***synchronization*** involves a combination of the rate of image transmission and the matching of the position of scanning at both ends of the circuit. Synchronization is discussed at greater length in Chapter 2 and is essential to properly reproducing an image.

Today we would classify Bain's system as a binary format, in which portions of the image were transmitted as either black or white. Such a binary format represented the limits of the telegraphic circuits of the time.

In 1847 an Englishman, F. Bakewell, introduced his ***chemical telegraph***, a major improvement to Bain's concept. Bakewell replaced the cumbersome transmitting and receiving pendulums with ***synchronous*** motors — electrical motors that operate at a constant speed when driven by an AC voltage of constant frequency. The metal type at the transmitted end was wrapped around a cylinder that was driven by one synchronous motor. Precision clockwork was then used to move the transmitting stylus along the length of the drum during image transmission. At the receiving end an identical drum/motor/clockwork system was used for receiving, with the chemically-treated paper wrapped around the receiving drum. Baker's use of drums, driven by synchronous motors, would form the basis of almost all subsequent mechanical facsimile systems. In 1861 the Italian priest, Abbe' Caselli, replaced the raised metal type with a layer of metal foil, enabling him to transmit and reproduce writing and simple drawings.

**Figure 1.1**. A facsimile image of President Calvin Coolidge, transmitted in the mid-1920s using the "Ranger" facsimile system. Yates, 1929. *ABC of Television.*

**Figure 1.2**. A 1950 wirephoto of President Truman and Admiral Radford returning from the Wake Island Conference. This image demonstrates the quality that was typical of facsimile photos from the mid-1930s until the recent transition to all-digital image services. The vertical streaking in the image represents noise or fading during reception of the short-wave fax signal. United States Navy photo, US National Archives.

In the years to follow, workers such as Senlacq in France and May in England began to study photochemical properties of various metals, including selenium. Some metals could be made to generate a small electrical voltage when exposed to light, while others showed dramatic changes in resistance when exposed to light of varying intensity. These observations were exploited by experimenters such as Shelford Bidwell, who in 1881 eliminated the wire stylus and the need for a metal "original" at the transmitting end. Bidwell's scanning phototelegraph scanned the original image using a tightly focused beam of light, creating a minute electrical signal using the light sensitivity of selenium.

By the end of the 19th Century, the introduction of practical telephone systems opened the possibility of transmitting and reproducing true gray-scale images. The transmission of image information was accomplished by varying the amplitude or frequency of an audio tone. Once vacuum tubes and practical amplifier circuits became a reality, the technology advanced rapidly. By the mid-1920s systems could actually transmit crude versions of photographs (**Figure 1.1**) in as little as 15 minutes. Extensive research by AT&T and the interest of the major wire services in supplying news photographs to newspapers drove continued advances in the state-of-the-art, and by W.W.II, the transmission of high-quality photographs by telephone line ("wirephotos") or radio was common (**Figure 1.2**).

## THE TELEVISION PROBLEM

Television represents an even more daunting challenge than facsimile, something which is obvious if we compare a photograph with a moving picture. A "movie" creates the illusion of motion by projecting individual photographs at a high rate of speed — say 18 images per second. The human visual system has an inherent ***latency***, such that if a sequence of pictures arrives fast enough, we don't see the individual images. Instead, the sequence of pictures is perceived as one continuous image. If the camera photographed a scene at 18 images/second and these images are projected at the same rate, the eye sees a moving image, provided of course that the original subject was moving.

The goal of early television experimenters was to transmit moving images. In theory sequential scanning could be used to rapidly generate pictures of a moving scene that, if reproduced fast enough at the receiving end, could provide the illusion of motion. The major technical problem is how to transmit enough information about the scene fast enough to create a moving image at the receiving end. Facsimile systems have the luxury of time. The drum at the receiving end of the system may be rotating at a precise but leisurely rate of 60 or 90 rpm, and it may take 15 minutes or more to transmit a detailed picture. To transmit a moving picture we would have to transmit at least 12 or 15 images each second! Means have to be developed to accurately scan an image at such very rapid rates, transmit the image data, and reproduce the veritable flood of image data at the receiving end. As we shall see, most of the early scanning techniques for television, like facsimile, were basically mechanical. Early television experimenters faced two linked problems:

- How to scan an image rapidly and accurately enough to send complete pictures at a rate that would provide the illusion of motion, and
- How to accurately transmit the information from this rapid scanning, given the limitations of amplifiers and radio channels of the time. As we shall see in Chapter 2, this is primarily a ***bandwidth*** problem.

Given both of these problems, we might predict that the earliest television systems were very limited in terms of resolution — the ability to transmit and reproduce both spatial and tonal detail in an image. To create the illusion of motion at the receiving end, the technology of the period could transmit a highly detailed picture if lots of time were available but a much coarser and less-detailed image if it had to be transmitted at 15 images or more each second.

### *MECHANICAL TELEVISION*

One historical minefield that I have no intention of wading into is the question of who "invented" television. Television is a technology that by the mid-1920s became technically feasible given the confluence of science, electrical/electronic engineering, and an infrastructure that could supply reliable electronic components to a mass market. This, more than any other factor, explains why so many individuals were working on the problem and achieving some measure of success at essentially the same time. If we wish to characterize television as having an "inventor", then it was invented in a variety of places by a number of individuals all of whom were attacking the problems at the same point in time. If you are from the US, you will answer the invention question by citing the work of Charles Jenkins; someone from the UK will opt for the Scot, John Logie Baird; and a Russian will vote for Boris Rosing. All these individuals and others were true trail-blazers in the era of mechanical television and deserve recognition. If we expand the question to include all-electronic television systems, we get still another cast of characters who overlap the mechanical pioneers in time.

One unambiguous benchmark we can look to is the contribution of the German experimenter, Paul Nipkow. In 1884 Nipkow described all the basic elements of a mechanical television system (**Figure 1.3**). Scanning at both the transmitting and receiving end of the circuit was accomplished by a circular disk, containing a series of holes or lenses in a spiral arrangement. The number of evenly-spaced spiral holes is equal to the number of lines in the image. For example, a 30-line spiral would be used in a 30-line television system. The disks would spin at high speed, driven by synchronous motors at each end of the circuit. If it is desired to produce say 15 30-line frames each second, the motors would be selected to provide a disk rotational speed of 900 rpm (15 rpm × 60). At the transmitting end a lens would focus a brightly-illuminated version of the image on the edge of the scanning disk. The scanning spot would sample the image and the light from the moving sport would energize a photocell, producing a voltage proportional to the brightness of the spot at any instance. At the receiving end, the signal from the photocell would cause the brightness of a light-source to vary in step with the light variations at the transmitter photocell. The light-source would be viewed through the receiver scanning disk, identical in form and speed, to the disk at the transmitter. Given the latency of the human visual system, the observer would see a reproduction of the original scene while squinting through the scanning disk at the receiving end.

Nipkow filed a German patent on the whole system, and the spiral scanning disk is known as a "Nipkow Disk" in honor of his contribution. So, did Nipkow invent mechanical television? Hardly! Nipkow had grasped all the essentials of a working television system, but such a system could not be constructed given the technology of the mid-19th Century. By the 1920s such a system could be built and refined; and investigators such as Charles Jenkins in the United States and John Logie Baird in the United Kingdom did so, engaging in a flurry of invention that had the two of them and others tripping over each other with claims and counterclaims regarding invention and improvement. Despite a frustrating amount of variability in terms of precisely how each system was implemented (Baird, for example, employed vertical scanning while Jenkins used horizontal scanning), there were a number of common threads that characterized the brief rise of mechanical television:

- **Image resolution** generally ranged from a low of 24 lines to a maximum of perhaps 60 lines.
- **Frame rates** varied from 12.5 to around 25 images/second. The systems had to be fast enough to minimize image flicker, but bandwidth was always a limiting factor if conventional broadcast sets were to be used as receivers. Slower frame rates might be employed for specific

objectives, such as Baird's ***Phonovision*** experiments with recording images.

- Most systems began by using simple **Nipkow disks**. By the early 1930s these had been replaced in studios (and "high-end" home receivers) by mirror drum or spiral mirror scanners.
- Due to bandwidth limitations, most initial public demonstrations were limited to moving silhouettes. As amplifiers improved and higher frequencies were employed for transmission, systems evolved to true gray-scale capabilities.
- Once a reasonable level of quality and reliability was achieved, **broadcast services** were initiated to promote the new medium. Jenkins, for example, constructed a short-wave station (W3KK) that began regular evening broadcasts in July of 1928. The BBC began a scheduled, late-evening service using the Baird system in September of 1929.

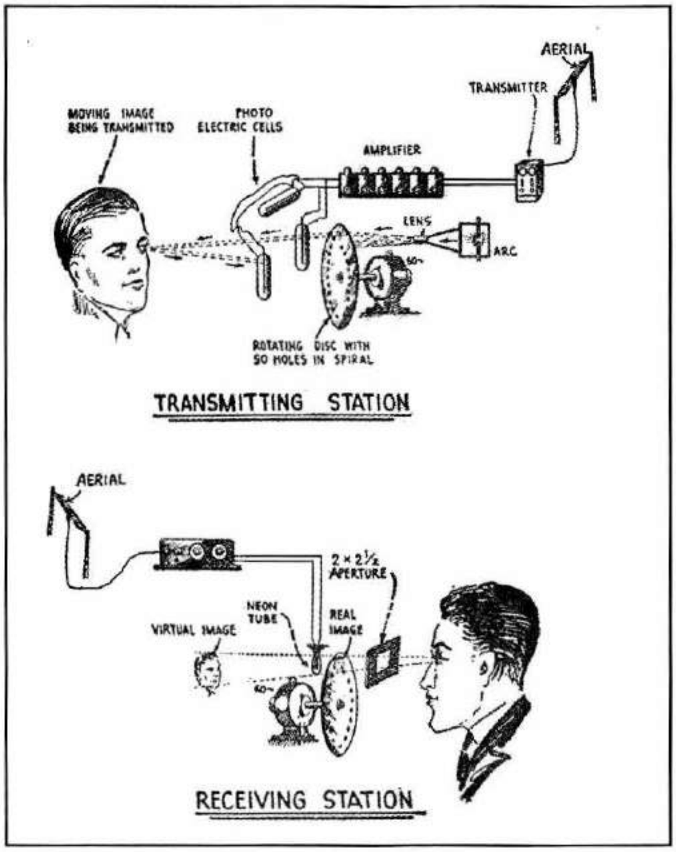


**Figure 1.3**. The basic components of a mechanical television system (modified from Yates, 1929, *ABC of Television*). The transmitting end of the circuit was equipped with a ***Nipkow Disk***, equipped with a spiral array of holes corresponding to the number of scanning lines making up the picture. Systems of the late 1920s to mid-1930s typically had 24 to 60 lines. The disk was rotated by a synchronous motor whose speed depended on the frame scanning rate. A 15 frame/second system would employ a 900 rpm motor. The motor was operated from the AC mains or from an amplified tuning-fork standard to assure precise speed. An intense beam of light was projected through the disc, creating a "flying spot" of light that scanned the subject in a darkened studio. A bank of photocells was used to convert the light intensity variations into a signal that was used to modulate the transmitter. At the receiving end, a similar disk was used to scan a flat-plate neon lamp whose brightness varied with the audio output of the receiver. The TV viewer would observe the image by looking through a mask positioned in front of the receiver scanning disk. The image, ranging in size from a postage stamp to a little over 2 inches-square, depending on the size of the disk, would be reproduced in shades of pink to black. The most basic home systems used simple motors with variable speed control, and synchronizing the picture was a real challenge. More complex systems featured elaborate speed control via image synchronizing pulses transmitted with the picture and/or drive reference signals transmitted on another frequency/band. If simultaneous audio was provided, still another voice receiver would be added to this basic layout.

Given the fact that today we take high-resolution, full-color images for granted, it may be difficult to understand the enthusiasm that greeted these first crude efforts at television transmission. While the images appear rudimentary by current standards (**Figure 1.6**), they actually looked better than any photograph can convey. There is a somewhat magical aspect to looking through a spinning disk and seeing that moving image. Amateurs and other non-commercial experimenters were entranced by the new technology. In no small part this was due to the fact that a "televisor" was actually a fairly simple add-on to a basic broadcast receiving set (**Figure 1.5**). A motor from an electric fan, equipped with a rheostat for speed control, a homemade scanning disk, and a neon tube wired to the output amplifier of the broadcast receiver were the basic requirements. It was not elegant, but practical enough to enthrall enthusiastic amateurs. Still another factor was the fact that unlike later VHF and UHF television transmissions, most broadcasts were made on the long-wave or medium-wave broadcast band, resulting in the potential for long-range reception late at night, when most TV transmissions were scheduled. Using the DX potential of the 45 meter band and the enthusiastic cooperation of amateurs, Baird was successful in the world's first trans-Atlantic television broadcast in 1928!

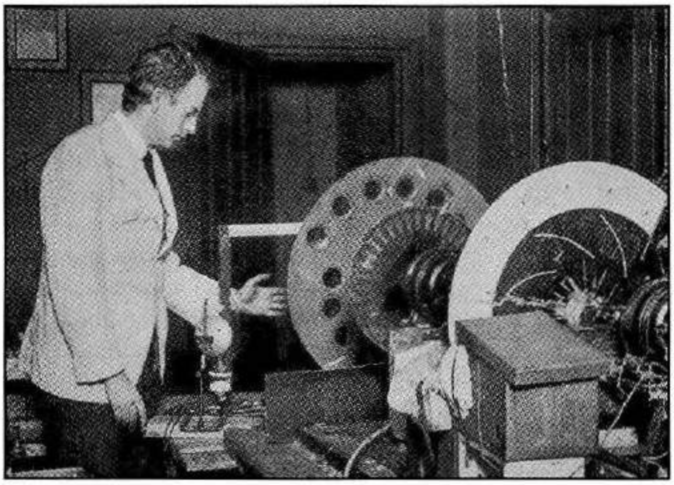


**Figure 1.4**. John Logie Baird (UK) experimenting with an elaborate arrangement of scanning discs, including a lens-equipped Nipkow disc. This equipment clearly represents a "flying spot" camera system, designed to project the scanning beam into the subject. One of the photocells used to convert the varying light intensity into an electrical signal can be seen immediately in front of Mr. Baird. In practice, such a system would have been operated in a darkened room to prevent saturating the photocells.

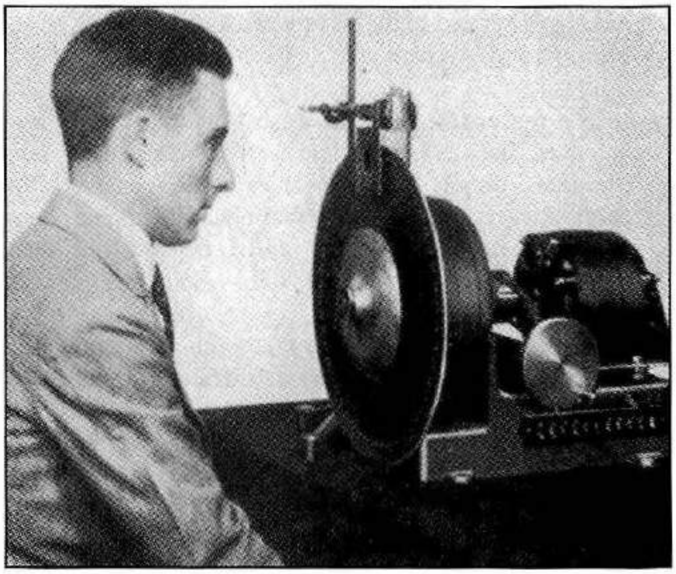


**Figure 1.5**. A laboratory version of a scanning disk receiver developed by AT&T as part of the company's experiments with mechanical television. The viewing mask can be seen in front of the disk with the large, flat-plate neon tube behind the disk. This was a fairly elaborate system that used a large 60 Hz synchronous motor for basic speed control and a smaller 2000 Hz motor, driven by a reference signal transmitted on a second frequency, distinct from the video signal, for fine speed control. The large wheel on the side of the unit adjusts the image framing to achieve perfect synchronization. In a home system, this entire unit would have been housed in an elaborate cabinet with a matching receiver for the separate voice, video, and sync signals. Yates, 1929. ***ABC of Television.***

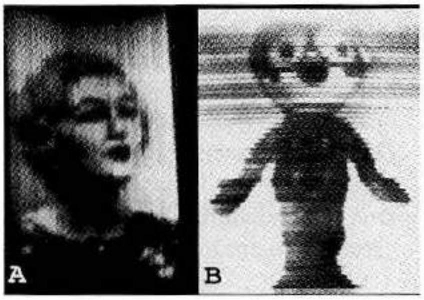


**Figure 1.6**. Very few photographs exist of actual television images from the mechanical era. The very dim display and the difficulty in holding sync with some systems made photography very difficult. (**A**) A photograph of Jane Carr, performing in a BBC production from the Baird studios in London about 1930. (**B**) An image of a model of Felix the Cat as transmitted during the RCA/NBC experimental broadcasts in New York City during 1929. This image was produced using a scanning disk flying-spot camera. The archival material with this photo says that it was displayed on a CRT display system (kinescope), but the slight curve to the scanning lines indicates that a scanning disk televisor was used to make the photograph (courtesy of the Sarnoff Corporation). Note that the Baird system employed vertical scanning while most of the systems in use in the US used horizontal scanning. Modern experiments with mechanical television confirm contemporary observations that the moving image on the TV display had the appearance of much greater clarity that any still photographs might convey.

The early 1930s was, despite the world-wide economic depression, a time of rapid technological progress. Part of the enthusiastic reception of the earliest television formats was the idea that they would inevitably improve, particularly in resolution. One factor in the limited resolution of early systems was the bandwidth problem discussed earlier. This soon ceased to be a factor as progress resulted in wide-bandwidth amplifiers, and the ability to transmit TV signals on higher frequency bands (shorter wavelength) where bandwidth problems were less stringent. Actually achieving higher image resolution also required an increase in the number of scanning lines, and here mechanical television hit a serious barrier to further improvement. In a practical environment (as opposed to the laboratory), mechanical systems were pressed to deliver anything more than about 120 lines of image resolution. This is about equivalent to that achieved with early amateur slow-scan television (see **Figure 1.11**); and, although the images did move, their potential for education or entertainment was clearly limited. Such limitations were readily apparent to potential investors and without large amounts of capitol, which was hard to come by in any context in the mid-1930s, further development of mechanical TV was doomed. While this was certainly true in terms of commercial development, a dedicated group of contemporary experimenters are exploring the fascinating realm of mechanical television under the general heading of Narrow Band Television. You can read about some of this activity in Chapter 4.

## *ELECTRONIC TELEVISION*

While it might be argued precisely what the upper resolution limit might be for mechanical television systems, there was no doubt that there was one and that the resolution limit was sufficiently low to inhibit the commercial development of the medium. Even while the first efforts were being made to produce workable mechanical TV systems, other experimenters and engineers recognized that another device — the cathode ray tube (Figure 1.6B) — had no such limitations. The cathode ray tube (or CRT) contains an electron "gun" that accelerated a tightly focused bean of electrons at the flat end of the tube, which was coated with a phosphor layer. The electron beam, striking the phosphor, would excite the phosphor atoms and produce a spot of light. What was even more useful was that the trajectory of the beam could be altered by either an electrostatic or magnetic field, permitting the beam to be scanned both horizontally and vertically across the phosphor face of the tube. The intensity of the electron beam could easily be modulated or varied by a relatively small voltage applied to the control grid of the tube, so that the scanned beam could actually "paint" a picture on the face of the CRT! Since the electron beam was without any practical mass, the speed of scanning and hence the resolution of the raster was a straightforward engineering problem relating to linearity and frequency response of the scanning drive circuits. Since these were electronic, as opposed to mechanical problems, the resolution of an electronic television system was limited primarily by bandwidth considerations, another electronic as opposed to mechanical problem.

The practicality of the CRT as an image display device was demonstrated repeatedly through the 1920s by workers in Russia, Japan, Germany, Great Britain, and the United States. While electronic TV receivers were more complex than their mechanical counterparts, they had great potential for higher resolution and commercial exploitation if a suitable camera system could be developed. The camera pick-up tube that firmly launched commercial electronic television was the ***Iconoscope*** (Figure 1.7B), usually attributed to the inventive genius of the Russian emigré Vladimir Zworykin, first while working for GE and later RCA. The situation is actually far more complex. In 1927, an Idaho farm-boy, Philo Farnsworth, at the ripe age of 21, put together an all-electronic television system that was demonstrated in 1928. At the heart of Farnsworth's TV camera was his "Image Dissector" (Figure 1.7A). While Zworyikin had made progress on his Iconoscope, the history of litigation and contracts between Farnsworth Television and RCA makes it clear that aspects of Farnsworth's patents were essential in the operation of Zworykin's device. To complicate matters still further, the storage capabilities of the Iconoscope could not be realized without incorporating the patents of the Hungarian engineer, Kalman Tihanyi, who was also hard at work in the mid and late 1920s. When the time comes for the birth of a new technology, intellectual parentage can be a complex question indeed!

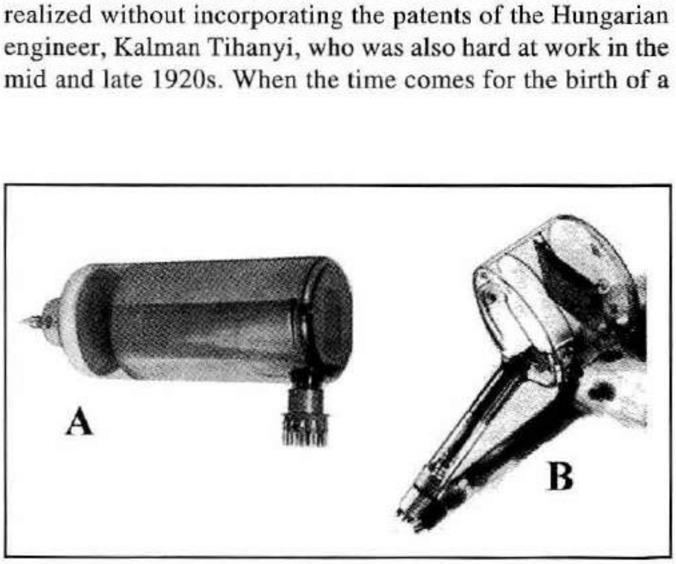


**Figure 1.7**. Two image pick-up tubes that ushered in the modern era of all-electronic television. **[A]**. The Farnsworth "Image Dissector". **[B]**. The R.C.A. "Iconoscope". Modified from Zwyorkin and Morton, 1940. *Television* (John Wiley & Sons, New York).

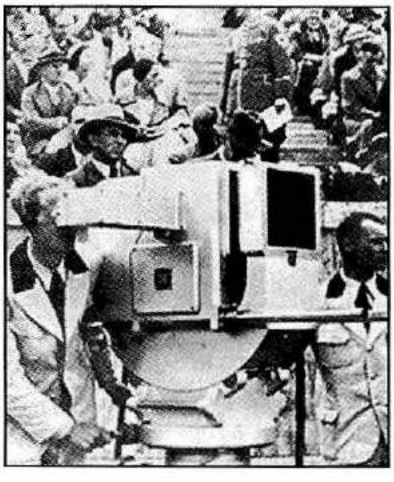


**Figure 1.8**. German camera operators covering the Berlin Olympic Games of 1936. The German broadcast service, which had been operating since 1935, transmitted 180 line images at a rate of 25 frames/second. The image-pick-up tube in the cameras combined licensed technology from Farnsworth and RCA.

In 1935 Germany introduced a 180 line/25 fps all-electronic national broadcast service that utilized both Farnsworth and RCA technology. This system was used to televise the 1936 Berlin Olympics and was upgraded to 441 lines in 1937. Some measure of service was continued throughout the war years, including a station set up in occupied Paris with an antenna on the Eiffel Tower.

In Britain, a 405 line service (EMI system based on the "Emitron" camera tube) was initiated in 1936 and continued until the outbreak of the war. By the onset of hostilities in 1939, it was estimated that Britain had almost 20,000 television sets in service. In the US, RCA poured over 13 million dollars into electronic television development at the height of the Depression. The 304-line RCA service went on the air via NBC in 1937. Initially service was centered in New York with 400 receiving sets, but by the end of the decade there were probably 7,000 sets in the US with some broadcast service available in major cities. By that time the system had been upgraded to 441 lines. Most Americans got their first good look at television at the RCA exhibit at the 1939 World's Fair. US TV broadcasts and production of TV sets ceased with the country's entry into the war in 1941 and did not resume until 1946. Just prior to the industry shut-down, the Federal Communications Authority (today's FCC) adopted the EIA recommendation for a 525-line/30 frame/second interlaced standard, which would be in force when TV broadcasting resumed after the war.

There was comparatively little amateur involvement in electronic television during the late 1930s. The commercial receiving equipment was complex and expensive, and the associated industrial base didn't have the capacity to produce additional CRTs and other "big-ticket" items. Needless

**Figure 1.9**. A studio shot from the RCA/NBC studios in New York. This was typical of the picture quality that introduced most Americans to broadcast television during the 1939 World's Fair. Zwyorkin and Morton, 1940. *Television* (John Wiley & Sons, New York).

to say, there was no surplus market where such components could be obtained at low cost. Tremendous technical strides were made during the war years, and the US electronics industry had huge production capacity at war's-end that could be brought to bear on the fledgling TV industry. From a mere 7000 sets in 1941, the audience for commercial TV blossomed to an estimated 10 million sets by 1950. Several competitive systems were on the horizon that would permit a full-color broadcast TV service; and in 1954 the National Television Standards Committee (NTSC) selected the RCA dot-sequential color system, in part due to its compatibility with the very large installed base of monochrome (black and white) TV receivers.

### *POSTWAR AMATEUR TELEVISION*

The rapid development and expansion of color TV receivers freed up lots of older black and white sets in the back rooms of TV service shops across the country and helped fuel the first boom in Amateur Television (ATV) activity on the part of Amateur Radio operators. Through the 1960s, most operation was done using monochrome equipment. Operation was confined to UHF frequencies and above (beginning with what is now the 420-450 MHz/70 cm band), which meant that virtually all activity was local in nature and severely impacted by adverse terrain. Low-noise converters and repeaters did not yet exist. All of this meant that, outside of major metropolitan areas, if you got interested in ATV you had to recruit at least one other amateur! What made the task more difficult was that everything in the station, with the exception of the TV set, had to be home-built using a truckload of vacuum tubes! That included receiving converters, transmitters, video and aural sub-carrier voice modulators, time-bases, and the camera itself! Finding suitable reference material for building even a simple ATV system was a challenge. The major Amateur Radio journals did feature occasional articles on the subject, but the material was widely dispersed over many years and hard to locate unless you had access to a good collection of back issues. In this environment, one of the most useful contributions was Mel Shadbolt's 1962 book, *Ham TV*. This 100-page, paper-bound booklet took you step-by-step through the construction of a well-designed low-power ATV station! The results were fun and exciting, but it was a lot of effort to work the guy across town (**Figure 1.10**).

Today's situation is quite different. Color TV and camcorders abound, along with low-noise solid-state receivers, compact transmitters, and computer-designed antennas that actually perform as advertised. The exciting world of contemporary ATV is covered in Chapters 5 and 6. As I write this, we are at the cusp of still another revolution in commercial TV — the transition from the 1950s-vintage NTSC analog TV standard to the new world of high-definition digital television — HDTV. This will present challenges as to the future direction of ATV, a subject that is discussed in Chapter 10.

## SLOW-SCAN TELEVISION

While ATV provided the opportunity for a relatively short-range image communication option with the familiar medium of television, there weren't many choices when it came to longer paths on the HF or VHF bands. Facsimile would have been one obvious choice, but there were several factors that tended to work against amateur use of fax:

- **Multiple Modes** — The different fax services all used

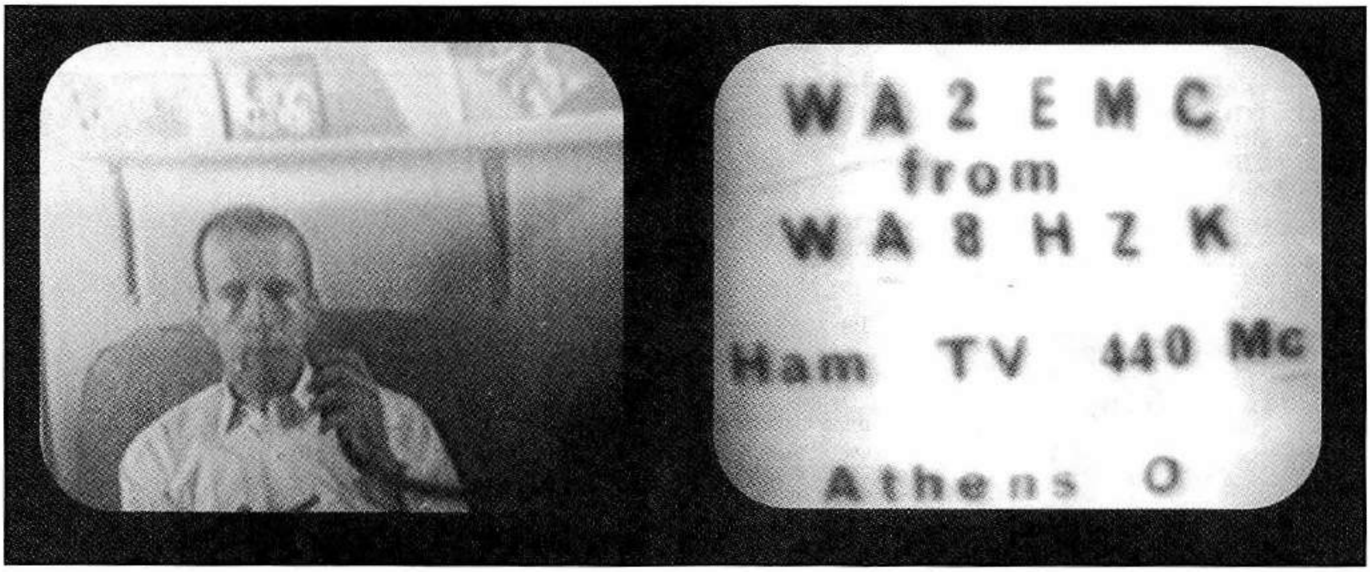


**Figure 1.10**. Typical ATV pictures exchanged between the author (then WA2EMC on the left) and Ron Silver, WA8HZK (right), from Ohio University in Athens, Ohio during November of 1965. I was working on a Master's degree and was operating from a local rooming house, using a desk-top rack full of homebuilt vacuum tube gear and a homemade vidicon camera. Ron was operating from his room in the Delta Upsilon fraternity house and was using a B&K TV Analyst as a flying spot scanner and a modulator/transmitter circuit he built from an article I had written for the old ***ATV Experimenter*** magazine (1964). We maintained simultaneous audio communications using 6 meter (50 MHz) AM. In those days, surrounded by the hills of southeastern Ohio, we had the 420-450 MHz band all to ourselves!

different specifications. The equipment tended to be large and bulky and restricted to single mode operation. The design of the hardware also tended to make it difficult to alter equipment for one mode for use with another. This lack of standardization inhibited experimentation.

- **The Time Factor** — Commercial photographic fax systems were designed to transmit very detailed images over an extended period of time — fifteen minutes to a half an hour or more, depending on the mode. Amateur stations were required to identify by voice or CW every ten minutes, so most fax modes were not suitable for use on amateur bands.
- **Regulatory Limitations** — The FCC had included modes such as television in the amateur rules, but apparently it was not thought that amateurs would make much use of facsimile. The 11 meter band included fax privileges, and that band was withdrawn from the Amateur Service with the creation of the Class D Citizens Band in September of 1958.

There was, of course, some experimentation with fax, but never on a scale that created a critical mass of operators to sustain significant on-the-air activity. That was to change in the late 1950s with the work of a young engineering student, Copthorne Macdonald, who undertook a Senior project at the University of Kentucky. The goal of the project was to combine aspects of television, the use of CRTs for display and as flying spot scanners for transmission, with a signal transmission rate compatible with the audio bandwidth used in standard AM, SSB, and FM voice transmission. To stay within the phone bandwidth "window", relatively low resolution (by fax or TV standards) image data would be transmitted at the rate of 15 lines/second. The incoming image would be displayed on the face of a CRT equipped with a long-persistence phosphor which would retain the image for a number of seconds. Surplus radar tubes using P7 phosphors would hold a useful image for 6-10 seconds in a darkened room, so an 8-second frame period was selected. If the picture required 8 seconds to transmit at 15 lines/second, a complete image would consist of a 120 line image. A square image format was employed to make best use of the circular screen area provided by typical radar display tubes. The transmission consisted of an AM-modulated audio tone that could be routed into the microphone jack of any phone transmitter. For reception, the audio output of the normal station receiver was routed to the input of the display monitor. Since the signal was simply an audio tone, it could even be recorded on a standard audio tape recorder for later playback.

Macdonald described his system in a series of articles in *QST* in 1958. In effect, he had invented a form of ***cathode-ray facsimile*** for the transmission of still images, but the system came to be called ***slow-scan television*** (SSTV) and the name has stuck! Macdonald's articles ignited immediate interest in a handful an experimenters here and abroad, and the system was tested on-the-air for the next few years under special authorization from the FCC. These tests suggested that the amplitude modulated audio tone was adversely impacted by fading, so tests were done using FM modulation with much more consistent results. In1962 Macdonald presented the results of the systems tests in *QST*, along with a revised set of standards using the FM modulated audio tone to convey the image information.

Defining the birth of SSTV is easy, but I was initially at a loss as to how to summarize the 40+ years since then in anything approaching a short history. It wasn't until I stepped back and looked at trends that I realized the history of SSTV can be conveniently divided into clear-defined intervals along decade boundaries:

- 1960 to 1969 — The Analog Experimenters
- 1970 to 1979 — Analog Operators and Digital Experimenters
- 1980 to 1989 — Stand-alone Scan Converters Reign Supreme
- 1990 to the present — SSTV and Personal Computers

Each of these periods will be briefly highlighted in the paragraphs that follow.

### *THE EXPERIMENTERS*

This is an appropriate name for this period since, given the lack of any commercial equipment, everyone had to build his own gear, including monitors and cameras. Anyone experimenting with the mode was, by definition, adventurous, and experiments and new ideas were tried at a furious pace. A further complication was that all HF operation had to be conducted under special authorization from the FCC, a situation that lasted until SSTV was permanently authorized as part of the FCC's 1968 "Incentive Licensing" program. Two pieces of gear, both designed by Macdonald dominated much of the decade — the "Macdonald Monitor", described in *QST* in 1965, and the "Macdonald Camera", an analog camera built around a Westinghouse 7290 vidicon. The 7290 tube had a high-resistance target that permitted an image to be

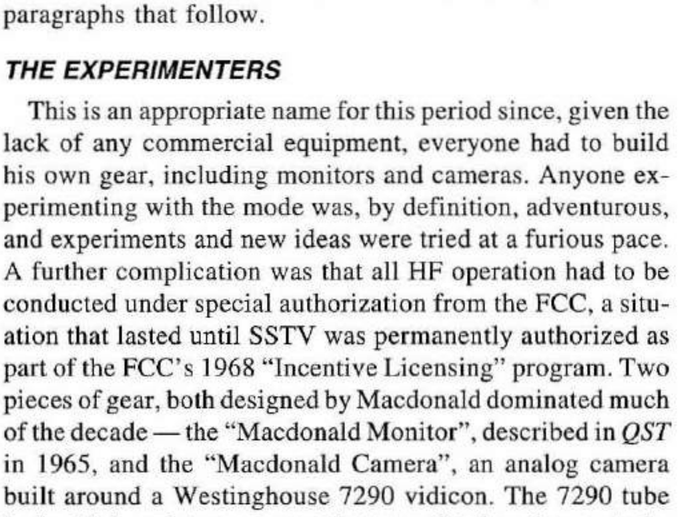


**Figure 1.11. [A]** Typical vacuum-tube SSTV equipment from the mid-1960's. The central cabinet is the "Macdonald Monitor" (*QST*, 1964). The open chassis and the camera-head on top of the monitor is the Macdonald camera from a 1965 *QST* article. This photograph was taken of the author's SSTV gear in use at W8SH, the club station for the Michigan State Amateur Radio Club. **[B]** The author's SSTV station in 1972. Behind the Microphone is a Macdonald hybrid monitor (never published) with an elaborate SSTV switching unit in a matching cabinet to the left. Next to that is the control unit for a combined SSTV signal generator and a flying spot scanner, with the optical unit on top of the three smaller cabinets. A solid-state Robot 70 monitor is on the extreme left along with a home-built sampling camera just visible on the far left.

exposed by a mechanical shutter at the start of frame transmission, essentially "freezing" images so that a subject could actually move around during much of the 8-second frame transmission. There were few stations of the period that did not have one or both of these pieces of equipment (**Figure 1.11A**). Most of the early monitor circuits used tubes and electrostatic CRT's originally designed for oscilloscope service. By 1967 the first solid-state, magnetic deflection monitors were developed. The Westinghouse 7290 vidicon tube was hard to obtain, so many stations simply employed flying-spot-scanners or experimented with the use of standard vidicons (and later Plumbicons) in an open-shutter mode (see **Figure 1.12**). Most of these problems disappeared in 1969 when W9NTP demonstrated the first SSTV ***sampling camera***. A standard vidicon was used and scanned at a rate significantly faster than the SSTV rates, eliminating a lot of problems, including signal response and the problems inherent in trying to focus a camera when you had to wait 8 seconds for each image! A combination of analog and early digital sampling was used to generate the SSTV signal. Another significant advance at the end of the decade was the development of the first analog color techniques (W4UMF, WB8DQT). The first two-way color SSTV QSO took place late in 1969 between W8SH and K4YPX.

### *ANALOG OPERATORS AND DIGITAL EXPERIMENTERS*

Amateur success with magnetic-deflection monitors and sampling cameras led, naturally enough, to the introduction of the first commercial SSTV gear. San Diego-based Robot Research was the most successful with respect to marketing. Their Model 70 SSTV monitor and Model 80 sampling camera dominated the early commercial market, and a significant number of new amateurs got on the air, fueling the first real boom with respect to SSTV. Like most other facets of Amateur Radio, the majority of operators focused on working slow-scan, not experimenting. SSTV still had lots of limitations, chief among them the fact that you had to be in a dimly-lit room to watch the fading image on the face of the P7 CRT. In 1972 the *SSTV Handbook* (W9NTP and WB8DQT) commenced publication. It summarized the current state-of-the-art with respect to 8-second analog slow-scan while introducing circuits that actually featured those strange devices known as analog and digital integrated circuits!

The focus of much of the work during the '70s was the development of scan converters for SSTV. I will discuss scan converters at greater length in Chapter 6, but for now they can be considered as a black box that can input an image signal in one format and output it in another. In 1973 several Amateurs (WB9LVI, W6MXV, and W0LMD) demonstrated the first all-digital camera scan converters. These miraculous boxes took the output of a standard TV camera, operating at broadcast/ATV rates (using a standard TV monitor to compose and focus the picture) and transformed the image data to an 8-second SSTV signal. You couldn't move the subject during the frame transmission (as the scan converters worked in real-time), but that was a small price to pay compared to even the simplest camera systems that preceded these first scan converters. The year 1973 also saw the first demonstrations of analog scan converters (W9NTP and SM0BUO), employing "double-vidicon" storage tube technology to permit an SSTV image to be displayed on a standard TV monitor with normal room lighting! The first all-digital receive scan converters, using shift-registers for image storage, appeared in 1974 (WB9LVI, W6MXV, and W0LMD). These units also permitted the display of SSTV pictures on a standard TV monitor, but with none of the fussiness associated with the set-up of analog scan converters. What's more, the digital units would display the same picture, without degradation, for as long as power was applied. Future trends were becoming even clearer!

In 1975, W9NTP demonstrated a full-color shift-register

**Figure 1.12**. Early SSTV DX. In this case, pictures from Art Bachman, SM0BUO, tape-recorded during a 10 meter QSO with W8SH in 1968. The upper "mug shot" was a live picture using a home-built camera of Art's design that used a ***Plumbicon*** camera tube. The lower ID image was transmitted from a flying spot scanner.

receive scan converter. Robot introduced their Model 300 analog scan converter that year (using Princeton storage tube technology); but experiments with digital scan converters had obsoleted the concept of analog storage, and few of the Model 300s were sold. In 1976, W9NTP demonstrated a transmit and receive scan converter that could produce color SSTV pictures, using a B&W TV camera and a 3-color filter wheel, and display full-color SSTV on a color TV monitor. That same year WØLMD and WB9LVI produced digital scan converters using random-access memory (RAM). This was extremely significant, since the storage capacity of the earlier shift registers was limited and lots of chips were needed for image storage. The storage capacity of RAM chips was already higher than any shift-register and was increasing at a rapid pace. This translated to much simpler scan converter circuits and lower costs! Robot also introduced their famous Model 400 digital scan converter that year — using RAM chips for image storage. The 400 employed both receive and transmit capabilities. The Model 400, teamed up with a B&W TV camera and a TV monitor, would get you on the air, instantly rendering obsolete all the analog gear that had come before. The 400 drove a major increase in the number of SSTV operators (who no longer had to turn down the lights to enjoy the hobby). The 400 was also very popular with some of the early color SSTV experimenters, since the most significant modification for color was the addition of parallel memory boards to accommodate the additional red/green/blue image data. The rest of the decade was dominated by the use of the Robot 400 (which was compatible with earlier analog equipment) and by the modification of both Robot and home-built scan converters.

### ***STAND-ALONE SCAN CONVERTERS REIGN SUPREME***

The early years of the 1980s saw new scan converters and new modes, mostly dealing with different approaches to sending color images. Things got a bit chaotic during this period, for many of the new modes were not "open" in the sense of being well documented; and they certainly were not compatible with each other. The original 8-second analog gear was now completely outmoded. Even operators with Robot 400 monochrome scan converters were pretty much on the sidelines as the "mode wars" began to heat up. The pivotal event of the decade was the introduction in 1984 of the Robot 1200 color scan converter. The 1200 was a complete, integrated color SSTV system, capable of instantly capturing full-color images from any color TV camera or VCR and displaying in-coming SSTV pictures on any color monitor or TV set. In addition to the older 128-line format, the 1200 had the memory resources to handle 240-line images of significantly higher quality (see **Figure 1.13**). With the 1200, Robot introduced a whole new series of color modes. At first this only added to the problem of multiple modes, but the real potential was based on the fact that the 1200 was fundamentally different from most of the scan converters that had preceded it. The earlier systems primarily used hard-wired logic to control how they operated. As a result, any modifications to implement new modes meant extensive hardware modifications. Most operators were as reluctant to do that with expensive scan converters as most of us are to make any real changes in the transceivers we use!

The 1200 was different. In effect, it was a collection of universal SSTV "tools" — a good slow-scan front-end, all the memory resources needed, and all the other hardware modules needed to do the job. All of these resources were under the control of a simple-minded "computer" in the form of a 4-bit microprocessor. As the 1200 left the factory, it was programmed to handle the Robot color modes as well as a few monochrome options. What was not universally recognized at the time was the incredible flexibility provided by that microprocessor! In fact, other than providing some better clock/timing references, all you needed to do to let the Robot 1200 send and receive other modes was to swap out the factory PROM (**P**rogramable **R**ead-**O**nly **M**emory) with an EPROM ( **E**rasable **P**rogramable **R**ead-**O**nly **M**emory) loaded with new program instructions! This potential was independently exploited by two Amateurs in the UK — Martin Emmerson (G3OQD) and Ed Murphy (GM3BSC). Each of them had his own ideas about how best to send color pictures and implemented these ideas with new EPROMS that introduced two new families of color options — the "Martin" and "Scottie" modes. Since the new EPROMS were products whose sales potential was dictated by market demands, both included other modes, including those of their competitors.

As the 1980s drew to a close, the Robot 1200 was the only serious commercial contender on the slow-scan scene; but

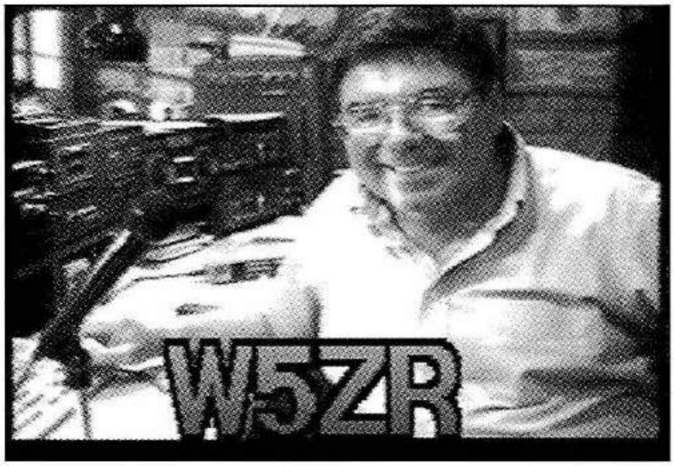


**Figure 1.13**. With the introduction of the Robot 1200 scan converter, medium-resolution (240-line) SSTV images, in full-color, became the *de-facto* standard for SSTV on HF. These pictures essentially equal the practical resolution obtainable with conventional television, with none of the range limitations. This image was transmitted by Bert, W5ZR, using a Robot 1200 scan converter and received by the author on 20 meters. Bert's picture illustrates another aspect of the Robot 1200 — the capability of interfacing with a PC to store or modify images. A number of vendors began offering software to take advantage of this feature, allowing images grabbed from the TV camera to be modified by the addition of graphics or the use of other special effects.

you had to have the latest EPROM installed to hope to keep up with what was going on. On-the-air picture exchanges were dominated by the exchange of high-quality medium-resolution (320 × 240) color images using primarily the Martin and Scottie modes. The Robot 1200 also had the capability to interface with an external computer, permitting images to be saved and recalled. As the graphics capabilities of the PC improved, vendors supplied software that let you customize pictures with callsigns or special effects. While the 1200 brought new people into slow-scan, others were leaving the mode, unwilling or unable to afford the significant costs associated with the scan converter, EPROM upgrades, and the associated color TV gear.

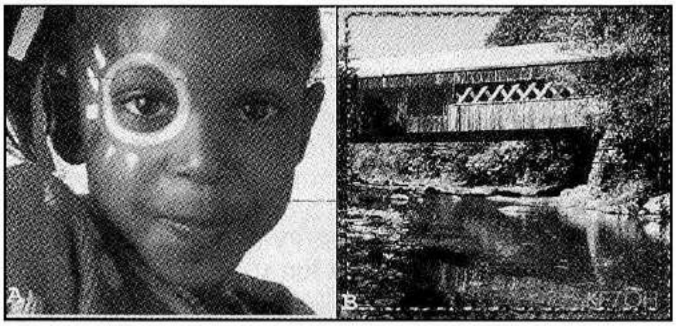


**Figure 1.14**. The use of computers for SSTV is fast blurring the lines between facsimile and slow scan. Whether you want to get up close and personal, as in this portrait from KC5RW (A) or handle scenic views such as the covered bridge (B) from KF7OH, the higher-resolution modes provide new opportunities for image communication. Both of these pictures were received on 15 meters using the Fax480 mode, which requires just over two-minutes for the transmission of a 512 x 480 image — just about the time required for a medium-resolution color image (see Figure 1.13). High-resolution (640 x 480) color images require 6-7 minutes for transmission.

### *SSTV AND PERSONAL COMPUTERS*

Although slow-scan had reached a point where it was easy to send high-quality color pictures just about anywhere in the world, the economic factors limiting the potential for future growth were very real. In 1992 Robot Research discontinued marketing of the Model 1200, due in large part to limited sales. The reality was that things were happening in the world of personal computers that would soon render obsolete any expensive stand-alone scan converters like the Model 1200. It turns out that the experimenters were still around, but they had changed their tactics!

If you were experimenting with SSTV about the time the Model 1200 made its debut, you were confronted with some harsh realities. First, color SSTV scan converters were complex and relatively expensive to build. There were amateurs who could and did build systems with similar or even superior capabilities, but Amateur Radio was changing. Fewer and fewer individuals were building their gear — particularly complex projects. Growth in SSTV could no longer be sustained using home-built equipment, no matter how innovative it might be. But there was another possible route — the personal computer. A computer had many of the features and resources needed for a scan converter — a processor to run things, banks of memory for data storage, and a nice keyboard interface to communicate with the computer. Robert Suding (W0LMD) did some of the earliest work with computerized slow-scan in the late 1970s, but home computers were too far from the mainstream for this work to have much impact. By the mid-1980s computers were a bit more common in the amateur station and some, like the RadioShack Color Computer™ (CoCo) had excellent expansion potential. The CoCo, like other home systems of the era, lacked the I/O and display capability to handle slow-scan directly; but it could do so with external signal-processing and display hardware, as demonstrated by Clay Abrams (K6AEP) and the author in 1984 (Abrams and Taggart, 1984). While the CoCo SSTV system fell short of the capabilities of the Robot 1200, it did show that the SSTV-computer connection had some real potential. By the late 1980s the Amiga computer did have the display capabilities to handle slow-scan, and Ben Blish-Williams (AA7AS) developed the AVT Master system that was later marketed by AEA.

The real computer force to be reckoned with was the IBM PC. Introduced as an open system, its capabilities grew steadily under pressure from business users who wanted more disk storage capacity and expanded memory, along with sharper and more colorful display capabilities. With the introduction of the VGA display standard, PCs could easily surpass the 1200 in spatial resolution, but not color. By 1992, when Robot discontinued the 1200, home PCs were getting close to the display capabilities of the stand-alone scan converters and would surpass them in just a few more years. What's more, the IBM PC and its clones were now thoroughly mainstream, and getting more and more common in amateur stations around the world. First it was logging and record-keeping, but the machines could also be used for RTTY, CW, Packet, and a host of new digital modes. In effect, all that was needed to spark a real boom in SSTV was a way to get the slow-scan signal into the PC. After that, everything is software! John Montalbano (KA2PYJ) introduced the parallel-port ***ViewPort*** SSTV interface and software package in 1992, John Langner (WB2OSZ) debuted the ***Pasokon*** ISA bus card and software in 1993, and Ben Vester introduced a simple serial port interface and shareware in 1994. Given the power and speed of PC computers, any SSTV mode can be accommodated with ease and convenience; and, if you already have the computer in the shack, you can jump into slow-scan with little or no additional investment.

The ultimate in convenience is SSTV with no added interface. The secret was to use the almost universal PC sound card. The sound card is basically a digital signal processor (DSP). With suitable programming, the Soundcard can supply the needed clock signals, all the demodulation functions, and some precision filtering as well. Since the PC didn't share the memory and display constraints of the Robot 1200, even higher resolution formats (**Figure 1.14**) can be supported, steadily erasing the boundaries between fax and slow-scan. In the case of software using the PC sound card as an interface, the station set-up is the same as that needed to run a host of other fascinating digital modes, such as PSK-31. If you are configured to operate any of these "new" modes or even "old-fashioned" modes like RTTY using your computer and Soundcard, all you need to operate SSTV is software! Chapters 7 and 8 are specifically intended to guide you in putting together your SSTV station and what you can expect once it is operational.

## WEATHER SATELLITES

The idea of observing the Earth's weather from space is quite recent compared with most of the topics we have discussed. Prior to WWII, it took a special kind of optimism to think seriously about space travel. The tremendous strides achieved by the German rocket program during the war certainly altered the US military's view about the strategic possibilities of space. In 1946, the Rand Corporation produced a classified report that listed weather reconnaissance as one of the possible roles for an orbiting vehicle. The Air Force initiated an on-again-off-again weather satellite program that was transferred to the new National Aeronautics and Space Administration (NASA), formed in the immediate wake of the national panic that followed the Soviet launch of *Sputnik* in 1957.

The defining moment came on April 1, 1960, when a Thor-Able launch vehicle (**Figure 1.15A**) lifted off from Cape Canaveral, carrying a 119 kg (263 pound) satellite shaped like a large hat-box. It was a very expensive hat-box indeed, covered with 9,200 solar cells to charge its internal NiCad batteries and containing a pair of special TV cameras built by RCA. In principle these cameras were very much like the Macdonald SSTV camera discussed earlier. The cameras were equipped with a shutter and the vidicon camera tubes had high-resistivity targets. The tube targets were quickly exposed when the shutters briefly opened and closed, and then the image charge distribution on the target was read out over a period of several minutes. The image data could modulate a down-link VHF transmitter in real-time, and the picture also could be recorded using an onboard tape system for later high-speed relay to specially-equipped ground stations. One camera had a wide-angle lens while the second had a narrower field of view.

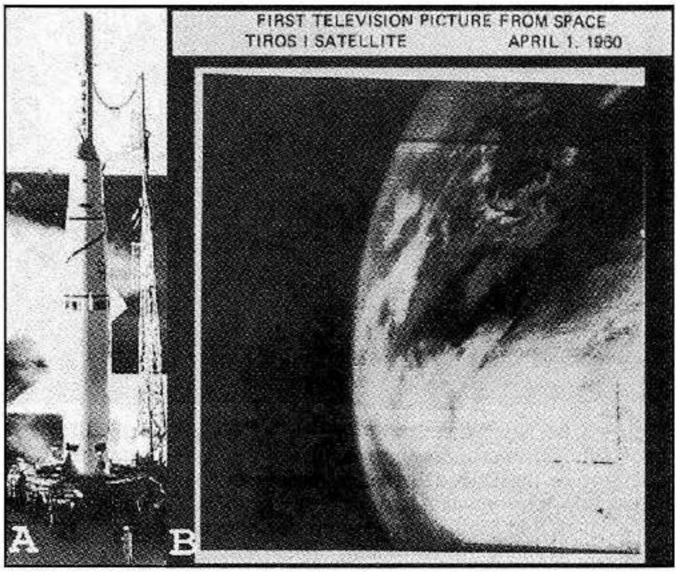


**Figure 1.15.** Systematic observation of the Earth's weather from orbit began on April 1, 1960 with the launch of the TIROS 1 spacecraft using a Thor-Able booster (**A**). A short time later, the spacecraft televised its first picture from orbit (**B**). In this oblique view, the Gulf of St. Lawrence and Nova Scotia are visible in the upper-center of the image. Photos courtesy of the National Aeronautics and Space Administration and the National Oceanic and Atmospheric Administration.

This was a very sophisticated package for 1960 and the marvel was that the spacecraft, known as **TIROS-1** (**T**elevision/**I**nfra-red **O**bservational **S**atellite) actually worked! Not long after reaching orbit, TIROS-1 returned the first weather satellite image from space (Figure 1.15B). The spacecraft stabilization system was not completely operational, due to the pressure to meet the launch deadline, so many of the images were oblique views; but over its 77-day lifetime it took 22,952 cloud-cover pictures. The success of this single spacecraft was enough to dispel any lingering doubts as to the desirability of an operational weather satellite program. By 1965, **ESSA** satellites, the operational name for the TIROS spacecraft, were transmitting pictures on a regular basis (**Figure 1.16**). In the years since, uncounted lives have been saved and property loss averted or mitigated because of the timely warnings provided by these "eyes in the sky"!

So what does all of this have to do with Amateur Radio? The answer is simple! When these satellite meteorology programs were first conceived, it seemed obvious that the systems were so sophisticated that ground stations would be confined to governmental space and weather installations and perhaps some high-end academic research institutions. The reality today is that literally anyone who wants to "look in" on these satellite transmissions can do so at minimal cost! What has come to be called the "small user community" includes classroom teachers, students doing science fair projects, and thousands of ordinary people with an interest in radio, space, or weather. All of this has been possible for two reasons:

- The governments of the world have generally designed major components of their weather satellite systems in an "open" manner, including information on frequencies, image formats, and spacecraft orbits.
- A world-wide group of dedicated "amateurs", many of whom actually are Amateur Radio operators, have labored for decades to develop ever more affordable hardware and software to literally bring this satellite technology "down-to-earth".

The story starts in 1965, about the same time the very first weather satellites were becoming operational, with an article by Wendell Anderson (K2RNF) in the November issue of *QST*. Anderson's article described the modification of surplus wide-band FM receivers for weather satellite reception, some antenna basics, and a complete drum-type photographic facsimile recorder for printing out the pictures. The

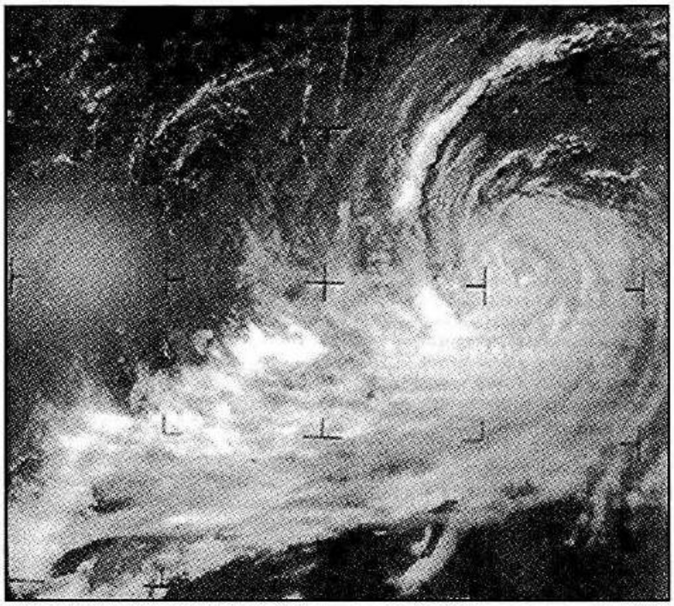


**Figure 1.16.** By 1965 the TIROS research and development phase was complete and the operational spacecraft, designated ESSA (for the Environmental Science Services Administration) once they were in orbit, became fully operational. Here Hurricane Faith is imaged as it moves onto the North Carolina coast on September 1, 1965. The cross-hairs and other reference marks on the image are etched into the face of the storage vidicon camera tube, providing a means to check the scanning geometry and linearity over the operational lifetime of the spacecraft.

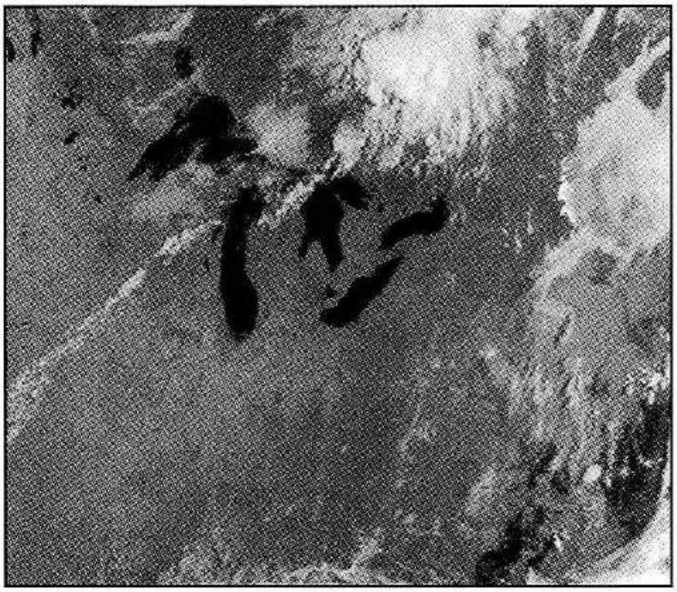


**Figure 1.17**. Today, US NOAA (TIROS-N series) and Russian METEOR spacecraft continue the observation of the Earth's weather from low, near-polar orbits at both infra-red and visible wavelengths. This is a portion of a NOAA visible-light pass (June 8, 2001) in which the Great Lakes are particularly prominent.

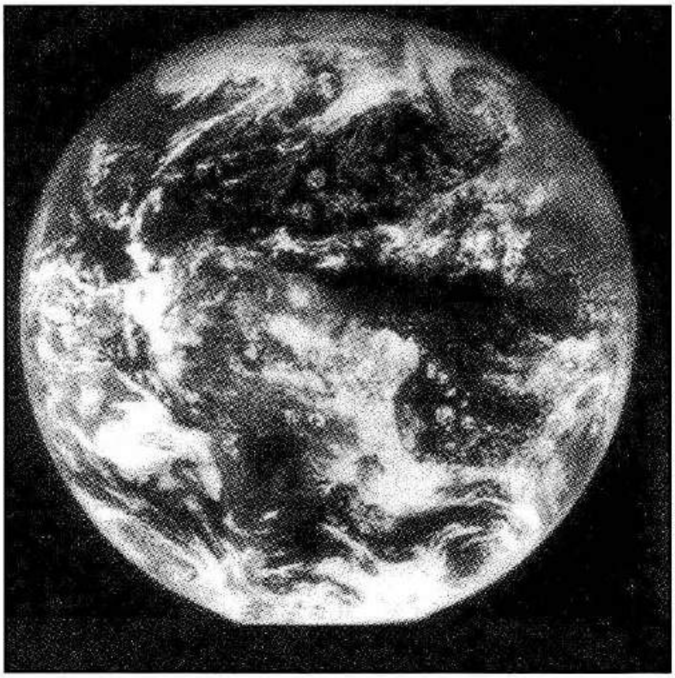


**Figure 1.18**. North and South America as viewed by the ATS-3 geostationary spacecraft, a prototype of the current SMS/GOES operated by the United States government. The full-disk image production was transmitted to specially equipped ground stations, reformatted into lower-resolution products, and then retransmitted through the spacecraft to more modest ground stations throughout the hemisphere as part of the WEFAX program.

fax drum was a kitchen rolling pin, but the images he was getting looked like they came out of a government ground station! Most of the early satellite work was done with fax machines of various sorts, some home-built and others converted from wirephoto surplus units.

By the early 1970s there were several changes in the satellites themselves. The TV cameras of the earlier generation of operational spacecraft were the weak link, as the delicate photosensitive target of the vidicons would degrade to the point where pictures were marginal, despite the fact that the spacecraft continue to function. In a curious reversal of historic design trends, the electronic vidicon camera tubes were replaced by opto-mechanical scanning systems in the new **ITOS** (**I**mproved **T**iros **O**perational **S**atellite). While earlier satellites were limited to transmitting cloud-cover images in visible light, ITOS and the current TIROS/NOAA polar-orbit spacecraft obtained multi-spectral imagery in both visible light and infra-red (IR) wavelengths, permitting images to be obtained on the dark side of each orbit. Amateurs began experimenting with CRT display systems, using film to capture the images that were "painted", line-by-line on the face of the television-like display. As the US was enhancing its low polar-orbit satellite systems, the Soviet Union (and later, Russia) was developing comparable systems along somewhat different lines. These spacecraft transmitted real-time imagery in the same general frequency range as US spacecraft. Ground stations designed to receive and display signals from US spacecraft were compatible with the Soviet/Russian spacecraft with only minor modifications. In the 1990s, US and Soviet polar-orbit spacecraft were joined by spacecraft launched from the Peoples Republic of China. Today we are in the enviable position where relatively simple ground stations can capture real-time imagery (**Figure 1.17**) from a wide range of spacecraft in low, near-polar orbits.

Another innovation of the mid to late 1960s was the parallel development of geostationary weather satellite systems. Geostationary orbits (see Chapter 7) permit a spacecraft to observe one entire hemisphere of the earth from what appears to be a stationary spot in space (**Figure 1.18**). The Applications Technology Satellite (ATS) series was the prototype system, transmitting full-disk images to specially-equipped ground stations, which then reformatted them at lower resolution and re-transmitted the images back through the ATS spacecraft. This imagery, known as WEFAX, was transmitted on VHF frequencies in a format very similar to that used by the low-orbit weather satellites, making it a simple matter to receive and display the pictures.

With the success of the prototype ATS spacecraft, the US proceeded to develop a fully operational system — the SMS/GOES program, designed to obtain high-resolution, multispectral imagery 24 hours a day. The WEFAX image options were expanded with the SMS/GOES series, but WEFAX transmission was moved from VHF to 1691 MHz. Fortunately, a number of experimenters, most of them Amateur Radio operators, were able to develop effective and affordable down-converter hardware, so permitting satellite enthusiasts to continue to receive WEFAX images.

The major revolution in satellite ground station technology in the past decade has been a steady transition to the use of personal computers for display of the images from an ever-more-diverse collection of polar-orbit and geostationary weather satellites. The combination of computer display and ever more effective options for receiving these spacecraft has made it extremely easy to add weather satellite capability to any Amateur Radio station.

## SUMMARY

It is easy to see that the world of image communications has enough variety to satisfy a wide range of interests. This rich array of choices corresponds to a point in history where both computing and RF technology have matured so that accessing these fascinating modes is easier than at any time in the past. Much of this handbook will be devoted to more detailed information on each of the major image communication options. In the next chapter we will begin our journey by looking at some of the characteristics of electronic imaging that are common to most of the options we will examine in greater detail in later chapters.

## CHAPTER 2

# ANATOMY OF AN IMAGE

## INTRODUCTION

In our first chapter I was a bit cavalier in the use of terms, tossing in concepts such as scanning, image resolution, and bandwidth, without giving them the attention they deserved. That oversight was intentional, as I wished to paint a broad-brush ("low resolution") picture of the history of image communications without constant asides to deal with the technical details. This chapter will correct that deficit, for it is all about the details of transmitting and receiving images by wire and radio! The primary goal of this Handbook is to entice fellow amateurs to get involved with communicating via pictures. To that end, I want each of the mode specific chapters to be as basic as possible. The fact is, you can get on the air knowing very little about the details of whatever mode you will be using; and if that is the best way to get you started, so be it.

Those of us who have been involved in this sort of thing for a long time tend to wallow in the technical details, but you don't need to begin your own exploration of image communications that way. In my later coverage of the major communication modes, I will typically divide each subject into pairs of chapters. The first chapter of each pair will emphasize equipment requirements, how to set up a station, and how to get the equipment on the air. The second chapter of each set will describe how to operate in that particular mode, and the range of options and activities you can enjoy when you are on the air or just "watching". In essence, each pair of chapters should be sufficient to actually get you into the fun represented by each mode. If you waded in without much technical background, you eventually would run into questions based on your experience on the air. It may be as simple as the meaning of some of the terminology you will encounter, or it may deal with issues or problems that arise, either in the operation of your own station or what you see coming from someone else. At that point, this chapter is where you should start looking for an answer to your questions.

Every piece of gear we use in this hobby came with a manual (provided we bought it rather than building it) that we were urged to read prior to firing up the equipment. If you read the manuals first — including this chapter — then bravo! Of course, most of us don't, and we end up opening the manual only when we have a question or problem we can't work around. Either way, reading it first or coming back later, this chapter should contain a lot of material you will find useful and even interesting. It is not intended as a comprehensive technical treatment, but it is certainly enough to deal with most issues.

The concept of sequential scanning is probably the single most significant idea underlying any common form of image transmission. As Bain realized back in 1843 (see Chapter 1), there is no way to send a picture in its entirety down a telegraph wire. The only practical solution to the image transmission problem was to break the image up into a lot of small pieces. If we then can transmit the average brightness of each of the pieces and reproduce each one at the far end of the circuit, we can create a reproduction of the original image. The process of breaking the image down (and later reconstructing it) on the basis of small pieces, or units, is known as **scanning**. To assemble a picture at the receiving end of the circuit, we need to know a lot of things:

- The size and shape of the "piece" or sample (**picture element/pixel**)
- The geometric organization used in the collection of samples so we can reassemble them in the same way they were sampled (**the scanning pattern**)
- The precise rate or timing for the transmission of samples (**pixel/line rate**)
- Exactly when the sampling process was started (**synchronization**)
- How we will convey/transmit the average brightness of the sample (**video modulation**)

This seems like a lot of information, but all of it is required if we are to have a prayer of putting together some semblance of the original image. Fortunately, in the real world we will simplify by agreeing in advance to use "standards". Standards represent agreed-upon values for things like the size and shape of the pieces, how brightness information is handled, how the pieces are organized, how fast they will be sent, and what signal we will use to say when the whole process starts. The "agreed-upon standards" constitute a package of information that represents the essence of what we call video ***modes***. If the receiving station knows the mode being used at the transmitting end, the image receiving problem consists of simply waiting for the start of the image, collecting the brightness information at the proper rate and time, and reassembling the image in the proper order. We will examine categories of video modes later, but first let's take a generic look at the concepts inherent in the scanning process.

## PICTURE ELEMENTS AND SPATIAL RESOLUTION

The basic sampling piece or unit is known as a ***picture element*** or ***pixel***. In an analog imaging system, pixels are generally considered to be round, although in practical circuits the actual sampling area may be somewhat oval. In digital system (particularly displays), pixels are either square or rectangular. In the case of PC-class computers with VGA/SVGA displays, pixels are square, which greatly simplifies the discussion to follow. With square pixels of a given size, we can consider an image to be broken down into an array of pixels, with the size of the array being a function of the size of the pixels, relative to the image and the proportions or ***aspect ratio*** of the image. If the pixel size is small compared to the size of the image, the pixel array will have a large number of elements and relatively high ***resolution*** — the ability to display fine detail in the image. As pixel size increases relative to the image, the pixel array gets coarser; and less image detail can be displayed.

**Figure 2.1.** My granddaughter, Tori, caught in the act during an Easter-egg hunt. This will be used as a reference picture to illustrate the effects of both spatial and tonal resolution. The original is a continuous-tone photograph which was scanned at a spatial resolution of 1280 × 960 pixels with 8-bit (256 tonal values) grayscale coding. While some weather satellite/fax images have higher resolution, this image has considerably higher resolution than any current amateur imaging mode.

All of these concepts are easier to understand if we look at a real image such as the one in **Figure 2.1**. This image has a lot of fine detail and is basically rectangular in shape. The ratio of the width of the image to its height defines the image ***aspect ratio***, which in this case is 4:3. The spatial resolution we can achieve is a function of how many pixels we use to sample the picture. We will look at four possibilities relative to the width of the image — 80, 160, 320, and 640-pixels. Since the image has a 4 (H):3(V) aspect ratio, the four possibilities are a grid of [80 × 60], [160 × 120], [320 × 240], and [640 × 480] pixels. The array size and total number of pixels in each array are summarized in **Table 2.1**. **Figure 2.2** shows our test image at each of the display resolution values. **Figure 2.3** illustrates the center section of each of the test images, enlarged to compensate for the loss of resolution inherent on the half-tone printing process. Even a quick examination of the two figures supports our first major generalization:

**The greater the number of pixels in the sampling/scanning array, the higher the resolution or potential to portray detail within an image.**

From the outset, it is helpful to begin thinking of the image pixel array in terms of information. Since each pixel represents the **average** brightness of the area represented by the pixel, large pixels (smaller pixel arrays) result in a greater loss of information about the image. It is this information

**Table 2.1.**

Four different pixel arrays (**A-D**) for an image with a 4:3 aspect ratio. The total number of pixels in each sampling grid is included (**Total Pixels**), as well as the ratio of the total pixels for each mode (**Content Ratio**) compared to the total number of pixels in the smallest array (**A**). **B** thus has four times the total pixels as **A**, and **C** has four times the total pixels relative to **B** or 16 times the content of **A**, etc.

| **Array** | **A** | **B** | **C** | **D** |
|---|---|---|---|---|
| **H × V** | 80 × 60 | 160 × 120 | 320 × 240 | 640 × 480 |
| **Total Pixels** | 4,800 | 19,200 | 76,800 | 307,200 |
| **Content Ratio** | 1 | 4 | 16 | 64 |

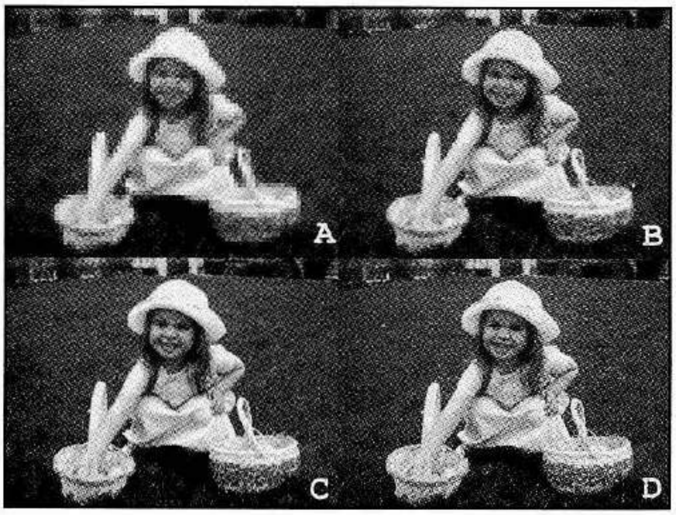


**Figure 2.2**. The image in Figure 2.1 displayed at four different spatial resolutions: **[A]** is displayed with a grid of 80 × 60 pixels, **[B]** at 160 × 120 pixels, **[C]** at 320 × 240 pixels, and **[D]** at 640 × 480 pixels. Since the actual resolution is likely to be obscured by the half-tone screening used to print the figure, Figure 2.3 is provided to show a subset of each image at higher magnification.

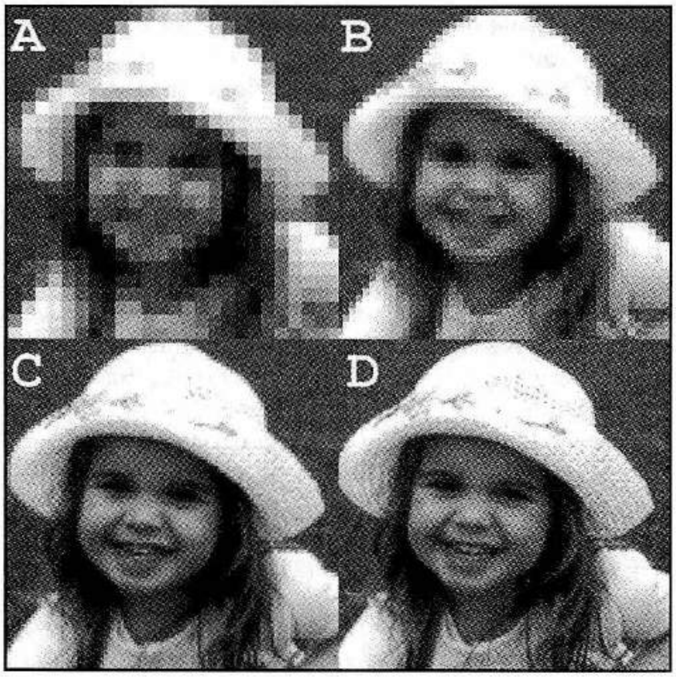


**Figure 2.3**. Given the limits of half-tone printing, the center section of each of the images in Figure 2.2 has been enlarged to better illustrate the limits of the various display resolutions: **[A]** 80 × 60 pixels, **[B]** 160 × 120 pixels, **[C]** 320 × 240 pixels, and **[D]** 640 × 480 pixels. For general reference, **[B]** is roughly comparable to the original 128 line SSTV scan converters, **[C]** is comparable to the medium resolution SSTV formats now in use, and **[D]** is equivalent to the current high-resolution SSTV formats. The actual resolution obtainable on fast-scan ATV will fall somewhere between **[C]** and **[D]**, while facsimile formats will typically have higher resolution than the original test image (Figure 2.1).

that lets us reconstruct details within the image. For example, the image subset in Figure 2.3B contains four times as many pixels (pixels = data points) as Figure 2.3A, and the difference in image detail is obvious. Figure 2.3C has four times the pixel content of Figure 2.3B and 16 times that of Figure 2.3A; and the resulting increase in information content is interpreted as a more detailed image.

In comparing resolution, as we are doing in Figures 2.2 and 2.3, it is critical that the images being compared are shown at the same size. If low-resolution images are displayed using a smaller format, they will look better simply because the eye will tend to miss some of the lack of detail. This leads us to a second generalization:

**When displaying images, the size of the display should be proportional to the resolution of the image in question.**

In effect, we can partially compensate, in terms of perception, for the lack of image detail by using a smaller display format for lower-resolution images. Enlarging a low-resolution image, much like looking at a newspaper halftone through a magnifying glass, only emphasizes the lack of actual detail in the image. This elementary principle was over-looked in the late 1960s when the development of magnetic-deflection monitors made possible the use of larger tubes (up to 12 inches) for SSTV monitor displays. At normal viewing distances, all the shortcomings of the early 120-line images were painfully obvious and the pictures weren't at all impressive. However, such larger display screens were useful when the monitor had to be viewed at a greater distance, since the perceived image was then relatively small.

There are some points with respect to perceived resolution in digital vs. analog systems that are worth noting at this point. Pixel geometry and sampling is very precise and discrete in digital systems. By contrast, analog sampling is a much messier business, but this is sometimes an advantage. With respect to display, for example, the analog "pixel" is a circular spot that moves along in a linear fashion — a **scanning line**. In effect, analog data are essentially continuously interpolated and integrated with time. The result is that the equivalent analog data often have a "softer" appearance when compared with the digital version of the same image. In **Figure 2.4** the facial area in the 160 × 120 pixel version of Figure 2.1 has been enlarged in the original digital display Figure 2.4A, and in analog form, Figure 2.4B. Both image subsets have the same total information content, yet most viewers would prefer the analog version. The "softer" (actually more integrated) display tends to de-emphasize the effect of the low-resolution sampling, hence obscuring the artifacts created by the low pixel density. When digital scan converters were first developed, they had limited memory capacity and hence low pixel density. Even though the scan converters featured much greater operating convenience, many operators still preferred the perceived quality of the analog displays,

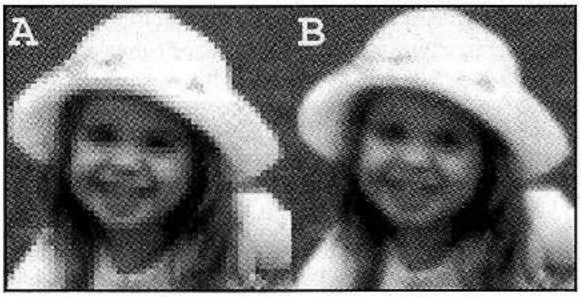


**Figure 2.4**. A comparison between the center-section of a 160 × 120 pixel digital display **[A]** and an equivalent analog display **[B]**. Both images have precisely the same image data content but the analog display **[B]** would be judges superior by most viewers. This apparent increase in resolution is due to a number of artifacts of analog sampling that are discussed in the text.

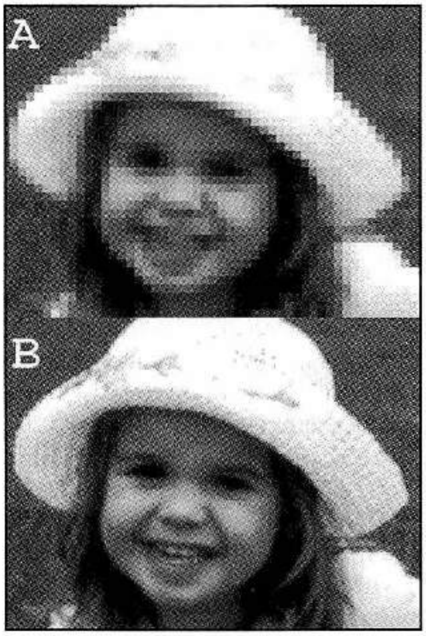


**Figure 2.5.** When working with low-resolution modes, the best results will be obtained if you concentrate of specific areas of interest within the larger image. For example, if the image in Figure 2.1 is sampled at 160 × 120 pixels, facial details are poorly resolved **[A]** since the face only occupies a small part of the total image area. If the face is the primary object of interest, zooming in and sampling just the face with the 160 × 120 format **[B]** produces a much more effective picture.

particularly when the entire 8-second frame was captured in a photograph. It should be noted here that motion, in either an analog or digital display, creates the same perceived increase in resolution. If you have ever paused your VCR to view a single frame of a conventional TV image, it is remarkable how limited the quality actually is. When a stream of such images is integrated by the brain, given the limits imposed by the latency of the human visual system, the picture appears to be much "clearer" or "sharper". It really isn't with respect to data content, but the effect is useful in terms of perceived resolution.

When the resolution of an imaging system or mode is limited, careful thought is needed to take best advantage of the resolution that is available. For example, if the image in Figure 2.1 is transmitted using a 160 × 120 pixel array as in **Figure 2.5A**, facial details are really quite marginal, since the face occupies only a small proportion of the total pixel array. If the face is the most important element, it would be better to "zoom" in on the image so that the face was sampled by most of the pixel array as in Figure 2.5B. The resolution of the system hasn't changed, but the close-up looks much better because you take best advantage of the resolution that is available. Faces are particularly good subjects when resolution is limited, in large part because the brain has tremendous capacity to process facial details. Resolution was so limited in many early mechanical TV systems that faces were the only subject matter that viewers could recognize. The fact that these early systems displayed moving pictures also enhanced the perception of relative image quality.

## SCANNING GEOMETRY — ORGANIZING PIXEL ARRAYS

So far we have discussed the image as a simple array of pixels. If we were talking about working entirely within the digital realm, it wouldn't matter what pattern we used to transmit the pixels, as long as the same sequence was used at each end. That, in fact, represents a marvelous way to encrypt an image. If a unique pattern or key is used to select the order or sequence for transmitting the individual pixels in the array, the receiving station would have to reassemble the picture using the same key.

Fortunately, the vast majority of our imaging modes are the products of analog technology. By definition, things have to be very linear in the analog world if complex operations are to be performed in a predictable way. **Figure 2.6A** shows the basic layout of a facsimile system — the oldest of our imaging technologies. In the case of a fax transmitter, the photograph or other material to be transmitted is wrapped around a cylindrical drum. The drum is driven by a synchronous motor (**M1**) that causes the drum to rotate at a very constant speed — let's say 240 rpm or 4 revolutions per second. An optical system, mounted on a carriage, is used to focus a small, intense spot of light on the surface of the drum. As the drum rotates, the spot of light traverses a straight line across whatever portion of the image is located in line with the light source. Since the drum rotates four times every second, the light spot essentially traverses or ***scans*** the image at a rate of 4 lines/second or 240 lines/minute (lpm). In the case of a transmitter, the system would have a photocell of some type to pick up the varying light intensity reflected from the drum, using this varying electrical signal to modulate the fax signal. The arrangement at the receiving end of the circuit would be similar, except that the light spot would be replaced by a modulated light source to expose a sheet of negative film or photographic paper wrapped around the drum. If electro-sensitive paper were used, the light source would be replaced by a wire stylus that would apply a varying voltage to "write" the scan line brightness variations onto the paper surface.

If all we did was to rotate the drum, the same area of the image would be scanned again and again, repeating the scanned line to no purpose. If we examine Figure 2.6A, we will see that there is a second motor in the system (**M2**), driving a threaded rod that engages the carriage containing the optical system or stylus. M2 operates at a slower speed

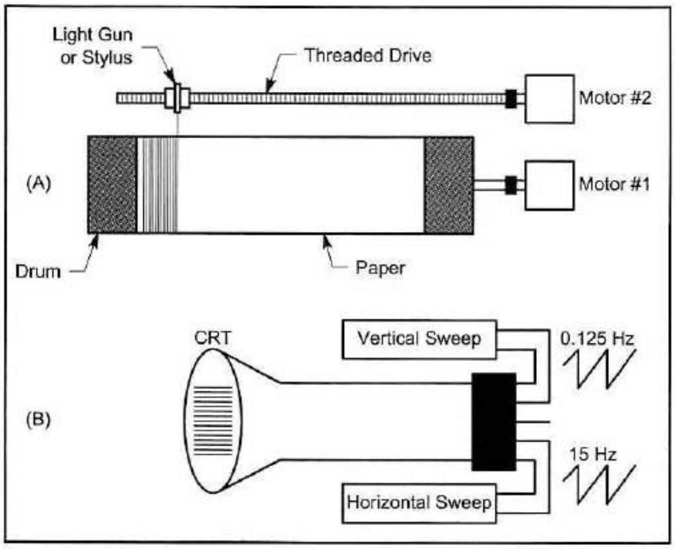


**Figure 2.6. [A]** A simplified diagram of a facsimile transmitter/recorder, illustrating the mechanical origins of linear image scanning. **[B]** Linear scanning implemented using an electrostatic cathode-ray tube (CRT).

than M1 — let's use 36 rpm as an example. By the time the drum completes one rotation, the second motor, driving the carriage via the threaded rod, has moved the entire assembly along the drum by a small increment. As a result, the next rotation of the drum will scan a line just below the first one. As scanning continues, eventually the spot of light at the transmitter and the light-gun/stylus at the receiving end will have scanned the entire image area, one line at a time.

The mechanical aspects of the facsimile transmitter/recorder thus establish the geometry of the scanning process. If the drum has a diameter of 2.25 inches ( 5.72 cm), the circumference of the drum will be 7.06 inches (3.1416 × 2.25). If we assume the scanning lines are horizontal with respect to the image, the width of the scan line/image is 7.06 inches (~18 cm). If we further assume that the image we are transmitting is essentially square (aspect ratio = 1:1), the time, in minutes ($T_m$), required to scan from the top to the bottom of the image is:

$$\mathbf{T_m = H / ((1 / P) \times S)} \tag{2-1}$$

Where:
H = image height
P = drive rod pitch
S = drive rod rpm

We know that H=7.06 inches, S is 36 rpm, so the drive rod pitch is the only value that we need to define. Since $^{1}/_{4}$-24 pitch threaded rods can be obtained from most hardware stores, let's use a value for P of 24 threads/inch (9.45 threads/cm):

$$\mathbf{T_m = 7.06 / ((1 / 24) \times 36)} \tag{2-2}$$

$$\mathbf{T_m = 7.06 / 1.5 = 4.7 \text{ minutes}} \tag{2-3}$$

With the system specified, it will require **4.7 minutes** to completely scan/transmit the image. Note that the answer is the same if you use the metric values for **H** and **P**. Since we know that the image is being scanned at a rate of 4 lines/second or 240 lines/minute, our image, as transmitted, will consist of 1128 scanning lines (240 × 4.7).

In practical terms, to realize this relatively high resolution, the spot/stylus trace has to be sufficiently small so there is no significant overlap from line to line. The mechanics of the system also have to be finely tuned, for any wobble or other unwanted movement can cause a pattern of overlapping scan lines along with unwanted gaps between lines. While the mechanical aspects of the system basically predefine how the image is scanned, they also make it difficult to change scanning geometry to accommodate multiple image modes. The only options that are readily available include multiple operating speeds for the two motors (via external gearing or the basic construction of the motors themselves). Most mechanical fax systems are designed for a single mode or rarely two modes. It is also worth noting that we had the luxury of choosing whatever options we wanted in this example. If we were designing a fax recorder to receive images in a pre-established format:

- the drum rotational speed would have to match the line-rate of the image format
- drive rod pitch and drive motor speed would have to be selected to create an image with the proper number of scan lines and image aspect ratio

Note that we really didn't mention pixels when discussing the resolution of our hypothetical facsimile system. Pixels are very real entities in the digital world, but are somewhat more theoretical in the analog world, where the scanning "spot" is in constant motion in two axes! In the world of analog video, the **scanning line** is the definitive entity and systems are characterized by the line rate (in lines/second or lines/minute) and the **number of scan lines** that comprise the image. In looking at how our sample facsimile system might be viewed in digital terms, it wouldn't make much sense to sample pixels with much greater density than the number of lines in the image, since the latter defines the vertical resolution limits. We might choose a sampling strategy of selecting 1200 pixels during each video line. Since our image has 1128 lines, the pixel grid for the facsimile system would have a resolution of 1200 (H)× 1128 (V). This is essentially equivalent to the sample image in Figure 2.1 and indicates the high-resolution that can be achieved with a facsimile system.

In the transition from facsimile to mechanical television, the problem was how to scan multiple images each second, given the limits of the scanning mechanics. The problem was initially solved using a scanning (Nipkow) disk (see Chapter 3) with a spiral series of holes. These holes served to scan the image with every revolution of the disk. The number of scanning lines was equal to the number of holes on the disk, and the line rate was a function of the speed of the motor driving the disk. Many of today's mechanical television experimenters use a disk with 32 holes — hence the image has 32 scanning lines. If a 750 rpm drive motor is used, the disk will scan the images 12.5 times each second (750 / 60). Such a system would produce 12.5 image or frames each second. Since the image or frame rate is easier to express than the line rate (which, in this system would be 12.5 × 32 or 400 lines/second), television systems are often characterized by the number of image lines and the frame repetition rate. In this case, we would be talking about a 32 line/12.5 frames/second (fps) system.

As noted in Chapter 1, early television systems were typically limited to images of 60-120 lines, simply because of mechanical constraints. If television were to advance, some means had to be found to circumvent the mechanical limitations and that means turned out to be the cathode ray tube (CRT). Figure 2.6B shows a simple diagram that illustrates how scanning is performed using a CRT. The scanning tool in a CRT is a tightly-focused beam of electrons, accelerated in a vacuum, that strike the phosphor coating at the flat end of the tube, creating a spot of light. Since the electron beam is in a vacuum and has almost no mass, it is easily deflected by plates inside the tube that are charged to high-voltage potential (***electrostatic deflection***) or by magnetic fields generated by current-carrying coils wrapped around the neck of the tube (***magnetic deflection***). Figure 2.6B illustrates an electrostatic deflection system. If a high-voltage ramp (the voltage increases in a linear fashion with time) is applied to the horizontal deflection plates of the tube, the spot can be adjusted to move from one side of the tube to the other at a rate determined by the frequency or ramp repetition rate. Let's assume the ramp has a frequency of 15 Hz and that the beam can be reset to its starting position by rapidly discharging the ramp voltage to its initial value. The result will be the formation of a scanning line on the face of the tube that repeats 15 times each second. The varying voltage applied to the horizontal deflection plates is known as the ***horizontal deflection*** waveform. The very short time required to reset the trace to its starting position is known as the ***retrace interval***. If, at the same time we are scanning the tube horizontally, we also apply a lower-frequency voltage ramp to the vertical deflection plates, the scanning line can be deflected up or down, depending upon the polarity of the applied vertical deflection voltage. If we apply an 8-second voltage ramp to the vertical plates, we can move the scanning line from the top to the bottom of the CRT display in 8 seconds. Since the horizontal deflection is producing 15 lines each second, the result, after 8 seconds of vertical deflection, is a pattern of 120 scanning lines on the face of the tube. This pattern of lines is known as a ***scanning raster***. This is precisely the scheme employed in early electrostatic SSTV monitors.

Precisely the same raster can be created by using a magnetic deflection CRT, equipped with vertical and horizontal deflection coils around the neck of the CRT. In this case the deflection circuits are designed to produce a ramp-like waveform with respect to current and the current induces vertical and horizontal magnetic fields that deflect the scanning beam. While electrostatic CRT displays are used for oscilloscopes, most imaging monitors employ magnetic deflection. Magnetic deflection of the beam requires current; but that current can be generated at low voltage, compared to hundreds of volts of deflection voltage required for an electrostatic CRT. Electrostatic tubes are also typically limited to 1500-2000V for accelerating the electron beam, which means the trace is not very bright. In contrast, even a small electromagnetic CRT uses 7-10 kV of acceleration voltage, producing a much brighter image display.

Unlike mechanical systems, the nature of the scanned raster on a CRT is simply a function of the drive circuits; and it is comparatively easy to design a CRT display for more than one mode. Until very recently, all televisions sets and computer monitors were built around magnetic deflection CRTs. The primary difference between the two applications is that TV scanning wave-forms have historically been generated by analog circuits, while multi-mode computer monitors use digital circuits to synthesize the scanning ramps. The main drawback with respect to magnetic CRT displays is the bulk and weight of the tube at larger screen sizes and the need to generate a very high voltage for the acceleration potential and moderately high voltages for focus and modulation of the trace. Solid-state display technology has now improved to the point where both TV sets and computer monitors can employ flat-screen arrays of liquid-crystal (LCD) pixels. These panels operate at low voltages and "scanning" is simply a matter of using digital circuits to address the pixels in the proper order. As prices continue to fall as display and color resolution increases, the time will certainly come when CRT monitors join mechanical television displays on the dusty shelves of museums devoted to the history of technology.

As is often the case in introducing a topic, I have glossed over a few complications in order to look at the "big picture". Usually those complications were avoided by using phrases such as "Let's assume...". Well, it's time to look at the assumptions. One of the first assumptions we made was that scanning would be horizontal with respect to the image, but that need not be the case. Most image modes we will use, including fast-scan and slow-scan TV employ horizontal scanning. With high-resolution modes, there is no technical advantage to either vertical or horizontal scanning. Whichever is used is a matter of history or convenience. **Figure 2.7A** illustrates a picture with horizontal scanning while 2.7B illustrates the same image with vertical scanning. In the case of low-resolution imagery, there may be a subjective or perceptual bias toward one format or another. When Baird developed the standards for his 30-line mechanical TV system in the late 1920s (Figure 1.6), extensive viewer evaluation suggested that vertical scanning seemed to result in better potential for facial recognition when coupled with a vertically elongated aspect ratio. Since line scanning can be oriented either horizontally or vertically, the **orientation** of the line scanning has to be specified for any particular mode. The **direction** of the line scan, with respect to the origin/start and end, has to be specified as well. Finally, the line scanning **rate** must be specified. Usually this will be lines/second,

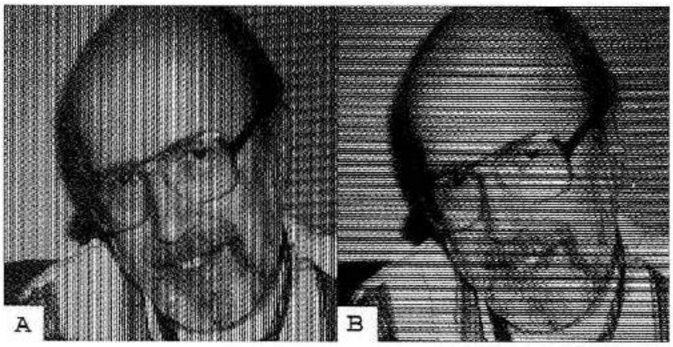


**Figure 2.7.** Examples of vertical **[A]** and horizontal **[B]** image scanning.

**Table 2.2.**
An example of the scan geometry definitions for two different imaging modes.

| PARAMETER | 8-Sec. SSTV | 32-line NBTV |
|---|---|---|
| **Aspect Ratio** | 1:1 | 2:3 |
| **Line Scan Orientation** | horizontal | vertical |
| **Line Scan Direction** | left to right | bottom to top |
| **Line Scan Rate (Hz)** | 15 | 400 |
| **Frame Scan Orientation** | vertical | horizontal |
| **Frame Scan Direction** | top to bottom | Right to left |
| **Frame Scan Rate (Hz)** | 0.125 | 12.5 |
| **Image Lines** | 120 | 32 |

especially for television signals, but fax systems may be documented in lines/minute.

The next cluster of definitions concerns the **frame** scanning — the geometry associated with the succession of line scans from the start of the image to its end. The parameters here parallel those of line scanning — orientation, direction, and rate. If we know the line scan rate ($\mathbf{R_L}$) and the frame scan rate ($\mathbf{R_F}$), it is easy to calculate the number of scanning lines (**L**) making up a particular image

$$\mathbf{L} = \mathbf{R_L} / \mathbf{R_F} \qquad (2\text{-}4)$$

**Table 2.2** provides an example of how the line and frame scanning specifications can document the scanning geometry for two quite different imaging modes.

To this point, our discussion has concentrated on the spatial aspects of image resolution and organization. Now it is appropriate to pause and look at the question of tonal resolution — how faithfully the image reproduces the range of grayscale tones in the original image.

## TONAL RESOLUTION

In the days when all image communication systems were analog, tonal resolution was a matter of keeping track of linearity and dynamic range of the various items in the equipment chain:

- Adjust lighting, gain, or other parameters at the camera (or its equivalent) end of the circuit to make best use of the dynamic range available.
- Optimize gain and linearity in the video modulation circuits.
- Assure that the video demodulation circuits were operated within their dynamic range.
- Adjust the equivalent of brightness and contrast at the display end of the circuit for best image reproduction.

The key was to have at least one primary element — camera or monitor — properly adjusted for the mode in question. If, for example, you had set up the adjustments on your monitor using a signal of known quality, you could then use the monitor to adjust and optimize the operation of a new camera. Similarly, if the camera system was properly adjusted, it could be used to provide a test signal to set up a new monitor. Problems inevitably arose when both items were uncalibrated! It is possible to set up analog image gear without benefit of elaborate test equipment, but either the monitor or camera must be set-up using a properly calibrated source.

In the world of analog video, tonal resolution is a matter of signal dynamic range and reference levels. In the digital imaging world, tonal resolution is determined by how much memory is allocated for storing pixel data. The number of grayscale steps is determined by the number of memory bits allocated for each image pixel:

| BITS/ PIXEL | TONAL SCALE STEPS |
|---|---|
| 1 | 2 (binary) |
| 2 | 4 |
| 3 | 8 |
| 4 (nibble) | 16 |
| 5 | 32 |
| 6 | 64 |
| 7 | 128 |
| 8 (byte) | 256 |

**Figure 2.8** illustrates the tonal/grayscale quality attained with 1, 2, 4, and 8-bit pixel coding. In the early development of digital scan converters, the capacity of memory devices (shift-registers or RAM) was limited, and they were very expensive. Thus, there was considerable incentive to look at the best tradeoff in both spatial and tonal resolution to reduce the cost and complexity of these pioneering systems. While binary (1-bit/2-tone) data could be used for drawings and simple ID slides, useful grayscale display seemed to demand a minimum of 4-bit coding, where each pixel could represent any of 16-possible brightness variations from black (0) to white (15). 4-bits (a "nibble") represents one half of a byte, so it is possible to "pack" data for a pair of pixels into every byte, thus reducing the memory storage requirements. Depending upon the image content, there could be significant grayscale contouring in 4-bit imagery, particularly at lower resolution. The contouring or "paint-by-numbers" appearance is considerably reduced at higher levels of image spatial resolution, but the problem can be eliminated entirely by using more memory-bits to store pixel data.

Beyond four bits, the possibilities are obviously 5-bit (32-step), 6-bit (64-step), 7-bit (128-step), or 8-bit (256-step). The odd-numbered possibilities (5 and 7-bit) are typically rejected due to the fact that an odd-number of bits is tedious to handle in terms of video memory management. Pictures in 64 steps look quite good, compared to 16 steps; thus, some early systems employed 6-bit coding, which complicated memory management slightly. However, 8-bit/256-step coding does produce better images; and the cost of memory is no longer a factor in a world where PC video cards now come with 2-4 megabytes of RAM as the standard entry-level configuration. Eight-bit coding also has the advantage that each pixel represents a single byte, and the byte is the standard unit for memory manipulation. In the case of grayscale images, there is no need to go beyond 8-bit coding. Brightness levels at 256 steps cannot be differentiated on a display screen, so there is nothing to be gained by increasing the required memory for pixel coding. That is not the case when it comes to color, a point we will consider in a later section.

## IMAGE RESOLUTION, TRANSMISSION TIME, AND BANDWIDTH

Since it is obvious that higher pixel densities produce better images, one could ask why even bother with lower-resolution formats. Why not just transmit the image at the highest attainable resolution (pixel density)? The answer begins with the **Total Pixels** entry on Table 2.1. The pixels represent data, which is typically sent in a simple serial stream. It takes time to transmit the data; and, all other things being equal, increased resolution means that a longer time is required for transmission.

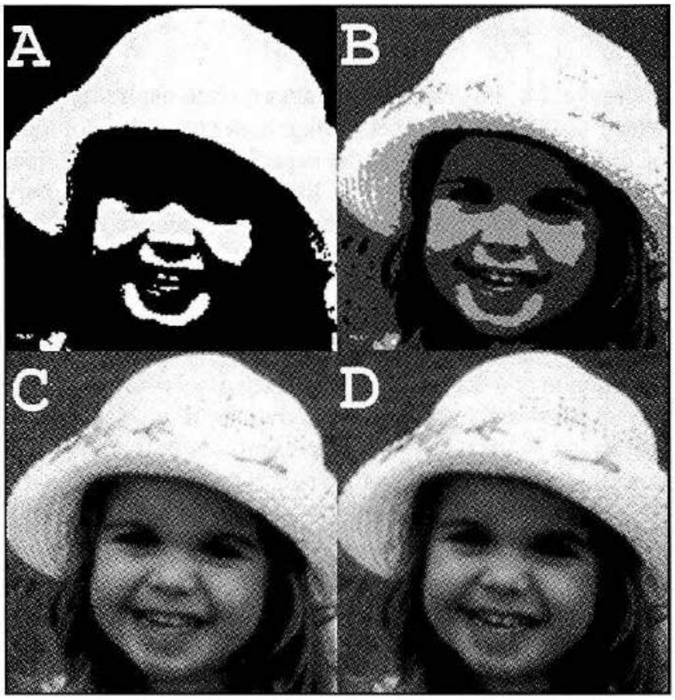


**Figure 2.8.** Varying levels of tonal resolution. **[A]** 1-bit/pixel (2 grayscale values), **[B]** 2-bits/pixel (4 grayscale values), **[C]** 4-bits/pixel (16 grayscale values), and **[D]** 8-bits/pixel (256 grayscale values).

As a baseline, let's look at the case of the 160 × 120 format — very close to the original SSTV transmission format. In that format, video data were transmitted at a rate of 15 lines per second. In this case, the "lines" would be equivalent to 128 pixels. If 15 lines are transmitted each second, the pixel transmission rate is 15 × 160 or 2400 pixels/second. Since our image contains a total of 19,200 pixels, the time required to transmit the entire pixel array is 8 seconds (19200/2400). It should be obvious, based on our earlier discussions, that a 320 × 240 image is going to look better than one with a 160 × 120 pixel array (see Figure 2.2); but such an image will have four times as many pixels (76,800) as the lower-resolution image. Remember, resolution is essentially equal to data! If we transmit the "bigger" image at the same rate (2400 pixels/second), it will take a total of 32 seconds (76800/2400) — four times as long!

If you have stayed with me this far, you should be nodding your head — yes, four times the image data should require four times the image transmission time — ***but only if we send the data at the same rate***! Why can't we send the data four times faster and still get the job done in 8 seconds? Well, we could, but it will cost us somewhere else — notably in the ***bandwidth*** required to handle the image signal. Let's do a very simple analysis to highlight the nature of the problem. A reasonable approximation of signal bandwidth can be calculated as follows:

$$\mathbf{B = ((P \times L) \times F)/2} \qquad (2\text{-}5)$$

where:

B = bandwidth (Hz)
P = pixels per line
L = number of lines
F = frames / second

Substituting, we get:

$$\mathbf{B = ((160 \times 120) \times 15)/2 = 1200\ Hz} \qquad (2\text{-}6)$$

Now, let's take our second image, transmitted at the same rate as the first. We know P = 320 and L = 240. If we use four times the transmission time, F must be 0.125/4 or 0.03125:

$$\mathbf{B = ((320 \times 240) \times 0.03125)/2 = 1200\ Hz} \qquad (2\text{-}7)$$

Thus, if the image is transmitted at the same rate as the first one, our bandwidth stays the same. We transmit four-times the image data, but we do so entirely on the basis of increased time to transmit each frame. If, however, we increase the frame rate to transmit the image in 8 seconds instead of 24 (x 4), we get the following:

$$\mathbf{B = ((320 \times 240) \times 0.125)/2 = 4800\ Hz} \qquad (2\text{-}8)$$

This leads to still another generalization:

**Increasing the resolution of an image requires either a proportional increase in the time required to transmit the image, a proportional increase in the bandwidth of the transmission channel, or some combination of the two.**

Within the amateur service, both fax and SSTV transmissions must not exceed the maximum total bandwidth as a SSB (phone) signal. Given modulation constraints (which will be discussed in Chapter 3), it is difficult to achieve pixel transmission rates significantly in excess of 2500/sec. and still stay within the required bandwidth restrictions on the HF bands. The problem becomes even more acute when we increase the image file size to accommodate color — something we will discuss shortly.

On the HF bands, time is likely to be the major constraint, assuming the legal bandwidth requirements are observed. In theory, we could send images that required up to ten minutes for transmission (to allow for the mandatory station identification at ten-minute intervals); but such transmissions would be far too long in our relatively congested HF bands. Any transmissions in excess of 3-4 minutes will present practical problems on bands below 15 meters. On 15 meters and higher HF frequencies, useful work can be done with high-resolution formats requiring 6-7 minutes, provided the bands are not too crowded and one avoids the standard SSTV calling frequencies. The chapter on SSTV Operation will cover some of the criteria for the selection of optimum modes under various situations.

It should be noted that the audio bandwidth restrictions apply only to the HF bands. On VHF and UHF bands, where wide-band FM (WBFM) is an option, significantly wider bandwidth can be employed. For example, the standard **NBTV** format involves sending a 32-line image at a 12.5 fps frame repetition rate. If we send 64 pixels on each line, the required bandwidth is:

$$\mathbf{B = ((32 \times 64) \times 12.5)/2 = 12.8\ kHz} \qquad (2\text{-}9)$$

This is obviously too wide for HF use but would be workable on any VHF or UHF band were WBFM was a legal option. Of course the ultimate wide-band mode is conventional TV, where we transmit 525 lines of video 30 times each second! If we assume that each line has 427 pixels (see Chapter 3), the required bandwidth is:

$$\mathbf{B = ((427 \times 525) \times 30)/2 = 3.36\ MHz} \qquad (2\text{-}10)$$

In practice we actually need more bandwidth (see Chapter 8), but the extremely wide nature of the broadcast TV signal is the reason the mode is restricted to UHF and microwave bands.

## SOME COLOR IMAGE BASICS

By this point you should be getting the idea that television is nothing more than electronic trickery that takes advantage of the limitations of the human visual system. The TV picture itself is an illusion, since it really isn't a picture at all — just a fast-moving spot of light that, given the latency of the human visual system, gets merged into what appears to be a continuous image. Similarly, the moving images on the TV screen aren't "real", but simply a rapid series of still images that the brain links into the perception of continuous motion — again a product of visual latency. Latency and some other attributes of human vision are also exploited to give the illusion of color in various imaging modes. To see how all this works, we will look at a very basic discussion of color imagery, broken down into several sub-topics:

- Mixing Primary Colors
- Image Analysis
- Transmitting Color Image Data
- Image Synthesis
- Digital Aspects of Color Imagery

We are at a slight disadvantage in that the budget for this book didn't allow for color printing, but if we discuss the topic carefully in this step-by-step fashion, it should be possible to convey some very basic information about how color imaging works.

### *MIXING PRIMARY COLORS*

Starting in basic science lessons in elementary school, we are introduced to the pioneering work of Isaac Newton on the qualities of light. Newton observed in 1666 that when white light was passed through a clear glass prism, the light dispersed into a literal rainbow of color. This ***visible spectrum*** runs from red at one end to violet at the other, with seemingly infinite gradations of other colors between these two extremes. Earlier workers had experimented with prisms, but they thought that the prism changed the color of the light passing through it. Newton was able to show that if any one of the colors of the spectrum were passed through another prism, the color did not change. His conclusion was that what we see as white light is actually a mixture of light of all possible colors in the visible spectrum. These colors were somehow fundamental properties of light, since they could not be broken down into additional colors.

What we perceive as "colors" actually represent variations in the frequency or wavelength of light. The "red" end of the visible spectrum has a wavelength of approximately 760 nm ($760 \times 10^{-9}$ meters) while the "violet" end of the spectrum represents a wavelength of approximately 380 nm. Later experiments showed that the ***visual perception*** of a complete visible spectrum did not require that all colors of the spectrum actually be present. As few as two or three ***primary*** colors could be integrated by the visual system to produce the equivalent of a full spectrum of colors. A range of colors can serve as primary colors, as long as they are sufficiently different in wavelength for the human brain to perform a useful integration. In practice, the easiest way to generate a good analog of the visible spectrum is to use **red**,

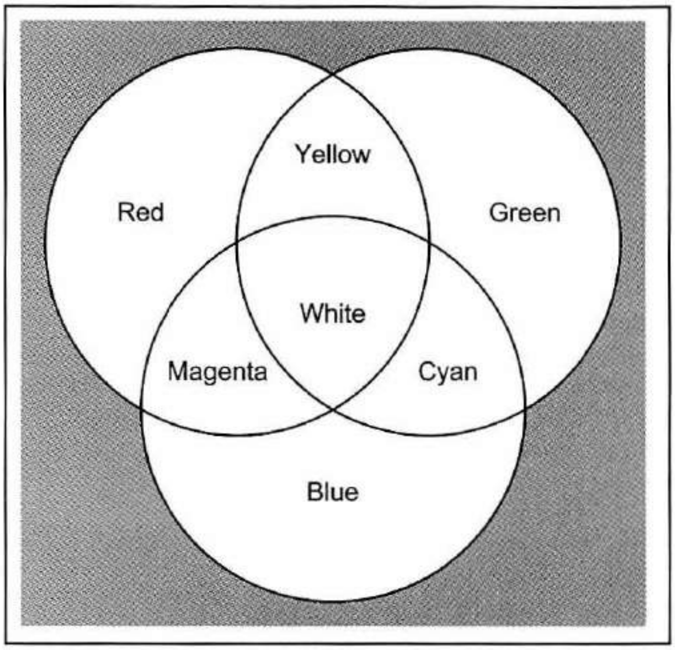


**Figure 2.9**. Additive mixing of light of three primary colors — red, green, and blue.

**green**, and **blue** as the primary colors.

**Figure 2.9** shows the effect of projecting overlapping circles of red, green, and blue light of equal intensity where no other source of light is present. Note that in addition to the three primary colors, the following "new" colors will be produced where the primary colors overlap to varying degrees:

| COLOR #1 | COLOR #2 | COLOR #3 | "NEW" COLOR |
|---|---|---|---|
| RED | GREEN | BLUE | WHITE |
| — | RED | GREEN | YELLOW |
| — | RED | BLUE | MAGENTA |
| — | GREEN | BLUE | CYAN |
| — | — | — | BLACK |

Also, although it seems trivial, note that where no light of any color is falling, the eye perceives BLACK — essentially the absence of color! If the intensity of all three colors is varied equally, the intensity of all the colors can be varied from very dark to very bright. This gets even more interesting if we vary the brightness of each source independently. For example, if red is brighter (+) than the other two primary colors:

| COLOR #1 | COLOR #2 | COLOR #3 | "NEW" COLOR |
|---|---|---|---|
| RED+ | GREEN | BLUE | PINK - RED+ |
| GREEN | ORANGE | | |
| — | RED+ | BLUE | MAGENTA |
| — | GREEN | BLUE | CYAN - |
| — | — | BLACK | |

Depending upon the relative brightness of the individual primary colors, virtually any perceived color can be produced when the colors are "mixed". The ability to create new colors by the mixing of red, green, and blue light provides the basis for almost all color imaging systems.

Prior to moving on to how this color effect can be put to practical use, a few more notes should be included for the sake of completeness. First, the color mixing which I have described is what happens with projected light — a phenomenon known as ***additive synthesis***. Additive synthesis is the phenomenon that is exploited with color slide and movie film and by the screen of every color television and computer monitor. However, it is possible to synthesize color ***subtractively***, using yellow, magenta, and cyan filters in a transmitted light mode. This is how color prints are made and is the reason for the unusual combinations of colors you see in a color print negative. Subtractive synthesis is used for transmitting commercial color fax images, where the color picture will be printed for publication; but the approach is not typically used in other aspects of color image communication. Note also that I have concentrated on the interaction of three primary colors. Useful color can be generated with just two primary colors and the colors can look quite good with specific subjects. However, the widest spectral synthesis and the fewest problems with color "voids" or other artifacts will be noted when three colors are employed.

### *IMAGE ANALYSIS*

From our previous discussion, it should be evident that it is possible to synthesize a full-color image from red, green, and blue image data. The first practical problem is how to obtain the three-color primary image data — a process known as ***image analysis***. The key to the analysis phase is the use of three primary color filters. The "color" of a filter is the result of the fact that a filter only passes light of a certain range of colors — red passes red light, green passes green light, and so on. If you care to experiment with color filters, it is best to start with filters with defined characteristics. The following filters are more-or-less standard for color analysis work:

**Red — #25**
**Green — #58**
**Blue — #43B**

Strictly speaking, the filter numbers apply to Kodak Wratten™ gelatin filters, but the same numbers are employed by manufacturers of glass photographic filters such as Tiffen and others. In each case, the filters will pass either the red, green, or blue light values, with brightness of the filtered image being proportional to the color spectrum in question.

**Figure 2.10A** illustrates a colorful image displayed in a grayscale format. In most cases, grayscale images are produced using a weighted average of the three primary color components — typically 30% red, 59% green, and 11% blue. Since I cannot present the image in color, a few comments on the color values of the scene will help you to appreciate the color-filter versions which follow.

- The general background behind the figures is a light blue.
- There is a light-green drape along the upper edge in the background and a light blue "ribbon" in the center, behind the figures.

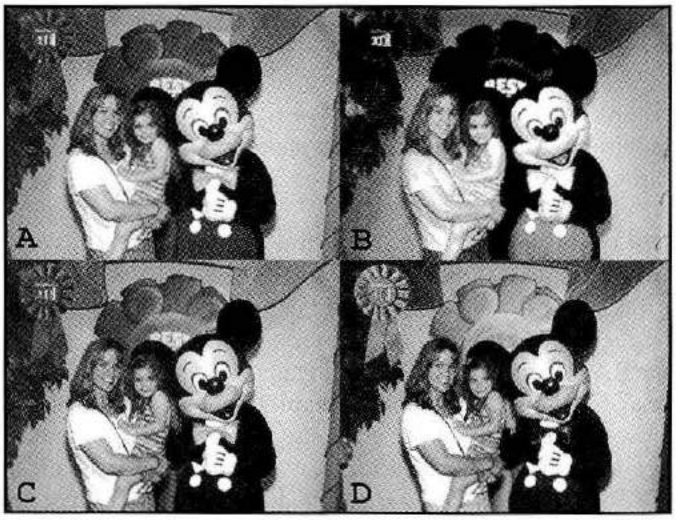


**Figure 2.10**. Building a color image. **[A]** shows a grayscale version of the original color image. **[B]** The color image as seen through a **red** (#25) filter. **[C]** The scene through a **green** (#58) filter. **[D]** The flower imaged through a **blue** (#47B) filter.

- There is a smaller dark blue ribbon in the upper-left quadrant of the image.
- Micky's trousers are a dark red with white buttons. His coat is black, his shirt is white, and he has a yellow bow tie.
- "Mom" has light blue jeans and a white blouse.
- There is an orange fake palm trunk to the extreme right of the image.

Let's assume we have a film-camera loaded with broad-spectrum (panchromatic) black and white film which we will use to photograph the scene through the three primary color filters. The three grayscale images that result are known as ***color separations*** because we have used the filters to "capture" and separate the three primary color components in grayscale form.

**Red** (Figure 2.10B). The grayscale view through the red filter indicates brighter tones associated with colors with a strong red component and darker tones where red is minimal or absent. Examples of bright (red-rich) areas include all white areas of the image, the yellow bow tie, the orange "palm" trunk, and, of course, the red trousers.

**Green** (Figure 2.10C). The grayscale view through the green filter indicates brighter tones associated with colors with a strong green component and darker tones where green is minimal or absent. Examples of bright (green-rich) areas include all white areas of the image, the yellow bow tie, and the orange "palm" trunk.

**Blue** (Figure 2.10D). The grayscale view through the blue filter indicates brighter tones associated with colors with a strong blue component and darker tones where blue is minimal or absent.

In effect, these three grayscale views contain all the color data required to reconstruct the full-color image. The Westinghouse 7290 "storage" vidicons used in early SSTV cameras (and most flying-spot-scanners) had almost no sensitivity at the red end of the spectrum. In order to prepare a color image for transmission, it was necessary to actually take black-and-white photos as described. The photos would then be carefully positioned, in sequence, in front of the camera to send the red, green, and blue image data. The conventional vidicons used in later sampling cameras had a much broader spectral response and the red, green, and blue views could be transmitted by using the filters (or an automatic filter color wheel) directly with the sampling camera, thus eliminating the photographic step.

Today, of course, you are far more likely to frame-grab an image from a color TV camera or scan the desired image with a color flat-bed scanner. The filters are still there, incorporated at a near-microscopic level into the CCD or other image-sensor array. You never see the grayscale color separation views either, but they are there as well, stored in distinct areas of the computer memory while you are looking at a color version of the image on the computer monitor screen.

### TRANSMITTING THE GRAYSCALE COLOR SEPARATIONS

Once the color separation data are prepared, either in the form of grayscale photos/images or as data stored in a computer memory, there are three distinct approaches that can be taken in transmitting the separation image data:

- Frame-sequential Format
- Line-sequential Format
- Pixel or Dot-sequential Format

***Frame-sequential*** is the easiest to envision, since it involves simply transmitting in sequence, the red separation image, followed by the green image, and finally the blue image. Of course, the "color" sequence had to be defined or specified in advance as it is possible to transmit the sets in any order. There also has to be mutual agreement as to the how many images of each view will be sent. CBS produced a frame sequential fast-scan TV system in that late '40s and early '50s that was one of the two main contenders in the race to define color TV standards in the United States. A normal monochrome CRT was used in the receiver (or in projection variants), with a high-speed synchronized color wheel. The system produced superb color images, but its mechanical complexity and lack of compatibility with monochrome transmission standards ultimately doomed its adoption as a universal standard.

The earliest experimental and practical SSTV color systems used the frame-sequential approach. Since a minimum of one complete frame of each color separation had to be sent in sequence, the minimum time required to send a color image was three times that required for a single grayscale frame — typically 24-25 seconds. Timing was not particularly demanding and excellent color quality was possible when all frames were received with little interference. However, the complete color image was not available until all three frames had been received. If transmission was interrupted for any reason, the entire color image was lost. In addition, any noise or interference that impacted selected portions of any one of the color separation frames would lead to color banding effects that distracted significantly from the perceived quality of the final color image. These are significant problems on our crowded HF bands and no frame-sequential SSTV modes are now in regular use.

***Line-sequential*** color works like the frame sequential mode except that individual lines of each color separation are transmitted in sequence:

**Red Line #1, Green Line #1, Blue Line #1**
**Red Line #2, Green Line #2, Blue Line #2**
**and so on...**

Different line-sequential modes may differ in the order in which the lines are transmitted. The Image transmission time is three times that for equivalent monochrome formats. The line-sequential approach is not practical with analog systems and therefore the first examples were introduced as digital scan converters became common. This approach provides a good trade-off between the various considerations that define the utility of a mode. The picture appears to readout in full color and, should transmission be interrupted, the portions of the image that have already been received are displayed in full-color. Interference and noise tends to impact lines of all three primary colors, so visual disruptions of the image appear to be less pronounced. Timing parameters are more tightly constrained but easily realized if system timing is related to a crystal time-base. Most of the current popular SSTV color modes are variants of the line-sequential approach.

In the Robot modes, each transmitted line consists of the equivalent of a full line of luminance data, followed by chrominance data in one of two possible formats. The advantage of the Robot formats is primarily one of time. All the SSTV color formats discussed to this point require transmission times three times longer than the equivalent monochrome image. In the case of the Robot modes, transmission time is either 1.5 or 2X the equivalent monochrome time, depending upon the mode variant selected. In general the Robot modes are now little-used on HF, although several new high-resolution modes have adopted a similar format to shorten the time required for image transmission.

In ***dot/pixel sequential*** color data are processed at the pixel level. There are no current SSTV modes using a pixel-sequential format, but all commercial broadcast color television modes use the technique. Extreme timing accuracy is required in order to avoid unwanted color shifts or artifacts. In the NTSC system for example, the color demodulator is phase-locked to the 3.58 MHz color sub-carrier (see Chapter 8). PAL and SECAM formats use a slightly different (and superior) approach, but the object is the same — to obtain a very accurate time reference for demodulating the chrominance component of the TV signal. This subject will be discussed in somewhat greater detail in Chapter 8.

### *DISPLAYING COLOR*

In the earliest analog experiments with color SSTV, there was no way to view the image directly on the P7 SSTV monitor. Instead, the signal, consisting of multiple frames of red, green, and blue chrominance data were typically recorded on audio tape and then replayed into the SSTV monitor. The display was then photographed sequentially through red, green, and blue filters as the appropriate frame was displayed. If color Polaroid™ film was used, the picture could be viewed within a few minutes. It wasn't the least bit practical, but it did work!

Digital scan converters eliminated all the fuss and bother by the use of blocks of image storage memory dedicated to the R-G-B image data. Depending upon the mode, incoming image data were routed to the appropriate memories as the slow-scan picture arrived while the memories were simultaneously clocked at fast-scan rates. For best image quality, the R-G-B color data were routed through three separate D/A (digital to analog) converters and straight into the video inputs of an R-G-B color monitor. Alternatively, the data were routed to an NTSC (or PAL) encoder, creating a composite color signal that could be viewed on a standard color TV monitor or on a broadcast set if an RF modulator were used following the NTSC encoder. From the late 1970s through the mid-1990s, dedicated scan converters performed the scan conversion function. By the late 1990s, computers became the tool of choice — a topic discussed at greater length in Chapter 7.

In the case of ATV, the received images are simply converted to a channel covered by the station television set and the set automatically performs the color decoding and display, just as it would with a commercial broadcast signal.

### *DIGITAL MEMORY REQUIREMENTS*

Some mention should be made at this point regarding the memory requirements for digital image display. The memory capacity, in bytes, required to store/display an image is:

$$\mathbf{M = (H \times V) \times B} \qquad (2\text{-}11)$$

where:
M = bytes of memory
H = number of pixels/line
V = number of lines
B = bytes/pixel

For example, a medium-resolution version of the image in Figure 2.10A would have 320 pixels/line and 240 lines. Since it is a grayscale image, each pixel is coded by a single byte (256 grayscale values):

$$\mathbf{M = (320 \times 240) \times 1 = 76{,}800} \qquad (2\text{-}12)$$

Color pictures require more memory since we must store data on the three primary colors. Since memory capacity is not an issue, it is more or less standard to use a byte of memory (8 bits) for each of the three primary colors. If you recall, 8 bits can encode for 256 possible tonal values, so if we have 8 bits allocated to each primary color, this is

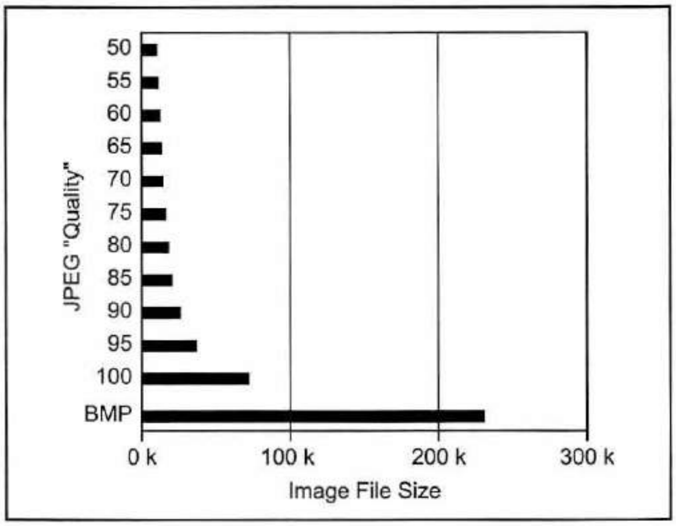


**Figure 2.11.** JPEG image file size at various "Quality" settings. The original image is Figure 2.10A, saved as a 320 × 240 × 24-bit file. The original BMP file (uncompressed) is included for comparison.

sufficient for 256 shades of red, green, and blue respectively. Since each byte represents 8 bits and we use three bytes for color data storage, this approach to coding is often referred to as **24-bit color** ($3 \times 8$) or **truecolor**. The total number of colors that can be displayed with 24-bit coding equals:

$$\mathbf{256 \times 256 \times 256 = 16{,}777{,}216} \tag{2-13}$$

When you see "24-bit color" and "over 16 million colors" on the advertising hype for cameras or scanners, you now know where those numbers come from.

The memory required to store the color version of Figure 2.10A ($H = 320$, $V = 240$, and $B = 3$) is thus:

$$\mathbf{M = (320 \times 240) \times 3 = 230{,}400} \tag{2-14}$$

**Color images typically represent three times the data of an equivalent monochrome image and thus require proportionally more time and/or bandwidth for transmission and reception....**

Obviously these memory requirements escalate rapidly as image resolution increases. High-resolution SSTV images (640 × 480) require 307,200 bytes for monochrome images and 921,600 bytes for 24-bit color. Facsimile and weather satellite images, even though they are not in color, have such high resolution that file sizes in the 2-5 megabyte range are common. The memory requirements of our images also impact the requirements for disk storage.

### *FILE FORMATS AND IMAGE COMPRESSION*

If we were to save an image in a binary file format, the disk storage required would be equal to the memory storage requirements previously discussed. However, most common graphics file formats have additional overhead in terms of headers and data table which increase the required file size. The bit-map (**.BMP**) file format is the native Windows™ graphics format and is fast and easy to use. All BMP files contain a 1078-byte file header that contains the information needed to properly reconstruct the stored image. If we know the memory requirements for a specific image (230,400 bytes for the 320 × 240 color version of Figure 2.10A for example), the BMP file size is the sum of the memory allocation + 1078:

$$\mathbf{230{,}400 + 1078 = 231{,}478\ bytes} \tag{2-15}$$

Obviously, as images get larger and more detailed, file sizes increase dramatically. Weather satellite images, for example, can easily exceed 2-3 megabytes per image file, and these pictures aren't even in color!

As graphics applications became more popular, particularly in conjunction with the growth of the Internet, programmers sought approaches to reducing disk storage requirements and the time required to download images. What evolved were multiple strategies for ***image compression***, all of which take advantage of the fact that any image contains a certain amount of redundant data — multiple adjacent pixels of the same or similar values, repeated patterns of pixels, etc. By coding such blocks as units, a significant reduction in file size can be realized. Compression algorithms fall into two broad categories — loss less approaches and compression routines in which some data are lost to further reduce file size. One of the most widespread **loss-less** options is the **GIF** (**G**raphics **I**nterchange **F**ormat) format, created by Compuserve™. A simple image, such as an ID slide, may compress to just 10% of its original size; but compressed files may be 80-90% of the original file size in the case of complex images. GIF images are quite common, particularly because they are compatible with the HTML language used to create web pages on the Internet. The format does have one major disadvantage — it only works with images with 256 or fewer colors (8-bit color). GIF files are a good option for monochrome images, but we need something else to handle 24-bit color images. There are a few other 24-bit loss-less formats (.PNG and .PCX for example), but they are not as widely used.

More significant levels of compression can be obtained if you are willing to lose some image data. The **JPEG** (**J**oint **P**hotographic **E**xperts **G**roup) format may well be the most common approach to image compression. Its popularity is based on three factors:

- The ability to compress 24-bit color files
- The option for selecting the degree of compression/image data loss
- Compatibility with HTML

When you proceed to save an image in the JPEG file format (.JPG extension on a PC), a graphics program will typically give you the option of controlling the degree of compression or the amount of data loss. Terminology varies, but less compression always means less data loss and vice versa. **Figure 2.11** shows the degree of compression achieved in the JPEG format using various "quality" levels. A medium-resolution copy (320 × 240 × 24-bit) version of Figure 2.10A was saved as a bit-map image (no compression), and multiple copies were saved at different quality levels.

As expected, the bit-map image file size is 231,478 bytes. Even at the highest quality setting (100), which is equivalent to minimal data loss, the file size was reduced to about 30% of the original. At a value of 90, the file is only about 12% of the original bit-map version. File size continues to decrease at lower "quality" settings, but the decrease is non-linear and clearly indicative of diminishing returns. While the degree of file compression is impressive, it comes at a price. When the files are displayed, definite compression-related artifacts begin to become evident at quality levels below 90 and become very objectionable by the time the quality factor declines to 70. These artifacts are most evident at edge boundaries and in areas of relatively uniform color distribution and represent image defects that I consider to be unacceptable. If limited disk space forces the use of compression, a quality index of 100 will produce a significantly smaller file with minimal data loss. It is my personal opinion that, with the availability of inexpensive hard-drives of very large capacity, not to mention optical media, that there is very little reason to resort to image compression. I do use GIF compression (loss-less) for large weather satellite image files and save all color SSTV images in bit-map (BMP) format.

**Never employ image compression to files that will be subject to later alteration...**

Let's assume we recall a JPEG image that has been subject to significant compression. Perhaps we want to add a call sign or other information or do some sort of image processing. The reconstituted image will have artifacts; and, when we again save the image after the work session, the original compressed image will be compressed. If it is later loaded back to the screen, any defects will have been compounded. In just a few editing cycles, the image will have become significantly degraded! Note that this does not apply if you simply load the image to look at it or print it. The problem only arises with multiple image saves. An image may be degraded to some extent, depending on the degree of compression, when you first save it, but it won't get any worse as long as you refrain from saving it again. It is also possible to copy the file any number of times with no additional decline in image quality — just avoid multiple "save" operations.

## SYNCHRONIZATION

A final topic of discussion is synchronization — keeping the display of an incoming image "in-step" with the scanning process at the transmit end of the circuit. Synchronization involves two distinct components:

- **Rate** — the basic rate at which pixels are clocked to the transmitter must closely match the rate at which incoming pixels are displayed.
- **Position** — some means must be provided to assure that the starting point for the scan of a particular line during transmission corresponds to the start of line scanning at the display end of the circuit.

Some systems emphasize extreme accuracy with respect to timing while others work using less precise timing data but compensating by constantly updating position data.

### *FACSIMILE*

The key synchronizing strategy with facsimile transmissions is the use of high-precision timing with respect to the operation of the equipment at both ends of the transmission circuit. As an example, let's examine the case of a classic drum-facsimile system (Figure 2.6A). The key to the operation of such a system is that the drum motors (M1) at both the transmitter and receiver operate at precisely the same speed for the duration of image reception. To achieve this, synchronous AC motors are typically used. Assuming the motors were designed to operate using 110 VAC at 60 Hz, one might assume that it was possible to use the mains voltage to power the motor since the 60 Hz power grid frequency is sufficiently accurate to run AC-powered electrical clocks. Unfortunately, while the long-term accuracy of the 60 Hz power mains is good, the short-term accuracy is not and, unless both motors were powered by the same AC grid, short-term fluctuations in frequency would badly distort a picture. In practice, the drive frequency for the drum motors is always derived from a precision source — typically a high frequency crystal oscillator and a digital divider chain. The accuracy requirements with respect to speed are stringent enough that the crystal oscillators must have provisions for very fine frequency adjustment to match them precisely to an external standard.

While accurate time-bases can assure that the two facsimile drums are rotating at the same speed, we also need to start them in step with respect to position. In other words when the transmitter drum starts the scan of the first line, the receiving drum should be positioned so that the light-gun or stylus is also starting its scan. To assure this, analog facsimile formats include a phasing interval at the start of the transmission to allow the receiving drum to get into step with the transmitter. The phasing interval runs anywhere from 5 to 15 seconds and consists of either white level or black level signal, depending upon format. A contrasting black or white level pulse is sent, corresponding to the start of the line scan on the transmitting drum. The receiving system detects this pulse and compares it with a pulse produced by the receiving drum as it starts its line scan. If the pulses do not overlap (and it's unlikely they will), the receiving drum is speeded up or slowed down slightly until they do, at which point the receiver drum is returned to the proper speed. This **phasing** assures that the two drums are operating at the same speed and properly phased or aligned with respect to scanning. The two systems will then continue to run in phase for the duration of the image transmission with no further attention.

The control of the second motor (Figure 2.6A, M2) that controls the equivalent of vertical scanning is not nearly as critical. The same circuits that control phasing are usually arranged to start the motor driving the lead screw as soon as phasing is achieved. A synchronous motor is typically used for M2 as well, but sufficient accuracy will usually be achieved by powering M2 from the mains supply.

### NARROW BAND TV

A significant amount of work in the area of Narrow Band Television (NBTV) replicates some of the apparatus from the era of mechanical television. One of the simplest mechanical receiving systems (Figure 1.4) uses a Nipkow disk operated by a high-speed synchronous or DC motor. Successful picture display requires that the disk be operated at just the proper speed and that the received image is properly phased with respect to the disk or its equivalent at the transmitting end of the circuit. Problems of speed regulation and phasing are analogous to similar problems with mechanical facsimile, but the solutions may be slightly different in practice as a result of the higher speeds associated with the TV transmission. In practice, many systems employ hybrid solutions that mix some of the technology from facsimile with the triggered displays used for CRT television display. Some of these approaches will be discussed in somewhat greater detail in Chapter 3.

### SYNC PULSES AND CRT DISPLAY SYSTEMS

As noted in Figure 2.6B, the scanning of a cathode ray tube is controlled by ramp generators driving either high-voltage, low-current electrostatic sweep circuits or low-voltage, high-current magnetic sweep drivers. In either case, the key to synchronization is to control the ramp generators. This can be done in one of two ways:

- **Triggered Sweeps** — The scanning ramps, both vertical and horizontal, are triggered or initiated by specific signals or pulses that are part of the video signal. If there is no video signal, there is no raster.
- **Phase-lock Sweep** — Both the vertical and horizontal sweeps are triggered by internal free-running oscillators. This results in the production of a scanning raster on the screen, even in the absence of a video signal. If a video signal is present, the free-running oscillators lock to the synchronizing pulses, thus insuring proper picture display.

The imbedded signals that provide the timing for either approach are known as **sync pulses**. Strictly speaking, sync signals might be better, since they need not be pulse-like with respect to the actual modulation waveform (see Chapter 3). The sync pulses are typically of two distinctly different types:

- **Line Sync** — The signal that triggers each scanning line is typically short in duration with respect to the time allotted for each line. For example, the original 120-line SSTV format transmitted 15 lines/second, or 66.66 ms per line. The line sync pulse was set to 5 ms duration — long enough to assure reliable detection but not so long as to take up too much valuable line transmission time. The detected pulse was used to either directly trigger the line sweep of the P7 monitor or to lock-up a phase-lock sweep oscillator running at a frequency just a bit slower than the normal sweep rate. If a line pulse was missed due to interference, no line would be triggered in the first case, or the sweep line would be just slightly misaligned in the second. It was the job of the camera circuits to generate the line sync pulse at the start of each line.
- **Frame Sync** — This is the sync signal that either starts the vertical scanning or resets the scanning as more than one image is sent in sequence. The display system has to be able to differentiate between line and frame sync, so the frame sync pulse is typically significantly longer than the line pulse. In the case of the original 120-line SSTV format, the frame sync pulse was 30 ms in length — essentially half the duration of the line interval. When a frame sync signal is detected, the frame sweep is either triggered directly, or the phase-lock sync circuit locks to the frame pulse repetition rate.

Sync-driven displays have the virtue of relative simplicity and are not at all critical with respect to timing, since, in effect, the display is reset to the transmitter time-base at the start of every line. However, missed sync signals or false triggering on interference can disrupt an image, particularly in systems using triggered sweeps. The phase-lock approach reduces this problem considerably. At least one SSTV monitor, designed by W6MXV, employed lock-out circuits to minimize false triggering. In the case of a 66.66 ms line, a line sync pulse would trigger both the line sweep and a single shot with a period of 50-55 ms. The output of the single-shot would gate out any additional sync signals until it timed out. The result was relatively high immunity to false triggering for most of each horizontal line, making the monitor very effective under adverse conditions.

### SYNC SIGNALS AND COMPUTER/SCAN CONVERTER PROCESSING

Both microprocessor-controlled scan converters and computer-based systems handle image synchronization in similar ways, depending upon the mode being copied. For fax signals, including satellites, the system requires an accurate clock signal that will yield some integer number of pulses per image line. Suppose, for example, we had a 4096 Hz clock signal and were going to copy a 240 lpm (4 lps) signal. In this case, there would be 1024 clock cycles per line (4096/4). The start of the image and/or the first image line is determined in software, at which point the system would then sample the picture and send the value to display memory with every clock cycle. If the clock signal was accurate, the picture would be properly configured in memory. There is a strong parallel here between the classic fax machine and the computer processing model. Once the fax machine has detected the line start at the beginning of the picture, it simply prints the image, relying upon the accuracy of the drum drive. In the case of the computer, once the line start is detected, the system loads pixel data according to the clock signal without any additional external checks.

Things are a bit trickier when dealing with some of the earlier SSTV modes up through the various Robot Color options. Since all of these were originally designed for line sync operation, there can be some variation in precise timing from one system and even one unit to another. For example, we might have a clock on the scan converter that would generate a precise number of cycles per nominal line — say 320. However, if you blindly loaded by just using the clock, the image probably would be skewed because of timing errors at the other end of the system. If I were programming such a system, I would proceed as follows:

- Detect the line sync pulse.
- Use the clock to sample and process pixels while watching for another line sync pulse.
- If I reached 320 samples prior to detecting the pulse, I would stop sampling and wait for the next pulse.
- If the next line sync pulse came prior to completing the 320 samples, I would fill the remaining memory locations out to 320 with black and start a new line.

Timing in these earlier SSTV modes is loose enough that you even could use a timing loop approach in lieu of an accurate clock. The clock approach, if the clock is externally calibrated, requires no adjustment on the part of the user. With timing loops, some adjustment in the loop count would be required in moving from computer to computer and a program would require some means of making and checking such adjustments.

Newer medium and high-resolution modes are very much like fax in that, even if sync pulses are included, the timing at the transmitter is referenced to an accurate clock. These modes can be received in a synchronous mode by detecting the start of the first line and then proceeding to load the entire image using the clock reference. Timing loops are a poor choice for synchronous modes unless you calibrate to the line sync pulses as previously described. While this approach works well under strong-signal conditions, you lose the noise-immunity provided by being able to ignore the sync pulses once the frame transmission has started.

## ON TO VIDEO MODULATION AND MODES

In this chapter we have discussed some of the more basic attributes of images in a general sense. Now it is appropriate to move on to the details of how we actually modulate video signals and the standards that make up the various image modes.

## CHAPTER 3

# NARROW-BAND TELEVISION

*Looking forward while looking back...*

## INTRODUCTION

As noted in Chapter 1, the first decade in the history of practical television (1926-1936) was dominated by mechanical systems for scanning and displaying images. While short, the era of mechanical television has a strong appeal. Back in the early 1960s, Lew West (W2PMV) and I would meet in Sam Milbourne's (WB2INC) basement in Oakland, New Jersey. Sam had a well-equipped shop that served to cut, punch, and drill the many panels and chassis that went into the developing modular ATV stations we were putting on the air. One evening, for example, we would do all the metalwork for three video modulators. By our next get-together, each of us would have wired our own unit and it would be time to test each of them. Believe me, it is much easier to trouble-shoot a project when you have three carbon-copies sitting side-by side.

We would transmit TV signals across Sam's basement, critiquing the images while partaking of cookies and coffee supplied by Sam's patient XYL. Sam also had quite a library, and that included a significant number of magazines dating from the mechanical TV era. Sam was kind enough to lend me these precious issues and I spent endless hours reading about television experimentation in the late 1920s and early '30s. The fascination was hard to explain, since, intellectually, I knew that the relatively poor pictures we already were producing with our first attempts at ATV were light-years ahead of the best that mechanical TV had to offer. That said, I couldn't help wondering what those early TV pictures were like and why they had such a captivating effect on the experimenters of the time, all of whom were quite aware of the limitations of the technology. I remember saying to Sam and Lew that one day I would find an old mechanical TV receiver, or build one if need be, just to see what they were like. Both of my older mentors thought that was a great idea; but they reminded me that I would also have to build a mechanical camera, since none of the local radio stations were still transmitting mechanical TV signals in the wee hours of the morning!

Both Sam and Lew are gone now, but my fixation on the earliest days of television remains. One of my great discoveries later in life, which I should have expected, was that this peculiar mania about mechanical TV was actually shared by hundreds of others across the world! Many of these very interesting people are part of the ***Narrow-Band Television Association*** or **NBTVA**. Many of the NBTVA membership are in the UK, but the group is truly international in scope. In this country, Peter Yanczer has spearheaded the formation of the ***Experimental Television Society*** (**ETS**). The two organizations are not in competition and have many active members in common. Like the ancient god Janus (who had two faces — one looking forward and the other back), narrow-band television experimenters participate in a range of activities:

- Collection of original mechanical television equipment, parts, and memorabilia.
- Restoration of mechanical TV gear
- Construction of replica equipment
- Construction of cameras and other picture generators
- Construction of different types of mechanical TV equipment using modern solid-state circuit elements.

- Experimenting with the use of narrow-band TV formats on HF, VHF, and UHF frequencies
- The use of computers to display and generate narrow-band TV signals in a variety of current and historic formats.

This chapter will attempt to show some of the current work that is representative of activity in the narrow-band television arena. I would particularly like to thank Grant Dixon, G8CGK, a very active member of the NBTVA and an old-time SSTV operator, for many of the pictures used in this chapter. Unlike the other areas of image communications, there are few kits or other commercial equipment options, so this is still an area where home-built equipment is the rule rather than the exception. In a way that is as it should be, since the pioneers of television from 75 years ago were also masters of the art of "home-brew" gear!

## NARROW-BAND TV FORMATS

Given the highly diverse equipment and standards that characterized the mechanical television era, you might expect that modern NBTV experimenters might be equally eclectic. For example, if you are restoring or replicating a piece of vintage TV equipment, the challenge might be to create a picture generator or camera that would produce pictures that could be viewed on your pride and joy. Both NBTVA and ETS (see **Appendix** for contact information) meetings feature exhibits by members of both receivers and cameras for just about any combination of standards. However, in order to encourage interoperability, the NBTVA does have a "common" format, based on a modification of the classic Baird mechanical standard, that represents a good target for the first-time experimenter. One of the advantages of this format is that the NBTVA has several audio CDs available containing sample pictures in "standard" format. This makes it possible to build a "televisor" (picture display monitor) or write a display program for a PC without the need to build a camera to check and optimize the display system.

## NBTV DISPLAY SYSTEMS

Display systems for narrow-band TV run the gamut from classical scanning-disk systems to the most up-to-date PC. In this section I will attempt to cover some of the common options that you might want to explore if you want to get started in this very interesting activity.

### *SCANNING DISK TELEVISORS*

The most basic arrangement for NBTV display is a Nipkow scanning disk, driven by a synchronous or DC motor. Peter Yanczer (see suppliers listed in the Appendix) sells a wide range of scanning disks, mounting hubs, and drive motors, or you can construct your own. Since the quality of the disk is the single biggest factor with respect to image quality, it is important that it be built with some care.

**Materials.** Smaller disks have been constructed of materials such as cardboard or plastic, but aluminum is preferred for serious projects. The disk must be relatively rigid and strong. (Remember, it will be operating between 750 and 1800 RPM, depending upon the mode.) The larger the disk, the greater the centrifugal loads as it comes up to speed. The gauge chosen for the disk should be as thin as possible, consistent with the loads. Making a disk that is thicker than necessary presents several problems:

- It will be harder to drill the holes with accuracy.
- The thicker disk will be heavier, requiring the use of a larger drive motor.
- The thinner the disk, the greater the field of view when observing the images.

**Disk Size.** To determine the basic geometry of our disk, we need to know the mode specifications and the size of the holes. Lets use an example built around the 32-line NBTV "standard" and select a hole size of $^1/_{32}$ in. (0.03125 in or 0.8 mm). The size of the image with respect to the frame scan axis is:

$$FD = L \times H \qquad (3\text{-}1)$$

Where:
FD = frame axis dimension
L = number of scanning lines
H = diameter of the scanning hole

In our example H is 0.03125 inches and L = 32, so:

$$FD = 32 \times 0.03125 = 1.00 \text{ inch} \qquad (3\text{-}2)$$

Since the NBTV standard involves vertical scanning, **FD** is the **width** of the image. If we were working with a horizontal scanning format, **FD** would be the image **height**.

The length of the line-scan axis can then be calculated:

$$LD = (AV / AH) \times FD \qquad (3\text{-}3)$$

Where:
LD = line axis dimension
AV = vertical component of the aspect ratio
AH = horizontal component of the aspect ratio
FD = frame axis dimension (above)

In our sample case, we already know that FD is 1.00 inch, and the aspect ratio of the NBTV "standard" format is 2(H):3(V), thus:

$$LD = (3 / 2) \times 1.00 = 1.5 \text{ inches} \qquad (3\text{-}4)$$

Since the NBTV line axis is **vertical**, this will be our image **height**. If the line scanning were **horizontal**, LD would be the image **width**. With LD in hand, we can then proceed to calculate the minimum diameter of our scanning disk:

$$MD = (L \times LD) / Pi \qquad (3\text{-}5)$$

Where:
MD = minimum disk diameter
L = number of scanning lines
LD = line axis dimension
Pi = 3.1416

Since L is 32 and the calculated value of LD is 1.50 inches:

$$MD = (32 \times 1.5) / 3.1416 = 15.28 \text{ inches} \tag{3-6}$$

MD is actually the minimum disk diameter since we don't want to drill holes right at the outer edge of the disk. In practice, a disk diameter of 16 inches would work out just fine with these particular specifications

**Laying Out the Disk**. One approach to laying out the disk, which works very well if you have a CAD program, is illustrated in **Figure 3.1A**, which shows the disk layout diagram after three steps:

(1) Draw a circle with a radius of 8 inches (diameter = 16 inches).

(2) Plot 32 equally spaced radii. There are several ways to do this:

- Since the radii are spaced at 11.25 degrees (360/32), it could be done with a protractor, but that is the least accurate way to do the job.
- Draw an inner circle with a radius of 7.625 inches (diameter of 15.25 inches) and use a pair of dividers to mark points around the circumference at intervals of 1.5 inches. Use these marked points to carefully draw the radii.
- A CAD program will let you lay down the radii at 11.25 degree intervals or you can lay out a regular 32-side polygon equal to the diameter of the circle and run the radii from the apices of the polygon to the center point.

(3) Lay out a total of 32 inner circles, beginning with a radius of 15.625 inches, with each successive circle having a radius 1/32 inch smaller than the previous circle.

At this point, the intersections of the circles and radii mark the locations of our holes if we proceed in a careful fashion.

To mark the hole locations:

- Start with the right horizontal radius and mark its intersection with the outer-most inner circle. Remove **both** the radius line **and** the outer-most circle.
- Proceed clockwise to the next radius and mark its intersection with the outer-most inner circle. Remove **both** the radius line **and** the outer-most circle.
- Continue clockwise with each successive radius line until you have marked the location of all 32 holes.

If all has gone well, you should have a high-resolution layout diagram of the scanning disk with the location of all 32 scanning holes marked with precision. At this point the layout can be printed in four quadrants, which would then be carefully trimmed and mounted to the aluminum disk stock using rubber cement. I prefer to output the file as a .BMP format image on a ZIP disk. (The file for a 16 inch disk diagram is about 23 megabytes!) I then take the disk to a local copy center that has the facilities to print the image full-size. I usually have several diagrams made as mistakes are likely from this point on!

(1) Rubber-cement the layout diagram to the disk blank.

(2) Use a band-saw to cut out the disk.

(3) With a very sharp center-punch, take all the time needed to accurately center-punch all the hole locations, including the disk center-hole.

(4) Using a drill press, drill all 32 of the scanning holes using a 1/32 drill bit. Hobby shops are a good source of high-quality drill bits in such small sizes.

(5) Drill out the center-hole to a size appropriate for whatever approach you plan to use for the mounting hub.

(6) De-burr all holes, degrease the disk, and paint it a flat-black, carefully cleaning out the scanning holes as needed.

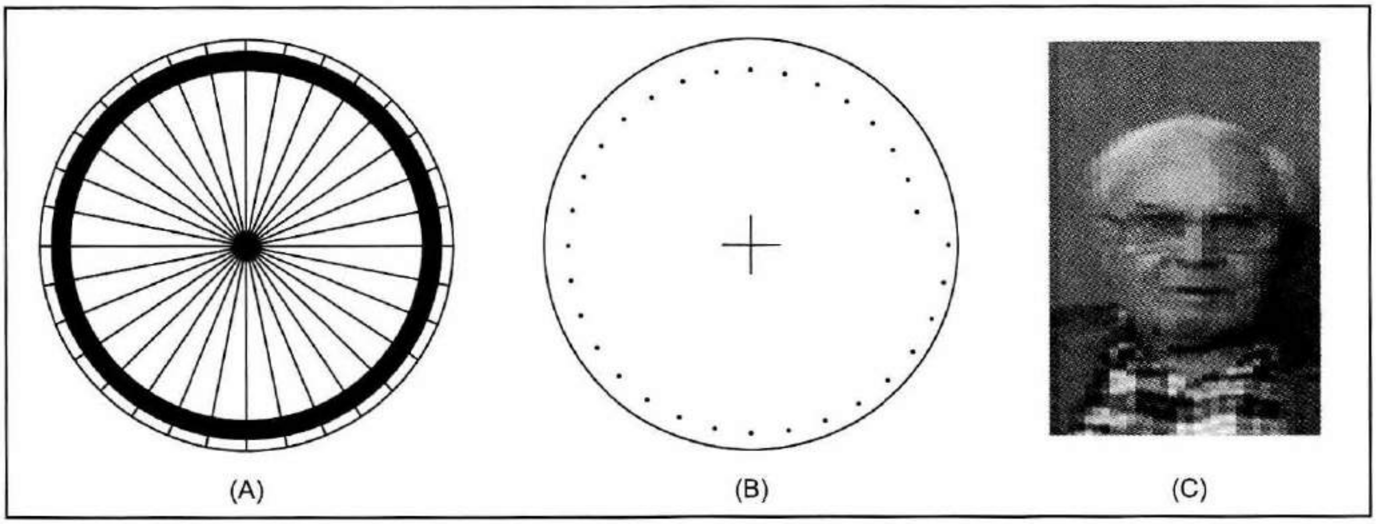


**Figure 3.1**. Laying out the basic Nipkow disk. **[A]** Disk layout with 32 equally-spaced radii. The black outer band is actually a series of 32 concentric circles. The outermost circle has a radius 3/8-inch shorter than the disk and subsequent circles have radii that are 1/32-inch shorter than the previous circle. **[B]** The intersection of the circles and radii provide a guide for the placement of the 32 1/32-inch holes. **[C]** If the holes are placed carefully and drilled with care, the result will be 32 evenly-spaced scanning lines within the 1 × 1.5-inch viewing mask. The sample image shown here is a "mug shot" of Grant Dixon, G8CGK. (Photograph from the collection of Grant Dixon).

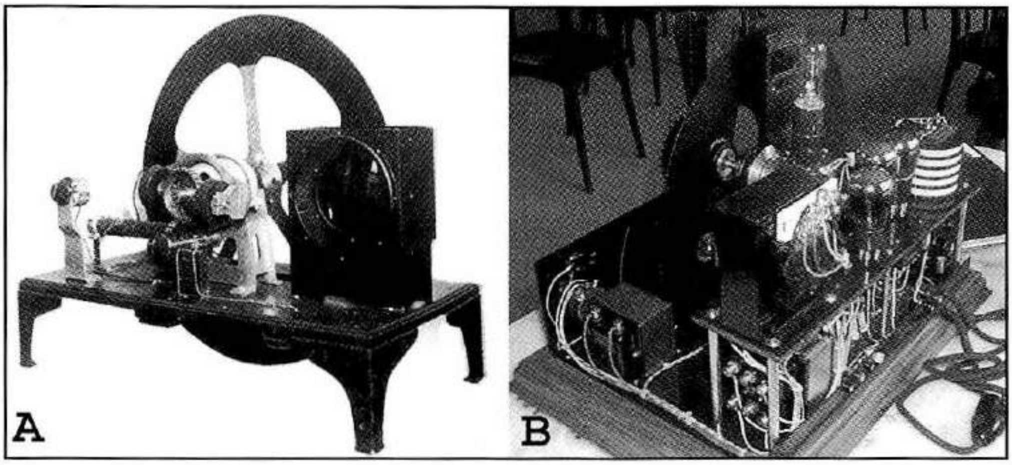


Figure 3.2. Mechanical layout of a scanning disk televisor. **[A]** A **Baird** 30-line unit from the early 1930s, with the cover removed. The disk drive motors and gearing are visible on the left. The magnifying lens on the right made it easier to view the relatively small image. A flat-plate neon tube is located behind the disk and lens-box assembly. Amplitude modulation of the neon tube's light output, together with the scanning provided by the disk, produced the image. Note that the disk has large cut-out areas, reducing the rotating pass and motor loading. **[B]** A superb reproduction of the **Telehor** receiver by Denis Asseman of Belgium. The neon tube is clearly evident at the top of the scanning disk. The Telehor was unusual in that it had dual mode capabilities. Configured as shown here, it would receive German transmissions, which used horizontal scanning. There was also a second magnifying lens that, by rotating the neon tube and mask assembly, would permit display of vertically-scanned image transmissions from Britain. (Photographs from the collection of Grant Dixon.)

The kinds of problems you are likely to encounter primarily concern accurate placement of the scanning holes. If a hole is displaced even slightly on any particular radius line, it will overlap its neighbor on one side and leave a dark gap between it and its neighbor on the other side. Slight errors in placement to one side or the other of a radius line will result in vertical displacement of image data, making the image more "jagged" then it should be. If the disk is temporarily mounted on a shaft driven by an electric drill or other motor, a light positioned behind the band of holes should show an even alignment of scanning lines with no overlap or gaps. You alone will determine what constitutes a realizable degree of perfection. Take your time and you can make a very good disk; but, after a few failed tries, the $60 to $100 you might spend for a professionally made disk may look pretty reasonable!

**The Rest of the Stuff**. Motor options, motor drive circuits, and video/sync circuits to drive the LED array are not complex. Several sources for this information include:

- **Peter Yanczer's Experimental Television Society** Web site (**http://pyanczer.home.mindspring.com/Tour/**) presents a complete tutorial in several parts for building your own televisor. Mechanical design, electronic circuits, parts lists, and even printed circuit board layouts are included.
- Peter Yanczer has published a book (*Mechanical Television*) that includes a huge amount of resource material at a cost of $17.50 (see supplier list in Appendix).
- **Erwin Meyvaert**, ON1AIJ, has a Web site (**http://users.pandora.be/ON1AIJ/**) that provides access to a whole range of simple and more complex circuits. Erwin's site also opens with two full-motion examples of 32-line TV that are fascinating to watch!

**Disk Televisor Limits**. The limits of the Nipkow disk quickly become evident if we consider what would be required to produce a higher-resolution display. For example, let's examine a system using a 64-line disk:

(1) If we wish to retain the $^1/_{32}$-inch hole size, the disk diameter has to be scaled up to 32 inches! This would be a large, unwieldy size that would require the use of a significantly larger drive motor.

(2) It would be possible to continue to use the 16-inch disk format, but that would present a host of new problems:

- The hole diameter would need to be reduced to $^1/_{64}$-inch, but drill bits start to get very fragile in that size range.
- The required precision in layout and drilling would increase by a factor of two.

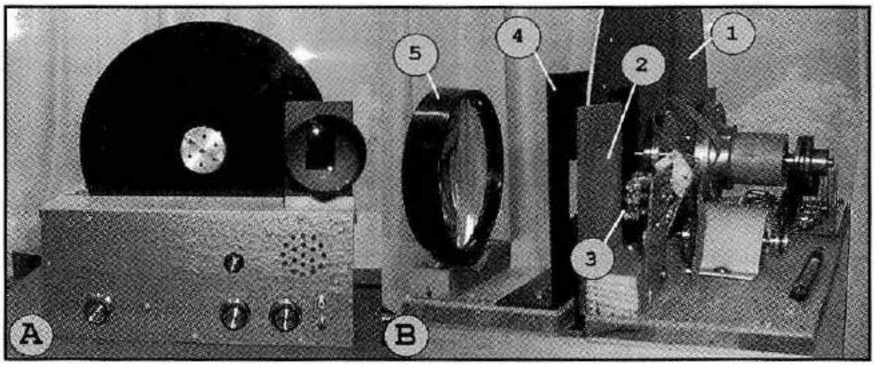


Figure 3.3. A 32-line scanning disk televisor built by Grant Dixon G8CGK. **[A]** Front-view of the unit. The lower chassis holds most of the electronics and a speaker to monitor the NBTV signal. **[B]** An oblique rear-view showing the relationship of most of the critical components associated with the Nipkow disk (1). The modulated light source is mounted behind the disk and consists of a bank of LED's wired in parallel (3) and a translucent plastic diffussor-plate (2) that creates a uniform light pattern.
A metal mask (4) is located in the front of the disk so the viewer sees only the area corresponding to the scanned raster. A magnifying glass (5) increases the apparent size of the image. (Photographs from the collection of Grant Dixon.)

- A $^1/_{64}$ inch hole has just a quarter of the area of a $^1/_{32}$ hole. In effect, picture brightness would be reduced by a factor of four!

The problem of decreased brightness can be overcome to some extent by replacing the simple holes in the disk with larger glass or plastic lenses (see Figure 1.4). However, that further increases the size and mass of the disk and each lens has to be centered and mounted with the same precision as the location of the simple hole. A large, heavy disk, rotating at 750 rpm or more with lenses that could come loose, represents a significant hazard! While the scanning disk approach has the virtue of simplicity, there are other options.

### *MIRROR DRUMS AND SCREWS*

The basic scanning-disk televisor produces a relatively small image (magnifying lenses are almost universal on both vintage and modern displays) that is not very bright. One solution to some of these problems is the mirror-drum, illustrated in **Figure 3.4**. Compared to a scanning-disk unit, a mirror-drum televisor was quite compact, yet it featured a back-projection screen significantly larger than the viewing area of a disk system. Because of the inherent brightness of the crater light source, the picture was also reasonably bright. The epitome of this technology in the mid-1930s was a projection TV system using an arc-lamp as the light source with the light intensity modulated by a Kerr cell inserted in the light path. In a darkened theater setting, pictures up to several feet square could be viewed by an entire audience.

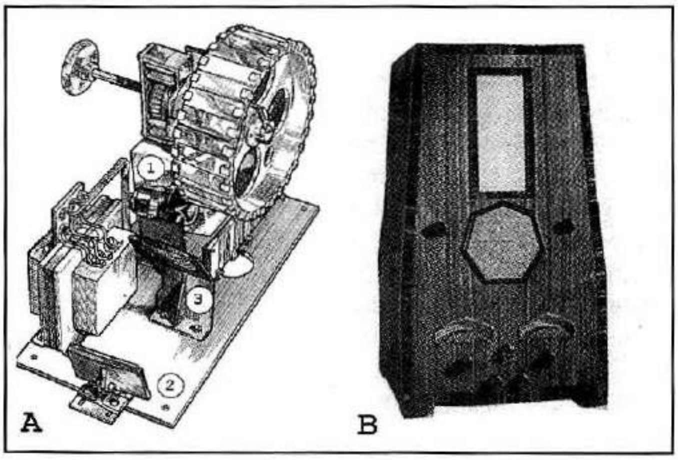


**Figure 3.4**. **[A]** A mirror-drum scanner. The modulated light source is a crater tube (**1**) that provides an intense beam with a small aperture. The beam from the crater lamp is reflected from a first-surface mirror (**2**) and through a collimating lens (**3**) that projects the bean onto the mirror-drum. The drum is equipped with a number of mirrors, equal to the number of image scanning lines, and the drum rotates at the frame rate. The angle of each mirror is adjustable and, when each mirror is properly set, the result will be a projected spot of light that will form the image raster. **[B]** An early 1930s-vintage **Grafton** televisor that used a mirror-drum scanner in a rear-projection configuration. The image appeared on the translucent screen above the central speaker. The very low aspect ratio of the screen indicates that the unit was designed for use with the 30-line Baird TV system. (Photographs from the collection of Grant Dixon.)

Mirror-drums require care in construction but have the virtue that each mirror can be adjusted to just the proper angle to produce a uniform raster, which is less demanding than the all-or-nothing layout requirements for a Nipkow disk! It should be noted that all the mirrors in such a system should be of the "first-surface" type, where the reflecting layer is at the surface of the mirror. Conventional glass mirrors have the reflecting surface at the back of the glass, creating "ghost" reflections from the glass surface and refractional distortions. First surface mirrors, including inexpensive coated mylar, are available from sources such as Edmund Scientific (see suppliers list in the Appendix). Initial adjustment of all the mirrors can be tedious but only needs to be done once! Modulated visible-light laser diodes provide excellent point light sources for modern televisors and are capable of providing a very bright image in a rear-projection system. AM modulation of laser diodes can be a tricky business, so you may want to check on a very good bias circuit designed by John Yurek, K3PGP, (**http://www.qsl.net/k3pgp/Construction/laserbias.htm**) if you are interested in investigating laser diode light sources. Laser diodes are bright enough to offer real potential in a projection system using a mirror wheel, but caution is required to assure that there is no possibility that anyone can look into the projected beam when the system is in operation. Although most diodes that might be used are low-power (<5 mW) Class III devices, they are still capable of causing temporary effects or even permanent eye damage. This is not an issue with rear-projection systems, since the "screen" is a translucent diffuser that greatly reduces the beam intensity.

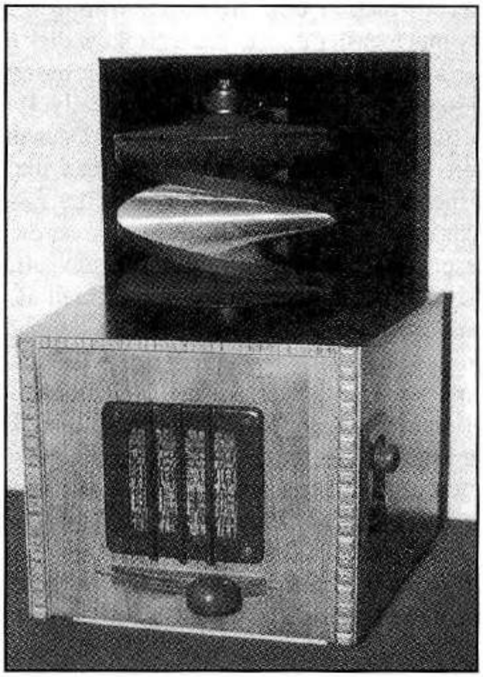


**Figure 3.5**. Mirror-screw televisors can be quite compact, yet yield pictures up to several inches square with a resolution up to 180 lines. This 120-line unit was constructed by Peter Yanczer. The drive motor is oriented vertically in the cabinet and the mirror-screw stack can be mounted on an extension of the drive shaft. (Photograph from the collection of Grant Dixon.)

The **mirror-screw (Figure 3.5)** has some features in common with a mirror drum, but it is much easier to construct and has the potential for achieving much higher display resolution. The mirror-screw is constructed from multiple narrow pieces of aluminum or stainless steel. Let's use the 32-line NBTV "standard" format to see how a mirror-screw is constructed. The thickness (gauge) of each piece represents the "thickness" of each scan line. If we selected $^1/_8$ inch as the thickness for our "strips", the frame-scan dimension (equivalent to the total thickness of the "stack" of 32 pieces) would be $32 \times 0.125$ or 4.00 inches. Because the frame scan is oriented horizontally, 4 inches represents the width of the display. Since the aspect ratio of the NBTV format is 2:3, the height of the display must be 6 inches. This is achieved by setting the length of the metal strips at 6 inches. The strips would be prepared by clamping them in a stack so that a single edge on each piece can be polished to a mirror-finish in one operation. The strips are then mounted on a common shaft so that each strip is offset from its neighbor by an angle equal to:

$$A = 360/L \qquad (3\text{-}7)$$

Where:
A = offset angle
L = number of image scan lines

In the case of a 32-line system, the offset would be 11.5 degrees. If the 32 pieces are mounted on a shaft, each offset 11.5 degrees from the previous one, you end up with a 360-degree spiral. A simple jig could be used to offset the pieces, so construction, other than the polishing of the edges, is actually much easier than either a Nipkow disk or mirror-drum. The system in Figure 3.5 is set up for horizontal line scanning so the drive shaft is oriented vertically. If line scanning is vertical, as it would be with the NBTV standard, the drive shaft would be horizontal. Other than the polished edges of the individual pieces, the rest of the assembly, as well as the open-sided "box" in which the screw operates would be painted flat black to minimize unwanted reflections. The modulated light source is projected as a line on the mirror-screw assembly. The line has the same width as the thickness of the individual pieces that make up the screw, the length of the line equals the stack height, and the line is projected onto the screw parallel to the center axis. When viewed in a dark room, the result is a spot of light that forms the complete image raster as the motor completes each revolution. Apart from its compact size and ease of construction, a mirror-screw televisor has a very wide viewing angle. They were very popular in Europe during the 1930s and are deserving of more attention in the NBTV community.

## CRT DISPLAY

While NBTV activity includes a major mechanical television component, experimentation is encouraged using any available technology. Cathode ray tube (CRT) displays are a very flexible NBTV option for the same reason that CRT technology came to dominate the development of television by the mid-1930s:

- **Flexibility** — It should be obvious by now that most mechanical TV projects are pretty-much limited to a single mode. In contrast, by using different time-bases in the line and frame sweep circuits and with different demodulator circuits, a CRT-based display can handle virtually any NBTV mode.
- **Resolution** — Within broad limits, mostly defined by screen size, a CRT system can display images at significantly higher resolution (and brightness!) than any of the common mechanical systems. With a screen size of three inches (about the upper size limit for displaying lower-resolution NBTV images), image resolution of up to several hundred lines is easily achieved.
- **Ease of Implementation** — There is no high-tolerance mechanical work to do, as all the tough jobs are implemented by electronic circuits.

If you like to build and tinker with electronic circuits, a CRT display can provide a very useful multi-mode option. Suitable displays can be constructed easily around small, flat-face display tubes like the 3RP1 and its variants, stealing sweep circuits and power supply ideas from solid-state oscilloscopes. Alternatively, you can simply use a modern, compact analog oscilloscope, in which case you simply have to build appropriate time-bases, ramp-generators for vertical and horizontal deflection, and demodulators that will drive the Z-axis input of the scope. Using a scope as the display is a popular option, since the scope eliminates the need to package the CRT, build the necessary high-voltage supplies and deflection amplifiers.

## COMPUTER-BASED IMAGE DISPLAY

So, what do you do if you have an interest in NBTV and don't have the time or ability to experiment with mechanical or electronic construction projects? The answer is the same one that will pop up in the case of almost all the video modes — you use a computer! Computer applications for NBTV range from DOS programs that may require a very simple hardware interface, to Windows software that uses the computer sound card to perform the various interface functions. Erwin Meyvaert, ON1AIJ, has a Web site (**http://users.pandora.be/ON1AIJ/**) that provides access to a whole range of freeware/shareware programs for NBTV, including both display monitors and transmit software from authors such as Con Wessilieff (ZL2AFP), Nino Porcino (IZ8HLY), and Lewis Graham.

A computer display provides all the flexibility of the CRT options discussed previously, with none of the work of building a lot of extra circuits or even purchasing a scope! A computer certainly provides the easiest entry point to NBTV and can meet all your needs for some time to come. However, if you get bitten by the NBTV "bug", it is highly likely that you will build some mechanical equipment. There is nothing quite as exciting as peering into an electro-mechanical wonder you have actually built yourself and seeing a moving TV image!

## NBTV CAMERA SYSTEMS

If you are going to build any type of NBTV display, you need a source of pictures to check out and demonstrate your system. Many of the approaches used in implementing a display can be modified to produce pictures.

### *SCANNING DISK CAMERAS*

**Figure 3.6** shows the two basic types of scanning disk cameras. In both cases the scanning disk, motor, and motor drive circuits are identical or very similar to what you used for a scanning disk televisor. Figure 3.6A shows a reflected light camera that, in principle, can be used just like any TV camera. The lens is set up to focus an image of the scene onto the plane of the scanning disk, located just behind the lens. As the disk spins, it scans the projected image. The light that passes through the disk is focused by a condenser lens into a phototransistor. The phototransistor should be chosen for response in the visible light range. Units sensitive to red, far-red, or infra-red produce some unusual images! The output of the phototransistor is amplified to produce the base-band video signal. Not shown, but essential, is a means for introducing line sync pulses into the video stream. This is typically done with a second set of holes that, in conjunction with an LED light source and phototransistor, produces a short voltage transition at the start of each line. This pulse can be shaped and mixed with the output of the video amplifier to produce the composite NBTV signal. The primary drawback to this type of camera is the need to provide very bright lighting for the subject. Typically, 150-200 W for a subject distance of a few feet will be required.

Figure 3.6B shows a similar arrangement for a "flying spot" camera. Here a bright light source, typically the light, blower and condenser lens from an old slide projector, is located behind the disk. As the disk spins, a moving or "flying" spot of light is projected out of the camera lens onto the subject. Some of the light reflected from the subject is picked up by a bank or array of phototransistors. The phototransistor array output is then amplified to produce the base-band video signal. The spectral sensitivity criteria for the phototransistors and the provisions for providing sync are the same as in the reflected-light camera system. Flying-spot cameras work quite well, but they have the disadvantage that they must be operated in a dark room so that ambient light does not saturate the phototransistor array.

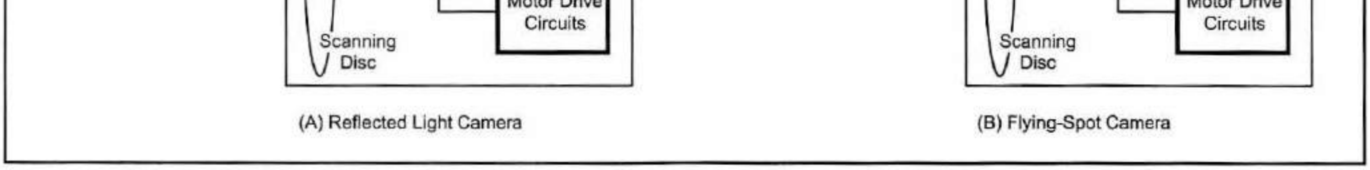
A carefully built scanning disk camera can do an excellent job and is, of course, in complete harmony with a mechanical televisor. **Figure 3.7B-C** provides a good idea of the quality that can be achieved. Given the commonality of components, including the scanning disk, motor, and motor drive circuits, it is quite practical to combine both the camera and televisor into a single unit (see Figure 3.7A).

### *MIRROR DRUM SCANNERS*

Provided the bright light source can be focused to a sharp spot, there is no reason why a mirror-drum cannot replace the scanning disk in a flying-spot camera. Because the "spot" is typically much brighter than that provided by the pinholes of a scanning disk, a mirror-drum scanner is inherently more sensitive than a disk-based system. A Class III laser pointer might seem like an ideal light source for a mirror-drum flying spot camera, but there are some problems with using a laser:

- **Safety** — The best subjects for live camera pick-up are people, and the last thing we want to do is scan the face of our subject with a laser beam that has the potential to cause eye damage.
- **Grayscale** — Laser light is essentially monochromatic light of a very specific color. If we use such a light source to scan an image, the result is likely to include some very unusual tonal effects.

While the previous discussion has focused on mechanical approaches to producing pictures, there is no reason not to use digital technology to get the job done if you choose to do so. Digital picture sources are particularly convenient when you are working at setting up a mechanical televisor, since you obviously need a reliable signal to tell if everything is working. When digitizing NBTV pictures, either during



(A) Reflected Light Camera

(B) Flying-Spot Camera

**Figure 3.6.** The two basic types of scanning disk cameras. The operating principles of both units are discussed in the text.

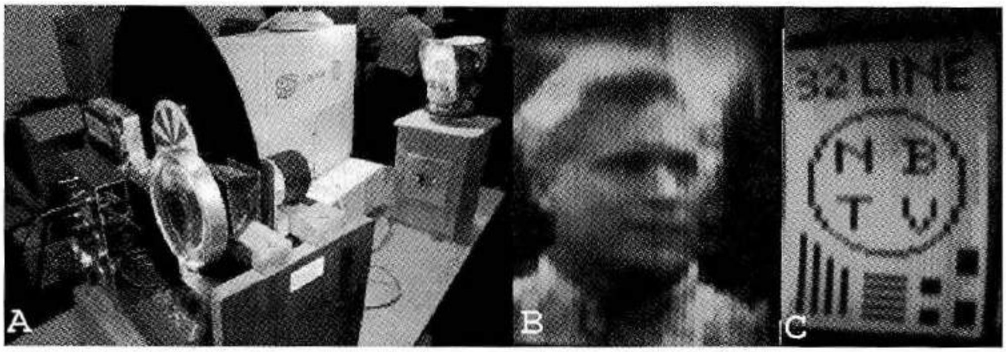


**Figure 3.7.** **[A]** Combination scanning disk monitor and camera built by Ernie Greenhough in the UK **[B]** 32-line scanning disk camera image of Jim Wood. **[C]** A simple test pattern. (Photographs from the collection of Grant Dixon.)

reception or to prepare pictures for transmission/display, there are a few things that can be done to optimize the quality of the images:

- **Use the best available tonal resolution**. Given the low resolution inherent in most NBTV formats, you might think that 4-bit (16 tonal values) video would be adequate, but this isn't the case. You actually may be able to use 4-bit video with high-resolution grayscale images, but the contouring effects that can occur will degrade a low-resolution image in a hurry. I would certainly advise the use of at least 6-bit video when transmitting images and would suggest that 8-bit video be used in digitizing for reception.
- **Increase the line resolution**. While the limited number of scanning lines sets the resolution with respect to frame scanning, line scanning is another issue! Remember, most NBTV formats were designed around analog scanning, so that tonal variations along a line are essentially continuous. If you digitize the lines using a relatively large number of pixels, you can approximate the "analog look" of each line and thus optimize image quality.

**Figure 3.8** shows the effect of pixel density on a sample image using the 32-line NBTVA standard. Note that the image looks best with 256 pixels per line and that there is a progressive loss of quality at 128 and 64 pixels per line. I didn't even bother to include a sample with 32 pixels per line (equivalent to the frame scan resolution) because the results would have been pretty awful! Increasing the number of pixels per line has two consequences, an increase in image file size and an increase in the required bandwidth, as shown below using a 32-line/12.5 fps image as an example:

| Pixels/line | File Size | Bandwidth |
|---|---|---|
| 256 | 8192 bytes | 51.2 kHz |
| 128 | 4096 bytes | 25.6 kHz |
| 64 | 2048 bytes | 12.8 kHz |

Given the inexpensive memory resources available today, the file size issue for NBTV images is academic. Bandwidth is certainly not an issue when setting-up or demonstrating equipment closed circuit, but it may be important if you are sending pictures over the air. My own preference is to digitize at 256 pixels/line and switch in a "smoothing" capacitor into the D/A output circuit if I need to reduce bandwidth for a specific test or operational situation.

### *CD DISKS*

For the past few years, the NBTVA has prepared a series of CD audio disks based on pictures acquired during the annual NBTVA convention. The disks feature images in both the 32-line NBTVA format and the 30-line Baird format. With a CD player and one of these disks, you can have a nice selection of pictures for setting up a televisor. Cost is about $8.00 (US) and purchase information is available on the NBTV Web site.

### *SCAN CONVERTERS*

At least two NBTVA members in the UK have constructed stand-alone scan converters that take the video from a standard TV camera (PAL in this case) and convert the image in real-time to one or more NBTV formats. Peter Smith's (G4JNU) unit is used to create the NBTV CDs noted previously. I am not aware of anyone here in the US who has built a similar scan converter for NTSC TV cameras. It would not be a difficult project, given the limited memory required and the fact that most projects would simply capture the luminance data and ignore any color information on the signal.

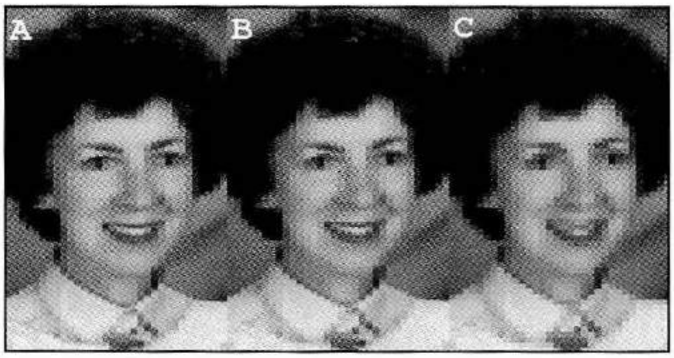


**Figure 3.8.** The impact of line resolution when digitizing low-resolution NBTV images. Although the limited number of scanning lines in most NBTV formats is the ultimate limiting factor on display resolution, it is important to remember that the lines themselves are analog. When digitizing such images, it pays to use 6 to 8-bit video coding and a relatively high pixel sampling density for each line. **[A]** A picture of my wife Alison set up in the 32-line NBTVA format, with 256 pixels (8-bit) per line; **[B]** shows the same image with sampling reduced to 128 pixels per line; and **[C]** shows the impact of 64 pixel sampling.

### *DIGITAL IMAGE GENERATORS*

Grant Dixon (G8CGK) has designed a versatile image generator built around a flash-memory storage chip (**Figure 3.9**). The original version of the circuit used an EPROM as the storage medium. It could hold up to 32 single-frame images, each of which can be selected via thumb-wheel switches, or a series of sequential images, representing about 2.5 seconds of full-motion video can be stored with provisions to cycle through the image sequence. The schematic for an EPROM version of the circuit is available on Erwin Meyvaert's Web site (see Appendix). The latest version shown here uses a FlashRam chip capable of storing up to 128 images. That represents a significant library of test images or over 10 seconds of full-motion video. Images programmed into the unit can come from any digital source with provisions to set the resolution to match the NBTVA format, including camcorder (with a frame-grabber), webcam, digital camera, or flatbed scanner.

My latest NBTV project is a small, old-fashioned-looking CRT monitor that is slowly evolving on my basement workbench. Since a source of NBTV video is really useful in developing, debugging, and setting up the various circuits, I decided to build my own portable signal generator along the lines of the unit designed by Grant Dixon. I developed a similar project for SSTV a number of years ago that I named the **ROMScanner**, so the new unit (**Figure 3.10**) was designated the **NBTV ROMScanner**. Rather than simply duplicate Grant's unit, I decided to incorporate what I considered to be some enhancements of the basic concept:

The **master clock**, which controls the output scanning rates, was tied to a crystal timing standard rather than a free-running oscillator.

The **number of pixels** per line was increased to 256 to maximize the "analog look" of the images.

The **grayscale coding** was increased to 6-bits (64 grayscale steps) for the same reason.

**Image Storage**. Images are stored in a 27C256 EPROM (**U6**), which has a capacity of 32K bytes. Since each image consists of 32 lines with 256 pixels/line, each picture requires 32 × 256 or 8192 bytes (8K). The EPROM thus can hold four images. Each image byte is organized as follows:

Bit 7 — Image bit 5 (MSB)
Bit 6 — Image bit 4
Bit 5 — Image bit 3
Bit 4 — Image bit 2
Bit 3 — Image bit 1
Bit 2 — Image bit 0 (LSB)
Bit 1 — not used
Bit 0 — sync bit (see text)

**Clock and Address Circuits**. Since each image contains 8192 pixels and we must transmit 12.5 images/second, pixels must be clocked out of the EPROM at 12.5 × 8192 or 102,400 pixels/second. This 102.4 kHz clock signal is obtained by digital division from a crystal oscillator made up of **U1A** and **U1B**. A **3.2768 MHz** crystal is used — a commonly available microprocessor crystal that costs under $5. The 3.2768 MHz signal is buffered by **U1D** and **U1C** and then applied to the input of an 8-stage binary counter (**U3**). Wired as shown, the counter divides the clock signal by 16, producing a 204.8 kHz clock reference that is routed to a pair of 8-stage binary counters (**U4** and **U5**). Thirteen of the output lines from the two counters drive address lines **A0** through **A12** of the EPROM (**U6**), effectively addressing the 8192 pixels of a stored image. Note that since **A0** is driven by the first output line of **U4**, the base pixel clock rate is 102.4 kHz (204.8 kHz/2). Which of the four stored images is being transmitted is a function of the logic levels at address lines **A13** and **A14** of **U6**.These lines are pulled HIGH and routed to a rotary **IMAGE** selector switch (**S1**) through a series of isolation diodes. The image being addressed is a function of the switch position, which controls the logic level at **A13** and **A14**:

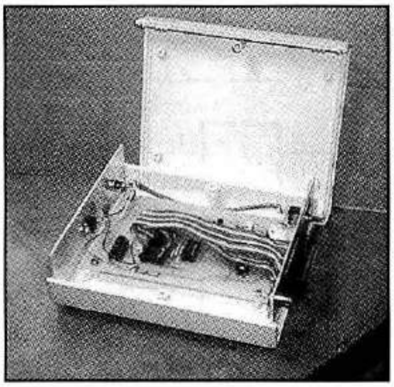
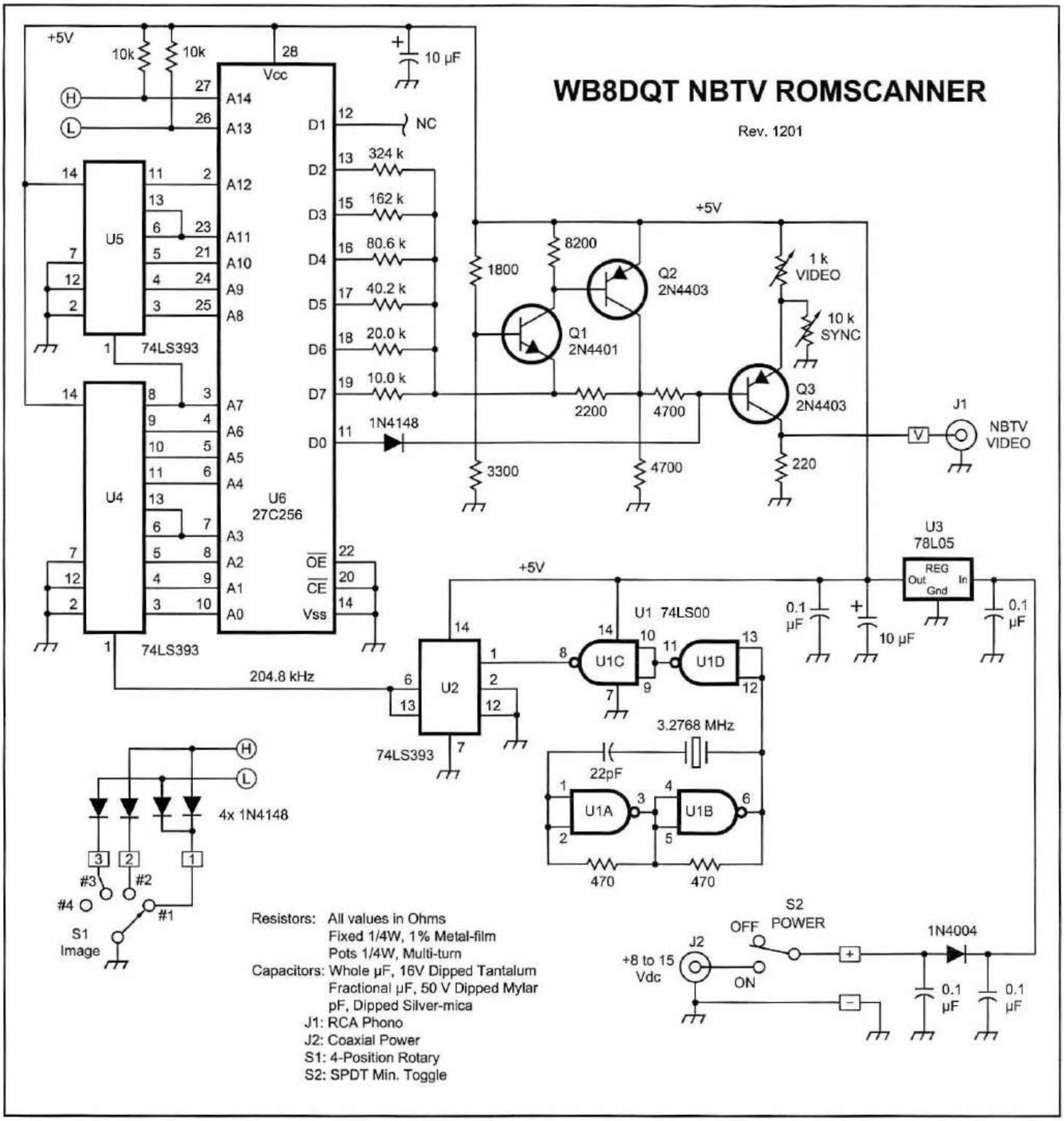


**Figure 3.9**. A flash-memory NBTV picture generator designed and built by Grant Dixon (G8CGK). The unit can store 128 individual images, any one of which may be selected using a front-panel thumb-wheel switch, or the unit can be operated in the streaming mode. In the latter case, the 128 images are derived from frames from a .AVI or other video file. When the 128 images are transmitted in sequence, the result is about 10.25 seconds of full-motion video, which is repeated in an endless loop. (Photograph from the collection of Grant Dixon.)

| Switch/ Image | A13 Logic | A14 Logic |
|---|---|---|
| #1 | LOW | LOW |
| #2 | HIGH | LOW |
| #3 | LOW | HIGH |
| #4 | HIGH | HIGH |

**Video and Sync**. The video/sync modulator is based on Grant Dixon's circuit, with the addition of an additional data bit and a different approach to formatting the image data. **Q1** and **Q2** comprise a digital to analog (D/A) converter, driven by a weighted resistor network connected to output bits **D2-D7** of the EPROM (**U6**). **Q3** functions as the NBTV modulator with the **SYNC** and **VIDEO** potentiometers used to adjust the output signal levels. The NBTV output waveform is routed to the **NBTV VIDEO** jack (**J1**).

**Power Supply**. The unit is designed to be powered by a wall-mount transformer supply. These are universally available and any unit that provides between 9 and 15VDC at 100 mA will power the circuit. The **POWER** input connector (**J2**) should be selected for compatibility with the



Resistors: All values in Ohms
Fixed 1/4W, 1% Metal-film
Pots 1/4W, Multi-turn
Capacitors: Whole µF, 16V Dipped Tantalum
Fractional µF, 50 V Dipped Mylar
pF, Dipped Silver-mica
J1: RCA Phono
J2: Coaxial Power
S1: 4-Position Rotary
S2: SPDT Min. Toggle

**Figure 3.10**. Circuit diagram of the NBTV ROMScanner signal generator. The 27C256 EPROM (U6) stores four 32-line (256 pixels/line, 6-bit grayscale) images. The active image output, selected by the IMAGE switch (S1) is in the standard NBTVA 32-line format and can be used to align and test NBTV display systems or as an image source to demonstrate NBTV televisors.

power module you intend to use. The input voltage is routed through the ON/OFF **POWER** switch (**S2**) and a diode to protect the circuit in case you accidentally wire the power supply connections backwards. The voltage is applied to a 5V regulator IC (**U3**) that provides the +5VDC to power the circuit. A front-panel LED indicator is included to provide a visual indication that the unit is ON or OFF.

**Results**. A set of two sample images from one of my EPROMS is shown in **Figure 3.11**. Properly set up, the **NBTV ROMScanner** will produce images of the highest possible quality. If your televisor can display them as shown, you can demonstrate your system with pride!

**Construction**. The *Image Communications Handbook* Web site (see Appendix) has a complete set of **NBTV ROMScanner** files that can be downloaded without cost. The ***romscan.zip*** software package contains the following files:

***romscan.gtl*** — Gerber layout file for the PC board top layer

***romscan.gbl*** — Gerber layout file for the PC board bottom layer

***romscan.exe*** — PC program for formatting and preparing image files for EPROM programming

***romscan.doc*** — WORD file containing complete parts list (referenced to the DigiKey catalog) and instructions for set-up and use

***setup.bin*** — a binary file containing test images for initial set-up that can be programmed into an EPROM for initial tests

***sample.bin*** — a sample image file containing the two images shown in Figure 3.11.

The two Gerber PC board layout files can be forwarded to almost any PC board producer to create the 3 × 4 inch board for this project. The parts layout for this particular circuit board is shown in **Figure 3.12**. I suggest the use of a **ZIF** (**z**ero-**i**nsertion-**f**orce) socket for **U6** so that you can easily remove and insert image chips without damage or excess wear. If you do end up changing EPROM chips, **be sure that the power to the unit is OFF** before swapping the chips to avoid permanent damage to the IC. The amount of off-board wiring is absolutely minimal and the system can be housed in a wide range of cabinets and utility boxes. In fact, I am building one into the new NBTV CRT televisor so that I can demonstrate it quickly without having to cart around additional support equipment. You may consider the PC board layout files to be in the **public domain**, which means anyone is free to have PC boards made up for personal use or for sale to others. The software products in the package are **freeware**, so you are free to use them or distribute them to others. However, **the software is protected by copyright**, so you cannot sell the programs or bundle them in packages for sale without my written permission.

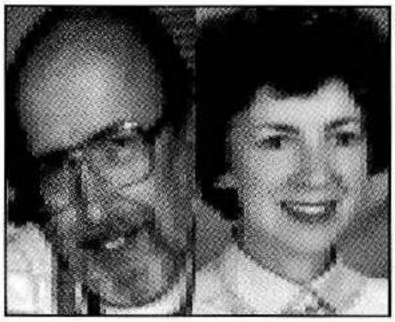


**Figure 3.11.** An example of two 32-line pictures as transmitted by the NBTV ROMScanner.

**Initial Set-up**. Initial adjustment of the unit is very simple if you program an EPROM with the **setup.bin** file. This file loads four test images into the EPROM:

(1) A 16-step grayscale

(2) Sync-level output

(3) Black-level output

(4) White-level output

With the set-up EPROM loaded, initial adjustments can be made in one of two ways:

**Oscilloscope**. If you have an oscilloscope available, connect the NBTV output to the scope vertical input, set the **IMAGE** switch to position **1** (grayscale), and turn the **ROMScanner** ON. Now adjust the **SYNC** and **VIDEO** pots (there will be some interaction) so that the sync-pulse at the start of each line goes to 0V, the lower-most step (black) is at 0.22V, and the uppermost step (white) peaks at 1.00V. At that point the unit is complete.

**Voltmeter**. The unit can be adjusted using an analog or

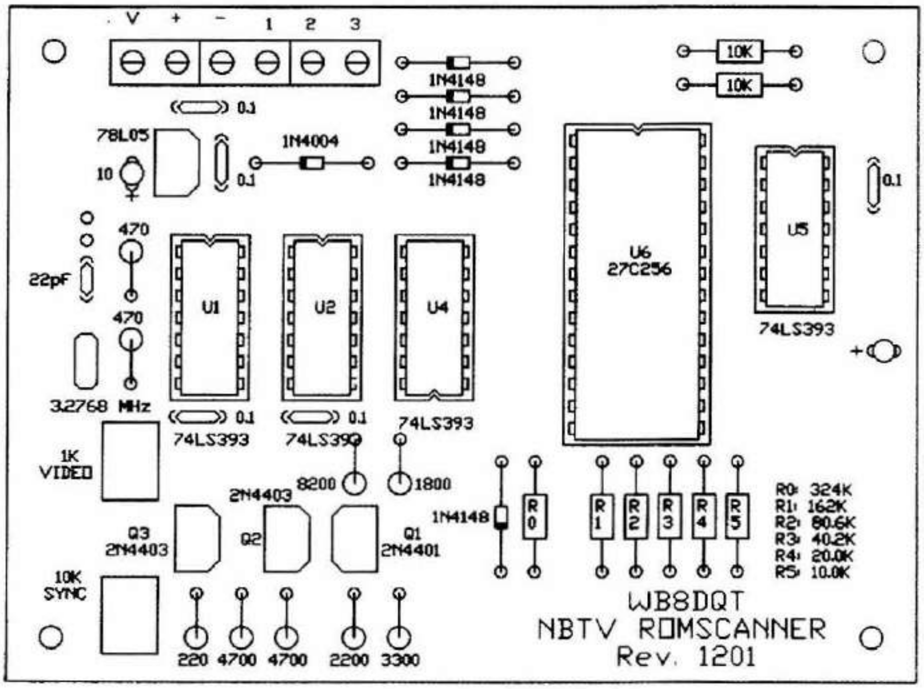


**Figure 3.12**. A double-sided 3 × 4 inch printed circuit board accommodates all the active components of the NBTV ROMScanner picture generator. Circuit board layout diagrams and all essential construction information is available without cost (see text).

digital voltmeter connected between ground (negative) and the **NBTV VIDEO** output (positive). While switching between images **2**, **3**, and **4**, adjust the **SYNC** and **VIDEO** pots (there will be interaction) to achieve the following results:

| SWITCH POSITION | FUNCTION | VOLTS |
|---|---|---|
| 2 | SYNC | 0.00 |
| 3 | BLACK | 0.22 |
| 4 | WHITE | 1.00 |

The ***romscan.exe*** program file is designed to simplify preparing images for programming into an EPROM chip. You will still need access to an EPROM programmer and its software, but the ROMSCAN program will take care of creating the file you will program into the chip. To use ROMSCAN you will need a collection of source images. These can be any 160 (H) × 240 (V) 8-bit grayscale .BMP image files. You can create such images by using the various features of your graphics/ photo software. If the original image is color, you will have to convert it and use a combination of scaling, cropping, and/or masking to get the image down to a 160 × 240 format. The program will not perform error checking, so remember:

(1) **8-bit** grayscale

(2) **Exactly** 160 × 240 in size

(3) **.BMP** file format

The program will let you select four source images and the order (1-4) of the images in the EPROM binary file. For each line of the four images, the program performs the following operations:

(1) Write 16-bytes to the binary file where the low (LSB) is set **HIGH** to enable sync output. The rest of the bits in each of the 16-bytes don't matter, but they will be set to black (0). Since a pixel clock cycle is 102.4 kHz, each clock cycle or pixel lasts for 9.77 microseconds. Since 16 consecutive bytes have the sync bit HIGH, the sync pulse will last for 9.77 × 16 or **156.25 microseconds** (0.15625 ms).

(2) The program will then write 240 pixels of image data to the file, in each case setting the low bit (D0) **LOW** to disable sync. This completes a line consisting of 16 pixels of sync followed by 240 pixels of video.

(3) Repeat 1 and 2 a total of 32 times to write the entire 32-line image to the file.

(4) Repeat 1-3 three more times to write the remaining three images to the file.

When done, the computer will ask you to specify a file name (8 characters maximum, no extension), at which point the file is saved and named. The result will be a pure binary file (***filename.bin***) exactly 8192 bytes in size. When your EPROM software asks for the file you intend to program into the chip, this is it — all ready to go.

### *COMPUTER*

Of course, there is no reason why a computer cannot be used as an image source. Erwin Meyvaert, ON1AIJ, has several image-generator programs on his Web site (see Appendix) that use the computer sound card as the output interface.

## NBTV OPERATIONS

Much of the current NBTV activity involves individual experimentation with demonstrations and coordination of activity at annual meetings of the NBTVA (Narrow-Band

**Figure 3.13**. Peter Yanczer, probably the most prolific NBTV experimenter in the US, demonstrates a scanning disk system constructed to test the feasibility of Baird's 1930s-vintage mechanical color TV system. Despite the limitations in resolution inherent in the system, it works quite well! Note that the holes in the scanning discs look rather large. These discs are equipped with small lenses and color filters instead of simply holes, thus improving their ability to gather or project light. Peter is the founder to the Experimental Television Society, a center for NBTV work here in the United States. (Photograph from the collection of Grant Dixon.)

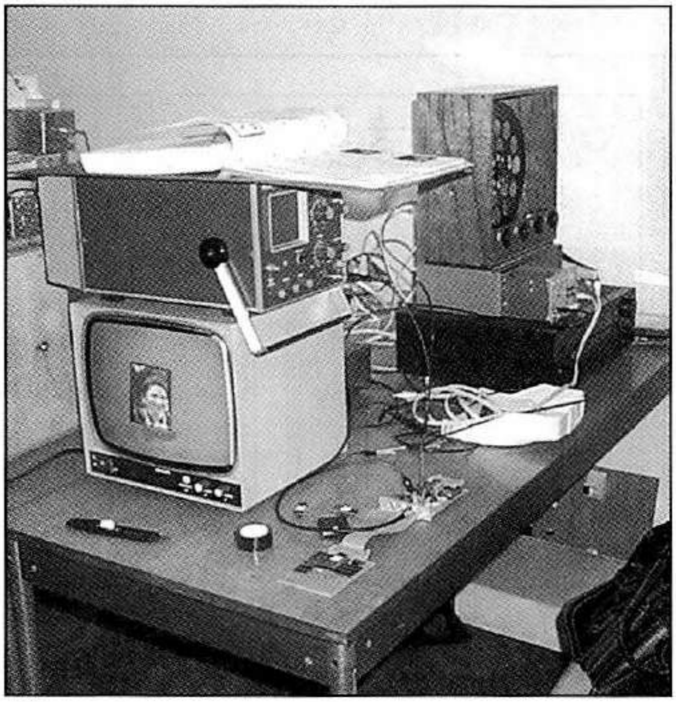


**Figure 3.14**. Klaas Rober's exhibit at the 1999 NBTVA Convention. Lots of interesting stuff here, including a scan converter displaying a 32-line image of Peter Yanczer's daughter, Karen. (Photograph from the collection of Grant Dixon.)

**Figure 3.15.** Grant Dixon presents an NBTV talk to the **Experimental Television Society** convention in 2001. (Photograph from the collection of Grant Dixon.)

**Table 3.1.**

Narrow-Band Television Association "standard" video format. As noted in the text, experimenters are encouraged to work with a variety of standards, but this format was created to provide a common standard for exchange of pictures via a range of recording media and to provide compatibility at meetings and demonstrations. Note that video data are analog and there is no specification with respect to the number of pixels/line. Pixel density does impact bandwidth, a factor which is discussed in the text.

| | | |
|---|---|---|
| **Aspect Ratio:** | | 2 : 3 |
| **Scanning Lines:** | | 32 |
| **Line Scan** | Orientation: | vertical |
| | Direction: | bottom to top |
| | Rate: | 400 Hz |
| | Pixels/Line: | not specified |
| **Frame Scan** | Orientation: | horizontal |
| | Direction: | right to left |
| | Rate: | 12.5 Hz |
| **Baseband Video** | Sync: | 0.00 V |
| | Black Level: | 0.22 V |
| | White Level: | 1.00 V |

Television Association) and ETS (Experimental Television Society). There is quite a bit of exchange of materials via the Internet. Recorded images are exchanged via CD and it is also possible to record images on the audio track of a video recorder. See the recording notes in Chapter 5 for how this can be done.

At present, there is relatively little on-the-air activity. An 80-meter net has been meeting on Saturday mornings in the UK, and you should check the NBTVA Web site for current activity. In order to reduce the bandwidth for these transmissions to the equivalent of SSB phone, frame rates are reduced to slightly over 3 frames/second. Wide-band FM on both the 2-meter and 70-cm amateur bands is an option that has been little-utilized but which has excellent potential. On either band, range should be almost equal to that obtainable on FM phone, and on 70 cm the range will greatly exceed that which can be achieved with conventional television. Given the fact that a computer and sound card are all that's required to generate a NBTV signal, why not see if there is anyone else in your local area who can be persuaded to give it a try?

Of all the available image communications modes, NBTV is certainly the most experimental, whether you are looking "backwards" in the sense of restoring or replicating old technology or applying the latest circuits and computer power to achieving specific results. Since much of the "tinkering" can be mechanical rather than electronic, it is a great activity for fussing around in the shop with no particular schedule to keep. The NBTV crowd is an interesting bunch, so attending meetings and corresponding via e-mail should definitely be on your agenda if you decide to get involved. As for myself, I now know what those experimenters from the 1920s and '30s saw when they looked into their spinning disks and whirling mirrors. What they saw was the future, embryonic though it might have been. What they saw and imagined was a world in which television in a multitude of forms was universal and accessible. In essence they saw not just broadcast empires, but individuals sending images through space. Those experimenters helped create today's image communications, and NBTV is an activity that can help you understand the excitement those flickering images created!

CHAPTER 4

# SSTV MODULATION, EQUIPMENT, AND SOFTWARE

*"Slow-scan television — it isn't expensive anymore."*
—John Langner, WB2OSZ

## INTRODUCTION

When Robot Research introduced their 1200C SSTV scan converter back in 1984, it was a pivotal event in the development of slow-scan television. In effect, the 1200 was the ultimate SSTV appliance, which — when teamed up with a color camera, monitor, and the station HF transceiver — could provide stunning color images with no need to tweak equipment or make constant adjustments to the camera or monitor. The feeling of SSTV omnipotence that came with owning a 1200 was only enhanced in the years that followed as custom EPROMs became available that permitted the 1200 to be used on new modes for which it was never designed. In fact, by the late 1980s, you either owned a 1200 with all the latest EPROM upgrades or you were standing on the sidelines watching the real "players".

Well, the 1200 was and is (if you can pick one up on the used market) a fine piece of gear, but it was expensive! By the time you had invested in the 1200, the latest EPROMs, and the camera and monitor, you had spent the cash equivalent of high-end transceiver, or even a transceiver and a modest amplifier. The 1200 with its ease of use had the potential to greatly increase the number of SSTV operators; but that potential was never fully realized, in large part due to economic considerations on the part of the average operator.

From the mid to late 1990s all that changed as the personal computer evolved the graphics capability to match and ultimately exceed what could be achieved with the 1200. While computers aren't exactly cheap, they are universal tools. Perfectly functional systems are available for very little on the used market. While there is still a modest niche for dedicated scan converters (all of which are much less expensive than the old 1200), probably 95% of all current SSTV operation is conducted using PC-compatible computers. We will take a look at both scan converter and computer options shortly. First let's begin with a look at SSTV modulation as a foundation for discussing equipment choices. You certainly can get on the air without knowing any of these details, but having even a very basic grasp of the subject will make you a better and more confident operator. It also should be noted that the basic discussion of SSTV modulation, demodulation, and equipment options to follow is also applicable to facsimile, including weather satellite reception.

## THE BASICS OF SSTV MODULATION

### BANDWIDTH AND THE AUDIO SUBCARRIER

To understand the basics of SSTV signal modulation, we need to return very briefly to the subject of video bandwidth that was discussed in Chapter 2. The basic formula for approximating the bandwidth of a video signal is:

$$B = ((P \times L) * F)/2 \qquad (4\text{-}1)$$

Where:
$B$ = signal bandwidth (Hz)
$P$ = number of pixels/image line
$L$ = number of image lines
$F$ = number of frames/second

As a benchmark, let's look at the original 8-second SSTV format, where P can be considered to be 120 and L = 120. Since the frame interval was 8 seconds, the number of frames/second is 1/8 or 0.125:

$$B = ((120 \times 120) \times 0.125) / 2 = 900 \text{ Hz} \tag{4-2}$$

The "baseband" SSTV signal thus would have signal components ranging from DC out to about 900 Hz. If we tried to input this signal directly to a SSB or FM transmitter, most of the DC and low-frequency components would be lost because most transmitter audio stages incorporate filtering to limit the audio response to a range of 300 to 2500-3000 Hz. While it would be possible to build a custom modulator, this would defeat the objective of using slow-scan in conjunction with standard voice gear. The solution to the problem is to modulate a mid-range audio tone with the 0-900 Hz video signal, thus creating a signal that the transmitter could handle. The audio tone that is modulated is known as an **audio subcarrier**. The earliest experiments simply amplitude modulated a 2000 Hz tone with the SSTV video signal — an approach known as subcarrier AM modulation or **SCAM**. While this approach worked fine on the bench, extensive on-the-air tests showed that there were several problems:

The signal strength (and hence the peak audio level) of different stations varies greatly due to the characteristics of the individual signal paths. The audio level at the receiving end would have to be readjusted for almost every station.

The peak audio level also will vary, depending upon the audio gain setting at the transmitting end — again, more adjustment at the receiving end of the circuit.

There are innumerable short-term variations in signal levels due to fading and other effects, all of which would require constant readjustment of the gain level at the receiver.

While some of these problems can be mitigated by the receiver automatic gain control (AGC) circuits, there was still considerable peak signal variation. All of these problems can be eliminated by going to FM modulation of the audio subcarrier — so-called subcarrier FM or SCFM. The audio modulation parameters were simple:

Synchronizing pulses — 1200 Hz
Black video data — 1500 Hz
White video data — 2300 Hz

An audio frequency range of 1500 to 2300 Hz for image brightness data had been used for many years in HF facsimile work (for reasons identical to the problems faced in slow-scan). The only parameter that had to be added was using a subcarrier frequency of 1200 Hz to handle the line and frame sync data. (Facsimile formats typically do not include sync pulses.) **Figure 4.1** shows a frequency plot for a single line of monochrome SSTV video. Each line of video began with a 5 ms "horizontal" sync pulse of 1200 Hz, after which the subcarrier frequency is shifted between black (1500 Hz) and white (2300 Hz) limits, depending upon the pixel brightness at any point along the line interval. A "vertical" sync pulse of 30 ms of 1200 Hz was used to start each frame. The 1200 Hz frequency was readily differentiated from the 1500-2300 Hz "video" range, and simple time integration could be used to differentiate between the 30 ms frame ("vertical") and 5 ms line ("horizontal") sync signals. Because video information is transmitted based on frequency variations in the subcarrier signal, a very wide range of on-the-air signal amplitude variation without degradation of video data will occur. With minor variations, which will be discussed in the context of SSTV modes, this basic SCFM format is used in the vast majority of current SSTV modes. Prior to looking at these modes, it is worth examining the basic approaches to demodulating and modulating an SCFM SSTV signal.

### *VIS CODES*

Back in the days of vacuum tubes and P7 CRTs, there was only one SSTV mode — the original Macdonald 1:1 format of 120 image lines transmitted over an 8-second interval. The start of each frame was triggered by a 30 ms pulse of 1200 Hz "sync" (the vertical of frame sync pulse) with each individual line triggered by a 5 ms burst of 1200 Hz (the horizontal or line sync pulse). With the advent of home-built scan converters and later the Robot 400, the format was

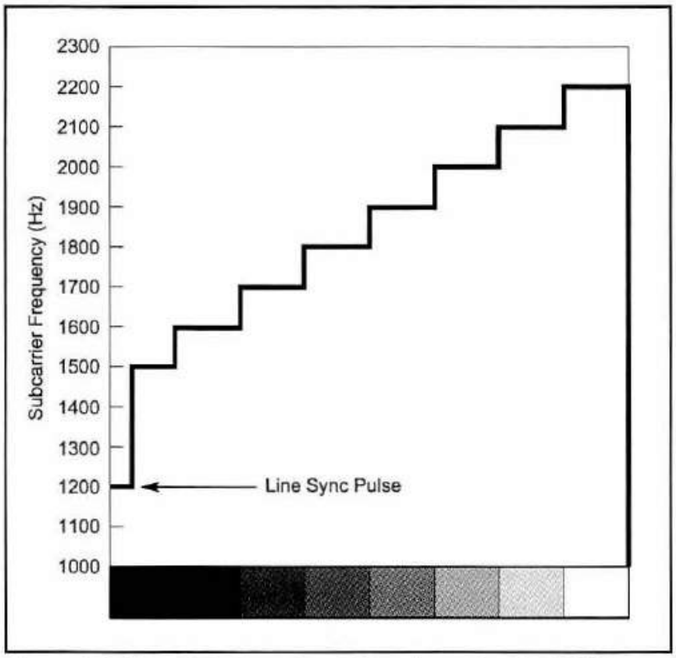


**Figure 4.1**. The original version of the sub-carrier FM SCFM) modulation format for SSTV. The figure assumes the transmission of an 8-step grayscale, shown along the bottom of the graphic display. Each line began with a 5 ms sync pulse of 1200 Hz. Once the sync interval was complete, the sub-carrier would be varied between 1500 Hz (black) to 2300 Hz (white), depending upon the brightness values during the line interval. Ideally, the amplitude of the audio sub-carrier will remain constant, although the audio filtering in most SSB transmitters will tend to decrease the sub-carrier amplitude at the high end of its frequency range. Propagation will also cause the subcarrier amplitude to vary at the receive end of the circuit. The advantage of FM sub-carrier modulation is that the video and sync information can be recovered, despite such amplitude variations, as long as a reasonable signal-to-noise ratio can be achieved.

modified slightly. Each line was defined as consisting of 128 pixels, and the number of lines was increased to 128 to better accommodate the new world of digital image storage. Since the line timing did not change, the result of moving to 128 line frames was to stretch the frame rate to 8.5 seconds. This small change had no real impact on existing analog display equipment; and, in practical terms, we were still dealing with a single mode. As scan converter memory dropped in cost and chips increased in capacity, 256-line monochrome modes appeared, along with different approaches to sending color images. None of these modes was compatible with the analog displays or the other new modes, and things got quite chaotic for a few years. With the introduction of the Model 1200, Robot Research used its market dominance to leverage a number of changes:

- Image aspect ratio was changed from the original 1:1 to our current 4:3.
- The line sync-pulse interval was lengthened from the original 5 ms to 9 ms.
- A whole new family of color modes were introduced.
- The 1200 Hz vertical sync pulse was eliminated and replaced by a "VIS Header".

**VIS** (which stands for **V**ertical **I**nterval **S**ignal) was a brand new concept in SSTV. Back in the "8-second" days, stations typically would send five or more images in sequence to optimize the chance that the station at the other end would get one good frame. If conditions were good, that also gave the receiving station more time to view the picture, since — unless it was being recorded — it would disappear as the last frame faded on the CRT display. The old vertical sync pulse assured that each new frame would reset the display properly (hopefully). As scan converters evolved, the multi-frame approach to frame transmission became impractical. The new modes required more time for transmission, which made multi-frame transmission less desirable; and, by their nature, scan converters solved the fading image problem. Pictures could be viewed for as long as the operator desired and even permitted, and the new mode permitted them to be transmitted back to the sending station or to others.

Still another factor was that the 1200 and most contemporary scan converters were controlled by microprocessors. Early scan converters had hard-wired functions that either required a mode-switch or rewiring of systems to switch modes. In contrast, microprocessor-based scan converters switch modes in software, making them far more versatile. Robot developed the VIS option to replace the conventional vertical sync pulse and accomplish two primary tasks:

- To start the single-frame image transmission
- To convey information as to the mode of the subsequent image, thus allowing the scan converter at the receiving end to switch to the appropriate mode without operator intervention.

The mode information is conveyed in a 7-bit binary format (128 possible mode values) using FM modulation of the signal subcarrier in a serial data format. The VIS data header, which lasts just under one second, is formatted as follows:

| FUNCTION | FREQUENCY (Hz) | DURATION (ms) |
|---|---|---|
| Leader | 1900 | 300 |
| Break | 1200 | 10 |
| Leader | 1900 | 300 |
| Start | 1200 | 30 |
| bit 0 (lsb) | 1100 (1) or 1300 (0) | 30 |
| bit 1 | 1100 (1) or 1300 (0) | 30 |
| bit 2 | 1100 (1) or 1300 (0) | 30 |
| bit 3 | 1100 (1) or 1300 (0) | 30 |
| bit 4 | 1100 (1) or 1300 (0) | 30 |
| bit 5 | 1100 (1) or 1300 (0) | 30 |
| bit 6 (msb) | 1100 (1) or 1300 (0) | 30 |
| Parity | 1100 (even) or 1300 (odd) | 30 |
| Stop | 1200 | 30 |

The VIS header worked very well; and as experimenters continued to develop new modes, they adopted the system, adding codes to designate their modes. In general this has worked out well, although there are a few duplicates due to lack of communication between developers. Although the 128 possible mode designations made feasible by the 6-bit format may have seemed ample in 1984, we are on the verge of running out of VIS designators! Some developers are attempting the "reserve" blocks of VIS designators to handle modes now in development. The fact is that we really have no need of so many modes, and most of those now on the "books" are like fossils of extinct life forms — artifacts of the history of slow-scan. At least 95% of the needs of the SSTV community can be met with as few as six carefully chosen mode options! Greatly reducing the number of standard modes also will make it far easier for software developers and would certainly encourage programmers who might think about writing SSTV software. This is a politically-charged subject which I will reserve for the discussion on the "Simplification of SSTV Modes" discussion on the *ICH* CD-ROM.

## SSTV DEMODULATORS

The issues in the demodulation of an SCFM slow-scan signal are quite similar to those dealt with in a typical FM receiver. In effect, we should have three stages of signal processing:

- **Filter** circuits to minimize the effect of signals outside of the video passband
- **Limiter** circuit(s) to remove undesired amplitude variations in the signal
- **Detection** circuits to convert the FM data back to baseband AM data

### *SSTV FILTERS*

In terms of filter design, we can assume that most of the energy in the SSTV video signal will fall between 1000 and 2500 Hz. The filtering on most SSB receivers is optimized to provide a reasonably flat response from around 300 Hz to between 2300 and 3000 Hz. For reasons we shall see shortly, we want to minimize the amplitude of any signals that fall outside of the SSTV video passband. It is obvious that a typical receiver isn't going to provide such protection in the 300-1000 Hz range. Even where the receiver filtering is helpful, it usually can be augmented by the judicious use of audio filtering. Unfortunately, in the interest of simplicity, many interface circuits eliminate any provisions for filtering. With strong signals and a clear frequency such circuits may work just fine, but their performance deteriorates quickly under poor band conditions. Effective filtering of the SSTV signal usually can be achieved with some combination of low-pass, high-pass, and band-pass filter elements.

Suitable filters can be constructed using inductors, resistors, and capacitors in various combinations. Unfortunately, design of such filters is complex if good selectivity and precision frequency characteristics are to be realized. A very good example of such an approach to filtering can be seen in the W0LMD filter/interface unit that I will reference in the later discussion of serial port interfaces.

When it comes to designing hardware filters, the most common approach involves the use of operational amplifiers (op-amps) in **active filter** circuits. Any recent edition of the *ARRL Handbook* will include design parameters for low-pass, band-pass, and high-pass active filters. Such filters can be highly effective; but achieving the desired design goals requires the use of precision components, including 1% resistors and precision capacitor values. Achieving the desired filter characteristics often requires the use of multiple filter stages, but this is easily accomplished given the number of dual and quad op-amp integrated circuits that are available.

**Figure 4.2** shows an example of a prefilter that incorporates both passive and active filter elements. This circuit was originally designed by John Langner (WB2OSZ) as the input stage for his Pasokon SSTV interface. The SSTV signal from the receiver is applied across two back-to-back zener diodes, limiting the peak audio to ± 5V. The two 0.022 mF capacitors and the two 22K resistors form a passive high-pass filter to minimize the impact of low-frequency interference. U1 is wired as an active low-pass filter to cut down on high-frequency interference. The filtered SSTV signal is available at point [**A**]. U1 can be virtually any type of op-amp. Single-stage circuits may employ a basic LM741. However, SSTV analog signal processing circuits tend to use a number of op-amp stages, so LM1458 dual or LM324 quad op-amp packages may be more desirable. While not shown here for the sake of simplicity, each op-amp package (single, dual, or quad) will require a balanced +12 and –12V power supply.

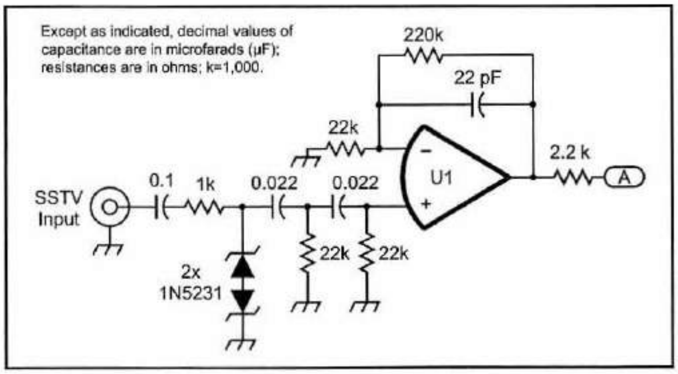


**Figure 4.2**. SSTV audio prefilter. All resistors ohms, ¼ W 1% metal-film; pF capacitors dipped silver mica; all other capacitors 50WVDC dipped mylar. See text for selection of U1.

The most up-to-date approach to filtering involves the use of **digital signal processing** or **DSP**. Using specialized DSP modules, highly effective filters with almost any performance parameters can be created by writing software to control the DSP signal processing. A number of stand-alone DSP filter accessories are available, many of which have — or can be user-programmed to produce — useful SSTV filters. Adding such a unit is particularly effective if your interface circuit doesn't have much in the way of filter circuits. The PC sound card, which can be found in most computers on today's market, is actually a sophisticated DSP system. Some SSTV software that uses the sound card as the interface takes advantage of this by implementing various filtering schemes as part of the software package. Not all software incorporates DSP filtering, but it can be very effective. The only problem with creating filters using the sound cardcard is that it greatly increases processor overhead, thus requiring a faster computer, especially in a multi-tasking environment. Some sound card software that uses DSP filtering permits you to select varying levels of filtering. If your computer is a bit slow, minimizing DSP filtering will often let you run the program on your computer, especially if you avoid multi-tasking.

### *SSTV LIMITERS*

As noted in earlier discussions, the incoming SSTV signal is subject to a wide range of factors that can cause the peak level of the signal to vary over a wide range. It is necessary to remove these amplitude variations prior to FM detection — a task accomplished using an **audio limiter**. The most common approach to implementing an audio limiter is to use an op-amp in an open-loop configuration. The voltage gain of an open-loop op-amp is very high (typically well in excess of 1000). The output voltage swing of the op-amp is limited by the supply voltage (typically +12 and –12V). If we apply a 1V P-P signal at the input of an amplifier stage with a gain of 1000, we would expect that the output signal might have a 1000V P-P waveform (1V × 1000); but this is obviously impossible due to the supply voltage limitations. What we actually would get with 1V P-P input is a square-wave signal clipped to the +12 and –12V supply voltage limits. Indeed, our hypothetical op-amp, with a gain of 1000, will clip any input signal to +12 and –12V output as long as the input exceeds 24 mV P-P. Single-stage op-amp limiters can deliver acceptable performance as long as they are not overdriven. Experimental work during the early 1970s showed that somewhat superior performance can be achieved using two-stage limiter circuits, but these are not commonly used in most interfaces today.

**Figure 4.3** shows an example of a useful op-amp limiter, originally designed for SCFM weather satellite demodulation. Filtered SSTV input is applied at point [**A**] and the input RC network provides some additional filtering. U1 is operated with a fixed gain of 1000, and the output is clamped to ± 8V by the back-to-back zener diodes in the feedback loop. A second set of zener diodes clamps the signal at point [**B**] to ± 5V.

In the case of systems utilizing the computer sound card, the limiting function is created by using the DSP capabilities of the card. Most simple hardware demodulators do not employ significant audio filtering. However, if one wishes to optimize an interface, such filtering is high desirable. The problem with a simple audio limiter is that its operation is *not* frequency dependent. The limiter will "lock" on the strongest input signal. If another audio signal, outside of the SSTV signal passband, happens to have greater amplitude than the desired SSTV signal, full limiting may not be achieved on the desired SSTV signal. No matter how the filtering is implemented, it should be placed ahead of the limiter to have the most beneficial effect. It should be noted that the SSTV audio passband is fairly wide, and no filtering will be effective for signals falling within the video signal "window".

### SSTV DETECTORS

The analog signal processing circuits discussed to this point are common to most SSTV systems; but detection and post-detection processing circuits diverge considerably, depending upon whether one selects analog or digital techniques.

**Analog Detection**. A basic analog SSTV detection circuit, originally used in the Weather Satellite FM demodulator circuits, is shown in **Figure 4.4**. U1 integrates the signal from the audio limiter (point [**B**]), driving a staggered low-pass active filter (U2) that functions as an audio FM slope discriminator. The output of U2 is an amplitude-modulated signal that varies across the SSTV audio spectrum. U3 and U4 are wired as a full-wave detector. The negative-going signal components are inverted to positive-going by U3, wired as an inverting amplifier with unity gain. The output of U3, now positive-going, is summed with the positive-going signal components from U2 at the input of U4. U4 is an inverting amplifier with a gain of 2, resulting in negative-going output of all signal components at point [**C**]. The signal at [**C**] now covers twice the frequency range of the original subcarrier signal, and this component must be filtered out of the signal prior to A/D conversion.

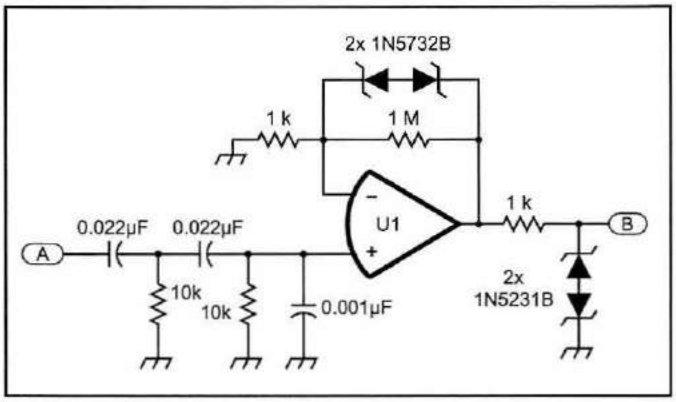


**Figure 4.3**. An example of an SSTV audio limiter. All resistors ohms, ¼ W 1% metal-film; pF capacitors dipped silver mica; all other capacitors 50WVDC dipped mylar. See text for selection of U1.

The circuits to accomplish this are shown in **Figure 4.5**. U1 is wired as a 700 Hz low-pass filter, followed by a second low-pass stage (U2) with a cut-off of 566 Hz. U2 incorporates a variable **OFFSET** control to set the output of U2 to 0V when 1000 Hz is applied to the input of the SCFM prefilter (Figure 4.2). The **GAIN** pot at the output of U2 sets the peak drive level to U3 which provides a gain block, signal inversion, and some additional filtering. The GAIN control is set to provide a peak output of 5V with 2300 Hz input to the SCFM prefilter. The output of U3 will thus vary from 0 to 5V over a 1000 to 2300 Hz frequency range. Analog to digital (A/D) conversion is provided by U4, which is wired to run in a continuous conversion mode. The 8-bit video values are updated approximately every 70 ms, and the value can be read using a byte-wide input port.

**Digital Detection**. Although the various SCFM detector and post-detection filter circuits are not particularly complex, a number of stages are required to achieve linear grayscale output. In contrast to the analog approach, digital circuits can be quite a bit simpler and do not require any of the set-up adjustments required by the analog circuits. Many microprocessor and micro-controller modules have frequency-capture circuits that can measure the subcarrier frequency directly from the limiter output with few additional components.

**Figure 4.6** shows a similar capture circuit built using external digital logic. Direct digital detection requires an accurate clock signal. In this circuit, U1A and U1B form an oscillator whose frequency is controlled by a 4.194304 MHz crystal. This may seem to be a rather odd frequency, but the

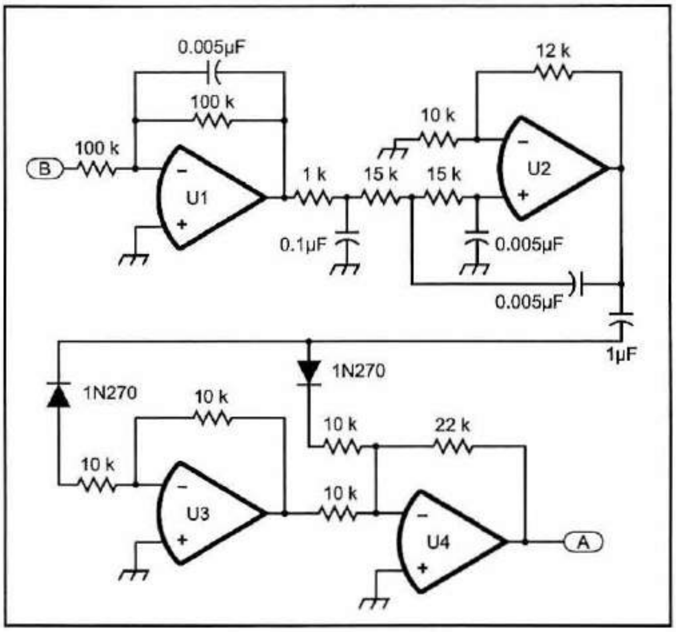


**Figure 4.4**. An example of an SSTV analog audio discriminator/detector. All resistors ohms, ¼ W 1% metal-film; pF capacitors dipped silver mica; all other capacitors 50WVDC dipped mylar. See text for selection of U1-U4.

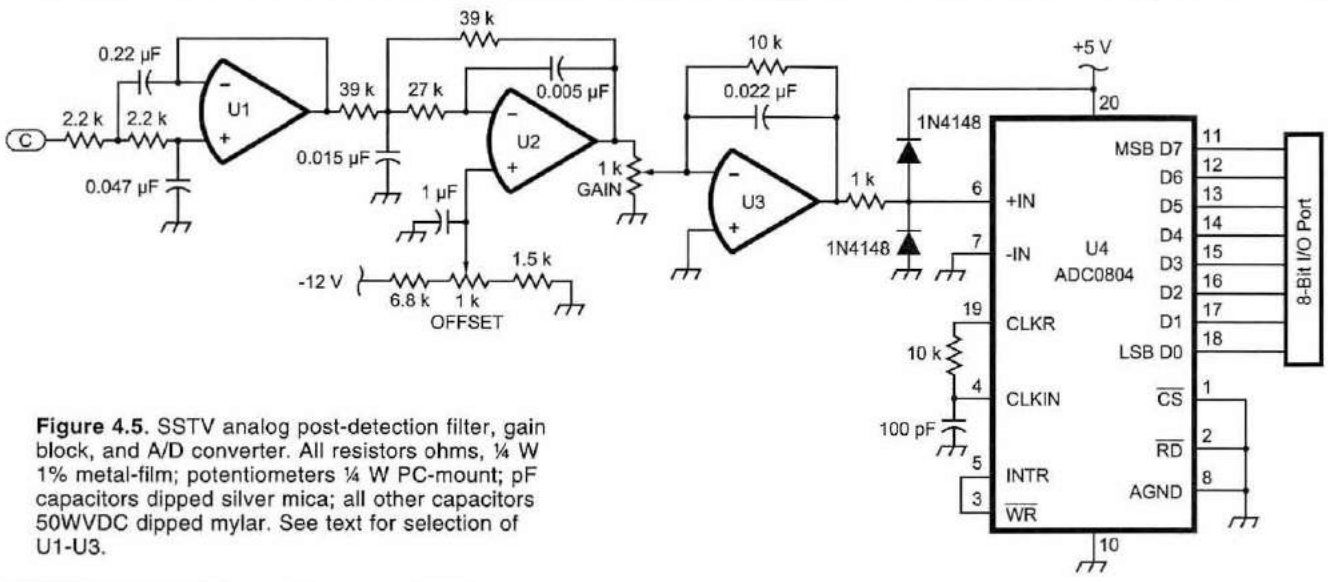


**Figure 4.5.** SSTV analog post-detection filter, gain block, and A/D converter. All resistors ohms, ¼ W 1% metal-film; potentiometers ¼ W PC-mount; pF capacitors dipped silver mica; all other capacitors 50WVDC dipped mylar. See text for selection of U1-U3.

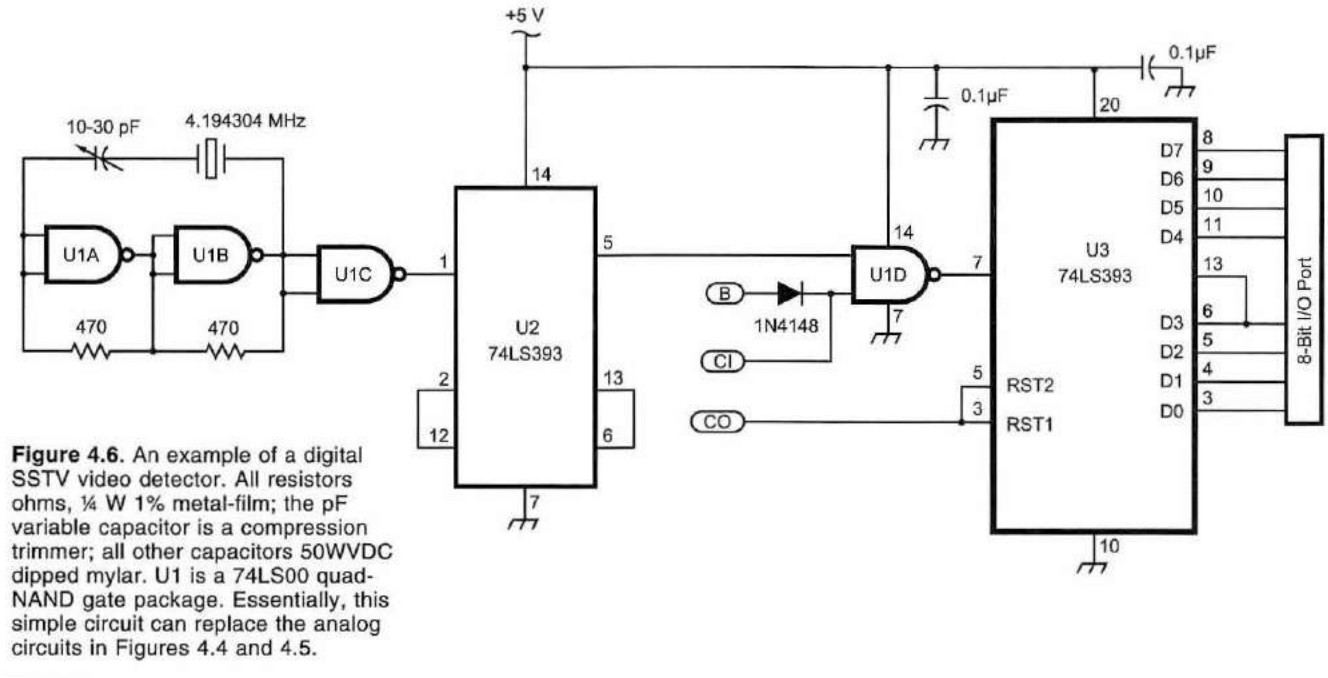


**Figure 4.6.** An example of a digital SSTV video detector. All resistors ohms, ¼ W 1% metal-film; the pF variable capacitor is a compression trimmer; all other capacitors 50WVDC dipped mylar. U1 is a 74LS00 quad-NAND gate package. Essentially, this simple circuit can replace the analog circuits in Figures 4.4 and 4.5.

crystals are widely available at low cost; and, as we shall see shortly, other useful frequencies can be obtained by binary frequency division from the master oscillator. The oscillator output is buffered by U1C and applied to the input of a multistage binary counter (U2). As shown, the chip pro-vides a divide-by-eight function, resulting in an output of 524.288 kHz. This clock frequency has a period of 1.9073 microseconds, a value that will become relevant shortly. The 524 kHz clock is applied to one input of a NAND gate (U1D). The other gate input is connected to the output of the SSTV limiter circuit (Figure 4.3) at point **B**. Since there is a diode between point [**B**] and the gate input, the input will go **HIGH** during the positive half of the output cycle from the limiter. In essence, for one half of the duty cycle of the frequency at the output of the limiter, the gate input will be **HIGH**, allowing the gate to pass the 1.9 microsecond pulses from the 524 kHz clock. The output of U1D is connected to the input of another binary counter (U3), and all eight data bits can be read at a byte-wide I/O port.

To see how the circuit operates, let us assume that the counter (U3) has been reset by a very short logic **HIGH** applied to point [**CO**]. If the 8-data bits are read after the reset, the value should be 0 as all the counter output lines will be **LOW**. Now assume the limiter is producing output at 2300 Hz. A 2300 Hz signal has a duty cycle of 434.78 microseconds. The positive-half of the limiter output wave-form will thus be **HIGH** for half of this interval or 217.39 microseconds. During the time this 217.39 microsecond **HIGH** is applied to one input of U1D, a total of 113 clock pulses (217.39/1.9) will be passed through U1D to the counter. If we wait for the gate input of U1D (point [**CI**]) to go **LOW**, count inputs to U3 will cease; and the value (113) can be read from the output lines at any time during the second half-cycle (217.39 microseconds) of the 2300 Hz output from the limiter. Once a value has been read, a **HIGH** reset pulse can be applied to point [**CO**] to reset U3 so it is ready to count during the next ½ cycle of the subcarrier signal. With the clock values shown in Figure 4.6, the following count values would be obtained over the SSTV subcarrier frequency range:

| **SUBCARRIER FREQUENCY** | **U3 COUNT** |
|---|---|
| 1000 | 6 (262)* |
| 1100 (vis 1) | 238 |
| 1200 (sync) | 218 |
| 1300 (vis 0) | 201 |
| 1400 | 187 |
| 1500 (black) | 174 |
| 1600 | 163 |
| 1700 | 154 |
| 1800 | 145 |
| 1900 | 137 |
| 2000 | 131 |
| 2100 | 124 |
| 2200 | 119 |
| 2300 (white) | 113 |

The count of 6 for 1000 Hz input reflects the fact that the 8-bit counter has a maximum capacity of 255, and 1000 Hz would produce 262 clock counts. Since the counter will have passed 255, the result is equivalent to a reset; and the remainder (6 counts) is what would be read. A simple look-up table can be used to convert the count values directly to video intensity values for image display. In essence, three digital chips, requiring no set-up adjustments, can replace all the analog detection and filtering circuits in Figures 4.4 and 4.5! The circuit does require an 8-bit I/O port, but so does the analog A/D converter in Figure 4.5. We also require an output bit ([**CO**]) to reset the counter and an input bit ([**CI**]) to sense the logic state of the gate input. Note that the output count has a non-linear relationship to frequency, so the frequency resolution deteriorates at the upper end of the subcarrier frequency range. Resolution can be improved easily by a factor of two by setting up a second counter circuit gated by inverting the gate signal applied to U1D. This would require a total of two 8-bit I/O ports and four control lines, but a few more chips can permit both counts to be read from a single 8-bit I/O port if desired.

The circuit in Figure 4.6 requires some care in the selection of the clock frequency. The frequency must be low enough so that we stay below 255 counts at the lowest frequency we want to read (1100 Hz) but high enough that we make optimum use of the 8-bits of counting capacity. The 524 kHz signal derived from the 4.194304 MHz crystal works out well in this regard. Additional frequency division also can generate both 4096 Hz and 2048 Hz clock signals which work well as pixel clocking frequencies for a variety of fax and SSTV modes, hence the odd but readily-available master oscillator crystal!

### *SSTV MODULATORS*

Given the fact that virtually all scan converter and computer-interface systems have SSTV transmit capability, it is useful to examine the two basic approaches (**Figure 4.7**) to producing the SCFM SSTV signal. Figure 4.7A shows a very good analog modulator using an NE566 function generator chip. Wired as shown, the frequency output is inversely proportional to the control voltage (point [**IV**]) applied to pin 5. Set-up involves grounding point [**IV**] and adjusting the 10K SET pot for 2300 Hz output as measured at pin 3 (square-wave) or pin 4 (triangle-wave). Once adjusted, the circuit will produce an output frequency range of 2300 Hz (0V applied to [**IV**]) to 1100 Hz (6.26V applied to [**IV**]). The input/output function is extremely linear, and a change of 0.52174V at the input will shift the output frequency by 100 Hz. The control voltage can be obtained readily by using an op-amp and summing resistors to produce the desired voltage range. A simple look-up table in software can be used to relate pixel brightness values to the bit pattern applied to the D/A converter. Figure 4.7A shows the output derived from the triangle-wave output pin (4).

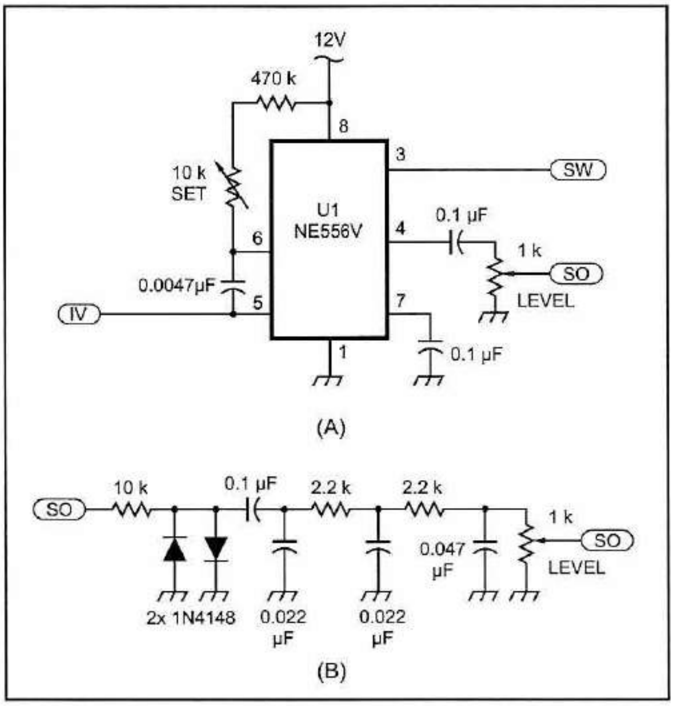


**Figure 4.7.** Examples of SSTV modulator circuits. **[A]** An analog circuit using an NE566 function generator. **[B]** A digital modulator using a single output bit. All resistors ohms, ¼ W 1% metal-film; potentiometers ¼ W PC-type; all capacitors 50WVDC dipped mylar.

The output at this pin has relatively low harmonic content, and the signal ([**SO**]) can be applied directly to transmitter audio input via a 1K LEVEL control. It is possible to take the output from pin 3 (point [**SW**]), but this is a square-wave and very rich in harmonics. Use of the [SW] output would require an R-C low-pass filter circuit such as that shown in Figure 4.7B.

Figure 4.7B shows a modulator based on direct switching of an output bit (point [**OB**]). There are several ways to create a range of audio frequency output using a single bit:

Brute-force programming, where the computer uses an accurate clock signal to time the HIGH and LOW states of the output pin. For example, if the computer sets the bit HIGH for 217 microseconds and then resets the bit LOW for an additional 217 microseconds, the result is a 434 microsecond duty cycle, corresponding to approximately 2300 Hz ($1 \times 10^6/434 = 2304$ Hz). This approach does work, but is very processor-intensive since the system has to tally every cycle of the high-frequency clock signal.

Many microprocessors and micro-controller modules have programmable frequency generators that can be set to a specific output frequency by simply setting up the internal clock frequency and loading binary values to a control register. The "speaker" output of a basic PC can be controlled in a similar manner. This approach is much easier on the processor, since the frequency control values need only be updated at the relatively low pixel clock rate.

No matter how the subcarrier waveform is generated, it is a square-wave rich in harmonics. The signal should be routed through a low-pass filter prior to using it to drive the transmitter audio input. In the sample circuit shown in Figure 4.7B, the square wave at the output bit (point [**OB**]) is limited to less than 1V P-P, using a pair of back-to-back silicon diodes, and then is routed through a simple R-C passive low-pass filter consisting of the two 2200 Ω resistors and the 0.022 and 0.047 mF capacitors. The output signal (point [**SO**]) is taken from the 1K LEVEL control and applied to the transmitter input.

In the case of systems based on the use of the computer sound card, the desired subcarrier tone is synthesized directly by utilizing the DSP functions of the sound card, which also can supply any filtering that might be required. Since most sound cards can synthesize sine-wave output waveforms, additional filtering is rarely required.

## PUTTING THE PIECES TOGETHER — A BASIC SCAN CONVERTER

Scan converters have been mentioned repeatedly up to this point with very little explanation as to how they actually work. While a scan converter is a bit complex for most amateurs to design and build, **Figure 4.8** shows a block diagram that should be sufficient to illustrate the basic principles. For the sake of simplicity, let's assume we want to input, store, display, and transmit a basic 320 × 240 line monochrome image using 8-bit grayscale coding (see Chapter 2). Such an image would require 320 × 240 or 76,800 bytes for storage. Figure 4.8 assumes a 128K block of random-access memory (RAM), so there is plenty of storage

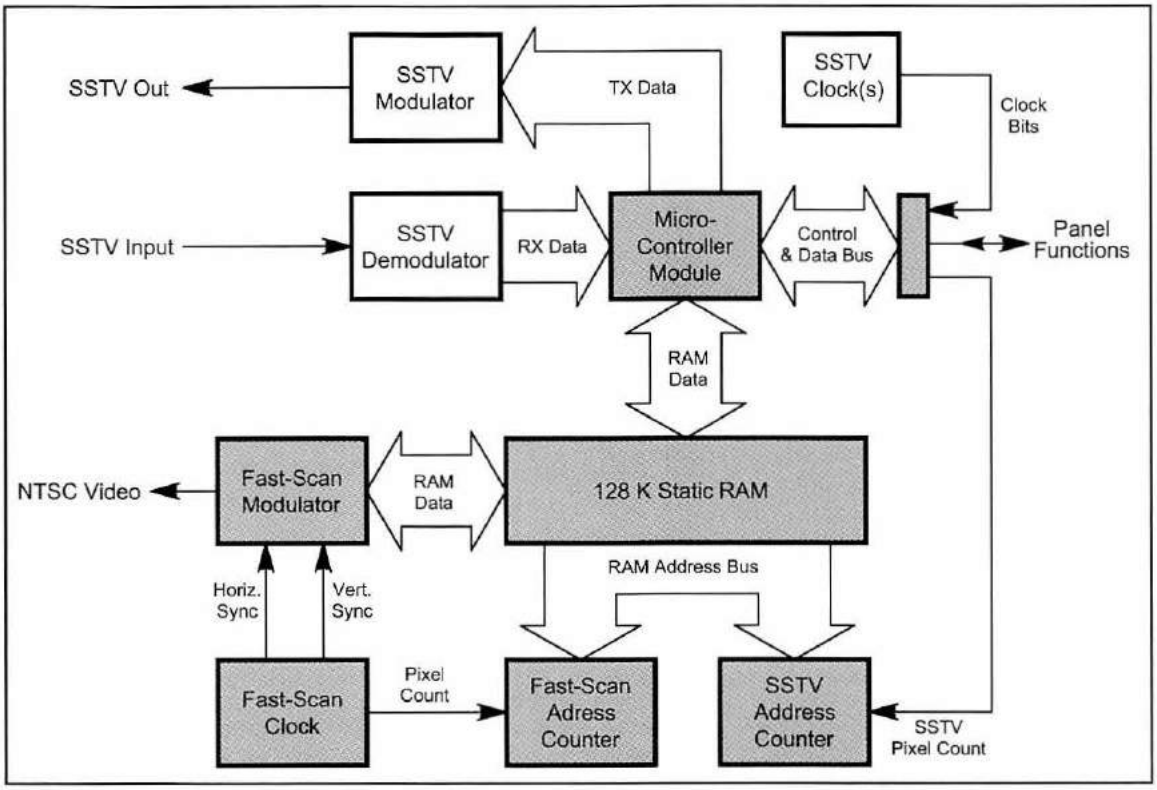


**Figure 4.8.** A block diagram of a dedicated, microprocessor-controlled SSTV scan converter.

capacity for our hypothetical image. I chose static RAM for our hypothetical stand-alone scan converter because static memory will retain its data regardless of the clock rate. Dynamic RAM, used in most computers, must be addressed constantly at a relative high rate to "refresh" and retain the memory contents.

The functions of our scan converter will be controlled by a micro-controller module containing a CPU, memory, I/O and other functions that permit the module to function as a stand-alone computer. We will assume the module has several byte-wide I/O ports dedicated to different functions in this application:

- **RAM DATA** — a bi-directional port to permit the module to write to or read from the 128K RAM module.
- **RX DATA** — an input port to let the module read 8-bit values from the SSTV demodulator.
- **TX DATA** — an output port that lets the module write 8-bit values to the SSTV modulator
- **CONTROL AND DATA BUS** — 8 or more bits, as required, to input bits from the SSTV CLOCK, bits to toggle (and reset) the SSTV address counter, and enough I/O bits to support panel functions such as mode and control switches, indicators, etc.

Addressing of the static RAM module is controlled by two independent counters. The **fast-scan address counter** is clocked at a relatively fast rate (slightly over 5 MHz) to permit 320 pixels of image data to be clocked out during each fast-scan TV line interval. This fast-scan pixel count is derived from a crystal-controlled **fast-scan clock** that also produces the reference pulses for the 15,750 Hz fast-scan horizontal sync (**HOR SYNC**) and the 60 Hz fast-scan vertical sync (**VERT SYNC**). The fast-scan modulator contains a D/A converter connected to the **RAM DATA** bus and several transistors that mix the D/A video with the sync signals from the fast-scan clock, producing a composite NTSC video output that is routed to an external TV monitor. Most of the time the RAM addressing is controlled by the fast-scan address counter, and the TV monitor will display the contents of the RAM memory module. On power-up, the RAM module simply contains random data bytes, which would produce a random, noise-like display on the TV monitor.

However, the RAM module can also be addressed by the SSTV address counter. The system logic is set up so that whenever the microprocessor module wants to read or write data to RAM, the RAM address control is switched from the fast-scan to the SSTV counters for the duration of the read or write operation. Let us assume that the micro-controller reads the front-panel switches, decodes the current mode as 320 × 240, and senses that a function switch has been cycled from STANDBY to RUN. At this point the micro-controller would perform the following operations:

- Read the output of the **SSTV DEMODULATOR** looking for a pattern that would indicate the start of the image.
- When a start is detected, reset the **SSTV ADDRESS COUNTER**.

Using the pixel-rate clock signal from the **SSTV CLOCK** circuits, read 8-bit video values at the proper intervals and write the values to RAM. Each time a write operation is performed, a pulse is sent on the **SSTV PIXEL COUNT** bit to advance the **SSTV ADDRESS COUNTER** to the next RAM location.

When 320 samples have been processed, assuming we are dealing with a line-triggered image format, the processor will wait until it reads a line sync pulse from the **SSTV DEMODULATOR**. At this point it will repeat the loading of 320 image pixels until 240 lines have been processed.

The micro-controller would then suspend all writing activity until it senses another function call, based upon the status of the front-panel mode and function switches. It also would be checking the front panel controls during every stage; and, if the function switch were cycled from RUN to STANDBY, it would suspend image loading.

While all this has been going on, the **FAST-SCAN ADDRESS** counters have been cycling through the RAM whenever the micro-controller module was not writing to the RAM. In effect, as the 240 image lines were being written to RAM, the developing image would have been visible on the external monitor. That image will continue to be visible as long as power is applied or until the micro-controller begins to overwrite the old image data with a new picture! This is the essence of how scan converters work. The image can be clocked into RAM at one rate (in this case, clock rates appropriate to specific SSTV modes) while continuously being read out at fast-scan rates for display.

- Once an image has been loaded into RAM, the micro-controller can retransmit the image very easily:
- Generate an appropriate START sequence using the **SSTV CLOCK** and sending the appropriate data to the **SSTV MODULATOR**.
- Send data to generate a proper line sync pulse, and then output 320 pixels of RAM data at the appropriate rate determined by the **SSTV CLOCK**.
- Repeat #2 until 240 lines of image data have been transmitted!

The real power of a system of this type is that it is not limited to a single mode. Assuming that the proper interface circuits are available (along with appropriate clock signals) and suitable software for the micro-controller module, images in almost any mode can be loaded into RAM for display on the fast-scan monitor! The functions of such a system can be further expanded:

- **Fast-scan Frame Grabbing**. Adding a fast-scan demodulator and some additional logic chips to interface to the RAM, images from a fast-scan camera or other source could be captured on demand, permitting SSTV transmission from any fast-scan video source.
- **Color**. This is a bit more demanding, but readily accomplished by having three RAM modules (for red, green, and blue image luminance data), adding circuits to provide proper color modulation in the FAST-SCAN MODULATOR, and, of course, adding additional circuitry to upgrade the frame-grabber option to color.

A full-color scan converter system is not a simple project.

It requires a major effort to design, build, and debug the hardware. You also would have to write and debug the microprocessor code, all of which probably would be written in assembly language to achieve the operating speed required. Much of the cost associated with a scan converter, such as the Robot 1200, reflects the fact that it was a product of early-1980s technology. Much of the same performance could be achieved today with a handful of large-scale integration ICs. As a result, the relatively few commercial scan converters, which we will review shortly, are considerably less expensive than the old 1200.

If you wanted to construct such a scan converter, it would be considerably easier to do so with today's technology, but there are some very good reasons to ask why one might undertake such a project. Refer back to Figure 4.8 and look at the circuit modules that are shaded in gray. All of these modules and more are present in a typical PC-compatible computer:

- The micro-controller module is equivalent to the basic computer itself. However, in comparison to the micro-controller, the PC is faster and has significantly greater memory and hardware resources.
- All of the remaining scan-converter circuit modules are available in the form of your ISA or PC-bus graphics card. What's more, the graphics card has much more RAM, is already configured for 24-bit color, features random access for all video data, and outputs color video to the PC monitor, which is far superior to a color TV monitor in terms of display capabilities.
- If you want the image frame grabbing function, simply add a TV frame grabber card to the PC. Precisely the same function can be achieved by using a color webcam at a fraction of the cost of a color camera and frame grabber!
- The PC also can input images from flatbed scanners, digital cameras, and CD-ROMs. These video sources are capable of generating pictures that can be used in high-resolution modes for which frame-grabbed TV images are inadequate.
- The PC has an operating system that lets you save and retrieve images from magnetic and optical disk drives, making it a simple proposition to save and reuse images.
- Images prepared on the PC can be modified as desired, including adding callsigns and any other graphics features you might wish to use.

In effect, a typical PC is a scan converter on steroids, providing all of the resources needed to support any SSTV operations. What's more, the PC has the resolution to support high-resolution image options such as fax and weather satellites, a wide range of imaging functions as part of ATV operation, and even unusual modes such as NBTV. In the case of SSTV, all that must be provided is interface circuitry incorporating the SSTV modulation, demodulation, and possibly the SSTV clock circuits. Suitable interfaces can range from the very simple to the more elaborate and sophisticated, but in all cases the circuits are trivial compared to what would be required to implement even the most basic stand-alone scan converter. Since you probably are already using a PC in your station to support logging, contest activity, or all the available digital modes, the appeal of using the same computer for slow-scan is pretty obvious. Many of the equipment options we will discuss in the sections that follow include various PC interfaces and the software to operate them.

Stand-alone scan converters are far less common in SSTV today; but they definitely have a niche in mobile and portable work, including the ultimate portable operation in the form of SSTV aboard the International Space Station! I also don't wish to discourage the hard-core experimenters among us from tackling scan converter projects if they are so inclined. I have built several scan converters for SSTV and weather satellites over the years and now am working on one for use on NBTV, so I definitely belong to the hard-core home-brew crowd. If you do consider such a project, keep in mind that it will involve both hardware design and construction and software development. If I were contemplating an SSTV scan converter project, I would look at the use of a PC-compatible micro-controller teamed up with a PC graphics card to handle the image storage and video output functions. Such an approach would eliminate most of the hardware design problems and would simplify software development, since the PC could be used to write and debug the software, using the multitude of freeware and shareware design tools that are available.

## PC-INTERFACE HARDWARE AND SOFTWARE

Not that long ago there was a clear distinction between hardware and software, but this is no longer the case. If you design and build an elegant interface, either it will have to be compatible with existing software, or you or someone else will have to write software to support its unique features. Without support software, the most comprehensive interface system is no more useful than if you had left all the components in a bag! I will discuss three categories of interface hardware:

- Systems based on the ultra-simple "HamComm" serial interfaces
- Systems based on the use of the computer sound card as the interface hardware
- Systems based on "smart" interfaces that connect to the computer using high-speed RS-232 serial ports

Each approach has its virtues, and I will do my best to provide an honest evaluation of what the advantages and disadvantages of each might be. I also will summarize some of the better-known software packages that support each interface type. It is far from practical to hope to note every software package that is available, so I will confine my summaries to a relatively small number of widely used programs. New programs appear with regularity, and older offerings fall by the wayside. One of the best ways to keep up with what is available, both in terms of hardware and software, is the "CQ SSTV" Web site maintained by Dave Jones (KB4YZ) in Bedford, Indiana (**http://www.tima.com/~djones/**). This site is so comprehensive in coverage that nothing but a visit will do it justice. In addition to every possible SSTV-related subject, you will find links to all current sources of hardware and software. You also can elect to do Internet searches using **SSTV** as the key word, and you will turn up hundreds of other sites ranging from hardware/software vendors to individual amateur home pages.

### *GENERAL NOTES ON SSTV SOFTWARE*

Software for operating SSTV falls into three major categories:

**Freeware**. This is software that is available for download without charge. The author usually retains copyright, which means that while you can use the software without limit and even distribute it to others, you cannot incorporate the code into other programs without the author's permission — and you certainly cannot sell it to others. Some freeware is very good, but don't expect a lot of program support from the author. He or she isn't earning any revenue from the program so can't be expected to burn the midnight oil solving user's problems.

**Shareware**. Shareware is freely distributed, under the copyright provisions noted above; but it is made available with the expectation that if you like the program, you will pay a nominal registration fee. Many authors will provide program enhancements when you register. You will be informed automatically of significant updates; and the author will be receptive (within limits) if you need some questions answered.

**Commercial Software.** This is software produced for commercial sale with prices ranging from as little as $30 to over $100. The more expensive products tend to be 32-bit Windows-compatible offerings that take full advantage of the DSP features of the sound card interface. None of this software is overpriced, considering the authors' time and monetary investment and support provided for the products. Almost all these offerings include evaluation copies of the software that can be downloaded without charge. To encourage you to purchase/register the software, there are usually limitations built into the trial copies:

- **Banner Call-sign**. Most current software permits you to place your callsign and some other information into the 16-line header at the top of most image formats. Most trial software locks out this option and prints "UNREGISTERED" in the header instead. This is a not-so-subtle notice to everyone you work that you are using a trial copy!
- **Nag Notices**. When you exit from some trial software, you will be presented with a notice that you have not registered and instructions on how to do so. Such notices usually will stay posted for 30 seconds or more and can become annoying. PS: They are meant to be!
- **Limited Features**. Some software will lock out features such as specific modes, the ability to save pictures you receive, or the ability to transmit.
- **Limited Operating Time**. Some trial software will simply quit after a specific operating interval — say 30 minutes. It is otherwise fully functional; but the need to constantly reboot, often with "nag" messages when the program quits, reminds you that you are using trial software.
- **Calendar Time Limits**. Some programs simply become non-functional 30 or 60 days after initial installation.

In noting the software available for different interface types, it is simply not possible to mention all possible programs. The ones I do reference will be those in common use and/or programs with which I have personal experience. If a piece of software is not mentioned, it does *not* mean that I consider it to be unsatisfactory. All the programs in general use do a good job in terms of displaying and transmitting pictures. If this wasn't so, a piece of software could never maintain a user base given all the alternatives that are available. That said, there is tremendous variability with respect to all sorts of features. Some products cover more modes than others, but all cover the modes in general use. Some products may let you do more image manipulation within the program, but that may not matter if you do most of your image alterations in a more comprehensive graphics program. Some programs may handle interference or noise better than others, but that could be as much a matter of the interface used as anything else. As with everything else in Amateur Radio, opinions on software abound and are voiced without restraint. Most of these comments are nothing more than personal, subjective opinions. Since it is easy to sample the different software products, don't hesitate to do so until you find a program that fits your operating style and objectives. You certainly should keep track of opinions, particularly at the beginning, but keep an open mind until you find what you want to use.

### *RS232 SERIAL PORT ("HAMCOMM") INTERFACES*

When you hear about getting on slow-scan with $10 worth of parts and a few hours at the bench, this is the interface they are talking about! The typical "Hamcomm" interface is the essence of simplicity:

- The **receive** end often consists of a single op-amp limiter stage with the output applied to the **DSR** line (DB9-6).
- The **transmit** audio is derived from the **TXD** (DB9-3) line.
- A logic signal to key the **PTT** circuit is derived from the **RTS** (DB9-7) line.
- The **positive and negative supply voltages** for the op-amp are derived from the **DTR** (DB9-4) and **RTS** (DB9-7) lines, respectively.

**Figure 4.9** shows my own version of this interface. While some experimenters have tried to reduce this already-simple interface to the absolute minimum number of components, there is no point in cutting corners. With suitable software, this interface can copy RTTY, CW, and lots of other modes besides SSTV. While there are innumerable versions of this circuit published on the Internet, most omit all the complex details of actual audio, transmit, and PTT connections, leaving you to figure out that part for yourself. The version that I have presented here incorporates a reasonable amount of filtering and includes all the messy interface details. The

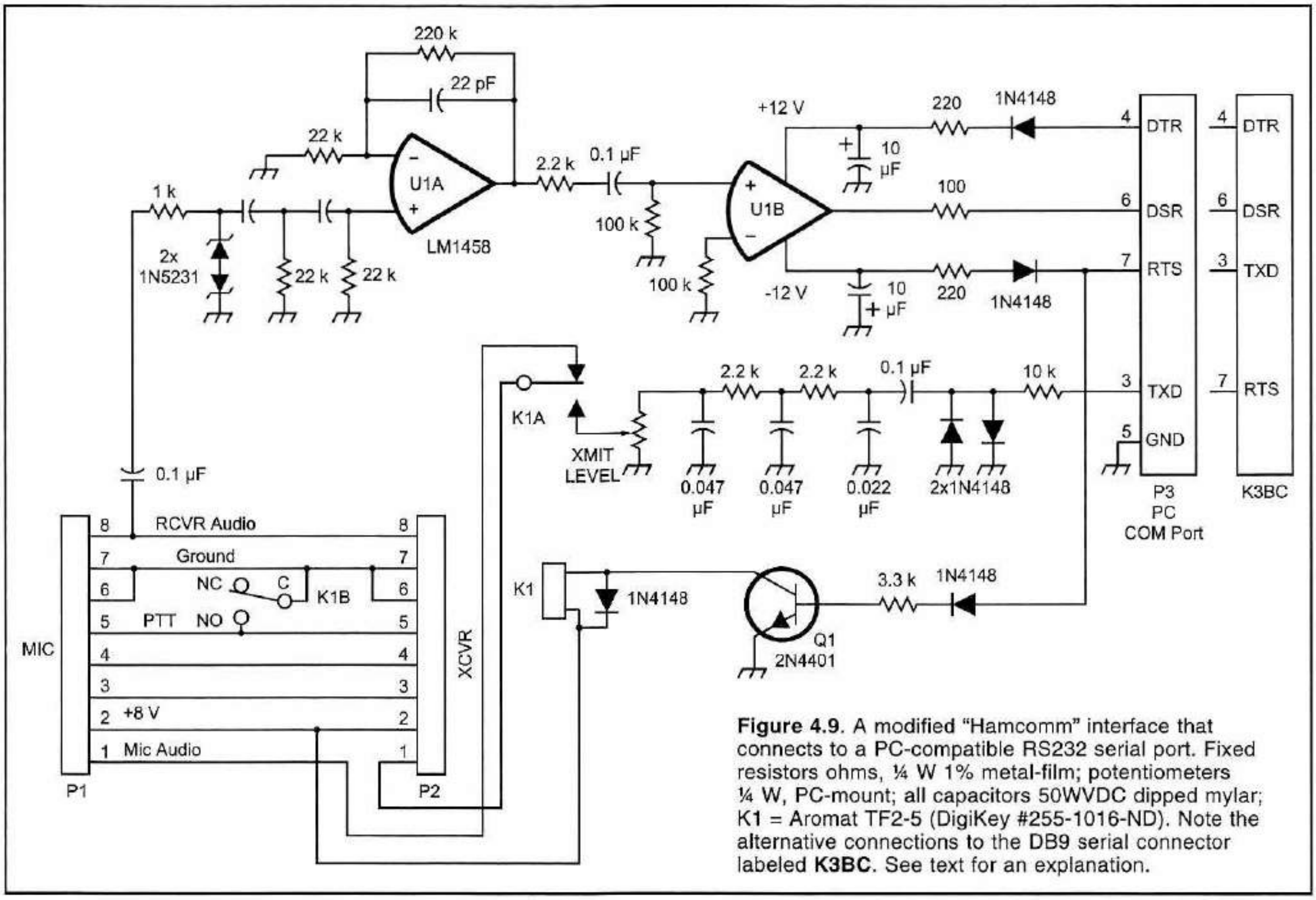


**Figure 4.9.** A modified "Hamcomm" interface that connects to a PC-compatible RS232 serial port. Fixed resistors ohms, ¼ W 1% metal-film; potentiometers ¼ W, PC-mount; all capacitors 50WVDC dipped mylar; K1 = Aromat TF2-5 (DigiKey #255-1016-ND). Note the alternative connections to the DB9 serial connector labeled **K3BC**. See text for an explanation.

**receive** portion of the interface uses a two-stage circuit. The first stage (**U1A**) is the WB2OSZ Pasokon filter circuit driving the second stage (**U1B**), wired as a simple open-loop limiter. The receive audio is tapped off the receive audio line available on the microphone connector for most modern transceivers. If your transceiver does not have a microphone connector with receive audio wired in, the audio input can be brought out to a phono jack and routed — whether to the speaker audio or to a phone-patch/line output connector on the rig. The **SSTV transmit audio** is derived from the serial TXD line and routed through a passive low-pass filter circuit to the TX LEVEL control. Switching between normal microphone audio and SSTV is accomplished with one-half of a DPDT relay (**K1A**). The relay is activated by the **PTT** signal from serial line RTS, driving a simple NPN switching transistor (**Q1**). The second set of relay contacts (**K1B**) activates the transceiver PTT line.

A few additional explanatory notes are in order. The numbered pins for the microphone (**MIC**) and transceiver (**XCVR**) connectors are based on my ICOM IC-707. Various manufacturers wire the typical 8-pin microphone connector somewhat differently, so check your manual for the equivalent lines for your rig and re-label the schematic. Also, in most cases the circuit can be adapted for connection to the **ACCESSORY** jacks on most modern transceivers. Also, K1 is a relatively uncommon relay in that it has a 312 Ω coil. Most other 5V relays have a 125 Ω coil. The +8V supply line for most transceivers is rated at 40 mA load. The use of the Aromat relay specified keeps the relay current well-below this value.

**K3BC Note**: Ben Vester (K3BC) played a major role in the computerized SSTV revolution in the early '90s (see Chapter 1) by writing the first SSTV software for interfaces of this type. The interface circuit he published is wired slightly differently from others with respect to the serial port lines. If you want to use the Vester software, you should wire the DB-9 as shown under the K3BC heading.

**Other Home-built Options**. Many references to software that is compatible with interfaces of this type refer to the use of the **VolksRTTY** interface described by Terry Mayhan (K7SZL) in the April, 1998 issue of *QST*. This is a fine interface; but it is optimized, in terms of the filtering it provides, for RTTY, *not* SSTV. I would not recommend the use of the VolksRTTY circuit unless you modify the filter constants. In contrast, probably the best SSTV version of this type of interface is that designed by Dr. Robert Suding, WØLMD. Robert is one of the pioneers in the digital evolution of SSTV and has designed an interface that incorporates superb SSTV filtering. In fact, the interface includes a combination of three different filters to combat almost any interference problem. A complete documentation package for this circuit, including schematics and PC board layouts, can be downloaded from **http://www.tima.com/~djonesw0lmd.htm.** Robert makes a wide range of options available for constructing this interface, including bare PC boards ($20), complete kits ($70), and wired-and-tested units ($100). Robert can be contacted via **w0lmd@yahoo.com**.

**Selected Commercial Offerings**. I would hesitate to guess how many firms offer different versions of this basic type of interface, but here are three examples:

- **Model BP-2M** Bay Pac modem, available from **Tigertronics (http://www.tigertronics.com)**, $69.95. This is a "smart" circuit that can be reconfigured via software and thus is more elaborate than most.
- The **RASCAL** interface from **Bux Communications (http://www.buxcommco.com** or **(http://www.packetradio.com/psk31.htm)**, kit $27.00, wired-and-tested $49.00.
- **Donners Digital Interface Sales (http://home.att.net/~n8st)**, $40.00.

If these don't meet your needs and you don't want to build your own, a little Internet surfing using "Hamcomm" as the search parameter certainly will yield still other options.

### *RS232 SERIAL PORT ("HAMCOMM") SOFTWARE*

There are more program options out there for RS232 serial port interfaces than any other option which means you have a lot of choices. Almost all of this software operates under DOS; but if you think of DOS in terms of crude menus and a command-line interface, you are in for a pleasant surprise. The high-end programs are just as flashy and functional as the best Windows options (see **Figure 4.10**). None of these programs can be operated in a DOS window under any of the Windows operating systems. SSTV software is very timing intensive, and Windows steals too many system resources for the DOS program to keep up with its SSTV tasks. You will have to restart the system in the MS-DOS mode and then run the program in question.

- **Absolute Value Systems (http://www.ultranet.com/~sstv/lite.html)**, operated by John Langner (WB2OSZ), produces **Pasokon TV Lite**, a serial port successor to the Pasokon TV interface software that started the PC slow-scan revolution. The program is comprehensive in terms of the modes that are supported and sports a very user-friendly screen interface (see Figure 4.10). One of the unusual (and very useful) aspects of this program is that it is self-calibrating in terms of the reference clock. Most SSTV programs have to adjust their timing reference to correct for the picture "slant" that results from a slight frequency difference between the computer/sound card clock and the timing of the slow-scan pictures in both receive and transmit. Virtually all SSTV software incorporates routines to accomplish the correction, which must be done whenever the software is installed on a different computer. **Pasokon TV Lite** has no time correction routine to worry about because the program performs a statistical analysis of received pictures and computes the correction factors automatically. The software sells for $33.00, which makes it a real bargain! A free demo version of the software, **EZ SSTV (http://www.ultranet.com/~sstv/ezsstv.html)** is available and is highly functional. The demo version is mode-limited (although it does include the most popular medium-resolution color modes as well as Fax480) and has a more basic screen/menu structure. It includes the auto-time correction feature and provides an excellent introduction to using your computer on SSTV.

**Figure 4.10.** An example of the Main Menu Screen for John Langner's **Pasokon TV Lite** software. An image, whether received off the air or recovered from disk, occupies most of the screen. The extreme upper left of the screen contains a graphic tuning indicator. To the right of the indicator is a box of graphics tools that function much like a basic paint program, permitting you to add text to any image, add graphical effects, and perform many other specialized functions. Below the tuning indicator, arrayed down the left side of the screen is a series of boxes for the major SSTV mode "families."

In this case, the "Scottie" group has been selected, and the various sub-mode options appear to the right of the main mode listing. In this case the selected mode is Scottie 1. A variety of functions — including receive, standby, and transmit — are available in the cluster of controls at the lower left. Below the main image is a series of thumbnail images reflecting the most recent images received or loaded from disk. Any one of these can be saved to disk, transmitted, or posted for full-screen display with the click of a mouse. Most high-end programs will have all of these functions, although there may be considerable variation in screen layout and the details of implementation.

- **GSH-PC (SAWSCAN) (http://ourworld.compuserve.com/homepages/dl4saw)**, written by Geza Szabados-Hann (DL4SAW) is a highly regarded program that is in wide use. It has excellent coverage with respect to modes and all the features one expects from more comprehensive software. There is a free trial version of the software (no SSTV transmit, no multitasking, limited graphics modes) that will acquaint you with the primary features of the software. The registered version of the software (currently Ver. 2.3) costs 75 DM + 5 DM shipping and handling. I would expect the price to be quoted in Euros in the very near future, but in any case, the US dollar-price will fluctuate with the exchange rate.

- **CombiTech** (**http://www.mscan.com/mscan/download.html**) markets **MSCAN**, a well-established, multitasking program for DOS that is currently in Ver. 2.3. The program was written by Mike Versteeg (PA3GPY) and supports all commonly used SSTV modes, as well as some fax modes. A free trial version is available (with some feature limitations), and the registered version costs $43.00.

### *SOUND CARD INTERFACES*

Programs that use the computer sound card require quite a different interface compared with anything we have examined to this point. This is because the required interface has nothing to do with slow-scan! All the needed SSTV signal demodulation is performed by the sound card so that when we speak of a sound card interface, we are talking about how to connect the sound card inputs and outputs to the station transceiver(s). There has been a literal explosion of sound card software in Amateur Radio over the past few years, opening up a wide range of old and new digital modes in addition to slow-scan. If you already have a working sound card interface for running modes such as PSK31, you are ready to run slow-scan with nothing more than a suitable piece of SSTV software. Conversely, once you are set up to run slow-scan with your computer sound card, you can try any of the other modes with nothing more than new software. It is just this sort of versatility that mandates the use of a computer in any state-of-the-art Amateur Radio station.

**Figure 4.11** shows one approach to such a universal sound card interface. As was the case in Figure 4.9, the microphone pin-outs shown are based on my ICOM IC707 transceiver. You should consult your transceiver manual to determine the equivalent pin-outs for your specific equipment. The major issue with sound card interfaces is preventing hum on the transmit signal caused by complex ground-loops created when the audio circuits from the transceiver are directly connected to the sound card and computer. The easiest way to avoid this problem is to use transformer coupling between the sound card output and input circuits and the rest of the interface.

Figure 4.11 specifies inexpensive transformers available from the DigiKey catalog (see **Appendix**). Suitable transformers often can be obtained "off the rack" at some RadioShack stores. Receiver audio is coupled directly to the sound card input using **T2**. The PC controls for sound card audio input levels can be adjusted to assure that the audio level at the input does not overdrive the sound card. Most sound card software gives you an indication of the input signal level, and it should be obvious if you need to readjust the input gain. The SSTV output signal is coupled via **T1** directly to the 1K **TX LEVEL** control on the interface. No filtering is required as the sound card will produce a nice sine-wave output. Coarse adjustment of the output level can be made using the sound card control panel in your PC software, with final adjustments made with the TX LEVEL control. If you don't change the master output level from the sound card, the final adjustment of the TX LEVEL control

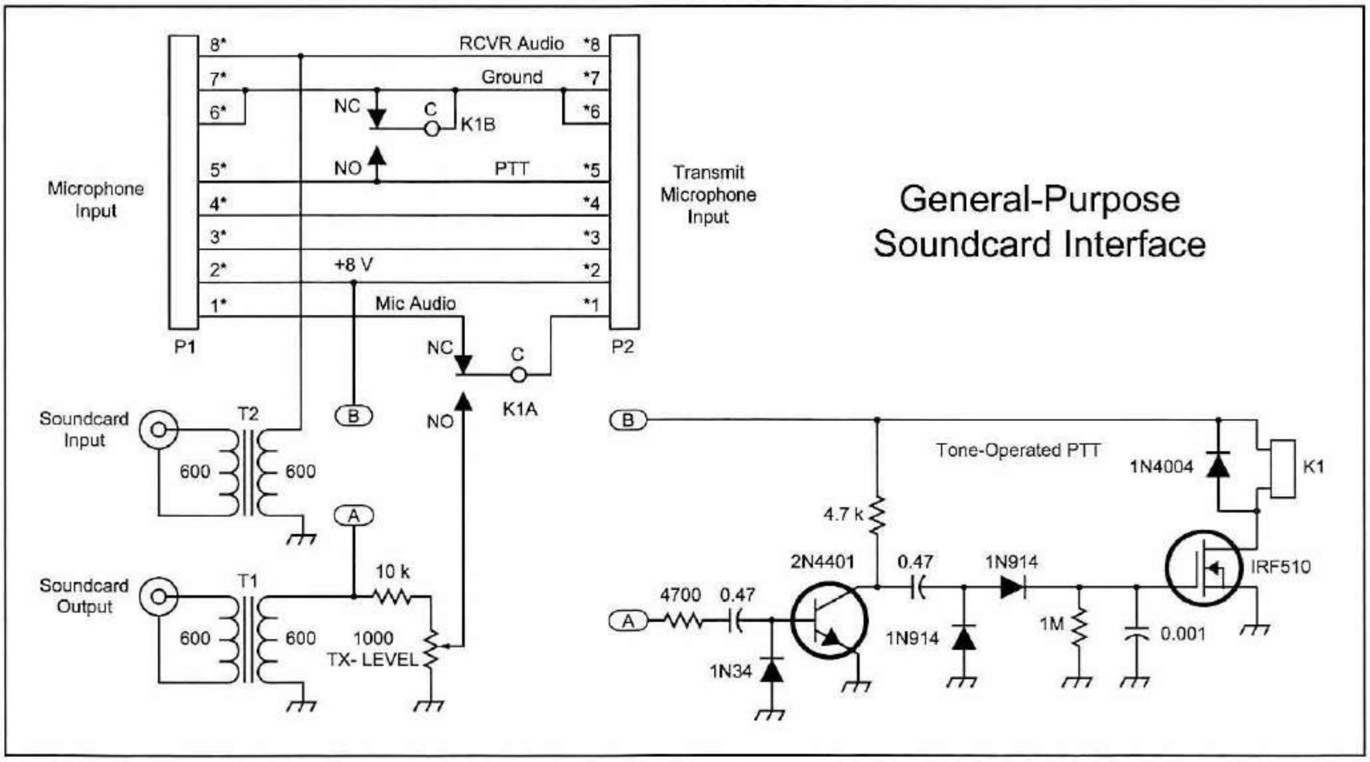


**Figure 4.11**. A general-purpose sound card SSTV interface. Fixed resistors ohms, ¼ W 1% metal-film; potentiometers ¼ W, PC-mount; all capacitors 50WVDC dipped mylar; K1 = Aromat TF2-5 (DigiKey #255-1016-ND); T1 and T2 = Tamura TTC-02 (DigiKey #MT4133-ND).

can be treated as a "set and forget" adjustment. I prefer to be able to make very fine adjustments of the drive level to the transmitter and suggest the use of a multi-turn pot for the TX LEVEL control. It can be done with a single-turn pot but will require a bit more care.

The equivalent of a double-pole/double-throw (DPDT) switch is required for transmit/receive (T/R) switching. S1B is used to ground the PTT line when transmitting SSTV, and S1A switches between microphone and SSTV audio. In fact, a simple DPDT miniature toggle switch can be used for S1 if you are content to employ manual T/R switching. I have used an interface with manual switching for many years now, and it works just fine. If you want automatic T/R switching, there are two basic ways to accomplish it. Figure 4.11 shows a very neat little audio-operated relay circuit that will switch a relay (K1) when transmit audio is present at point **A**. This audio relay circuit was developed by WA8LMF for use in his mobile SSTV installation and works very well. Note that K1 is the same high-resistance unit featured in Figure 4.9, so that K1 does not overload the +8V line in the microphone circuit. K1 is a DPDT relay, and the two sets of contacts perform the switching functions associated with S1. Most sound card software provides for T/R switching with keying provided by an RS-232 serial (COM) port. If you would like to automate the T/R switching using a COM port, the circuit associated with K1 in Figure 4.9 can be used. Just be sure you have enabled the COM port T/R switching in your software. I prefer the tone-operated relay circuit in Figure 4.11 as it doesn't tie up a COM port and require an additional cable, but the choice is yours. Dave Jones' (KB4YZ) CQ SSTV Web site (**http://www.tima.com/~djones/**) contains many links to amateur home-pages with additional variants on home-built versions of the sound card interface.

### *COMMERCIAL SOUND CARD INTERFACES*

The popularity of the new digital modes that use sound card software has spurred several manufacturers to produce general-purpose interface hardware. Four options are shown below:

- **West Mountain Radio RIGblaster (http://www.westmountainradio.com)**. This is a popular interface for the sound card and is housed in a very substantial metal cabinet with a high-quality printed circuit board featuring transformer-coupled audio and optical-coupling for the serial PTT T/R switching circuit. Internal and external views are shown in **Figure 4.12**. Two basic models are offered — the base model ($109.95) and the RIGblaster Plus ($139.95). The Plus variant has additional provisions for serial keying of the rig for use on CW. Sub-models are designated on the basis of the type of microphone connector — M4 (4-pin), M8 (8-pin), and RJ (RJ-45). In all cases, customizing the unit for different function assignments for the microphone lines are accommodated by using internal jumpers. The models come with a 110VAC wall-mount power supply, all required cables, and a CD-ROM that includes a large number of freeware, shareware, and commercial demo software for virtually all the various sound card amateur modes (including SSTV).
- **Tigertronics SignaLink SL-1 (http://www.tigertronics.com/sl_main.htm)**. This unit is packaged in a rugged but somewhat smaller cabinet than the RIGblaster (see **Figure 4.13**) and features both transformer and opti-coupler isolation. The SL-1 is available in four configurations — 4R (4-pin), 8R (8-pin), RJ (RJ-45) and NC (no mic. plug) — depending upon the microphone connector. Internal microphone line variations are set with internal jumpers. The SL-1 employs an audio PTT circuit for T/R switching and thus requires no connection to a computer COM port. The unit can be powered from the AUX connectors on most modern rigs or from an external 12V supply (not provided). The base price is $49.95, which does not appear to include any cables. A wide range of sound card software is available for free download from the BUX Com Web site.
- **BUX Communications RASCAL (http://www.packetradio.com/psk31.htm)**. This is a highly compact unit housed in what appears to be a cast-aluminum enclosure. The unit is available wired-and-tested ($49.00) or as a kit ($27.00). Jumpers are not used to configure microphone lines. Instead, the unit is available in a wide range of sub-models, each keyed to specific radios and manufacturers. Some cables are integral to the unit, but you should contact the manufacturer to see what, if any, additional cables might be required.
- **MFJ Enterprises MFJ-1275 (http://www.mfjenterprises.com/products.php?prodid=MFJ-1275)**. This unit is packaged in an aluminum enclosure similar to the many other products in the MFJ line. The

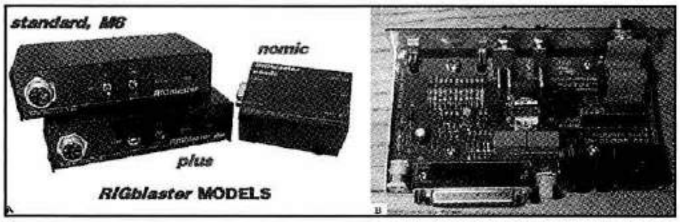


Figure 4.12. RIGblaster sound card interface from West Mountain Radio. [A] External view of the three standard models. [B] Internal view of the main printed circuit board as seen from the rear. Internal jumpers are used to configure the various lines associated with the microphone socket on the front panel.

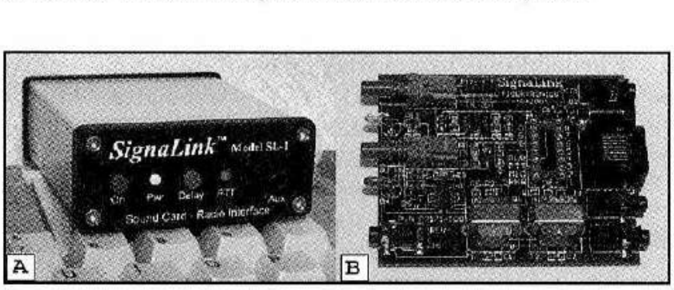


Figure 4.13. SignaLink sound card interface from Tigertronics. [A] External view — the small size of the unit is evident. [B] The internal printed-circuit board.

base unit costs $89.95 and appears to include required audio and computer cables — something you should check with the manufacturer. The unit is designed to be powered from an external 12VDC source and optional power supply units are available.

The models shown above represent some of the more widely used interfaces. Diligent Internet searches certainly would reveal still other commercial options you might wish to consider.

### *SOUND CARD SOFTWARE*

Listed below are some popular software packages that use the sound card as the SSTV interface. The list is not intended to be comprehensive, but each of these programs has a track record and a reasonable user base. Since demo versions are available for the commercial offerings, comparisons can be made easily. These are all Windows™ packages and provide a relatively rich and feature-laden operating environment. Supporting that kind of environment and manipulating the SSTV signal via the sound card, particularly when the DSP features of the card are heavily engaged, means that the computer is doing a lot of number-crunching. All the software packages benefit from the use of a fast (100 MHz+) Pentium-class machine with lots of RAM (16 MB minimum) and a copious hard drive. This is especially true if you want to operate in a multi-tasking environment, which is essential if you wish to simultaneously run frame-grabbing and graphics software or manipulate images (adding graphics, etc.) while the slow-scan functions are operating. If you are just getting started and your computer is less capable, there is always the option to use a serial interface and one of the DOS software packages previously discussed.

- **Silicon Pixels (http://www.siliconpixels.com)** markets two SSTV software packages. The flagship product is **ChromaPix**, a 32-bit software package with just about any feature or mode you could want (**Figure 4.14**). The demo version of the program is free and fully functional, but it inserts UNREGISTERED in the transmit header and times-out after 30 minutes of operation. You can reboot easily for another 30-minute operating "window", but the advantages of using a registered version ($120.00) soon become obvious. Their second (and older) product is **W95 SSTV**. This is a very capable piece of software (at a cost of $50.00 for the registered version) that has introduced numerous operators to the fascinating world of slow-scan. In terms of comparison, **W95 SSTV** is like a down-to-earth family station wagon, but **ChromaPix** is like moving up to a Lexus!
- **Don Rotier's (K0HEO) G.V. Associates (http://homepage.ntlworld.com/winpix)** wrote the first sound card SSTV program for Windows with WinPix and that product has evolved into **WinPix 32**. This is a 32-bit program for Windows 95/98/NT/2000 and along with ChromaPix is one of the two high-end commercial software offerings. The program is fairly demanding in terms of computer resources and works best with 32 MB of RAM under W95 and 64 MB with later Windows releases. The program handles 39 different SSTV modes and has all the bells and whistles you would expect. The demo program is free but stops working after 60 days. The registered version costs $79.00.

**Figure 4.14**. Main operating menu for the **ChromaPix** software. While some programs strive for simple, intuitive menus, ChromaPix aims to be complete without being intimidating. The program is promoted as "An SSTV Workstation", and that isn't an exaggeration. Just about any function you can imagine can be accessed through the multi-layer menu structure.

- **Harlan Technologies (http://www.hampubs.com/sstvwith.htm)** pioneered the use of the sound card for SSTV with the **SoundBlaster SSTV** software. Unlike other sound card offerings, this was and is a DOS program and thus is considerably less demanding with respect to computer performance. A demo program is available, and the registered version costs $49.95.
- **Mike Versteeg (PA3GPY) of CombiTech (http://www.mscan.com/mscan/products.html)** has introduced a version (3.13) of **MSCAN** for Windows which, in addition to a wide range of other interface options, also can be run using the sound card as the SSTV interface. The program has good coverage of the most commonly used modes and is particularly interesting in its support of unique operating modes. It has full support for SSTV repeaters, including the 1750 Hz tone burst, and also has beacon and other functions. There is a free demo version, and registration costs $43.00. MSCAN supports two new modes (TV1 and TV2) with a different approach to image resolution. Basically, the color image is transmitted in an interlaced format. First a low-resolution version of the image is transmitted, followed by a series of interlaced lines that improve image resolution as long as the image is being received. While still experimental, this approach gives you a complete, if reduced-resolution, image if transmission is interrupted later in the sequence.
- **Jamie Philbrook (KA1LPA) (http://jamie12.home.mindspring.com)** has introduced a progression of SSTV programs with sound card support:

**PROSKAN** — a multi-tasking DOS program (now in Ver. 3.0)

**WINSKAN** — the first Windows program (Ver. 1.10). This is a 16-bit program and thus will work with W3.1X as well as later versions of the operating system.

**SSTV32** — the latest release is a 32-bit application for optimum performance on systems running W95 and later releases.

All of Jamie's programs have been well-received and do a fine job. Demo versions are available for all three releases and registration cost depends upon the release.

- **Makoto Mori (JE3HHT)** has recently introduced a freeware program, **MMSSTV (http://www.qsl.net/mmhamsoft/mmsstv/index.htm)**. This is a 32-bit program that is still somewhat mode-limited, although it covers all the medium resolution modes you are likely to encounter on the air. The program has some very interesting features, including support for some basic logging functions. This is definitely a program to watch as it matures.
- **J.V. COM 32 (http://jvcomm.de/indexe.html)** is a new multi-mode software offering. It is a 32-bit program that will run on W95 and later versions of the operating system. The program handles weather satellite images, HF Facsimile, and slow-scan. There is a free demo program that is fully functional but will post "nag" messages on your received pictures. The cost of the registered version (currently 1.0A) is 60 Euros. The current US$ price is $55.03, but that fluctuates with the Euro/Dollar exchange rate.

### *"SMART" INTERFACES*

All of the interface options discussed to this point benefit from the speed and processing power of modern personal computers. Basically, you need a powerful computer to handle the load, especially if you are multi-tasking with frame-grabbers, webcams, and image processing or graphics programs at the same time as you operate SSTV. This data processing load can be considerably reduced by the use of "intelligent" or "smart" interfaces. Such units contain their own microprocessor and modulation/demodulation circuits. The microprocessor is internally programmed to process SSTV or other image signals, passing the data back and forth to the PC. Because the interface processor is doing much of the work, data processing on the PC is considerably reduced. This means you can use a less powerful computer, or a more capable computer can be used in a multi-tasking environment.

The primary limitation of this approach to SSTV interfacing is that you are limited to the modes and options programmed into the interface microprocessor — something that is typically not easy to change. You are also forced to use the proprietary software designed to work with the interface and its I/O, unless you are willing to document the interface and write custom software. This may not be an issue if a particular system does everything you might like it to do, but it does mean you will be more constrained with respect to what future options will be available to you. Since software from the manufacturer is typically integral to the "smart" interface hardware, both will be treated in the discussions below.

- **SC-4 Interface and Charly software**, Wrasse Electronic GmbH (**http://www.sstv.org**). Volker Wrasse (DL2RZ) has been manufacturing SSTV equipment since 1972 and puts out some high-quality products. The SC-4 SSTV interface unit is a compact (4.4 × 4.3 × 1.7 inch/ 112 × 110 × 42 mm) module packaged in a rugged aluminum cabinet. The interface (**Figure 4.15**) contains its own microprocessor, a large RAM array, and a high-speed serial interface. Communications with the PC are via a serial link using a standard DB-9 serial cable. The module connects to the radio gear using a DIN cable that carries the receive and transmit audio and the PTT circuit. The unit is powered from an external 12VDC capable of supplying 200 mA. The companion software is "Charly" (written by DJ6PS), currently in Version 4.0. The system requires an SVGA-equipped PC (486DX/50 or better) running W95/98. The program requires 20 MB of hard-drive space and 8 MB of RAM is recommended. The program (see **Figure 4.16**) appears to support all the features one might expect of a Windows SSTV program, including a basic range of graphics functions. The available modes are fairly comprehensive with the registered version of the software, but the demo version appears to cover only the most common medium-resolution modes. The base price of the SC-4 Interface, Charley 4.X software, and the serial and DIN cables is $195.00 plus $20.00 shipping and handling.
- **ROY 1**. Fontana Software (**www.roy1.com/roy1_e.htm**). This is an interesting offering from Italy that is getting some good reviews as the software matures. The interface incorporates two microprocessors and DSP signal processing. The unit is powered from a +12VDC source and communicates with the PC using a high-speed

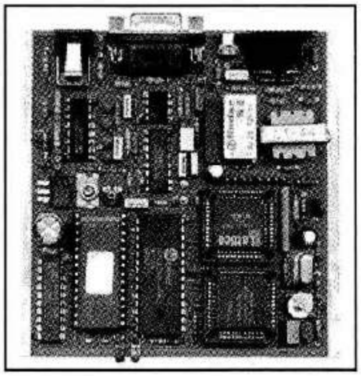


**Figure 4.15**. The printed circuit board for the Wrasse SC-4 "intelligent" interface. The circuit includes an imbedded microcontroller, a large block of video RAM, and a high-speed serial interface. The on-board microprocessor handles all the SSTV modulation/demodulation functions, greatly simplifying the PC SSTV software, which sends instructions and sends and receives image data through the serial link.

RS232 interface (standard 9-pin serial cable). ROY 1 features a precision clock oscillator that, once set, will assure that none of your images will suffer from poor timing and a resultant "slant" (see Chapter 5). The base price of the ROY 1 is $129 in kit form with software on CD-ROM. The kit documentation appears to require some upgrading, but experienced amateurs seem to get it built anyway! Assembled and tested ROY 1 units with registered software cost about $250.00 plus shipping.

- **ACE Project**. Martin Emmerson, G3OQD (**http://www.fortunecity.com/meltingpot/skipjunction/753/**). Martin (G3OQD) was one of the pioneers in the development of new EPROM software for the Robot 1200 and is the originator of the Martin 1 and 2 modes, as well as several new high-resolution formats. The Ace Project represents his approach to computer slow-scan with the use of an internal interface (see **Figure 4.17**) to ease the demands on the host computer. The interface is in the form of an ISA-bus card with on-board hardware and firmware (embedded controller software) that performs all the data-intensive routines for sending and receiving SSTV. Since the card is connected to the PC bus, there is no need for a cable between the interface and computer; and the computer provides the needed power as well. What sets the ACE interface apart from others is that the processor firmware is stored in Flash-RAM and thus can be updated at any time without opening the computer or swapping chips in the interface. As such, the ACE system represents a very interesting vehicle for basic and advanced SSTV and fax experimentation. The hardware features active filters for the slow-scan signals, image buffer RAM, and an integral PTT circuit. The on-board clock is extremely accurate and stable, eliminating any problems with image slant or the need to use slant-correction routines. Software development is a collective enterprise with contributions from a number of individuals. Right now the software appears to cover most modes, and new features are being added on a regular basis. If you want to learn more about the ACE Project, contact Martin via e-mail at **martin@G3OQDemmerson@freeserve.co.uk**.

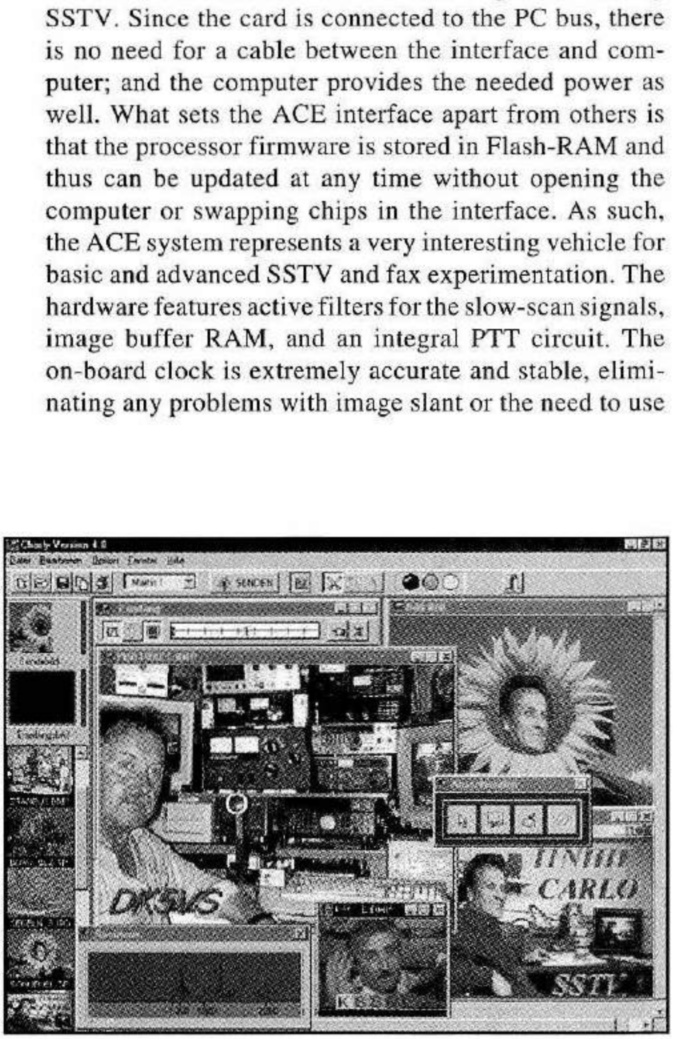


**Figure 4.16**. The "Charly" SSTV software for the Wrasse interface (see Figure 4.15) supports many of the functions and features of the typical Windows sound card software, but the software overhead is greatly reduced since the computer is not performing the actual SSTV reception or transmission.

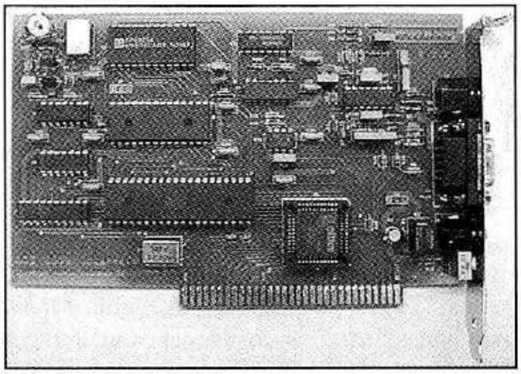


**Figure 4.17**. ACE SSTV Project printed-circuit board. This is an integrated SSTV modulator/demodulator PCI-bus board that operates independently of the computer's CPU. Unlike most intelligent interfaces, the ACE board incorporates Flash-RAM technology, permitting the board's firmware to be updated at any time without the need to switch EPROMs or micro-controller modules.

### *SSTV SCAN CONVERTERS*

In 1998 the Kenwood Corporation introduced a scan converter, the **VC-H1**, that revolutionized the scope of SSTV operations. They achieved this not with any new modes, but by shrinking a complete SSTV system to the size of a modest HT! The unit (**Figure 4.18**) features a built-in 1.8 inch TFT color monitor and a CCD color camera that can be detached from the main assembly. The internal firmware handles eight standard SSTV medium-resolution modes and a fast mode designed for use on VHF where signal bandwidth is less critical. The unit has memory to store 10 images and can be cabled to interface directly with an HT on VHF or UHF or directly to a mobile or fixed-station HF/VHF/UHF transceiver. Callsigns or other text can be superimposed on the pictures, and there are several programmed modes that permit pictures to be transmitted automatically. External NTSC video sources or monitors can also be interfaced to the unit.

While the VC-H1 does have mode limitations and cannot handle high-resolution modes, it more than compensates in terms of portability and versatility. Everything from backpacking on VHF or HF, portable QRP, mobile slow-scan, and even lofting SSTV cameras and transmitters to the edge of space via balloons are all areas where the VC-H1 excels. Many of these activities will be discussed in Chapter 5; and most would be impractical, difficult, or even impossible to achieve with a laptop running standard SSTV software. The moderate price of the VC-H1 (street price of under $400.00) means that many active slow-scanners pick one up just for the novelty of having a thoroughly mobile SSTV option. It

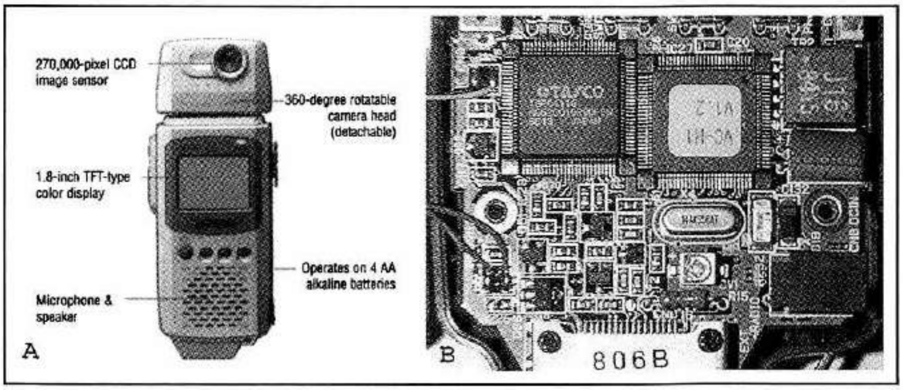


**Figure 4.18**. External **[A]** and internal **[B]** views of the Kenwood VC-H1 scan converter.

is also worth noting that the VC-H1 makes a good option for fixed-station use where the use of a computer is impractical or where the operator wants a compact station without the added bulk and complexity of a computer.

## SSTV ON THE MACINTOSH

There is little doubt that most of the imaging options available for personal computers are confined to IBM PCs and clones. There seems to be comparatively little available for the Macintosh user, although there are some options. One of these is a versatile program known as **Multimode** from **Black Cat Systems** (**http://www.blackcatsystems.com/software/multimode.html**). The program is precisely what the name implies — a multimode program for operating (among other mode options) CW, RTTY, PSK31, Fax, and SSTV using a Mac with no additional interface hardware. The program requires a Mac with:

- Sound input
- A color Mac with a fast Power PC (PPC) processor (604, G3, G4)

A free demo version of the software can be downloaded from the Black Cat Web site. Registration runs $39.00 for the "Lite" version of the program and $89.00 for the high-end version. I am not a Mac user and cannot comment on how well the system works, but the evaluation software is free, so it is easy to check.

## CHAPTER 5

# SSTV OPERATIONS

The goal of this chapter is to get you up to speed on basic slow-scan operation. The chapter will cover bands and frequencies, setting up your station, sources of images, and the different modes you will encounter on the air. I will walk you through the basics of your early slow-scan contacts and then review some of the more advanced operating options. These will include 3D images; working DX, SSTV and satellites; and the possibilities for future SSTV operations aboard the International Space Station, based on extensive experience with SSTV aboard the Soviet/Russian *Mir* space station.

## BANDS AND FREQUENCIES

SSTV is permitted on any phone band in the US (although regulations may vary in other national jurisdictions). If your license gives you voice privileges on a particular band, then slow-scan is an option. Over the years, many amateurs have assumed that slow-scan is primarily an HF activity, but this certainly isn't the case. In the sections that follow I will discuss where you might find SSTV activity to check out your new system.

## VHF AND UHF

If you are within range of another slow-scan station on VHF or UHF, you have an excellent opportunity to check out your system and become familiar with the operation of the program(s) you are using. There are regular 2-meter and 70-cm nets in several parts of the country. Check out David Jones' "CQ SSTV" Web site (**http://www.tima.com/~djones/**) for the most current list of active nets and frequencies.

Two meter FM provides your best option in the VHF and UHF range if there is no scheduled activity in your area; and 145.50 MHz is the national SSTV calling frequency where you can check for activity. If you operate on sideband, check out 145.55 MHz. When looking for activity, don't simply fire up and send out an SSTV call. This is very poor operating practice and will quickly make you unpopular on frequencies without slow-scan activity! In most cases, evenings and weekends will provide the greatest chance of encountering other stations. You might also try a call on 144.34 MHz, the national voice frequency for ATV operators. If there is a local ATV group, it is probable that at least one member might be on slow-scan as well. Even if not, the members well may know local SSTV operators and can suggest active frequencies. Local repeaters are fine for searching out activity, but repeaters are rarely used for SSTV as it is annoying for mobiles and others monitoring the frequency. Repeaters, particularly those on 70 cm, are excellent vehicles for demonstrating SSTV at club meetings, provided the repeater owners(s) or licensee(s) are agreeable, based on advance arrangements. Six meter activity is not as common; but the band does provide the opportunity for DX, depending on the solar cycle and the situation with respect to Sporadic-E propagation. Check 50.680 MHz on FM and 50.950 MHz on SSB.

## HF BANDS

The greater range provided by the various HF bands increases the chance that you will encounter slow-scan activity, although there is considerable variability from band to band at different times of the day. The following represent the primary SSTV "calling frequencies":

| *BAND (METERS)* | *FREQ. (kHz)* | *NOTES* |
|---|---|---|
| 160 | 1890 | [1] |
| 80 | 3845 | [1] |
| 40 | 7170 | [2] |
| 20 | 14230<br>14233<br>14236 | [3] |
| 17 | 18160 | [4] |
| 15 | 21340 | |
| 12 | 24975 | [4] |
| 10 | 28680 | |

**Notes:**

[1] Expect multi-path propagation, which can severely disrupt images

[2] Activity variable between 7170 and 7173 kHz

[3] International SSTV calling/net frequency

[4] WARC bands have been little-used for SSTV

During the day and well into the evening (at the height of the solar cycle), 14230 kHz on 20 meters is virtually a sure bet. If you don't hear slow-scan after several minutes of listening, the band is either shut down or you forgot to connect the antenna! For decades this was *the* slow-scan frequency and is still the busiest HF frequency on the planet. Any activity you hear on this frequency is likely to be either a net or a roundtable. The point is, just because it seems quiet, don't hurry to jump in with both feet!

The two largest slow scan nets can be found on 20 meters on Saturdays throughout the year:

- **IVCA SSTV net** — 15:00 UTC, 14230 kHz. This is a popular net hosted by the International Visual Communications Association. One common feature of this net is informal "contests" involving pictures relevant to a specific theme or upcoming holiday.
- **The SSTV Net** — 18:00 UTC, 14230 kHz. This net has convened continuously since the 1960s. Usually there are two net-control stations. Check-ins transmit SSTV images to one or the other when requested, and the images are retransmitted (typically in the Scottie 2 mode) to stations on frequency.

A few additional notes about bands and frequencies are in order. First, just as with other modes, if you have a modest antenna system, the higher-frequency bands provide the best DX signals when the bands are open. Both 10 and 15 meters provide excellent DX potential for modestly-equipped stations. Of course, you can work DX on 20 meters and even on lower frequencies; but it's harder work and less productive for the time you invest. It is also worth noting that — for whatever reason — the WARC bands do not, as yet, have much slow-scan activity. Thus, if you are chasing SSTV DX, 15 and 10 meters are your best bet. How you work DX will be covered in a later discussion.

Forty meters can be a great regional band during the day. Your biggest problem on HF slow-scan is not DX; it's working fellows within 500 miles or so. Daylight operations on 40 fill the bill perfectly in that respect. At night you might expect similar results from 75 meters, but that is rarely the case. A typical night path on 75 or 160 involves **multipath propagation**. The signals are simultaneously reflected from multiple layers in the ionosphere; and, as a result, signals arrive just slightly offset in time due to the slightly different path lengths. The effect creates minor distortions in voice signals, which you may or may not notice, and is very hard on images. The result is scrambled sync and often severe color distortion. A group of stations may be doing just fine on voice, but the pictures can be so mangled that it is not worth continuing to work SSTV.

## IMAGE SOURCES

### *WHAT KIND OF PICTURES?*

Slow-scan is all about exchanging pictures, so what kind of pictures and where can they come from? After you have been operating SSTV for some time you will have accumulated a considerable image library, but you have to start somewhere. You might begin by evaluating potential pictures by what I call the **RIQ** scale — **R**elevance, **I**nterest, and **Q**uality:

- **Relevance**. This hobby is all about personal communication, so the best pictures are those that are relevant to you and your interests. At the head of the list are pictures of yourself: so-called "mug" shots. It's downright silly to work another station on slow-scan and never know what the operator looks like! I always have at least one mug-shot on the active drive/directory, and I try to slip it in early in a QSO so I don't forget. As shown in **Figure 5.1**, I usually combine the basic mug-shot with my callsign, name, and QTH. In effect, this one picture is like a mini-QSL. I also have a family. If we work any reasonable number of times, eventually you will have seen a picture of my wife, one or more of my three daughters, and our two grandchildren! Your station and antennas are also probably close to your heart and are legitimate sources of pictures. **Figure 5.2** illustrates a great example combining a mug-shot and station photo in one image. Pictures of your house and local or regional points of interest are great options (**Figure 5.3**). Pictures connected to your other interests, hobbies, and job may also be good possibilities.
- **Interest**. Whatever the subject, you should try to make the pictures as interesting as possible. Some operators avoid sending mug-shots because they think they are uninteresting, but this is far from the case. Even a mediocre photo of you will be inherently interesting to the operator at the other end because he or she wants to know what you look like. If you can find other interesting subjects relevant to you, all the better (**Figure 5.4**). I fly ultralight aircraft — something most people find at least

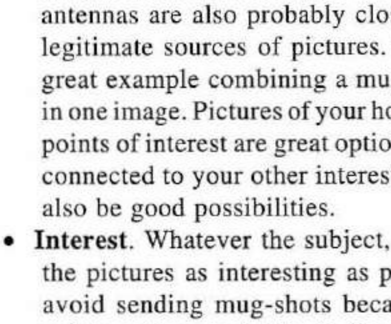


**Figure 5.1**. A mug-shot, combined with some simple text makes a general purpose picture that is useful in many ways.

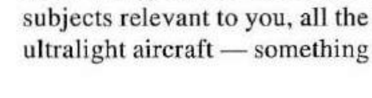


**Figure 5.2**. With the proper camera angle and good lighting, Robert (W0LMD) combines the classic mug and station-shots into a single picture. (320 × 240)

moderately interesting, so I always make sure I have some ultralight aircraft photos on the drive. Rob, KF7OH and I have spent endless hours on 15 and 12 meters exchanging high-resolution images that would take too long to transmit to be really practical for 20 meters. We have long since exhausted the usual photos that can cover 95% of most QSOs, but I look forward to each new contact for all of his pictures are interesting and/or fun (**Figure 5.5** and **Figure 5.6**).

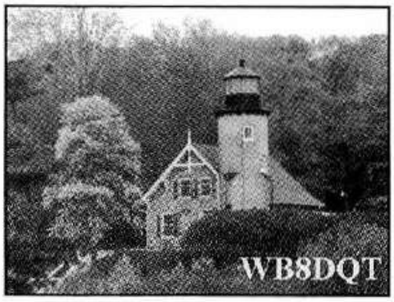


**Figure 5.3**. Scenic views from your local area are excellent subjects. Despite the resolution limitations (320 × 240), this springtime shot of the lighthouse on the White Lake channel in Michigan is quite effective.

**Figure 5.4**. Most of us have interests outside of Amateur Radio. VK7AAB obviously likes vintage aircraft!

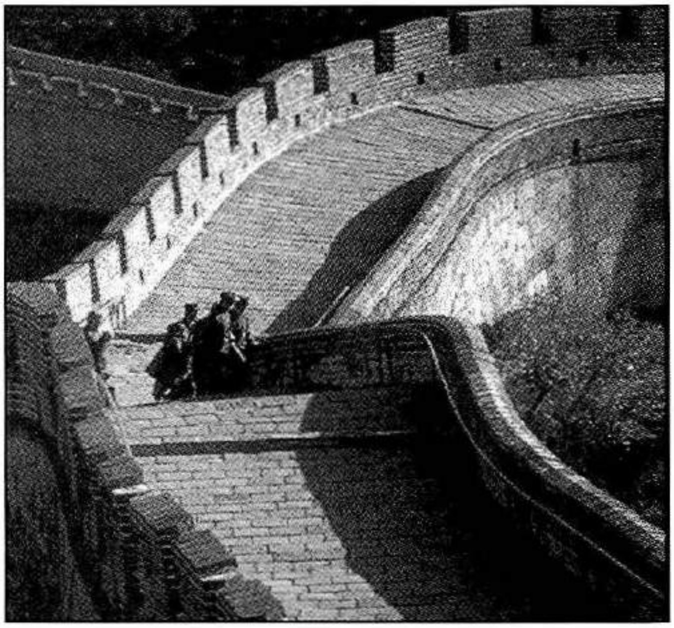


**Figure 5.5**. Scenic views obviously benefit from the use of higher-resolution formats. This is a Fax480 image (512 x 480) from KF7OH showing a section of China's Great Wall.

- **Quality**. Amateurs normally can be expected to take pride in the quality of their signal and how they operate, but pictures expand the quality envelope. Hallmarks of good image quality include factors such as focus, lighting, contrast, color, and composition. Many of these factors are common to good photography, and you can learn a lot by reading some very basic pamphlets and handbooks on photography. In the past, these issues were complicated by the issue of the adjustment of your equipment when transmitting images. Today's equipment and software has virtually eliminated that variable, and you can expect that your picture will be as good as the original source material.

Another factor in picture selection is the band on which the picture will be transmitted. Pictures intended for transmission on the low frequency bands, 75 meters for instance, will be subject to multi-path propagation. They should contain less detail than those typically sent using the higher resolution modes. A good example is shown in **Figure 5.7**.

It is important to remember that my informal **RIQ** system ranks the factors in terms of relative importance. I would much rather see a mediocre picture of the operator at the other end than a superb picture of the space shuttle scanned from some magazine! I have innumerable miscellaneous pictures in my image library that rank well in terms of interest and quality, but I always start my selections on the basis of relevance.

### *WHERE TO GET YOUR PICTURES*

The primary SSTV image sources include TV cameras, webcams, digital cameras, scanners, CD-ROMs, and over-the-air. Each of these sources will be discussed briefly in the sections below.

- **TV Cameras**. "Frame-grabbing" images from an accessory color TV camera (or camcorder), VCR, or TV set was the primary means of generating images with the Robot 1200 through most of the 1980s. Various software authors wrote programs to support image save-and-loads to external computers and, later, the ability to add graphics and otherwise manipulate images. The capability became more significant as the size of computer hard drives and the quality of the computer's VGA display increased. Live mug-shots were standard fare, as were images captured from broadcast and cable programming. Having enough room in the shack to set up the camera and properly illuminate the operating position has always been a problem for most amateurs (and continues to be in the case of ATV). Serious operators set up additional cameras with easels or on copy stands to capture images from printed material. The great strength of conventional TV cameras is their ability to capture motion, but SSTV is a mode centered on still images. Given that operating a TV camera in the computer environment requires the use of an accessory "frame grabber" board or module, I would not rate TV cameras as the preferred imaging source. There are low-cost, extremely compact color cameras available; so if one

**Figure 5.6**. Pictures of children are always a hit, especially if they are family or community related. A.J. (KC5RW) is a real artist when it comes to images of children.

**Figure 5.7**. Pictures for use on 75 meters should be selected carefully so they will be recognizable in the case of multi-path. KB1HJ's picture came through in pretty good shape, but it would have held up well even under more adverse conditions.

wished to use such a camera, it would not be necessary to tie up the family camcorder. One primary limitation of TV cameras as a video source is that they are limited in terms of resolution. They are entirely adequate for medium-resolution (320 × 256) images but unsuited as a source for high-resolution (512 or 640 × 480) images. Many programs provide support for common frame-grabbers boards/modules. If the frame-grabber is TWAIN compliant, the chances of its working with a specific piece of software are greatly improved.

- **Webcams**. In terms of cost, compact size, and ease of integration, webcams are high on the list of preferences as the primary image source for "live" pictures from the shack. You still have to provide good lighting for them to produce quality pictures, but the better ones easily produce 640 × 480 images which can be transmitted in any desired format. It should be noted that many digital cameras, particularly those equipped with a USB port, can be used as webcams. It has been my experience that even relatively inexpensive digital cameras produce even better pictures then relatively high-end webcam units. Since webcam operation usually is integrated via a TWAIN compliant interface, many SSTV software packages should work well with webcam units.
- **Digital Cameras**. Digital cameras represent a very flexible source of images for use on slow-scan. Even current low-end cameras feature 640 × 480 resolution (24-bit color) so will not limit the SSTV modes you can use. You basically can handle these cameras as you would a film camera but without the need to process and print film and scan the resulting prints. When digital cameras first became available, there was a tendency to send a lot of mediocre pictures. Many images from digital cameras can benefit from a bit of image processing prior to storing and using the pictures for SSTV.
- **Scanners**. If I had to limit myself to a single imaging source, the choice would certainly be a good flatbed scanner. Scanners presently represent the optimum trade-off between image quality (color and resolution), flexibility, and unit cost (well under $100 for many units, not counting rebates and discounts).
- **CD-ROM**. An amazing number of image collections, covering all sorts of topics such as travel, nature, space, and science are available on CD-ROM.

**Image Processing Software**. Both scanners and digital cameras typically come bundled with image processing software. This software lets you optimize the quality of your images, add graphics to the pictures, and perform a wide range of special effects operations.

**Computers and Images**. Images eat up disk space on a computer and also require a moderate amount of processor power to load, display, and save. Almost any current PC will have the primary attributes of a good image workstation:

- **A fast processor and ample RAM**. Fast Pentium CPUs or their equivalent are desirable, and at least 16K of RAM. 64K to 128K of RAM is preferred.
- **A fast, large-capacity hard-drive**. If you want to upgrade your hard-drive, it may be best to install a second drive rather than simply upgrade the primary unit. One of my computers has a secondary drive significantly larger than the primary unit, and all the image-related software and working image libraries are contained in the larger drive.
- **The ability to archive images on an external disk**. 100 MB or 250 MB ZIP disks are one popular option for archiving images, but it's hard to beat the ~700 MB capacity of a R/W CD-ROM drive. Such capacity can be built into the computer, or the drives can be external. In the latter case, USB interfaces (if you run Windows 98 or better) will provide a more flexible interface than other options such as the parallel port or an external SCSI connection.

If your station computer is a hand-me-down that is far from current, it still can perform in a creditable manner. Old 486 and slow Pentium machines with smaller hard-drives can deliver good results with many DOS-based serial port programs. The key is the use of a good graphics card and keeping the hard-drive free of extraneous material, including unneeded software.

## SSTV SYSTEM SET-UP

Assuming you have a working interface and computer, setting the station up for slow-scan involves two primary set-and-forget adjustments — adjusting the system clock frequency to eliminate "slant" on received and transmitted pictures and adjusting the SSTV transmit audio level to the station transmitter. These two adjustments are covered in the sections which follow.

### SOFTWARE SET-UP

The download file set for most programs will include a file — often in simple text (.TXT) format — describing how to install the software on your system. If there are configuration files that have to be modified or created, this usually will be described either in the initial text file or as part of the main program documentation. Once the program is installed, take the time to look up and read the following sections:

- **Image Receive/Display** — review how to use the program to receive and display pictures.
- **Tuning Indicator** — review the section on how to use the tuning indicator
- **"Slanted" Pictures** — review the section describing how to make corrections for "slanted" pictures. You might want to print out this section to make it easier to refer to later.

### RECEIVING YOUR FIRST PICTURES

At this point you are ready to receive pictures. If you are doing so with the help of a friend on VHF or UHF, just forge ahead. If you will be copying your first pictures on HF, we need to deal with the issue of proper tuning of the SSB receiving section of your transceiver. By now you are well aware of the fact that all the important video information about the picture is transmitted by varying the frequency of the audio subcarrier signal. If we want to reproduce the picture properly, the interface has to be supplied with a signal containing the proper audio-frequency variations. However, as you tune a SSB signal across an active frequency, the pitch or frequency of the voice signal will change. The same thing happens with respect to the frequency of the SSTV subcarrier. You have to have the signal tuned properly if the interface is to do its job of demodulating the image. Fortunately, the proper tuning point for SSTV is the same as that for the best or most natural voice quality. To receive your first image:

1. Make sure the receiver RIT is OFF.

2. Tune in the signal of the transmitting station for best voice quality. You should use a strong signal for these initial tests, and 14230 kHz or 14233 kHz will probably be your best bet as a starting point.

3. Set the program to the same mode the station is using. This probably will be Scottie 1 here in the US or Martin 1 in Europe.

4. As the station transmits a signal, observe the tuning indicator and carefully tune the signal so that the sync pulse corresponds to 1200 Hz on the tuning indicator.

5. Prior to the SSTV transmission, set the program to RECEIVE. The program should start to display when the next image begins.

6. Set the program to STANDBY when the transmission is complete and observe the picture.

**Figure 5.9.** Computer sound card clock errors result in a "slant" on received and transmitted images. This picture (320 × 240) was received from G0MJS right after my ChromaPix software was installed on a new computer, resulting in a slight slant to the left, best observed by looking at the right margin. All SSTV software has provisions to correct these clock errors.

At this point, unless you are very lucky (or your program is self-calibrating) the image probably will be slanted to the right or left (see **Figure 5.9**). This "slant" represents the frequency error in the internal clock the computer is using to load the image. Refer to the documentation on how to correct the slant or set the calibration, and try another picture. Repeat until your received pictures are perfectly vertical. From this point on, as long as the SSTV signal is properly tuned, the pictures should auto-start properly in the VIS header; and the program should switch to the appropriate mode. Note that many "demo/trial" programs do not cover all possible modes you might encounter, but they should cover the common ones. At this point you can experiment with saving received images and then reloading them from disk (always assuming your trial software will let you do image saves). If you switch to another program, you will have to repeat the "slant correction" adjustments since different programs approach timing in different ways and each must use its own correction data.

### TRANSMIT LEVEL SET-UP

At this point we need to adjust the output level from the SSTV interface to provide the optimum drive level to the transmitter. The adjustment procedure varies somewhat between FM on VHF and UHF and sideband on the HF bands, but let's deal with more basic issues at the outset. Most interfaces, including the home-built ones documented in Chapter 4, will incorporate a pot for setting the transmit level. Preset the LEVEL control to minimum (the wiper of the pot at ground). If you are using a sound card program, preset the sound card output to mid-range.

Initial level adjustments are best made with a dummy load. If you don't have one (shame!), find an unpopulated frequency on VHF/UHF FM or pick a "dead" band on HF. Ten meters (28680 kHz) in the late evening to early morning is usually a safe bet.

Start by choosing a mode. Anything will do, but I would select a "short" one like Robot 36 in case we run into T/R switching problems. Load a test image file, either one of your own or one acquired off the air, and proceed as follows.

**VHF/UHF FM**. Although you can accomplish the level adjustment by coordinating with another operator (preferably with SSTV experience), it is far better to do it on your own by using a monitor receiver to listen to your own signal. An HT would do just fine. Assuming you can monitor the frequency, proceed as follows:

1. Tune to a local repeater and adjust the receiver volume for a comfortable listening level.

2. Switch the receiver to your transmit frequency.
3. Use your SSTV program to start transmitting. The rig should key into the transmit mode, and the microphone should be disabled.
4. Listen carefully for hum or other undesired audio. You should essentially have a "dead" carrier or a very low level of SSTV audio.
5. Now slowly advance the transmit level control on your interface until the SSTV audio tone is **slightly lower** in amplitude than normal peaks for voice signals. Any "raspy" or rough audio is a sign that you are over-deviating and need to reduce the transmit level.
6. Critically listen to the SSTV tone; it should be pure and clean.

As a general rule, running slightly less drive/deviation is better than pushing the transmitter to maximum deviation.

**HF**. The following discussion will assume that you have a wattmeter in-line to observe your power output. Most modern rigs have a metering function that will let you assess power levels without the need for an external meter. Now check your transceiver manual to see if the rig is rated for SSTV or RTTY power output. Both modes feature continuous "key-down" operation (essentially 100% duty-cycle), and most rigs need to be de-rated in terms of power output compared to SSB. If the rig has an SSTV/RTTY power rating, this is the maximum continuous power you should shoot for in setting up the SSTV transmit LEVEL control. Exceeding this power level almost certainly will overheat your finals, particularly with the longer transmission times associated with the higher-resolution (512/640 × 480) image modes. Reducing the drive level also minimizes the chance of generating undesirable audio/RF products. If your transmitter has no published RTTY or SSTV power rating, your power output "target" should be 40-50% of the peak rated-output of the exciter. For the typical "100 W" transceiver, this would be **40 to 50 W maximum**! When making the adjustments that follow, do not use audio or RF speech processing as it will only degrade the quality of the signal.

1. Set the operating mode to upper sideband (**USB**)
2. Make sure the **microphone gain control** is set to where you usually keep it in normal SSB service.
3. Using your software, initiate SSTV transmit. The rig should key, and the microphone should be out of the circuit. Observe the wattmeter: You should see no output power if the LEVEL control is at minimum. Any RF at this point indicates either the presence of hum or that your carrier balance is misadjusted. The latter is unlikely with most modern solid-state gear.
4. **Carefully** advance the SSTV transmit LEVEL control until you reach the desired peak output (see previous discussion).
5. When the image transmission is complete, the transceiver should return to the receive mode. Check the heatsink on the finals for any evidence of overheating. If this seem a bit too hot, allow the rig to cool and then repeat the transmission sequence while reducing the power by 5-10 W.
6. Allow the transmitter to cool. Repeat, using Scottie or Martin 1 as your mode; and check the finals, reducing the transmit LEVEL as needed to keep the temperature within limits.
7. As a final test, try one of the high-resolution color modes, which require 6-7 minutes for transmission (the P or PD modes) and check the finals for overheating.

This is a conservative approach to adjusting the SSTV drive level and should assure that you have a clean signal and that any linear amplifiers are operated within their rated limits and not over-driven.

### *TRANSMIT IMAGE "SLANT"*

In some programs, especially those using a sound card interface, adjusting out the "slant" on received images also takes care of transmitting. If not, you have to adjust the system (refer to your documentation) to assure that the pictures you transmit are also straight. The typical way this is done is for the newcomer to transmit, get feedback (often a retransmitted image), and keep adjusting until things are right. This is not good practice, even when other stations are cooperative (which they usually are), as it ties up the frequency to no good purpose. One way around the problem is to tape your own SSTV signal and then display the results. If you have correctly adjusted for receiving, you can check your own transmitted pictures without ever putting the transmitter on the air! You cannot do this with a conventional audio tape recorder as the normal speed variations with such equipment ("flutter" and "wow") will defeat your efforts. You could do it by using a second computer equipped to record and playback .WAV files, but most of us don't have the second computer system. You also could do it with a digital audio tape (DAT) system, but those are kind of rare also. However, it can be done with a VCR or camcorder as follows:

1. Record a standard broadcast or cable signal at the video input
2. While recording, send the SSTV signal to the audio line input.
3. When playing back the tape, ignore the video channel but route the audio line output to the input of your SSTV system.

The reason this works (when a conventional recorder won't) is that the VCR/camcorder is a servo-controlled system designed to maintain a very constant playback speed to assure that the video signal is properly displayed. It does this by locking to the video sync signal, which is why we have to provide a video signal when making the recording. To test the VCR/camcorder you have available, record a few transmissions off the air and then display pictures from the recording. If all is well, your images will be straight! In my experience, 8 mm camcorders and decks are superior to your typical VCR, primarily because of the way that the audio is encoded for recording. However, we are not looking for the ultimate picture quality, just good speed regulation! If all is well, proceed as follows:

1. Route the SSTV output of your interface to the line input

of the recorder, start the recorder, and transmit a frame.

2. Rewind, start your receive software, and display the recorded image.
3. If there is any "slant", follow your software documentation to make a correction and then record and playback another frame.
4. Repeat as needed until your transmissions are "straight".

As in the case of removing "slant" from received images, you will typically have to repeat the exercise when trying out a new piece of software. Note that the VCR/camcorder technique works for both transmit and receive adjustments, so you may elect to use a good recording of one or two frames off the air, rather than having to wait for multiple transmissions when making the receive adjustments. Also, because of their longer transmission time, high-resolution images are more critical in terms of timing than shorter, medium-resolution formats. If your system is well-adjusted in terms of timing for high-resolution modes, it is sure to be just fine for any formats with a shorter frame interval.

## SSTV IMAGE MODES

One of the most daunting aspects of slow-scan when you first start to operate is the very large number of imaging modes that are handled by most SSTV programs. Fortunately, in most cases there is not much to worry about for two simple reasons:

- Most programs use the VIS header (see Chapter 4) to automatically set themselves to the proper mode if you catch the start of the image transmission.
- 95% of the time (particularly on 20, 40, and 75 meters), stations will be using just one of two modes.

Most of the dozens of modes that have been more-or-less closely defined and assigned VIS codes are artifacts of several decades of SSTV experimentation. Most are not used but remain as part of an unnecessarily-complex mode structure.

Given both the bandwidth and time constraints imposed by operations on our HF bands, SSTV modes can be grouped conveniently into three relative categories — **low**, **medium**, and **high resolution**, each of which is discussed briefly below after a short digression on the subject of image bandwidth.

### *IMAGE BANDWIDTH*

As noted in both Chapter 1 and Chapter 4, the basic reason for the "invention" of slow-scan was:

- To create an image mode that could be transmitted within the bandwidth limitations of an HF SSB transmitter
- To provide a transmission time acceptable in the context of operation on our crowded HF bands

The original 8-second SSTV format had a base-band video bandwidth of 900 Hz. When this signal was used to modulate a 1200-2300 Hz subcarrier, the resulting signal was a good "fit" to the audio characteristics of typical HF equipment. As long as the baseband video bandwidth falls below 1000 Hz, we have a slow-scan signal that meets all the legal requirements for use on HF.

**Table 5.1**

Medium-resolution color SSTV modes. The Scottie 1 mode tends to dominate here in North America, while Martin 1 is most popular in Europe. The mode used by DX stations tends to depend on who they have been or intend to work. See the text discussion of the significance of signal bandwidth.

| *MODE* | *VIS* | *H X V* | *TIME (SEC)* | *TIME (MIN)* | *BW (Hz)* |
|---|---|---|---|---|---|
| Robot 36 | 8 | 320 × 240 | 36 | 0.60 | 2133 |
| Robot 72 | 12 | 320 × 240 | 72 | 1.20 | 1066 |
| Scottie 1 | 60 | 320 × 256 | 109.6 | 1.83 | 1121 |
| Scottie 2 | 56 | 320 × 256 | 71.1 | 1.19 | 1728 |
| Martin 1 | 44 | 320 × 256 | 114.3 | 1.90 | 1075 |
| Martin 2 | 40 | 320 × 256 | 58.1 | 0.97 | 2116 |
| SC2-180 | 55 | 320 × 256 | 182 | 3.03 | 1350 |
| PD50 | 93 | 320 × 256 | 49.7 | 0.83 | 1648 |
| PD90 | 99 | 320 × 256 | 90 | 1.50 | 910 |

**Table 5.2**

High-resolution SSTV modes, arranged in order of increasing resolution and increasing transmission time. All of these modes are color with the exception of Fax480, which is monochrome grayscale. See the text discussion of the significance of signal bandwidth for these modes.

| *MODE* | *VIS* | *H X V* | *TIME (SEC)* | *TIME (MIN)* | *BW(Hz)* |
|---|---|---|---|---|---|
| PD160 | 98 | 512 × 400 | 160.9 | 2.68 | 1273 |
| Fax480 | 85 | 512 × 480 | 138.63 | 2.31 | 886 |
| PD120 | 95 | 640 × 496 | 126.1 | 2.10 | 2517 |
| PD180 | 96 | 640 × 496 | 187.1 | 3.12 | 1696 |
| P3 | 113 | 640 × 496 | 203 | 3.38 | 2345 |
| PD240 | 97 | 640 × 496 | 248 | 4.13 | 1280 |
| P5 | 114 | 640 × 496 | 304.6 | 5.07 | 1563 |
| P7 | 115 | 640 × 496 | 406.1 | 6.77 | 1172 |
| PD290 | 94 | 800 × 616 | 288.7 | 4.81 | 1707 |

Unfortunately, bandwidth criteria generally have been ignored by many of the people designing slow-scan modes since MacDonald's pioneering work. In the tables (**Tables 5.1-5.2**) that will be used for the mode discussions which follow, I have calculated the baseband video bandwidth for each mode and have included these values [**BW (Hz)** column]. Of the 18 modes covered in the two tables, two-thirds of them (66.6%) exceed 1200 Hz, 50% exceed 1500 Hz, and four (22%) exceed 2000 Hz! If it were not for the good-to-excellent audio and RF filtering in modern SSB equipment, we would have a real epidemic of excessively wide signals! There are three reasons why this is an unsatisfactory situation:

1. It is poor practice to modulate a signal that is excessively wide and then count on the filtering to keep it legal.
2. If the filters are doing their job, they effectively will reduce the base-band video resolution by 50% or more! If you are going to transmit an image at a specific resolution, sending it too fast (excessive bandwidth) only assures that you will lose much of that resolution.
3. The frequency of the subcarrier (1500-2300 Hz for video modulation) would have to be increased to realize the desired resolution at higher baseband video bandwidth.

Much of the concern with respect to bandwidth is valid in the context of HF operations. When transmitting SSTV on VHF and UHF FM, many of the modes with wider baseband video bandwidth will do a reasonable job, although limitations with respect to subcarrier modulation will still result in somewhat less-than-optimum performance. In the discussions to follow, all of which are biased toward HF operation, the most satisfactory mode options, with respect to bandwidth, will be noted.

### *LOW RESOLUTION MODES*

In the context of the 4:3 image aspect ration that is virtually universal today, low resolution modes are those with 120 image lines with 160 pixels/line (160 × 120). Given the fact that most modes append a 16-line header at the start of an image, primarily used for callsigns, names, or other simple printed material, we might expand the definition slightly to 160 × 136. Given the limited number of pixels/line, the header would not be terribly useful for text but could be used for additional image data. Unfortunately, this level of resolution has been basically ignored for decades; and there are few viable modes, none of which is in general use. This is unfortunate, since images at this resolution in either gray scale or color have the advantage of relatively short transmission times. Modes in this category would be very useful in the context of both DX and contest operations, where present practice is extremely inefficient and wasteful with respect to time.

### *MEDIUM RESOLUTION MODES*

Images in this category have a base resolution of 320 × 240, expanded to 320 × 256 with the inclusion of the popular 16-line header. This is the most popular resolution category today by far, and the more common modes are defined in greater detail in Table 5.1. On-air operations are completely dominated by color and Table 5.1 doesn't include any grayscale options, although I will allude to the potential usefulness of such an option in later operational discussions. A portion of the *ICH* Web site is devoted to a justification and definition of a medium resolution grayscale mode.

Even though I have not attempted to make the table all-inclusive, there are basically nine modes listed — each one of which is designed to transmit a medium-resolution color image! Three of these modes (Robot 36 and 72 and the Wrasse SC2-180) date from the early period in the development of color slow-scan. Each of these three modes is **line-triggered**, where each new line display is triggered or started by a line sync pulse. If sync pulses are missed or their arrival time is variable (as a result of multi-path, for example), the picture will be distorted. Because the line-triggering essentially provides a time reference for each line, line timing was never precisely defined; thus these modes cannot be displayed properly if sync pulses are missed. The only line-triggered mode still in general use is Robot 36, which has been used for past SSTV contacts with the *Mir* space station and which will be the default mode for the SSTV station aboard the International Space Station. Note that the baseband bandwidth of Robot 36 is excessively wide, leading to a loss of image detail on HF due to the filtering of the SSB transmitter. This is not a real problem on VHF and UHF FM where audio filtering is not as tight.

All the other medium-resolution modes are **synchronous**, in that pixel transmission rate is tightly controlled. Once the image starts and a single sync pulse is detected, the entire image display is then based on the reference clock signal. Despite the fact that these modes are synchronous, they all transmit line sync pulses throughout the frame. This adds very slightly to the frame transmission time; but the advantage is that another station, tuning into the transmission after the image start, can still lock to the image format and display what remains of the image. There are several so-called "AVT" modes which are not listed in the table. These modes do not transmit line sync pulses and depend on the image header to provide the initial synchronization. Quite apart from the fact that the AVT image formats never have been properly documented, their fatal flaw is that you cannot copy an image unless the header data is processed at the start of frame transmission. If you miss the image start, nothing can be displayed — an unacceptable situation on our crowded HF bands.

The synchronous modes in Table 5.1, which all differ in their detailed format, do not suffer from missing lines or misregistration if sync pulses are missed during the display of the frame. All of these modes are designed to transmit 320 × 256 images (including the 16-line header), but they vary greatly in their internal formatting and in the frame transmission time. Some of the modes (Scottie 2, Martin 2, and PD50) appear to be attractive due to a significantly shorter transmisson time. However, the increased pixel clock rate results in bandwidths that are really too wide for HF use. The filtering of a typical SSB trensceiver will reduce the displayed resolution significantly. The end result is images that are only marginally better than lower-resolution images transmitted at a more suitable bandwidth. The "fast" modes are most commonly encountered in SSTV net operations, where the net control station will receive images from a specific station (typically in Scottie 1 or Martin 1) and then retransmit to other stations using Scottie 2 or Martin 2 to save time.

Scottie 1 (S1) and Martin 1 (M1) are the most commonly used medium resolution modes; and, while the bandwidth is slightly higher than optimum, they produce excellent results. S1 appears to be the mode of choice in North America while M1 is favored in Europe. Beyond these areas, which mode is used depends upon which stations are being worked. Despite technical arguments that have been proposed, neither mode is inherently superior to the other. Based on image quality or noise immunity, there is no way that you can examine a received image and determine what mode was used to send it. Due to their relatively shorter transmission times, medium-resolution modes are best-suited for use on the bands between 20 and 160 meters.

### *HIGH RESOLUTION MODES*

While the Robot 1200 (with the proper EPROMs) could handle any medium-resolution format, the scan converter lacked the memory and display capability to handle images of higher resolution. Today's personal computers have no such limitations, making possible the transmission of high-resolution images limited only by the time required to transmit the frame. Table 5.2 shows the common "high-resolution" modes, all of which transmit images essentially four times that of the medium-resolution modes discussed in the previous section. All are color, with the exception of Fax480, which is a grayscale mode. Images can be spectacular (Figure 5.5), but the penalty is the time required for transmission. Here are two medium-resolution modes from Table 5.1:

| MODE | RESOLUTION | TIME MINUTES | BANDWIDTH (Hz) |
|---|---|---|---|
| Martin 1 | 320 × 256 | 1.90 | 1075 |
| PD90 | 320 × 256 | 1.50 | 910 |

Both come close to our target of 900 Hz bandwidth. Since the bandwidth of the PD90 mode is lower (better) than that of the Martin 1 mode, we would expect the transmission to take longer; but it is actually less! The reason is that PD90 uses a Robot color modulation format, thus saving some time. In fact, PD90 would be an excellent medium resolution mode, with shorter transmission time than other common formats; but it sees very little use because it is not yet supported by most software. In contrast, a 640 × 496 image has almost four times the resolution as these two medium-resolution examples and thus should require essentially four times the transmission time —somewhere between 6 and 7.6 minutes. A glance at Table 5.2 shows that most of the high-resolution modes boast significantly shorter transmission time! The reason is simple: Bandwidth considerations largely have been ignored in crafting many of these modes. Like the medium-resolution S2 and M2 modes, almost all of these modes have attempted to shorten the required transmission time by speeding up the pixel clock. The result will be the same — minor to significant degradation of image resolution as a result of filtering in the HF transceiver circuits. The problem would not be significant on VHF or UHF FM where the audio spectrum is wider than that employed at HF. In short, much to most of the increased resolution is lost on HF because of excessive baseband video bandwidth. If you want to *see* the increased resolution, your best bets would be P7 or PD240 for maximum resolution. The other modes may produce images that look a *little* better than their medium resolution equivalents, but not in proportion to the time required to transmit the pictures!

Perhaps I am biased in terms of my experience with Fax and weather satellite imagery, but I firmly believe that you should get all the resolution you are paying for, especially when the payment is in terms of transmission time. Time and spectrum are valuable resources — a theme I will return to time and again in the remainder of this chapter — and if SSTV is to coexist with SSB on our crowded bands, both resources have to be used responsibly. As a result, the high-resolution color image modes are best employed on HF bands that tend not to be as crowded — notably 17, 15, 12, and 10 meters. Of course they are ideally suited for use at VHF and UHF, where the higher bandwidth options can be used effectively to reduce the required transmission time.

The one exception to these generalizations is Fax480 (**Fig-ure 5.8**). Because Fax480 is a grayscale mode, transmission times are only slightly longer those of common medium-resolution color modes; and there is no resolution loss due to excessive baseband video bandwidth. In addition to providing excellent picture quality with modest transmission times on the higher-frequency HF bands, Fax480 has an outstanding reputation on bands such as 160 and 75 meters, where multi-path, static, and QRM are a common problems. There is no magic to this reputation because it rests on two simple facts:

- Grayscale images are always less subject to distortion than color images because the eye is very sensitive to color shifts.
- Bursts of static or QRM always will have a greater subjective impact on medium-resolution images because the interval of the interference will make up a greater proportion of the total image area.

The fact that Fax480 is a high-resolution grayscale mode with modest time requirements makes it a viable option on the lower-frequency bands when conditions get rough!

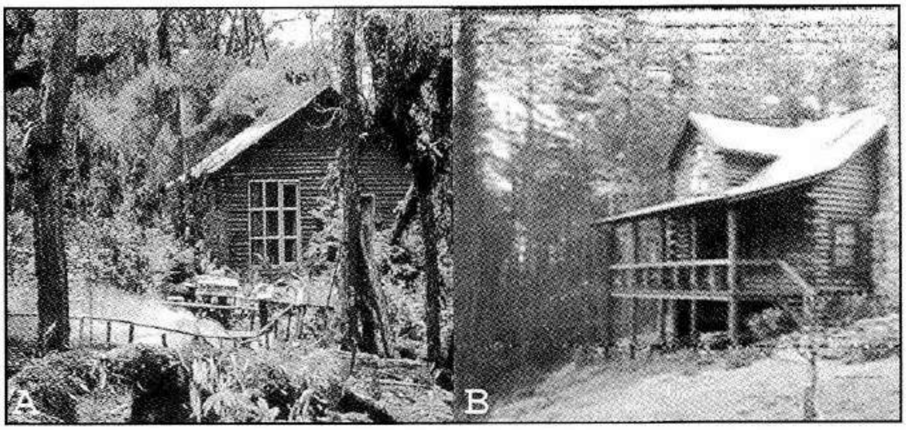


**Figure 5.8.** On 17-10 meters, higher-resolution modes permit the transmission of pictures with significantly more detail. Image **[A]** was transmitted on 15 meters by KF7OH using Fax480 (512 × 480). It is a very "busy" scene with respect to detail, all of which arrived with excellent clarity. Image **[B]** is from a medium-resolution (Scottie-1, 320 × 240) transmission by W8RFQ. This is an excellent picture, given the format resolution, that nicely shows the cabin in its scenic context; but fine detail is missing.

## BASIC SSTV OPERATING

The purpose of this section is to introduce you to the basic aspects of SSTV operations, from making your first contacts to working DX and contests. However, many of the directions in which SSTV operating practice have evolved are problematic at best. To put it bluntly, many current operating practices are inherently wasteful of time and spectrum; and most couldn't be better-calculated to arouse the ire of other operators, primarily on phone, with which we have to share the bands. The result is often a "range-war" mentality, inspiring irresponsible behavior by all parties! SSTV is undergoing significant growth as a result of the "computer revolution", and we certainly are going to be using more spectrum in the years ahead. The trouble is, Amateur Radio is also growing — a very good thing in itself — but that will inevitably increase competition for spectrum, especially as the current solar cycle declines in the years ahead. There will always be operators who are content to just keep operating as they always have; and that is not always the path to a more productive future. There are aspects of SSTV operating that are in need of reform, and that reform can be based only on an appreciation of the problems that have arisen and a grassroots effort to make changes where circumstances warrant. That is the responsible course both from the perspective of slow-scan and our heritage as Amateur Radio operators.

### *WHAT MICROPHONE?*

Before we look at any aspect of operating, it is important to highlight the first major problem — a reluctance to use the microphone — which has become significant in many areas, most particularly in Europe. Let me begin with a simple, bedrock principle:

**SSTV was never intended to be a mode independent of phone.**

Amateur Radio is all about communication, and no image mode can replace the need to actually speak with the station at the other end of the circuit. The Chinese proverb asserts that "The meaning of a picture is worth ten-thousand words", but there are many situations where a few well-chosen words can more than substitute for several minutes of picture transmission. SSTV was always intended to compliment normal phone communications; and, as such, a normal SSTV QSO should consist of interspersed voice and image material. Confirmation of an SSTV QSO does require that pictures be exchanged and that the pictures you receive exceed some subjective standard to qualify for a confirmed picture exchange. The subjectivity is no more of a problem for slow-scan as it is with any other mode. In fact, unlike other modes, the ability to save SSTV images to disk means that the quality of the exchange always can be verified independently if the matter is significant with respect to awards, contests, and the like.

Unfortunately, the impression has developed in some quarters that a valid SSTV contact must be entirely video with respect to content. This attitude often leads to a situation where multiple stations (many of which cannot hear each other) are blindly battering each other with picture transmissions that can consume up to two minutes a shot! In contrast, had phone been used to coordinate activities on the frequency, more contacts would have been completed in a fraction of the time. This is a particular problem with respect to working DX, but it also can turn a contest into an environment where it is easier to turn off the rig and watch TV!

Time and again, you will see operating recommendations to make better use of your microphone. This will not only improve the quality of SSTV contacts, it will do wonders with respect to general public relations on our bands. People tend to react very negatively to things they don't understand, particularly if those things are intrusive or disruptive. To a non-slow-scan operator, an SSTV signal is just so much bedlam and QRM that actually appears wider than it really is because of the high power-density of the signal. The phone portions of an SSTV QSO do mean something to other operators, and they are far more likely to act responsibly if they can relate to the fact that a real contact is in progress rather than a continuous barrage of unintelligible tones. Respecting the historical union of voice and image can make for better slow-scan contacts and can improve our image as well!

### *LEARN YOUR SOFTWARE*

A new piece of SSTV software is a lot like a new rig. There are all sorts of functions and features that you need to understand; otherwise you will look more than a little foolish when you try to get on the air. Some software interfaces are more intuitive than others; but, even if everything seems clear, it is worth reading the manual with respect to the most basic functions:

- Loading and saving images
- Manual mode selection
- How to use the receive tuning indicator
- How the thumbnail image system works on your software
- How to add text to images and how to use the basic image editing features

If you haven't done so already, follow the earlier instructions on setting the audio level for SSTV transmission. Proper tuning and the use of the tuning indicator can be practiced by monitoring QSOs, which will also let you correct the time-base using the software features to eliminate image "slant" as discussed earlier in the chapter.

### *YOUR FIRST QSO — A NET OR ROUNDTABLE*

As previously noted, the limited number of frequencies in use on bands between 160 and 20 meters means that most operation on these frequencies involves nets or group roundtables. One good bet for a first contact is to check into one of the two SSTV nets on 20 meters. Either of these nets will typically have two net control stations to accommodate propagation. Get tuned to the frequency and verify that your software is working by copying a few pictures. Most software has a "thumbnail image" gallery feature, and you should load the picture you intend to transmit into the gallery so you can call it up quickly. A "mug" shot with some basic information (Figure 5.1) makes a good "first" picture. Listen to the net control station that provides the best copy and, when they ask for additional check-ins, give a quick call-in on phone. **NEVER ATTEMPT TO CHECK INTO A NET OR BREAK INTO A ROUNDTABLE ON SSTV!** Doing so is disruptive, wastes a lot of time, and is completely ineffective. There may be other stations calling in; if Net Control misses your call, try again. Once your check-in has been acknowledged, sit back and wait your turn to transmit. When the Net Control station invites you to transmit:

1. Briefly introduce yourself if you have not been invited yet to do so.
2. Indicate that you have been copying pictures but that this will be your first transmission.
3. Briefly describe the picture you are about to send.
4. Announce your call and the transmission mode: **"WB8DQT transmitting Scottie 1..."**
5. Transmit the image.
6. As soon as the image ends, turn it back to Net Control.

The Net Control station will typically retransmit your picture for the benefit of others on the frequency who could not copy, and that will give you a chance to see how you did. If there were problems, the Net Control station will note what they were. The most common problems are:

- Slanted pictures
- Hum on the signal
- Too much or too little SSTV audio drive to the transmitter

These should not be issues if you carefully went through the set-up instructions given earlier, but they all are things that should be corrected before you try to transmit again!

Checking into a roundtable is essentially similar to checking into the net, but things will be less formal. Most groups will pause for breaking stations and this is your best opportunity to call in — again, voice — *not* video. Otherwise, make a *very* short call, including your callsign, in the short transmission from one station to another. Once you have been recognized, don't be shy about letting everyone know that you don't have a lot of experience transmitting. SSTV operators tend to be very helpful to newcomers. One of the nice things about roundtables is that with fewer stations you get to transmit more pictures, and the group often will try to talk you through any problems you might encounter.

### *CALLING CQ ON SSTV*

Calling CQ on slow-scan has much in common with any other mode:

1. Select a frequency
2. Listen carefully to determine if the frequency is in use
3. Call at least once to verify that the frequency is clear
4. Proceed with your call.

Ten and 15 meters are the bands where you are most likely to be calling CQ on HF, and their propagation characteristics make it harder to determine if a particular frequency is in use. Let's use 15 meters as an example. I would start by tuning to 21,340 kHz — the calling frequency for that band. If careful listening indicates the frequency is clear, I would confirm that with a short call:

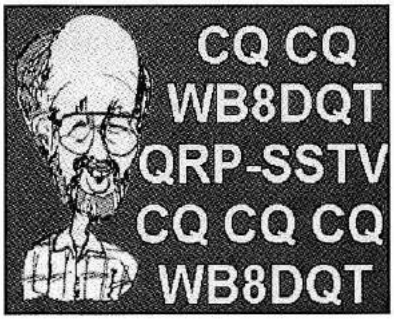


**Figure 5.10.** Most stations have at least one image that is used for calling CQ. The text discusses some considerations you might want to keep in mind when constructing your own "CQ" images.

**IS THE FREQUENCY IN USE PLEASE? WB8DQT....**

If the frequency is busy, you need to find another; and that is a subject worth discussing. The SSTV activity on any band will center on the calling frequency. If you need to move, the next frequency you try should be ±3 kHz. SSTV stations separated by 3 kHz can operate without causing mutual interference if neither of the stations is using excessive audio/RF bandwidth. If the stations are closer than 3 kHz, there will be mutual interference. Moving much further off frequency will lessen the chance that other stations will hear your call. Given the example of 15 meters, if we assume the calling frequency is our reference point, there is a range of potential operating frequencies centered on the calling frequency:

.... 21334 21337 **21340** 21343 21346 ....

Finding a clear frequency closest to the calling frequency provides your best chance of success.

Assuming you have found a clear frequency, you can call CQ in one of two ways. The first is on phone. For example:

**CQ SSTV CQ SLOW SCAN TELEVISION**
**THIS IS WB8DQT, WHISKEY BRAVO EIGHT DELTA QUEBEC TANGO**
**WB8DQT STANDING BY FOR ANY CALLS....**

This is the fastest and most efficient method, but may not always work. Many stations are tuning for the distinctive sound of a slow-scan signal and are paying little if any attention to voice signals. If the voice call doesn't get results, you will have to try method #2 — the CQ picture. It always pays to have at least one image in your collection designed for calling CQ. How this slide is designed can make a great deal of difference in its effectiveness. Figure 5.9 and **Figure 5.10** show two CQ images. Figure 5.9 is very attractive in its original color form but is not as effective as it might have been. Any color distortion or QRM will reduce the contrast of the text. Also, if you are going to use your call just once, it would be better to place it near the bottom of the image to maximize the chance that it will be seen, regardless of when the picture is acquired. One of my own CQ images can be seen in Figure 5.10. There are several aspects of this picture that make more effective use of the time required to transmit the image:

- The background (mid-range blue) and text (bright yellow) are chosen to maximize contrast.
- The text is in relatively large, block letters to improve readability under marginal conditions.
- The CQ and the callsign are repeated top and bottom to help assure that they can be read.

The most effective way of using a CQ image is to begin and end the transmission with short voice transmissions:

**WB8DQT CALLING CQ SSTV SCOTTIE 1**

**[TRANSMIT IMAGE]**

**WB8DQT CALLING CQ SSTV AND STANDING BY FOR ANY CALLS....**

The only problem with using this method is that if your image is transmitted in either Martin 1 or Scottie 1, the two most popular medium-resolution modes, picture transmission will require almost two minutes! By the standards of any other amateur modes, this is a *very* long CQ call; and it is not surprising that things can get pretty chaotic on and near a frequency when several stations are doing the same. In contrast, by calling CQ using the medium-resolution grayscale mode defined on the *ICH* Web site, image transmission time drops to about 40 seconds and the entire voice/image call can be completed in less than half the time compared to the use of color.

Ideally, any stations answering your call will do so on voice; and all of the preliminary aspects of the contact will be handled as in a standard phone QSO. From that point, the contact generally proceeds as an alternating sequence of images and voice commentary, using whatever modes both stations deem appropriate. In some cases, particularly where you are being called by a DX station, the reply to your call well may be a video transmission without any voice content. How you handle that situation will be discussed under a later section, "Working DX". First, however, we should digress for a moment and discuss signal reporting on slow-scan.

**Figure 5.11**. The video (V) component of the SSTV RSV signal reporting system attempts to provide a concise but subjective report of the image signal-to-noise ratio. The scale, as shown here, ranges from V5 (an image that is essentially "closed-circuit" with no noise) to V1 (noise dominated, but with some definable image content). V0 is not shown as it would represent a frame dominated by noise with little, if any, image content.

### *SSTV RST SIGNAL REPORTING SYSTEM*

Amateur Radio has traditionally used a three-part **RST** signal reporting system where the letters RST correspond to **R**eadability, signal **S**trength, and **T**one:

- **Readability** — a 5-step scale ranging from **R1** (unreadable) through **R5** (perfectly readable). See any *ARRL Handbook* for the accepted interpretation of the intermediate **R**-values.
- **Signal Strength** — a 9-step scale ranging from **S1** (faint signal, barely perceptible) through **S9** (extremely strong signal). See any *ARRL Handbook* for the accepted interpretation of the intermediate S-values. Most operators base the signal-strength report on the indication provided by the receiver signal-strength or S-meter.
- **Tone** — a 9-step scale ranging from **T1** (60 Hz AC, very rough and broad) to **T9** (perfect tone). The tone report is applicable to CW/Morse communications and is omitted when reporting phone signals.

Over the years, SSTV operators have added a third component to the **RS** reporting system for phone contacts. This third component (**V** for **V**ideo) is appended where the tone report would be used. Thus, a slow-scan signal report contains three numbers corresponding to the **RSV** report format. The usage of the **R** and **S** elements follows standard practice. The **V** component is derived from the long-standing **P** reporting system used for ATV contacts (see Chapter 9). The report is a 5 or 6-step scale ranging from **V0** (noise, no signal) through **V5** (a perfect or "closed-circuit" picture). **Figure 5.11** attempts to show the general relationship of the **V** report to the image signal-to-noise ratio. The system is highly subjective as there is no simple way to quantify the system in any objective manner. For example, a **V4** report would indicate a very good picture, but one where some

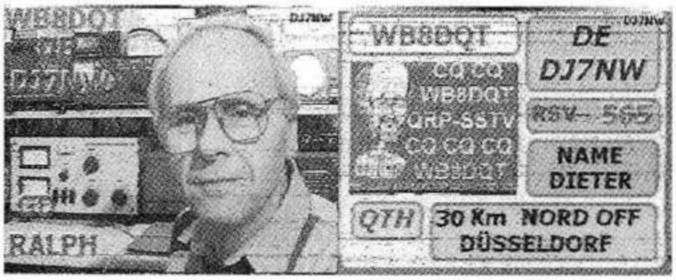


**Figure 5.12.** Significant variations in signal strength can be expected during DX contacts, given the time required to exchange pictures. Both of these images are from the same QSO with Dieter (DJ7NW). The picture on the right was Dieter's response to my CQ. It contains all essential information including the RSV signal report (see text) and a copy of my picture as he received it. A few minutes later, when Dieter sent his "mug shot" (left), the signal had improved significantly. This is quite common if your strategy is to try to catch band openings early, prior to the arrival of a crowd, including the inevitable "big guns".

**Figure 5.13.** It pays to have at least one image set up to give signal reports. This one includes a mug shot, a weather satellite image standing in for a map, and the text, where all I have to fill in is the station's call and signal report.

**Figure 5.14.** A small montage of DX images, including **[A]** GM3UCH (Scotland), **[B]** JZ1TZQ (Japan), **[C]** 5R8EW (Madagascar), **[D]** SM5EEP (Sweden), **[E]** PY4BL (Brazil), **[F]** EA6MQ (Spain), **[G]** XE1L (Mexico), **[H]** YV1AVO (Venezuela), and **[I]** DJ4FO (Germany). All of these images were originally in color and many of the graphics, which stand out with good contrast in color, are greatly subdued when the images are converted to grayscale format.

slight noise artifacts could be observed. A **V3** image would still be of reasonable quality, but noise effects would be more obvious. At the bottom of the scale, a V1 image would be very noisy, although one might be able to recognize major image components despite the fact that fine detail was completely obscured. In practice, the full range of V signal reports probably would be usable only on VHF/UHF. On our crowded HF bands, interference certainly may be the limiting factor for V1 and V2 signals. Since significant fading may also impact marginal signals, verbal comment is typically added to clarify how the signal was received. It is also common practice to retransmit received images, which lets you do your own evaluation of image quality since the "return trip" likely will add new noise and interference effects. Whenever possible, I try to save at least one image from any station I work, which is helpful later in making up QSL cards (see later discussion on that topic).

RSV reports can be given verbally, although for DX contacts they typically are incorporated into a picture, something that will be discussed in the section that follows.

### *IMAGE SIGNAL REPORTS*

When working DX (see next section) it has become almost universal to give the signal report in the form of an image. **Figure 5.12** shows a good example of such a report. The image on the right was DJ7NW's reply to my CQ. Note that by careful layout of the image, Dieter was able to convey a large amount of information in a single image. If you are going to exchange essential information by means of a picture, you should strive for the maximum amount of information, consistent with keeping it all readable. In this case Dieter was able to include a sample of my picture as he received it, my signal report, his name, and detailed information on his location.

In order to use the image report option effectively, you should keep a picture on file that requires adding as little information as possible in order to have the image ready to send with minimal delay. **Figure 5.13** shows my standard "report" picture. All I have to do is fill in the other station's callsign at the top and the RSV report and it's ready to go! Since all my HF work is done on QRP, I don't chance using smaller graphics. Everything is large and blocky and designed for maximum readability. The background is a bright blue with yellow letters, just like the CQ image. In this case, however, I include a small version of a mug-shot and a weather satellite picture, marked with a bright red dot to show my location.

Virtually all SSTV software has the provision to let you add graphics to an existing image. If you preset font size and the font and background colors prior to an operating session, it takes just a few moments to fill in the required information. The speed with which you can crank out a unique report may well determine how effectively you can work DX!

### *WORKING DX*

Working DX is a time-honored activity in Amateur Radio, but it has become very ritualistic on many modes. The typical "hello-goodbye" contact on HF SSB may put a new country in the log; but is pretty impersonal, despite all the ritual greetings that are exchanged. Even a minimal DX contact of SSTV has much more of a personal touch in that you typically get to see the operator at the other end, where he or she lives, the kids, the dog, or the local scenery (**Figure 5.14**). In short, DX contacts on slow-scan have a more personal touch, much closer to what you might have imagined such contacts to be when you first started in Amateur Radio.

Working DX would be much like any other QSO except for the fact that many DX stations have come to emphasize the slow-scan aspects of a contact to the virtual exclusion of using the microphone. The result is a cumbersome and time-consuming exchange sequence to complete a QSO. Some European amateurs, including Nils, SM5EEP, have been outspoken about the need to develop more efficient operating practices; but there are still too many SSTV DX stations who are very rigid in their interpretation of what constitutes an SSTV contact. Let's assume that I am checking out 15 meters, waiting for the band to open. Since I want to work into Europe, I will use Martin 1 as my default mode. Such a contact would go something like this:

**SEND CQ (114 seconds)**

**10-15 SECOND DELAY WHILE THE STATION FORMATS A REPORT IMAGE**

**REPORT IMAGE FROM THE DX STATION (114 SECONDS)**

**10-15 SECOND DELAY WHILE I FORMAT A REPORT**

**TRANSMIT REPORT FROM MY STATION (114 SECONDS)**

At this point it has taken over six minutes just to exchange the most basic contact information — even if everything goes perfectly, and there are no delays caused by interference or propagation variations! There may have been some minimal voice exchanges during all of this, but none of that will count toward confirming the SSTV QSO. SSTV DX operators are inclined to be a friendly bunch. Once the basic information has been exchanged, the microphone gets used more frequently; and, typically, several more images might be exchanged, depending upon conditions and how busy the frequency might be. Aside from taking a lot of time, the initial exchanges, involving very little voice work, will be unintelligible to nearby phone operators; and this may result in more unintentional interference than if other stations were aware of what was happening. The procedure even encourages a certain amount of chaos among other SSTV operators since it requires many minutes of listening to determine the status of a QSO.

So how might we conduct the initial stages of a contact in such a way as to save time and minimize on-frequency confusion? The answer is simple: Use the microphone. Let's replay the previous set of exchanges incorporating intelligent use of the microphone:

**CALL CQ (114 SECONDS)**

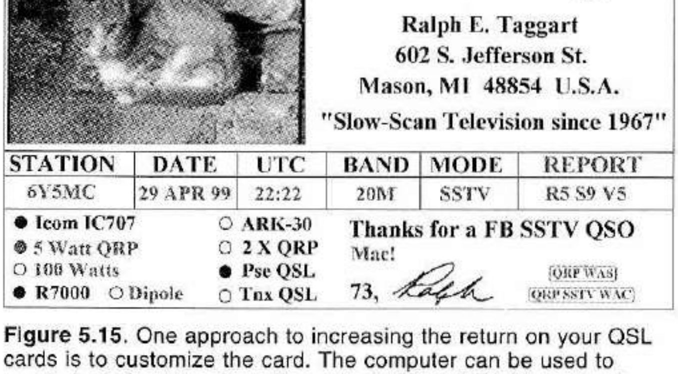
**DX STATION CALLS ME, GETS A RETURN, AND PASSES ON A REPORT ON MY PICTURE (30 SECONDS)**

**DX STATION TRANSMITS A PICTURE (114 SECONDS)**

**DX STATION GETS MY REPORT (15 SECONDS)**

At this point we would be free to terminate the QSO or continue, depending upon the inclinations of both operators. The point is, the "essentials" of the QSO have taken just 4.5 minutes instead of 6! The SSTV contact is just as valid as the first case, since all reports refer to pictures that have been copied, but there is a significant time savings. As an additional bonus, the more frequent use of voice keeps other stations apprised of the status of the contact and thus tends to keep the interference level to a minimum. Some DX stations are quite willing to operate this way, but you will have to be familiar with the first approach since others will not recognize a voice report.

Another major reform that would greatly improve the effectiveness of DX contacts is the matter of what kind of images are sent. If we grant that medium-resolution formats are desirable, based on their greater information content, why not look at the option for medium resolution grayscale images for the initial exchange? Such a mode, which would be extremely easy to implement, is defined in the *ICH* Web site. Using this mode, the transmission of a medium-resolution image would require just 41.5 seconds (with header), compared to 109 or 114 seconds with the Scottie or Martin 1 modes. If stations wished to use the video-only approach for the initial exchange, the entire process would take just 2.4 minutes instead of the 6 minutes required with Martin 1. If conditions were good, the



6Y5MC

**WB8DQT**

Ralph E. Taggart
602 S. Jefferson St.
Mason, MI 48854 U.S.A.
"Slow-Scan Television since 1967"

| STATION | DATE | UTC | BAND | MODE | REPORT |
|---|---|---|---|---|---|
| 6Y5MC | 29 APR 99 | 22:22 | 20M | SSTV | R5 S9 V5 |

● Icom IC707
◉ 5 Watt QRP
○ 100 Watts
● R7000 ○ Dipole

○ ARK-30
○ 2 X QRP
● Pse QSL
○ Tnx QSL

Thanks for a FB SSTV QSO Mac!

73, Ralph

QRP WAS
QRP SSTV WAC

**Figure 5.15**. One approach to increasing the return on your QSL cards is to customize the card. The computer can be used to create just about any layout you want. Since SSTV is a visual mode, my card options always include a sample of the other station's picture. I also have fancy, four-color cards. In that case, I have another layout to print on the blank side of the preprinted card — again, including a sample of the pictures as received at my station.

stations could proceed to send color images; but the entire initial exchange becomes significantly more efficient. The time required drops to just 2 minutes if we use a combination of video transmission and voice reporting. As we begin the downward slide from this last solar maximum, we may wish to look at such reforms to make it easier to handle the rapid growth in the SSTV community.

### *SSTV CONTESTS*

Slow-scan contests are relatively few in number and usually do not attract large numbers of participants. In a way this is good, since things can get pretty hectic on and around the relatively few SSTV calling frequencies. Such contests tend to reinforce the worst aspects of video-only DXing, as the rules typically require that *all* exchanges be made via slow-scan; and, of course, the essence of a contest is competition. Like the initial exchanges in DX contacts, contests would be less onerous if they generally used relatively fast modes, such as the medium-resolution format defined in the *ICH* Web site.

### *QSL CARDS*

If you decide to pursue awards, you will need to collect QSL cards for your significant contacts. The typical video report would be an excellent proxy for the time-honored cardboard card, but I don't know of any major awards that accept these images as a substitute for a conventional card.

Let me start by saying that DX stations are uniformly good about exchanging cards. Some will QSL direct, but most will opt to use the Bureau system. The point is, you will get your DX card in the vast majority of cases, even if you have to wait for it. Domestic cards are another matter entirely. It has been my experience that a significant percentage of domestic (US) slow-scan stations don't make an effort to keep a log; and many will not QSL, even if supplied with an SASE along with your card. In short, you can probably earn a DXCC on SSTV before you will qualify for a WAS!

The key to getting the best return on your cards is to make the card as distinctive as possible. **Figure 5.15** shows the computer-generated card I have used over the years. The thing that makes it distinctive is that it incorporates the image transmitted by the other station. The cards are printed out in full-color on card stock. In recent years, I have used a very high-quality four-color photo-QSL. The back of this card is blank and I use the computer to print out contact information appropriate for the mode used for the QSO. In the case of my SSTV contacts, the layout is a bit different from the one shown, but it still incorporates the image from the other station. Of course, you can use standard pre-printed cards, simply filling in SSTV in the mode box and an RSV report; but if you want to maximize your returns, I would suggest that you be a bit more creative.

### *QRP SSTV*

One of the persistent myths about slow-scan is that it is best-suited for extremely well-equipped stations — the "big guns". I suspect that this impression dates back to the Robot 1200 era, for individuals who could afford that scan converter generally were well-endowed with respect to amplifiers and big antenna arrays. While there is nothing wrong with having a "big signal", you can have a lot of fun operating SSTV with a far less impressive installation. I can say this with some confidence, as I have been operating SSTV for the past 25 years exclusively at QRP (<5 W) power levels. All the signal reports you can read in Figure 5.14 were achieved with a power output of 4.6 W into an R7 ground-mounted vertical. I have Worked All Continents on slow-scan at this power level and have 53 confirmed countries. I have also Worked All States but don't expect to earn the certificate any time soon, given the problems with getting domestic QSL cards.

The truth is that most of my SSTV peers consider me to be hopelessly eccentric when it comes to power, but they tend to be charitable because I've been around for awhile and generally have an amiable disposition. In all seriousness, successful QRP SSTV is more difficult than using modes like CW or PSK-31, but it can be done. A QRP operator who starts chasing DX, regardless of mode, needs to understand or at least work with propagation. One of the most effective strategies is to be waiting when a particular path opens. While I have some DX on 20 meters, I tend to leave that band to the "big guns", concentrating my efforts on 15 and 10 meters. Good propagation software can make life a lot easier. I use ***WinCap Wizard*** from Kangaroo Tabor Software (see **Appendix**) and have found it quite helpful.

The real lesson here is that you can operate HF SSTV with a very modest station. A basic 100W transceiver, operated into a well-matched antenna system, can yield excellent results regionally and plenty of DX with a bit of homework on your part.

## SPECIALIZED SSTV OPERATIONS

In the sections that follow I will provide a very brief introduction to somewhat more specialized SSTV activities. A comprehensive treatment of most of these subjects is beyond the scope of this handbook, but knowing what can be done is the first step if you should choose to try some of these operating options.

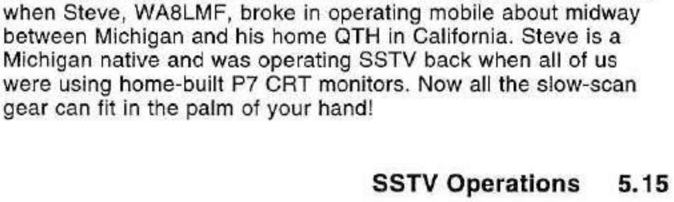


**Figure 5.16**. The Kenwood VC-H1 hand-held scan converter makes mobile SSTV as simple as normal phone operation. Rob, KF7OH, and the author were in QSO on 15 meters one afternoon when Steve, WA8LMF, broke in operating mobile about midway between Michigan and his home QTH in California. Steve is a Michigan native and was operating SSTV back when all of us were using home-built P7 CRT monitors. Now all the slow-scan gear can fit in the palm of your hand!

### *MOBILE SSTV*

There was a time, not very long ago, where mobile operation of HF presented some very real problems as cars became more compact. With today's miniature transceivers and effective mobile antenna systems, a very efficient HF installation need not be much more difficult than your typical VHF/UHF FM operation. Add miniaturized SSTV gear, such as a Kenwood VC-H1 (see Chapter 4), to the mix and mobile SSTV becomes entirely practical. The usefulness of this approach goes far beyond the occasional family vacation. Among the biggest problems faced by amateurs today are deed restrictions and covenants that may make it difficult or impossible to install a typical HF antenna system at the home station. While individual amateurs and the ARRL will continue to wage legal battles to try and improve this situation, one solution is to take your station on the road, operating from local parks, parking lots, and hilltops. In fact, choosing the right spot to operate mobile might actually work just as effectively as a sub-optimum or temporary antenna installation at home.

I remember one afternoon about a year ago when Rob (KF7OH) and I were exchanging high-resolution pictures on 15 meters when Steve (WA8LMF) broke in. Steve is an East Lansing, Michigan, native and we had many good times operating SSTV in the early '70s. He has been working out in California; and I assumed, based on the excellent signal he was putting out, that he was operating from his west coast QTH. The fact is, he had been home for a visit and was now about half-way back to California and operating mobile. We had a very nice three-way SSTV QSO (**Figure 5.16**) that certainly convinced me about the viability of the mobile option!

### *SSTV AT THE EDGE OF SPACE*

One of the more fascinating ATV activities over the past decade or so has been lofting TV cameras up 20 miles with weather balloons, then transmitting live pictures back to the ground using low-power 70 cm transmitters (see Chapter 9). Given a terminal (burst) altitude of 100,000 feet or more, amateurs hundreds of miles away can receive the pictures. The problem is that even with line-of-site reception, the very wide bandwidth (~ 4 MHz) of conventional ATV signals and the problems of flying an effective horizontally-polarized 70 cm antenna (with most ATV stations using horizontal polarization) can result in a situation where the quality of the signals at maximum altitude can be pretty marginal.

Such balloon experiments are ideally suited to SSTV; but, until recently, SSTV hardware was not compact enough to consider incorporation into a balloon payload where the flying weight of the hardware is typically in the 10-15 pound range. The Kenwood VC-H1 has changed all of that, and a few pioneering balloon groups have begun to experiment with SSTV. **Figure 5.17** shows one SSTV transmission from the VBX/3 balloon launch (7 August 1999), sponsored by the North Okanagen Radio Amateur Club and the Wild Rose Network in western Canada. The SSTV downlink signal was on 146.52 MHz, time-shared with an experimental voice repeater system and telemetry and APRS. The package was launched from Vernon, BC, and landed via parachute near Kamloops, BC, after a flight time of 3 hours and 40 minutes!

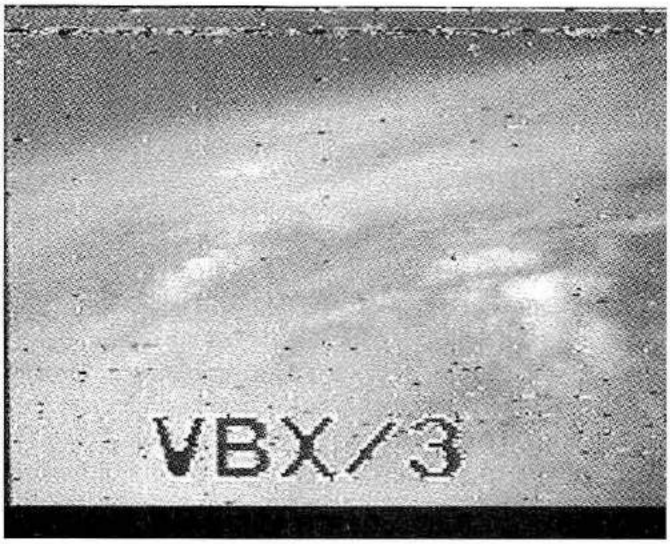


**Figure 5.17.** SSTV from the edge of space. Lofting ATV cameras as part of amateur balloon payloads has become relatively common, but SSTV represents a new option that is still in the experimental phase.

**Figure 5.18.** Single frame from an SSTV QSO between W0LMD and JH2ESW through the AO-40 amateur communications satellite. The "slant" of this image is not the result of a misadjusted clock frequency. It results from Doppler shift due to the speed and relative trajectory of the spacecraft relative to the receiving ground station (a topic to be discussed in later chapters on weather satellite reception). The direction of the slant — from left to right — indicates that the spacecraft was approaching W0LMD's ground station while this picture was being received.

Launching and recovering high-altitude balloon packages is a specialized business that requires among other things:

- Coordination and clearance from aviation authorities (the FAA here in the US)
- Design and packaging of a multi-purpose payload package that will survive the rigors of the near-space environment.
- The specialized activities involved in launching the weather balloons
- The all-important task of tracking the package in flight and recovering it after it parachutes back to the ground, following the terminal altitude burst of the balloon.

**Figure 5.19**. SSTV on the *Mir* Space Station. **[A]** The *Mir* SSTV equipment "stack", fabricated by Don (W9NTP) and Sue (W9YL) Miller of Wyman Research. From bottom to top the stack consists of a Tasco SSTV scan converter, the fast-scan monitor, the 2-meter FM transceiver, and a controller. Robot 36 was the default mode and the system worked very reliably. **[B]** Cosmonaut Gennady Padalka participating in an SSTV QSO as *Mir* passed over the US Midwest.

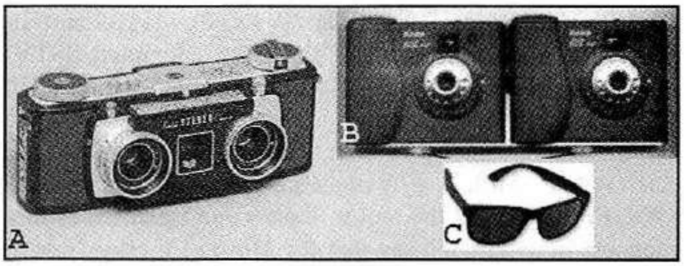


**Figure 5.20.** The classic way to shoot stereo (3D) photographs is to use a camera with two lenses, separated by the same distance as human eyes. Numerous very fine cameras were manufactured during the stereo photography craze of the mid-1950s and many are readily available on the used camera market. **[A]** illustrates a Kodak stereo camera of the period from the author's collection. Since most slow-scan operators won't want to mess with film, it is also possible to combine a pair of compact digital cameras to create a home-built stereo camera. **[B]** shows one of the author's dual-camera systems, created by combining a pair of Kodak EZ-200 digital cameras which are electronically synchronized. This camera produces 640 × 480 stereo pairs that are perfect for high-resolution SSTV or which can be reformatted to the more common 320 × 240 medium-resolution format. The most common and least-expensive way to view stereo images on a TV or computer monitor is to use a pair of red/blue glasses **[C]**.

An excellent introduction to this activity can be found in Lloyd Verhage's (KD4STH) two-part article, beginning with the January 1999 issue of *QST* (pp 29-32).

### *SSTV VIA AMATEUR SATELLITES*

The sophistication of amateur communications satellites has increased significantly over the past two decades, and there are a number of satellites that provide two-way voice capabilities. Any of these can support SSTV contacts as shown in **Figure 5.18**. Amateur satellite communications are highly specialized, but the operating protocols and support software (primarily for spacecraft and antenna tracking) are highly developed. A short but useful introduction to amateur satellite communications can be found in Steve Ford's (WB8IMY) "An Amateur Satellite Primer" in the April 2000 issue of *QST*. *The Radio Amateur's Satellite Handbook* by Martin Davidoff (K2UBC), available from the ARRL, is an essential resource for anyone considering the fascinating area of amateur satellite communications. David Jones' "CQ SSTV" Web site (**http://www.tima.com/~djones/**) contains a number of links to articles by W0LMD that highlight some of the unique challenges associated with SSTV satellite communications.

A number of recent amateur satellites have carried various sorts of cameras into orbit, and some are capable of store-and-retrieve operation with respect to images. These experiments have yielded some spectacular images with the major issue being very long download times, often requiring several passes even when special wide-band receivers are operated at 38,400 Bps. A good introduction to some of this work can be found in Stacy Mill's (W4SM) April 2000 article in *QST*, "Step Up to the 38,400 Bps Digital Satellites". While many of the current experiments are interesting, weather satellites (Chapters 6 and 7) provide, for the moment, a more versatile and far less expensive approach to viewing the Earth from space.

### *SSTV AND THE INTERNATIONAL SPACE STATION (ISS)*

One of the most exciting SSTV developments of the late 1990s was the deployment of SSTV equipment on the Soviet/Russian space station *Mir* in December of 1998. This effort was spearheaded by a small group within MAREX-NA (**M**anned **A**mateur **R**adio **Ex**periment — **N**orth **A**merican

**Figure 5.21**. A stereo or 3-D image is actually composed of two pictures—a "stereo pair". The left image represents the image as seen by the left eye, while the right image shows the scene as viewed by the right eye. Shown above is a stereo pair of my granddaughter Tori (right) and a friend, photographed at a playground in a local park. Because our eyes are separted by somewhat over 2.5 inches, the two views are not the same. You can see this easily if you observe the position of the trees adjacent to the right-hand upright of the wooden arch which frames the two girls. The differences between the two images, technically the result of parallax, are greater for objects closer to the eye/camera and less for objects at greater distances. This differential parallax is used by the brain to generate the perception of depth.

Division), including Don Miller (W9NTP), Hank Cantrell (W4HTB) and Farrell Winder (W8ZCF). A complete SSTV operating module (**Figure 5.19A**), consisting of a Tasco SSTV scan converter, fast-scan color monitor, two-meter FM transceiver, and a controller was constructed by Don and Sue (W9YL) Miller, of Wyman Research. G. Miles Mann (WF1F) transported the unit to Russia and trained the cosmonauts in its use. To say that the *Mir* SSTV effort was a success is a major understatement! The system readily demonstrated the ease of conducting face-to-face SSTV contacts with amateurs in the space station (Figure 5.19B), as well as the potential for unattended transmission of images of the station and the earth as viewed from orbit. All SSTV work was conducted on 2 meters FM, using the same antennas used to support both voice and packet communications with the station.

The success of the *Mir* program has resulted in the development of an expanded MAREX-NA team (the original *Mir* group plus G. Miles Mann , WF1F, and Jim Barber, N7CXI) to incorporate SSTV into the Amateur Radio options for the International Space Station. The ISS slow-scan package, known as SpaceCam-1, is computer based, using a software package developed by Jim Barber and his partner, Jim Montomery (VE3EC) of Silicon Pixels, developers of the highly regarded *ChromaPix* software. The software will run on any of the ISS IBM-760XD laptop computers and will support transmission of SSTV from any of the ISS video cameras. Initial operations are planned for two-meter FM, with a possible move to 70 cm at some later time. Preliminary approval already has been obtained from ARISS, and a number of amateurs are presently field-testing the SpaceCam-1 software. There are still issues to be resolved, but the future looks bright for slow-scan from the International Space Station. Check the MAREX-NA links on David Jones' "CQ SSTV" Web site (**http://www.tima.com~djones/**) for updates on progress of this exciting project.

### *STEREO (3D) SSTV*

In addition to sending standard color images via slow-scan, many amateurs enjoy exchanging 3D or stereo images. A stereo image is actually made up of two pictures (**Figure 5.21**), which, although they look identical, have subtle differences. In effect the left image of the pair represents a scene as imaged by the left eye, while the right image is the right eye view. Since the eyes are separated in space, the parallax difference is integrated by the brain to provide depth perception — 3D! The conventional way to take a stereo photograph is to use a camera that simultaneously photographs the two views (**Figure 5.20**A and B), although a stationary scene can be images with a single camera that is shifted laterally by the proper distance between the two exposures. Formatted properly — and some SSTV programs have stereo formatting options built into the software — the image can be viewed on the monitor using red/blue glasses (Figure 5.20C). Such glasses, in cardboard frames, can be obtained at low cost through specialized stereo photography vendors such as Reel 3-D Enterprises (**http://www.reel3d.com**).

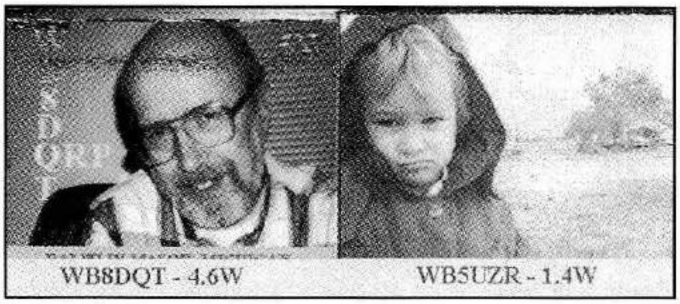


**Figure 5.22.** High power and elaborate antennas are not required for effective HF operation on SSTV. For the past 25 years the author has operated HF slow-scan entirely at QRP (under 5 W) power levels with modest antennas. Shown above is certainly one of the first two-way QRP SSTV contacts between the author and WB5UZR, who was running just 1.4 W out at the time. The author's picture was transmitted back from WB5UZR at the 1.4 W level, and most of the noise was picked up on the return trip!

Stereo SSTV has some very real potential, particularly with high-resolution image formats, but many of the results you will see on the air are mediocre at best. Stereo photography is a bit more complex then it first appears. (I have been an ardent stereo photographer even longer than I have been involved in Amateur Radio.) Getting superb results is not that difficult once you understand some of the basics of stereo photography, and if you take the time to acquire software that can properly format the stereo pairs for transmission. A detailed discussion of the subject is beyond the scope of this chapter, but I have provided an SSTV page on my stereo Web site that can get you started (**http://taggart.glg.msu.edu/stereo/sstv.htm**).

There is no doubt that SSTV has truly come of age with the marriage of Amateur Radio and the personal computer. Given the fact that you can get started with little or no additional investment, there is very little reason not to give it a try!

## CHAPTER 6

# SETTING UP A BASIC WEATHER SATELLITE GROUND STATION

### INTRODUCTION

At one level, it is easy to say that amateur weather satellite ground stations range from the very basic to extremely sophisticated. Defining "basic" versus "sophisticated" is becoming increasingly difficult, however. Given the state of the art with respect to receiving technology and computers, a "basic" station today can deliver results that are superior to much more complex stations just a decade ago and do so at relatively low cost. In consideration of space constraints, I will concentrate my discussion on the most basic aspects of setting up a weather satellite ground station. Such a station is capable of producing excellent imagery and may satisfy all of your aspirations for your system. For those interested in going beyond the basics, hopefully I can provide enough to get you started in your quest for more information. Your ground station equipment requirements are based on which of the two basic classes or categories of satellites you want to start with and where you want to go from there with respect to image resolution.

Of the two spacecraft categories, the **polar orbit** group represents the easiest first step. Actually, the term "polar orbit" is a bit of a misnomer. A true polar orbit is one in which the spacecraft track passes directly over the north and south geographic poles during each orbit. In the case of the polar orbit weather satellites, the orbits are actually near-polar, in that they are inclined 15-20 degrees with respect to the poles (**Figure 6.1A**). The orbits are essentially circular and also relatively low (800-900 km). Orbital periods are slightly over 100 minutes, so that a typical spacecraft will orbit the earth slightly over 14 times each day. Since the

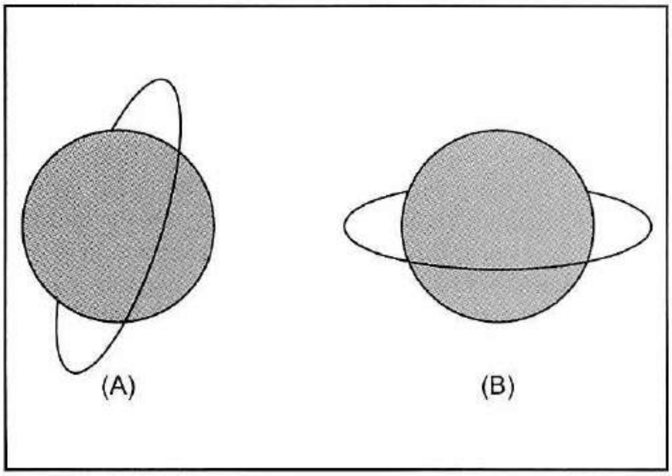


**Figure 6.1**. The two major classes of weather satellites are based on the geometry of the spacecraft orbits. **[A]** Polar orbit spacecraft are in relatively low (500-560 miles/800-900 km), near-circular orbits that are inclines to within 15-20 degrees of the poles. As the spacecraft orbits the earth (typically around 101-103 minutes/orbit), the earth rotates beneath the orbital track. As a result, these near-polar orbits permit each part of the earth to be imaged at least twice a day — once in daylight and once in darkness. The orbital track is not shown to scale. **[B]** Geostationary spacecraft have orbital tracks aligned with the equator. At an orbital altitude of 22,700 miles (36,500 km), each orbit of the earth takes exactly 24 hours, the same time the earth takes to rotate once beneath the satellite. Assuming the spacecraft orbits in the same direction as the earth's rotation, the spacecraft appears to remain fixed over the same point on the equator throughout the day — hence the term ***geostationary***. From geostationary orbit a spacecraft always images the same hemisphere. The orbital track is not drawn to scale.

Earth is rotating beneath the spacecraft as they traverse their orbits, each satellite passes over any given point twice each day — once in daylight and once in darkness. Both the US and Russia operate at least two polar orbit spacecraft at any one time, and these satellites transmit images constantly as they orbit the Earth. Russian spacecraft transmit primarily visible light data, so pictures are available during daylight passes. US spacecraft transmit both visible light and multi-channel infra-red (IR) imagery, so pictures are available whenever one of these spacecraft is in range, day or night. What makes these spacecraft a good option for the first-time satellite enthusiast is that they all transmit images in the VHF range, providing simple end inexpensive options for station antennas and receivers.

In contrast to the polar orbit spacecraft, geostationary weather satellites have quite different orbits. While the orbits are circular, the orbital track is positioned over the equator at an altitude of slightly over 36,500 Km (22,700 miles). At that orbital altitude, one orbit of the Earth takes 1440 minutes or 24 hours. The spacecraft are injected into orbit moving in the same direction that the Earth rotates on its axis. As a result, the spacecraft movement and the rotation of the Earth below occur at exactly the same angular velocity; and the satellite appears to remain over the same point along the equator — hence the term ***geostationary***. The position of the spacecraft, relative to any ground station, also stays constant, permitting ground station antennas simply to be locked on the spacecraft of interest with no requirement for tracking. These spacecraft transmit a wide range of images in the WEFAX image format that can be displayed with essentially the same hardware/software as the polar orbit images. Receiving the signals is just a bit more complex since these pictures are transmitted at a frequency of 1691 or 1694.5 MHz instead of the 137-138 MHz range employed by the polar spacecraft. Receiving these signals typically requires the use of a small dish antenna and the use of a low-noise **down-converter** between the WEFAX antenna and the VHF polar orbit receiver. For this reason, most amateurs start with a basic polar orbit installation, adding the converter and 1691 MHz antenna when they want to try WEFAX reception.

The following sections will provide a more detailed description of polar orbit and geostationary spacecraft and image products, followed by a summary of the hardware and software you will need to receive and display the images.

## POLAR ORBIT SATELLITE SYSTEMS

The primary operational polar orbit spacecraft are the Advanced **TIROS-N/NOAA** satellites (**Figure 6.2A**) operated by the United States and the **RESURS/METEOR** spacecraft (Figure 6.2B) operated by the Russian space program. Most people, visualizing satellites, tend to think of them as rather small; but these spacecraft are large — about the size of a family car — and extremely complex.

The primary imaging system on the US TIROS/NOAA spacecraft is the **A**dvanced **V**ery-**H**igh **R**esolution **R**adiometer (**AVHRR**) shown in **Figure 6.3A**. The AVHRR is a mechanical scanning system in which the primary optical element is an 8-inch (203 mm) Cassegrain mirror pointed straight down at the spacecraft sub-point — the point on the Earth's surface that is directly below the spacecraft at any given moment. Image line scanning is provided by a rotating mirror driven by a 360 RPM motor. During each rotation of the mirror, the Earth below is scanned from horizon to horizon at right angles to the spacecraft orbital track. Light from the mirror system is routed to a series of six sensors, each of which is sensitive to a different part of the visible/IR spectrum. Two of the sensors operate at visible wavelengths while the remaining four operate across the near and far IR spectrum. The near IR sensors essentially read the temperature values of the land, water, and clouds, while the far IR sensors provide data on the water content of the atmosphere. As the spacecraft moves along its orbital track, each scan of the surface is offset slightly from the previous one (Figure 6.3B), providing the equivalent of frame scanning. The AVHRR scanning operates continuously, so that the spacecraft generates a continuous strip of image coverage as long as it is above the horizon for a specific ground station.

At any given time, five of the six AVHRR channels are multiplexed into a wide-bandwidth digital data stream known as the **HRPT** (**H**igh **R**esolution **P**icture **T**ransmission) format. The HRPT image data are transmitted in real-time at frequencies near 1700 MHz. The HRPT signals provide dramatic and very detailed images at multiple wave-

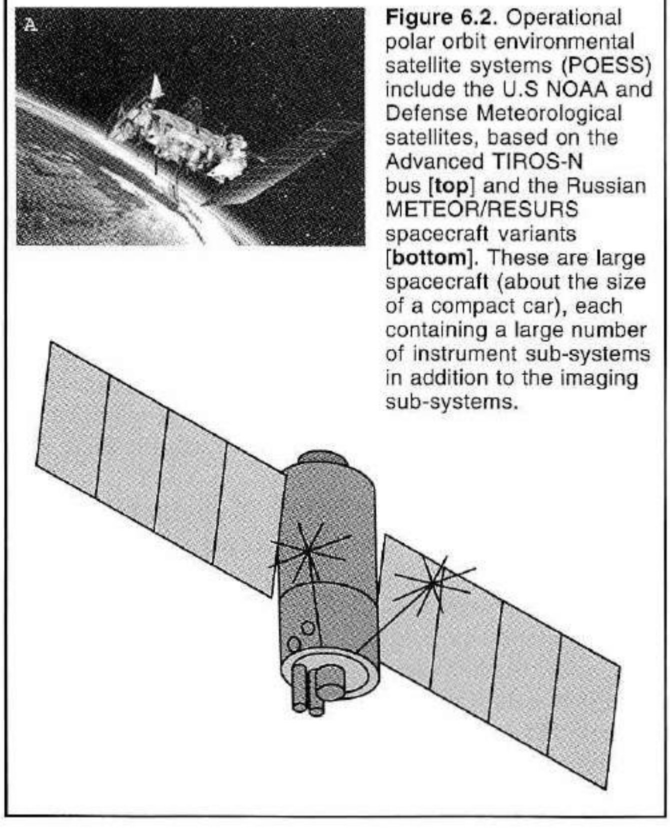


**Figure 6.2.** Operational polar orbit environmental satellite systems (POESS) include the U.S NOAA and Defense Meteorological satellites, based on the Advanced TIROS-N bus [**top**] and the Russian METEOR/RESURS spacecraft variants [**bottom**]. These are large spacecraft (about the size of a compact car), each containing a large number of instrument sub-systems in addition to the imaging sub-systems.

lengths. **Figure 6.4** shows a small segment of visible light HRPT data from a NOAA pass over the Pacific Northwest coast of the northern United States and southern Canada. Because of the geometry of the AVHRR, areas off toward either horizon are significantly distorted (fore-shortened), much like the difference in perspective you would get looking straight down from an aircraft, compared with the view off toward either side. Image resolution is essentially 1.1 km (all channels) along the sub-point track, decreasing toward each horizon.

It is possible to receive HRPT image data, but the station requirements are fairly complex:

- A small dish antenna (1 meter/3 feet in diameter) with a circularly-polarized feed
- A rotor system to track the antenna in both elevation and azimuth. Because the antenna needs to be tracked with moderate accuracy, most systems have the el-az rotor system controlled by a computer, using a tracking program.
- A low-noise (~0.6 dB) preamplifier located at the antenna feed
- A down-converter
- A wide-band IF receiver with a digital detector designed for the phase-shift modulation used for HRPT transmission
- Decoding hardware controlled by the computer system that organizes and stores the images.

Complete turn-key HRPT ground stations are available from vendors such as TimeStep and Quorum (see **Appendix**), starting in the $5,000 to $10,000 range. Home-built systems are described and documented on the **Remote Imaging Group** Web site in the UK (**http://www.rig.org.uk/**). While these systems are less expensive than the commercial versions, they do require significant financial outlay and do represent a demanding project best-suited to the experienced satellite enthusiasts.

Fortunately, the TIROS/NOAA spacecraft also transmit less detailed imagery in a much simpler format. Every third line of AVHRR data is sampled by an on-board computer, using pixel-averaging to eliminate most of the geometric distortion produced by the AVHRR scanning system. The result is a 120 line/minute (lpm) signal format known as **APT** (**A**utomatic **P**icture **T**ransmission). As a result of the line sampling and pixel averaging, APT image resolution is reduced to 4 km; but the pictures are still quite spectacular (**Figure 6.5**). In the case of a daylight pass the first (left) half of each line represents thermal IR data while the second half (right) is visible-light data. Night passes typically transmit data from one thermal IR channel and one water-vapor IR channel (see Chapter 7). The encoding of thermal IR data is such that cold objects are white while warmer objects are progressively darker. Contrast between clouds, land surface, and water is essentially a function of the relative temperature

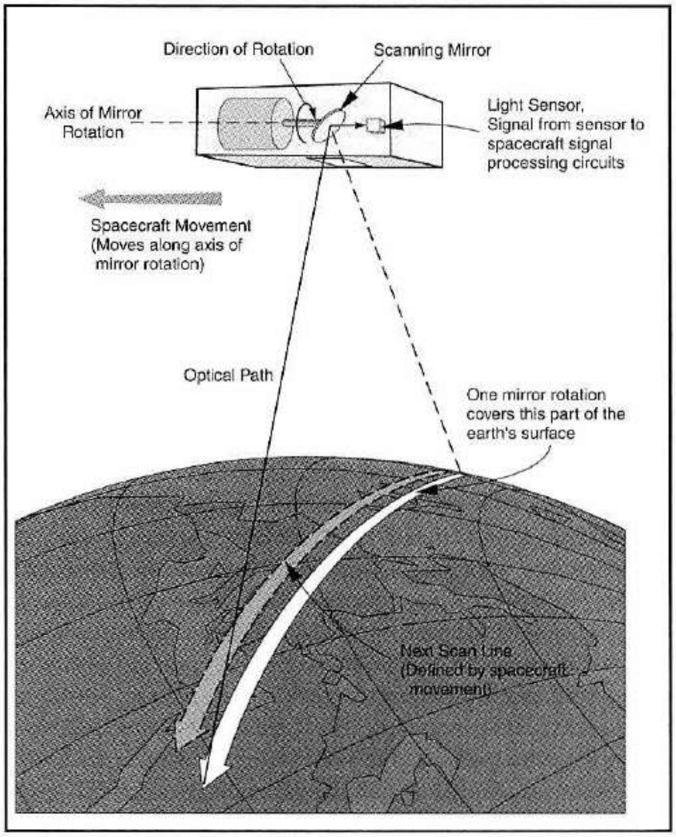


**Figure 6.3.** [**top**] The **A**dvanced **V**ery-High **R**esolution **R**adiometer (**AVHRR**) imaging system employed by the US NOAA/Advanced TIROS-N spacecraft (ITT Aerospace Division). [**bottom**] The rotating mirror of the AVHRR instrument provides the line scanning while the movement of the spacecraft along its orbital track produces the equivalent of the frame scanning. The scanning radiometer imaging systems on the various polar-orbit spacecraft differ from conventional image transmission in that the frame/"vertical" scanning is continuous.

**Figure 6.4**. The NOAA **HRPT** multi-spectral imaging format provides a resolution of approximately **1.1** km at the sub-point — the point directly below the spacecraft at any given moment. This is just a small segment of the HRPT channel 1 (visible) data as the spacecraft was passing over the Pacific Northwest. The Columbia River is clearly delineated along the lower edge of the image segment, and the eastern end of Vancouver Island appears in the upper left. Snow cover is clearly visible on the mountains of the Olympic Peninsula and the northern Cascades.

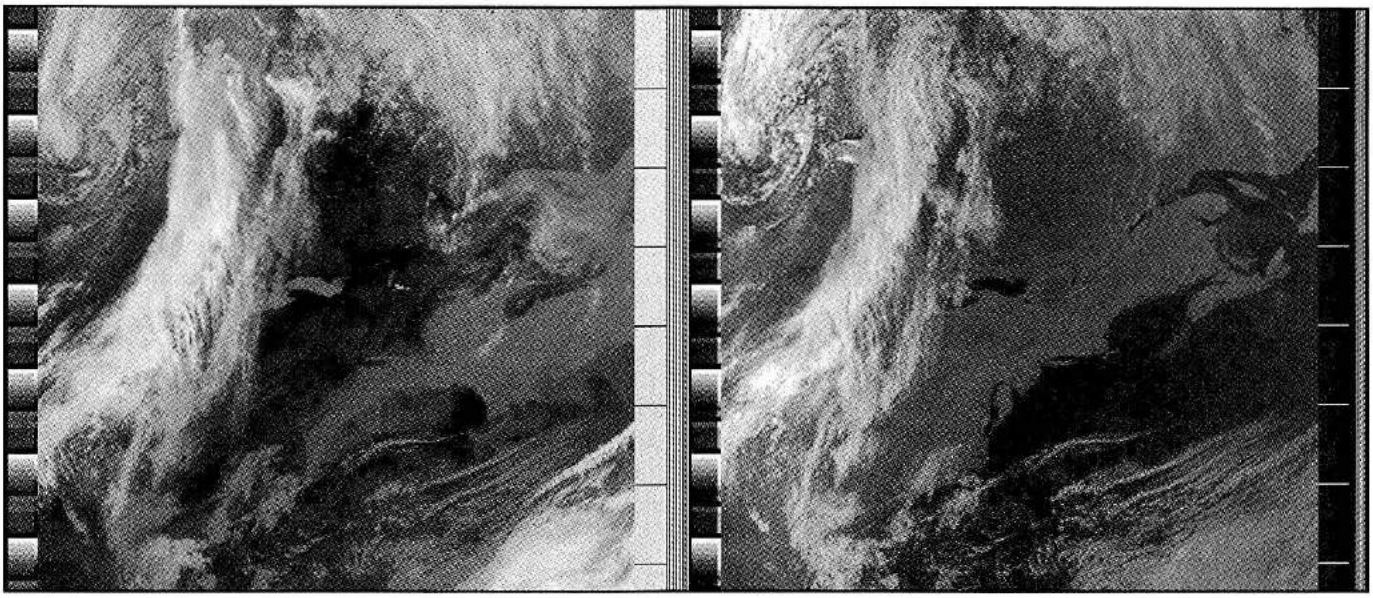


**Figure 6.5**. Every third line of the HRPT format is used to generate the low-resolution APT imagery from the NOAA spacecraft. Pixel averaging is used to minimize the geometric distortion caused by the AVHRR scanning, resulting in an APT resolution of approximately 4 km at the spacecraft sub-point. For daylight passes, the first half of each scanning line (left) represents thermal infra-red (IR) data while the second half of the line (right) is visible-light data. In the visible image (right) the eastern coast of North America from Georgia north to Nova Scotia can be seen angling from the lower left to the upper right. In the IR data (left) the warmer land areas (dark) contrast with the cooler ocean waters. The warmer (darker) areas of ocean water represent the limits of the Gulf Stream. The grayscale pattern at the left side of each image segment represents grayscale calibration and telemetry data. The vertical white area to the right of the IR scan is a narrow sector of space, which is white as a result of low thermal radiance, while the corresponding area in the visible segment is dark. The horizontal lines in the thermal and visible space-scan areas are minute-markers generated by the spacecraft clock. Slightly over seven minutes of image data are displayed here.

differential. High (cold) clouds are very bright while lower (warmer) clouds can tend to mid-range gray. During the winter, low ground temperatures reduce the contrast between the land surface and overlying clouds. The appearance of water features depends upon their temperature. During the winter, for example, the Great Lakes will appear darker than surrounding land areas because the water is warmer than the land. In summer, at least during the day, the water will appear lighter than the surrounding land because it is relatively cooler. Both cold and warm ocean currents can be resolved, as demonstrated by the Gulf Stream off the east coast of North America (Figure 6.5). The visible-light image data are essentially equivalent to a grayscale photograph, and contrast is essentially a function of ambient light levels and angle, both of which can vary throughout the day and which change significantly with the seasons (see Chapter 7).

The Russian **RESURS/METEOR** spacecraft (Figure 6.2B) also produce APT images (**Figure 6.6**). The Russian spacecraft also use a mechanical scanning system, but they do not generate the equivalent of HRPT imagery. Instead, the system directly produces the APT signal, including correction for scanning distortion. Although several Russian spacecraft have experimented with IR image transmission during night passes, the primary imaging system is visible light and most spacecraft only produce pictures during daylight passes. The RESURS/METEOR APT signal operates at 120 lpm but, since the entire line is devoted to visible data, the resolution of the Russian system tends to be better than that of the TIROS/NOAA APT format.

The People's Republic of China has experimented with spacecraft very similar to the US TIROS/NOAA series, but the system is not operational. The operating lifetime of APT systems has been rather short. In addition, the Russian and Ukrainian governments operate several other spacecraft types (**COSMOS**, **SICH**, and **OKEAN**) that generate visible light, infra-red, and radar imagery; but these spacecraft generally are confined to transmitting images while in range of Russian ground control stations. They are best monitored in Europe and are rarely heard in the Americas or elsewhere.

One of the attractive aspects of the APT signal format is that the images are transmitted on VHF frequencies using FM modulation the 137-138 MHz range, making it a relatively simple proposition to receive the signals. A typical station, discussed in greater detail in later sections, involves a simple, omni-directional VHF antenna, a mast-mounted 137 MHz preamplifier, and a synthesized or crystal-controlled receiver set up for the satellite frequencies.

The spacecraft image signal is a simple, amplitude-modulated 2400 Hz subcarrier. Maximum subcarrier amplitude (90-100%) corresponds to white while minimum amplitude (4-5%) is black. Intermediate amplitude values correspond to intermediate grayscale values. Simple AM modulation can be used because the signal is transmitted on FM, effectively eliminating the problems of variable fading that

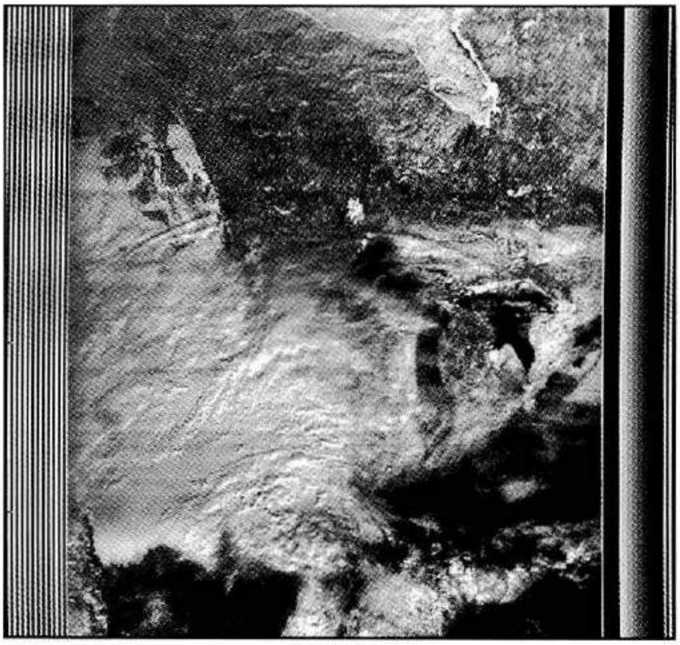


**Figure 6.6**. The Russian METEOR/RESURS spacecraft also employ scanning radiometers. Some of these spacecraft have experimental IR imaging, but most are visible-light systems, generating pictures only on the daylight side of each orbit. Michigan and several of the Great Lakes are visible on the right side of this winter pass. Ice-covered Lake Nipagon is directly north of Lake Superior, which was mostly ice-free. Lake Winnipeg is snow and ice-covered on the left side of the image while the southern tip of James Bay, also covered by snow and ice, can be seen in the top center.

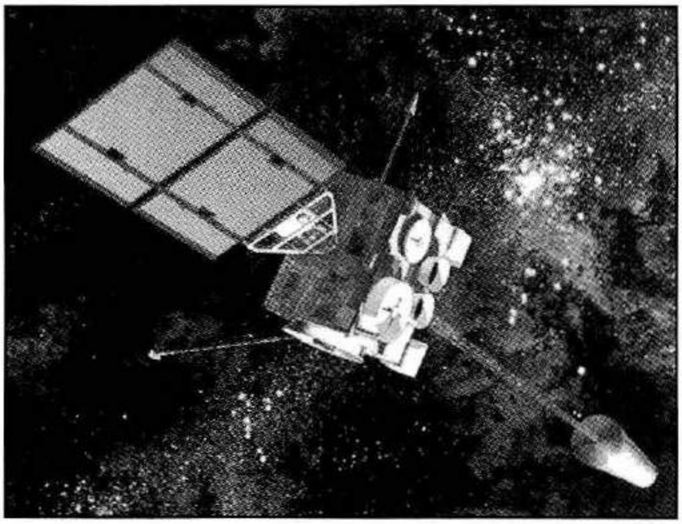


**Figure 6.7**. The geostationary GOES spacecraft employ a Visible and Infra-red Spin-Scan Radiometer (VISSR/SVAS) imaging system to obtain high-resolution (4 km resolution) of the entire hemisphere viewed by the spacecraft. This high-resolution imagery is ground-processed and retransmitted through the spacecraft at lower resolution as part of the WEFAX program. Similar operational spacecraft (METEOSAT) are operated by the European Space Research Organization and Russia (GMS). Japan (GOMS) and India both have analogous systems that are somewhat less than fully operational. Both high-resolution and WEFAX imagery are transmitted to the ground on S-band (~1600-1700 MHz) frequencies in the low-microwave range.

requires the use of FM subcarrier modulation on HF Fax and SSTV.

## GEOSTATIONARY SPACECRAFT SYSTEMS

Operational Geostationary spacecraft systems are similar to the US TIROS/NOAA polar orbit systems in that they transmit both high-resolution, wide-bandwidth digital imagery and lower-resolution analog image products; but in other respects they have a different mission, and that is reflected in the nature and accessibility of the image data. Since these spacecraft do not move with respect to the Earth's surface, the location of a spacecraft defines the hemisphere that can be imaged at any time during the day (visible and IR) or night (IR). The current constellation of geostationary spacecraft have the following sub-point locations along the equator:

| SPACECRAFT | AGENCY | LOCATION |
|---|---|---|
| METEOSAT 7 | EUMETSAT | 0° |
| METEOSAT 5 | EUMETSAT | 63°E |
| GMS | Japan | 140°E |
| GOES W | US NOAA | 135°W |
| GOES E | US NOAA | 75°W |

Although the spacecraft operated by the various agencies have similar missions, the details of each category of spacecraft differ from one another. The brief description of the imaging system that follows is based on the US **GOES** (**G**eostationary **O**perational **E**nvironmental **S**atellite) spacecraft (**Figure 6.7**).

The GOES imaging system is known as a **V**isible/**I**nfra-red **S**pin-**S**can **R**adiometer or **VISSR**. The VISSR instrument provides the imaging data for the GOES **V**ertical **A**tmospheric **S**ounder or VAS. The **V**isible/**I**nfra-red component of the VISSR acronym indicates that the instrument is a multi-spectral device and that there are a total of eight visible-light detectors and six IR detectors, two of the latter being used for imaging purposes. The **S**pin-**S**can component of the name accurately describes the nature of the VISSR line scanning. The main body of the spacecraft, exclusive of the antennas, spins at a nominal 100 RPM (600 ms/revolution), providing both stabilization and scanning. Light entering the VISSR instrument is reflected onto a vertical mirror and then through an elaborate optical system to the visible and IR sensors. During each scan of the earth the VISSR instrument obtains a total of six visible lines of image data and two lines of thermal and water vapor IR data. The resolution (at the spacecraft sub-point) of each of the six visible lines is 0.8 km while the resolution of each IR line is 6.9 km. With each revolution of the spacecraft, the vertical primary mirror is stepped by a small angle to image the next set of six visible and two IR image lines. A complete scan of the earth disk requires 1820 steps or 18.2 minutes. The resulting full-disk images are spectacular (**Figure 6.8**). During severe weather situations

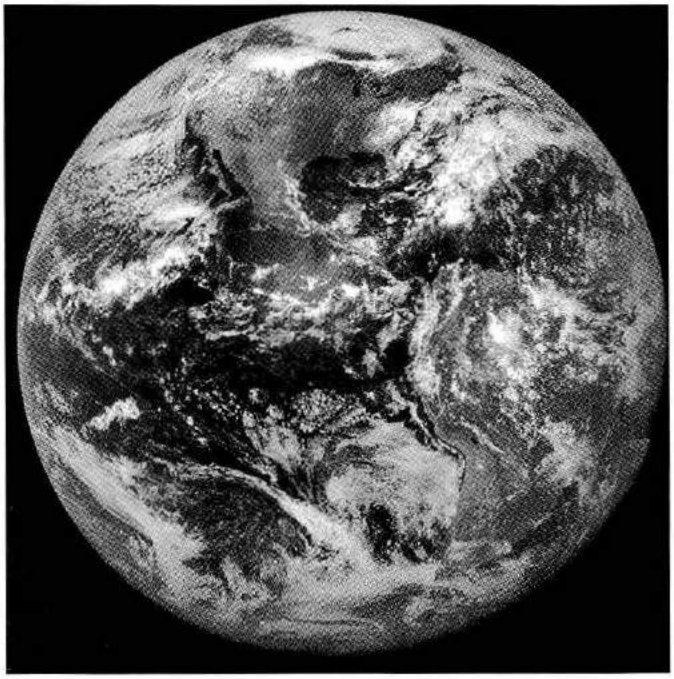


**Figure 6.8.** The multi-spectral, full-disk images obtained by the GOES and Meteosat spacecraft are stunning. This visible-light image, covering North and South America, was obtained by the GOES 8 (GOES E) spacecraft. Direct amateur reception of such images can be done, but it requires specialized receiving equipment. (Photo courtesy of the National Oceanic and Atmospheric Administration)

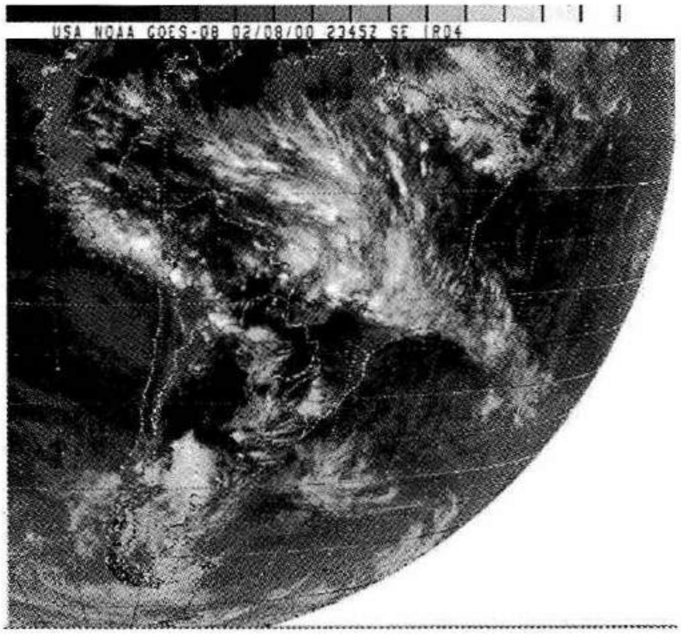


**Figure 6.9.** The high-resolution imagery from geostationary spacecraft are ground-processed and re-transmitted in sectorized format at lower resolution as part of the WEFAX program. This is the SE quadrant of the earth disk as imaged by the GOES 8 spacecraft, showing much of South America and adjacent ocean areas at thermal IR wavelengths. Visible and IR data are easily differentiated. In visible-light, the view of space beyond the limb of the planet will appear black. At IR wavelengths it appears white (cold). The country boundaries and latitude and longitude grids are inserted by the ground computer. Note that each image has a header consisting of a calibration grayscale and printed image ID data.

(tornadoes, tropical storms, etc.) the spacecraft will scan the relevant subset of the earth disk, providing more rapid updates where time is of the essence.

With each revolution, the spacecraft is only scanning the Earth for a relatively short interval. During the real-time Earth scan interval the spacecraft downlinks image and telemetry data at 1681.6 MHz in a four-phase digital format at a data rate of over 28 megabytes/second! Amateur reception of this data is not practical, but there is an alternate real-time data format available. During the longer period of each revolution, where the VISSR/VAS instrument is scanning empty space, the ground station computers at Wallops Island, Virginia, format the raw VISSR/VAS data and re-transmit it through the spacecraft in the same format but at a rate of only 2.1 Mb/sec (the so-called "stretched" VAS or SVAS mode). Amateur SVAS reception is possible, but the equipment requirements are complex:

- Large dish antenna (12-16 ft/3.6-4.9 m)
- Very low-noise preamplifier (<0.3 dB)
- 1697 to 70 MHz down-converter
- 70 MHz IF amplifier with a bandwidth of at least 8 MHz and a gain of at least 50 dB
- QPSK demodulator and synchronizer
- A computer-based image display

Fortunately there is a simpler alternative for geostationary imaging available via the WEFAX program. The formatted earth-disk images are sectorized by the Wallops ground station computers and retransmitted in an analog format very similar to that used for polar-orbit APT transmission. The signal, a simple AM modulated 2400 Hz subcarrier, is transmitted on 1691 MHz (1691 and 1694.5 MHz of the METEOSAT spacecraft). The signal can be received by ground stations equipped with a small dish antenna and a down-converter to convert the 1691 MHz signal to the 137-138 MHz range for reception by the APT receiving system. Each WEFAX image consists of a nominal 800 lines, transmitted at a rate of 4 lines/second. The primary WEFAX image products are sectors of the full-disk at both visible light and IR wavelengths (**Figure 6.9**). WEFAX transmissions also involve a wide range of other products — over 300 images each day — which are summarized in Chapter 7. WEFAX capability is a logical enhancement once you have a basic APT station in operation.

**Figure 6.10** diagrams the major hardware components for an APT/WEFAX station. Each of the elements in this equipment diagram will be summarized in the sections that follow. It is important to recognize that I cannot, in a single chapter, discuss every possible equipment supplier and option. What I have done is to highlight equipment that satisfies two very basic criteria:

- Items that I am personally familiar with or that I have observed in operation over the years.
- Items that tend to be at the low-end of the possible range of prices for specific station equipment.

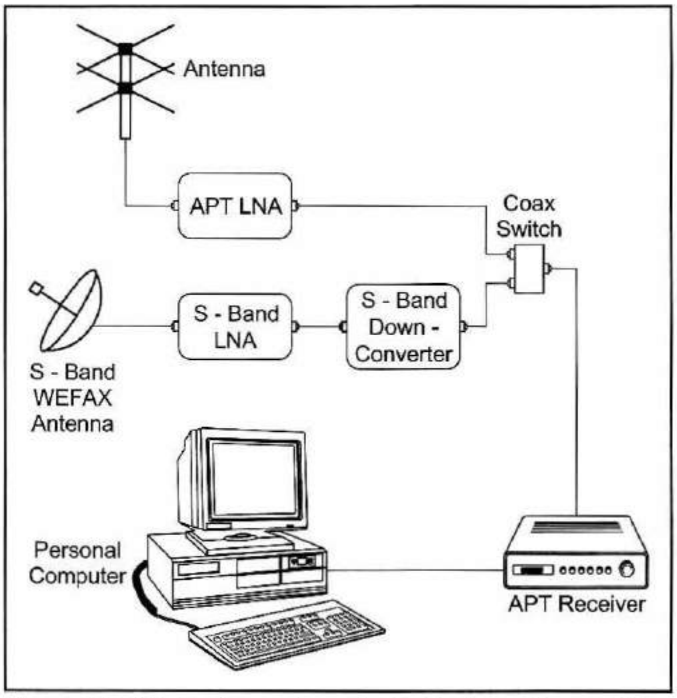


**Figure 6.10.** The hardware elements of a basic weather satellite ground station.

Just because an equipment item is not mentioned, this does not imply that it wouldn't be perfectly suited for your use. All the manufacturers that I do note are included, along with contact information, in the Appendix. Vendors advertising in this volume also should be consulted. The **Commercial Suppliers** page of the **Remote Imaging Group** Web site in the UK (**http://www.rig.org.uk/**) contains a listing, with links, to virtually all vendors of relatively low-cost equipment, including APT, WEFAX, and high-resolution image systems. You certainly should browse these vendor pages prior to making a decision as to which equipment you will build or purchase.

## ANTENNAS FOR APT (137-138 MHZ) RECEPTION

### *ANTENNA POLARIZATION*

During the 1960s and early 1970s, most APT ground stations used relatively high-gain antennas mounted on rotor systems that would permit the spacecraft to be tracked in both azimuth (direction) and elevation. Today, most basic ground stations employ simple, omni-directional antennas that do not require tracking. This change was made possible by the improvements in low-noise amplifier technology and advances in antenna design. Before describing the most common antenna options, a few words are in order with respect to the subject of antenna **polarization**. Antenna systems for terrestrial communication operate primarily with either vertical or horizontal polarization. Amateur operation on the popular two-meter (144-148 MHz) band provides an excellent illustration of both options. The simplest antenna for a car or other vehicle is a basic vertical antenna element ("whip") that responds best to radio signals that are **polarized in the vertical plane.** A typical FM mobile antenna operates just this way. Base station operators who want to operate on two-meters FM will use either a vertical omni-directional antenna or a directional beam in which the elements are oriented vertically. In contrast, most SSB and CW operation is point-to-point between home or base stations. Historically, these modes have used **horizontal polarization**, in which the elements of the directional antennas are oriented horizontally. Optimum reception occurs when the polarization at the transmitter and receiver end of a path are matched. If a station with vertically polarized antennas attempts to receive a horizontally-polarized signal (or vice versa), the signal losses due to mismatched polarization (so called "cross polarization") will exceed 20 dB! This is actually a bit of an advantage in terrestrial communications, since it tends to reduce the interference potential between FM and SSB/CW operations. Unfortunately, polarization presents a major problem with respect to space communications.

As a spacecraft moves along its orbital track, the geometric relationship between the spacecraft antenna and the ground station antenna is constantly changing, resulting in varying degrees of polarization match and mismatch during the course of a pass. The result is a relatively strong signal at some times, dropping to unusable levels at other times. The solution is to use **circular polarization**, where the radio wave rotates as in propagates through space. Maximum signal losses between a circularly-polarized antenna and a linearly-polarized signal (vertical, horizontal, or anything in between) is no more than 3 dB. Circular polarization can be achieved in two possible configurations — right-hand circular (**RHC**) or left-band circular (**LHC**). If the polarization sense matches, there is no polarization loss; but combining RHC and LHC will result in the same 20 dB+ polarization mismatch experience with a linear cross-polarized situation. Some Russian spacecraft use linear polarization and US TIROS/NOAA spacecraft employ RHC polarization, so the optimum ground station antenna polarization is RHC.

Setting up an antenna for circular polarization (either sense) is a matter of the geometry of the elements and the phasing lines that connect them. All commercial satellite antenna options are set up for RHC polarization. The various home-built antennas will be RHC with respect to polarization if you build them as indicated. The subject of antenna polarization and various approaches to achieving circular polarization are covered in any recent addition of the *ARRL Antenna Book*, available from the American Radio Relay League (see Appendix). You can receive polar orbit signals using an existing two-meter antenna system (vertical or horizontal), but you can expect deep fades in the signal at some points during a pass. Such an antenna will serve to verify the operation of your receiver but will not prove satisfactory for operational use.

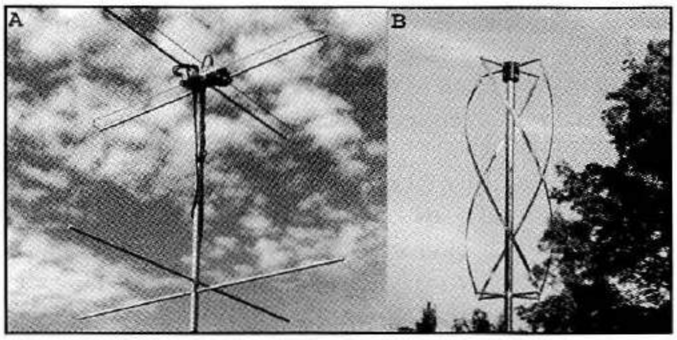


**Figure 6.11**. Two primary types of omni-directional antennas are typically used to receive the VHF (136-138 MHz) APT signals from polar-orbit spacecraft. **[A]** A "turnstile" antenna consisting of a set of crossed dipoles (phased for right-hand circular polarization), mounted over a pair of reflectors (Woodhouse Communications). **[B]** A quadrifilar helix (QFH) antenna, functionally identical to the VHF antennas aboard the US NOAA spacecraft (Timestep, Ltd.).

### *TURNSTILE ANTENNAS*

The simplest omni-directional antenna is a pair of crossed dipoles, phased for RHC polarization. The two dipoles usually are placed approximately ¼ wavelength above a set of crossed reflectors to increase the antenna gain by a modest amount. Such an antenna system, known as a "turnstile" array, is shown in Figure **6.11A**. Commercial versions of such antennas are available from vendors such as TimeStep and Woodhouse Communications. Such antennas are moderately priced (about $135 for the Woodhouse APT-2CP) and they do an excellent job. Given the inherent simplicity of a turnstile array, home construction is a reasonable option. The *ICH* CD-ROM contains a complete construction file (**zapper.pdf**).

The stock "Zapper" turnstile has appeared in several editions of *The Weather Satellite Handbook* and is used in several university classes on remote sensing due to its easy construction and good performance. My first "Zapper" turnstile prototype is still in service in my attic after 25 years and serves as my reference standard in evaluating other antenna systems. One common variant is to place the cross-dipoles over a hardware-cloth screen. This approach is bulky and heavy and confers no real advantage.

### *QUADRIFILAR ANTENNAS*

A somewhat more sophisticated antenna system is the quadrifilar helix, QFH (Figure 6.11B), an array that will definitely challenge your spatial relationship skills! Most versions of this antenna are variations on the same basic APT antenna system on the TIROS/NOAA spacecraft, designed by C. Kilgus in 1970. The basic antenna consists of four helical elements that can be phased in a variety of ways. Properly designed and constructed, these antennas can provide somewhat superior performance, relative to a turnstile; but the performance differential is not as great as many suggest. Commercial versions of the QFH are available from TimeStep, Quorum Communications, and other vendors. These commercial antennas are very rugged and are widely used in marine installations. They deliver excellent service but are considerably more expensive than the commercial turnstile arrays.

Home construction of a QFH array is pretty basic if you are careful to follow directions. Mistakes in phasing or the direction of twist of the elements can result in a completely non-functional antenna! Eugene Ruperto (W3KH) published a widely duplicated version of the QFH in the August 1996 issue of *QST* (pp 30-34). Home construction of several QFH variants is documented on members' Web sites that can be accessed through the Remote Imaging Group (RIG) homepage at **http://www.rig.org.uk/**. Ruud Jansen's web page (**http://www.hshaarlem.nl/~ruud/**) documents a widely-copied QFH variant.

### *DIRECTIONAL ARRAYS*

An omni-directional antenna is really all that is needed to copy the "best" passes of a particular satellite in daylight and in darkness. All of the APT images in this chapter and Chapter 7 were copied on omni antennas — evenly split between the Zapper and a home-built QFH. If you wish to copy the shorter passes to the extreme east or west of your station or have trouble with obstacles on your horizon, you may choose to look at the option of a directional array. Circularly-polarized Yagi antennas for 137 MHz are not widely available; but Woodhouse Communications has 8, 12, and 16-element arrays that deliver solid performance at a reasonable cost.

Unfortunately, the antenna set-up is only part of the story if you choose to use a directional antenna system. You will also require a rotor system that can track the antenna in elevation and azimuth. If you are handy with tools it is possible to construct a very basic az/el rotor system using inexpensive TV rotors. The biggest challenge is proper mounting and weather-proofing of the elevation rotor, since typical TV rotors are not designed to be mounted on their side. If you already have a directional (azimuth) rotor available, it is possible to add a second rotor designed to move an antenna in elevation. The Yaesu G550 will handle an antenna with a 10.7 sq ft wind loading and retails for about $300. The ultimate solution is a commercial rotor system designed for az-el service. One of the most widely used systems of this type is the Yaesu G5500. This rotor will handle antennas with wind loadings up to 8.6 sq ft and retails for about $630. Yaesu antenna rotors are available from most of the larger Amateur Radio outlets. The G5500 requires the use of two 6-conductor rotor cables; and the rotor controller, located in the station, provides for manual operation with simultaneous display of both elevation and azimuth. Most tracking software (see Chapter 7) will provide elevation and azimuth data at set intervals to let you keep the antenna pointed at the spacecraft. If you want to control the antenna automatically, you will need an appropriate hardware interface between the rotor controller and the computer. (The Yaesu GS232A interface retails for approximately $540, although home-built options are available.) You also will need a tracking program (see Chapter 7) that will produce the necessary control commands. The point is, a complete gain antenna system with tracking capability can easily cost $1000-$1500. The cost of even a relatively expensive commercial-grade QFH antenna is a fraction of that investment and will work almost as well! It is worth noting that, if you already have a station set up to track amateur communications satellites on 2 meters and 70 cm, your 2-meter array will deliver reasonable results due to the gain margin that will be available.

### *TRANSMISSION LINES*

The transmission line is the cable that carries the signal from the antenna down to the station receiver. It is beyond the scope of this volume to discuss transmission lines in any detail, but the subject is covered in any recent edition of the *ARRL Handbook* or the *ARRL Antenna Book*. For a basic polar orbit ground station, basic coaxial cable ("coax") of the RG58 type (nominal 50 Ω impedance) with foam dielectric will do the job. **Table 6.1** lists the losses (dB/100 ft.) for various coaxial cable types. For reasons that we will see shortly, cable losses are not a significant concern if you are going to mount an RF preamplifier at the antenna, but they should be considered if you will not be using a remote preamp. For every 3 dB of cable loss, the strength of the received signal is reduced by 50% — and the front-end noise figure of the receiver is increased by the amount of the signal loss. What is worse, the losses are additive. Table 6.1 shows that standard RG58 cable with foam dielectric has a loss of about 4.5 dB/100 feet at 140 MHz. If your transmission line is 100 feet long, your received signal strength would be reduced by approximately 150%. If the transmission line is 200 feet in length, the losses mount to 300%. If you are not going to use a remote preamplifier, you must employ some combination of:

- The use of a gain antenna
- A shorter run of transmission line
- Cable with a lower loss

This is not an issue when a remote preamplifier is used or with the short cable runs typical of portable or mobile installations (see discussion at the end of this chapter), but you should be aware of the significant signal losses that can occur if you ignore transmission line issues.

Suitable RG58 and RG8 coaxial cable is universally available, but you should buy brand-name coax from a reputable supplier. If you are shopping locally, the following points are worth checking when selecting coax:

- Make sure it is 50 Ω cable (RG58). TV systems use 75 Ω coax (RG59) which will increase your signal losses due to a mismatch between the cable impedance (75 Ω) and the input of your preamplifier or receiver (50 Ω).
- Examine the shielding braid beneath the outer plastic jacket. It should be tight, with no dielectric showing through gaps in the braid, and it should be tinned (silver color) instead of bare copper. Cheap CB-grade cable will not pass this test.
- Look at the dielectric — the plastic material between the shielded braid and the central inner conductor. It should be white and spongy ("foam"), not simply solid (translucent) polyethylene.

**Table 6.1**

Approximate losses (dB/100 feet) for various common types of transmission line.

| *Cable Type* | *140 MHz* | *450 MHz* | *1500 MHz* |
|---|---|---|---|
| RG58 "Foam" | 4.5 dB | 8.2 dB | 17 dB |
| RG8 "Foam" | 2.0 dB | 3.9 dB | 7.5 dB |
| Belden 9913 | 1.7 dB | 3.1 dB | 5.8 dB |
| 7/8 75 Ω hard. | 0.71 dB | 1.5 dB | 2.6 dB |
| 7/8 50 Ω hard. | 0.65 dB | 1.4 dB | 2.5 dB |

Getting the best performance from your antenna system also implies that you are using good connectors that are properly installed. (I use BNC connectors for all 137 MHz cables.) The subject of connectors and their installation is covered in any recent edition of the *ARRL Handbook* or the *ARRL Antenna Book*. You really should have one or both of these books as part of your library.

## APT (137-138 MHZ) RECEIVERS

If you are operating mobile or portable, or if you have a very short run of coaxial cable at your home station, your receiving system can consist of just a basic VHF FM receiver. If you are using an omni-directional antenna with more than 50 feet of transmission line, a remote 137 MHz preamplifier will be required. The following sections will discuss both options.

### *ANTENNA-MOUNTED PREAMPLIFIERS*

As noted in the earlier discussion of transmission lines, the most effective way to overcome line losses and degraded front-end noise figure is to mount a low-noise preamplifier (LNA) at the antenna. With an omni-directional array, a noise figure of <1 dB is desirable, which suggests the use of a **G**allium **A**rsenide **F**ield **E**ffect **T**ransistor (GAsFET). Innumerable preamplifier designs for the 2-meter band (144-148 MHz) have appeared in the *ARRL Handbook* and the amateur literature over the years, and any of these generally can be tuned to the 137-138 MHz range with no change in component values. Downeast Microwave supplies boards, kits, and wired-and-tested for a number of 2-meter and one 137-138 MHz (137LNAC) LNAs. Commercial preamps are available from a number of sources including Hamtronics and TimeStep. Representative units are shown in **Figure 6.12**. The TimeStep unit is housed in a weather-proof die-cast enclosure (Figure 6.12C). Weather-proofing other units is not difficult, as the units can be simply housed in inverted plastic freezer containers. The cover of the freezer box is cut to pass the input and output cables, which exit from below. It is best not to attempt to seal the enclosure as water will always get in. Instead, the cable access holes permit easy air circulation and the box itself will keep out the rain or snow. If the antenna is placed in the attic of a wood-frame building, no particular weather-proofing steps are required. This will exact a small penalty in signal strength, but it is usually not serious. All of my operational antennas are in the attic, and all

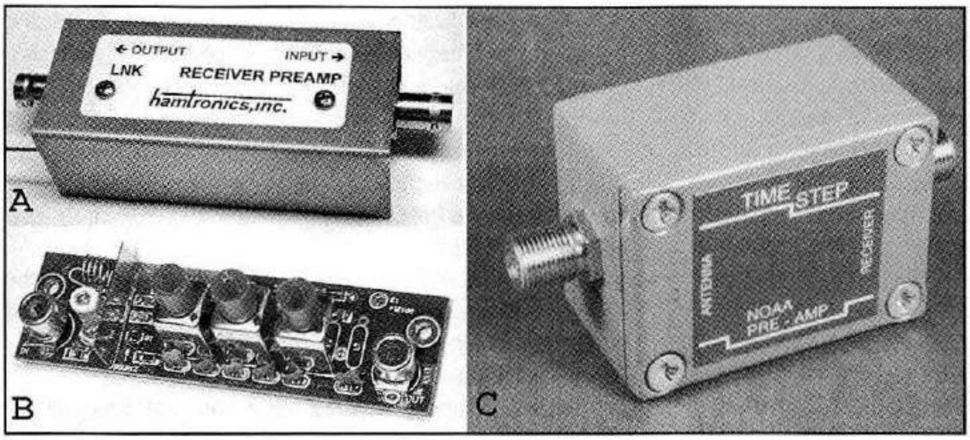


**Figure 6.12.** If the cable run to an omni-directional APT antenna is longer than 25 feet, a remote preamplifier located at the antenna can overcome line losses and set the system noise figure. **[A]** The Hamtronics LNK-137 preamplifier is not weather-proof and thus requires some sort of housing at the antenna. **[B]** The Hamtronics LPF-137 incorporates extra filtering which can reduce greatly the potential for problems with interference and spurious signals. **[C]** The Timestep 137 MHz preamplifier has a die-cast weatherproof housing.

the APT pictures in this volume were received on the attic-mounted antennas. Most preamplifiers are designed so that they can be powered via 12V DC sent up through the center conductor of the transmission line between the preamp and the receiver. A good quality RG58 foam coax will serve as the APT transmission line unless the cable run is over 100 feet. For longer runs, the use of RG8 foam cable is recommended.

One serious problem with preamplifiers mounted at the antenna is the generation of spurious signals if the antenna is subject to strong RF fields from a nearby source at some other frequency. This can be a real problem in urban and even suburban areas given the crowded nature of the VHF spectrum. Pager services operating at VHF frequencies are a very common source of spurious signals. Much of the potential for interference can be reduced or even eliminated with the use of sharply-tuned filters in the RF amplifier to significantly reduce the strength of out-of-band signals. The Hamtronics preamplifier illustrated in Figure 6.12B incorporates such filtering and works very well where RF "pollution" is a problem. All the Hamtronics models are available as kits and are quite easy to build. Most operators will not have the test equipment to optimize the preamplifiers; so, for many, the small surcharge for the wired-and-tested units is money well-spent.

### *THE WEATHER SATELLITE RECEIVER*

The first requirement is that the receiver tune the active spacecraft frequencies:

**137.30** MHz — Russian METEOR spacecraft
**137.40** MHz — Russian METEOR and other spacecraft
**137.50** MHz — US TIROS/NOAA spacecraft
**137.62** MHz — US TIROS/NOAA spacecraft
**137.85** MHz — Russian METEOR/RESURS spacecraft

Most practical receivers are either crystal-controlled or synthesized. Given the limited number of frequencies required, crystal control is simpler and avoids some of the potential for phase noise and spurious signals than can occur with some synthesized circuits.

The signals are frequency-modulated (FM) so, in theory, you can receive the satellite signals with any of the many general-coverage scanner receivers on the market. While you will hear the signal on such a receiver, you will rarely get useful pictures. The culprit is **receiver bandwidth**. Virtually all FM receivers incorporate one or more filters at intermediate frequencies to maximize the SNR of the signals. If the receiver filters are narrower than the bandwidth of the modulated signal, portions of the signal will be cut off by the

**Figure 6.13**. The Timestep ProScan receiver is an example of a commercially-built unit that is specifically designed for satellite reception.

**Figure 6.14**. The Multifax receiver is based upon a commercial scanning receiver, which has been modified for satellite reception.

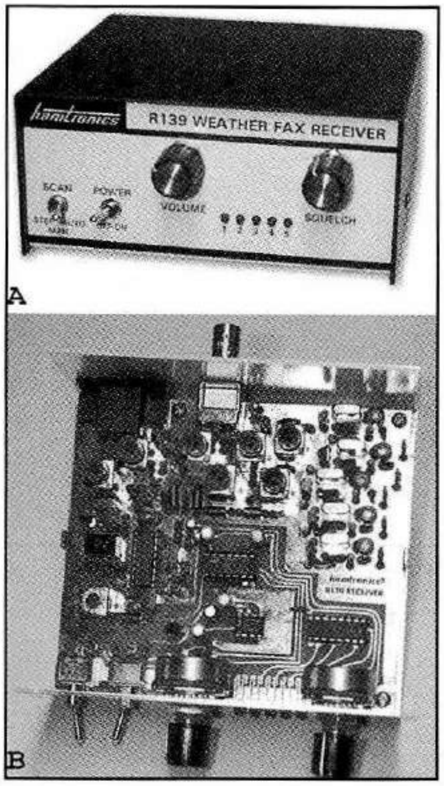


**Figure 6.15**. The Hamtronics R139 receiver is specifically designed for reception of weather satellite signals and is available either as a kit or a wired-and-tested unit.

filters, degrading the received image in a variety of ways. The required bandwidth for APT signals is a function of two factors — the frequency deviation imposed by the modulator and Doppler frequency changes created as a result of the high speed with which the spacecraft approaches or moves away from the ground station. For the US TIROS/NOAA spacecraft these parameters are as follows:

**FM deviation — ± 17 kHz**
**Doppler shift — ± 4-5 kHz**
**Total = ± 22 kHz**

Therefore, the receiver must have an IF bandwidth of at least **44 kHz** (± 22 kHz frequency offset) to properly pass the satellite signal without distortion. To allow for minor frequency errors in the local oscillator, a bandwidth of 45-50 kHz is usually a safe compromise.

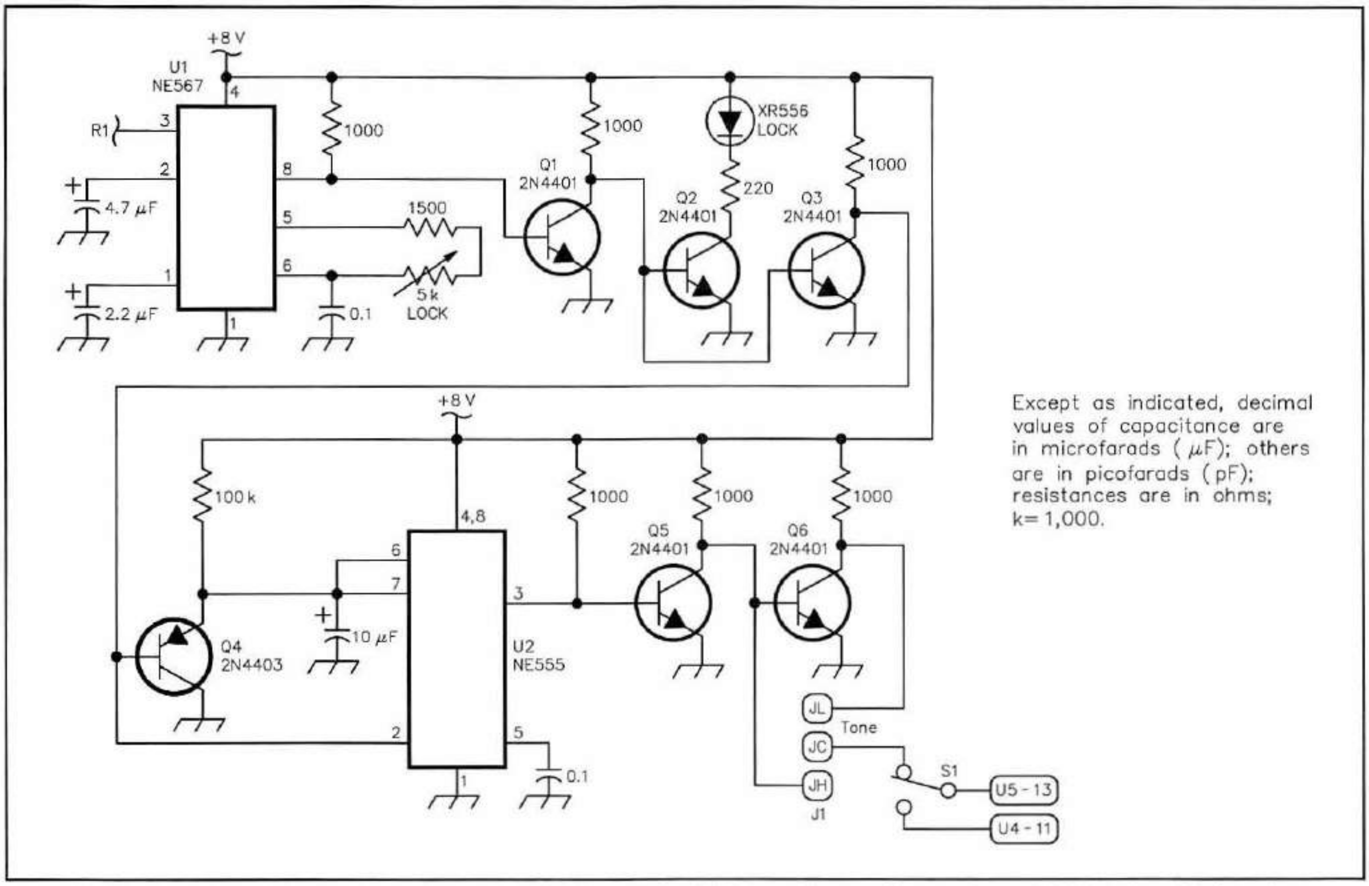
Unfortunately, the standard "narrow" IF bandwidth for most scanner receivers is just 15 kHz, as that is optimum for the narrow-band FM (NBFM) employed in virtually all public service and amateur VHF FM communications. The relatively wide satellite signal will be clipped severely by such a narrow filter, resulting in unsatisfactory image display. Many scanners also have a "wide" bandwidth option for receiving FM and TV sound transmissions. Unfortunately, to pass FM broadcast transmissions with minimal distortion, the "wide" bandwidth setting is typically about 200 kHz — about four times wider than optimum for satellite reception. While the "wide" position will pass the satellite signals without distortion, they are so wide that they let in a considerable amount of extra noise. The result is that the spacecraft signal-to-noise ratio (SNR) will be degraded by 6 dB compared to the use of a 45-50 kHz matched IF bandwidth. Such a receiver might be made to work with the use of gain antennas with all the tracking complexities, but they will rarely work well with omni-directional antennas. The most effective approach is to use a receiver with IF filters tailored for satellite reception.

Suitable commercial receivers are available from a number of vendors. **Figure 6.13** shows the TimeStep ProScan receiver, specifically tailored for APT reception. This receiver operates using manual frequency selection; or the receiver can be set to scan all the active channels (much like a conventional scanner), simplifying the automatic reception of satellite signals. Other manufacturers approach the problem by changing the IF filtering (and often making other modifications) on basic scanning receivers. **Figure 6.14** shows the satellite receiver offered by MultiFax.

There are comparatively few kit receivers on the market suitable for satellite reception. **Figure 6.15** shows one of the most widely used models, the R139 from Hamtronics. This receiver is available as a kit or as a wired-and-tested unit and the kit contains crystals for all the active polar-orbit APT frequencies. In the past the Remote Imaging Group in the UK (**http://www.rig.org.uk/**) has offered kits for the RX-2, a design that has been widely used in Europe. Kits for this receiver are once again available, but you do need to be a member of RIG to take advantage of the offering. They also have APT preamplifiers and antennas for sale under the same conditions.

### *THE SCANNING PROBLEM*

One of the attractive possibilities if your receiver can scan the active satellite frequencies, as most can, is simply to set the receiver in the scan mode and let your computer-based imaging system log pictures as the various spacecraft pass overhead. In theory this approach should work well, but results in the real world can be frustrating. The problem is the multitude of spurious signals that can appear as a result of intermodulation in the congested RF environment characteristic of most urban and suburban settings. The receiver scanning circuits are typically carrier-controlled, which means the receiver will lock and stop scanning on any signal that comes up on a channel, whether it is a satellite signal or not. At any given location, spurious signals may cause intermittent problems on some frequencies and can virtually disable others.



Except as indicated, decimal values of capacitance are in microfarads ( µF); others are in picofarads ( pF); resistances are in ohms; k= 1,000.

**Figure 6.16.** A tone-operated scan-control circuit for the Hamtronics R139 weather satellite receiver, which is adaptable for other models as well (see text). All resistors are ¼ W 1% metal-film with resistances in ohms. The 5K Ω LOCK control is a single-turn PC-mount potentiometer. All capacitance values are mF. Values <1 are 50V dipped polyester or mylar, and values >1 are 16V tantalum electrolytics. S1 — SPDT sub-miniature toggle switch.

What we really want is a receiver scanning system that will respond to actual imaging satellite signals and nothing else! We can implement just such a system based on the fact that any spacecraft we are interested in will be transmitting a 2400 Hz subcarrier tone. A nearly ideal scanning system is one that will scan all active channels until a 2400 Hz tone is detected, at which point it will lock to that channel as long as the signal is being received. **Figure 6.16** shows a circuit that will add tone-controlled scanning to the Hamtronics R139 receiver and which is readily adapted to other receivers as well.

**Theory of Operation**. U1 is an NE567 tone-decoder IC. It features an internal voltage-controlled oscillator (VCO) whose operating frequency is set by the 5K LOCK potentiometer and associated resistor (1500 Ω) and capacitor (0.1 mF). With the values shown, the VCO will free-run near 2400 Hz with the LOCK control near mid-range. It a 2400 Hz audio tone is applies at point R1, the VCO will lock to the input frequency and an internal transistor will pull pin 8 to a LOW logic state. This will cause the collector of Q1 to go HIGH, turning on both Q2 and Q3. Q2 has the LOCK LED in its collector circuit; and when Q2 goes ON, the LOCK LED will come on, providing indication that a tone has been detected. When Q3 goes on, it triggers a circuit known as a "missing pulse detector", made up of Q4 and a timer IC, U2. The timer has a period of approximately 1 second (based on the use of a 100K resistor and 10 mF capacitor on the timing pins (6 and 7). When a 2400 Hz tone is detected, U2 is triggered and produces a HIGH at pin 3. Tone detection can be expected to be somewhat variable, both as a result of modulation of the subcarrier and as a result of noise at the beginning and end of a pass. As long as Q4 is triggered within the 1-second interval, pin 3 of U2 will stay HIGH. If the tone drops out for more than 1 second, pin 3 of U2 will go low. Pin 3 of U2 drives two switching transistors (Q5 and Q6) that are connected in series. The collectors of these transistors are connected to pad JH and JL of jumper J1. Depending on whether a tone is detected or not, these jumper pins will show the following logic states:

| **TONE STATUS** | **JH** | **JL** |
|---|---|---|
| OFF | HIGH | LOW |
| ON | LOW | HIGH |

Depending upon the design of your receiver, the logic state on either JH or JL can be used to control the receiver scanning function.

**Construction**. Construction of this circuit is non-critical since it is operating at mid-range audio frequencies. It can be laid out on perforated prototype board or a small printed circuit board can be used. The *ICH* Web site has a page devoted to this circuit (**http://taggart.glg.msu.edu/ich/tone.htm**) with a complete parts list for the project, keyed to the DigiKey catalog. The package also features an on-line version of the board which, although not suitable for board fabrication, can serve as a wiring guide if you choose to wire the circuit using perf-board.

**Installation and Set-up**. This circuit was designed for use with the Hamtronics R139 receiver; and I will describe the installation and set-up with that receiver, followed by some notes on how to adapt the installation to other receivers. I will assume that you are mounting the board inside the R139 cabinet, since that is the simplest option. I also will assume that if you have built the receiver yourself, it has been checked out and aligned. The +8V power bus should be connected to any +8V point on the R139 circuit board. The input, point **R1**, should be connected to the top (hot lead) of the R139 volume control (**R1**). Install **S1**, the **TONE/CARRIER** switch, on either the front or rear panel. Install a jumper between **JC** and **JH** on **J1** and wire **S1** as shown in Figure 6.16. Remove **U5** from its socket on the R139 board, gently bend out **pin 13**, and reinstall **U5**. For point **U5-13**, connect to the pin you just bent, which no longer should be inserted in the socket. For point **U4-11**, connect to **pin 13** of the **socket** for **U5**. Set **S1** to **CARRIER** and confirm that the receiver scans normally.

Now wait for a good pass, where you have a noise-free signal. Preset the **LOCK** potentiometer to the middle of its range and adjust it slightly until the **LOCK LED** comes **ON**. The proper set point is midway over the range where the LED is **ON** in response to the 2400 Hz subcarrier. The circuit may show a LOCK indication near one end of the range of travel of the **LOCK** pot, but this is **not** the proper point. When properly adjusted, the **LOCK** pot should be *near the middle* of its range of adjustment. Now switch **S1** to **TONE** and the receiver should lock to the active channel. Within about a second after the tone drops out, scanning should resume. This circuit essentially will eliminate false-locks on spurious signals and make it simple to implement unattended image acquisition.

For other receiver circuits, scan control is typically implemented by either a logic HIGH or LOW signal. You need to determine what logic state will cause the receiver to scan. If it is **HIGH**, connect **JC** to **JH** on jumper **J1**. If it is **LOW**, jumper **JC** to **JL**. If the logic in the receiver is TTL compatible, the circuit should be powered from +5V instead of the +8V used for the R139. The line carrying the logic control signal must be broken between its source and the device that is being controlled. The **CARRIER** lug of **S1** should connect to the **source side** of the logic trace while the **common lug** is connected to the **device** side.

### *APT STATION COST*

The total cost of a basic APT receiving system depends greatly upon the vendors you select; but a basic system with a turnstile antenna, remote LNA, and receiver can be quite reasonable. As just one possible combination, for example:

| | |
|---|---|
| Woodhouse **APT-2CP** turnstile antenna: | $135.00 |
| Hamtronics **LNK-137** LNA (wired and tested): | $ 59.00 |
| Hamtronics **R139** Receiver (wired and tested): | $239.00 |
| Total: | $433.00 |

Shipping costs will add a bit to the total; and you will have to furnish the transmission lines and connectors, but your total expenditure would be under $500. You could spend a bit less or a bit more; but you should budget $400-700, depending upon the equipment you opt for after looking over what is available. If you are comfortable building your own equipment or modifying surplus or other commercial equipment, you can save a significant amount of money. However, you should be prepared to treat such an exercise as a learning experience and be prepared for the fact that some components may not work perfectly, at least at the outset! If you want inspiration for your home-building efforts, check the many member web pages that can be accessed from the RIG Web site (**http://www.rig.org.uk/**).

Once you have a basic APT system up and running, adding WEFAX capability is a simple add-on exercise.

## GEOSTATIONARY ANTENNAS

An antenna for receiving WEFAX transmissions from GOES or METEOSAT spacecraft must have significantly more gain than an APT antenna because the received signal is at a much higher frequency and is considerably weaker than the signals from APT spacecraft. Fortunately, antenna gain comes relatively easily at 1691 MHz! We want sufficient antenna gain to produce a reasonable gain margin in our system. It is possible to produce a workable WEFAX antenna using one of the 18 inch (46 cm) offset dishes used for DBS satellite service, but such a system will have a very modest gain margin. The Remote Imaging Group (**http://www.rig.org.uk/**) offers an active feed module (manufactured by TimeStep but not listed on their main web pages) for sale to RIG members. This feed is designed for use with a DBS dish.

My personal preference is to use a dish in the 3 foot (~1 meter) size range. While significantly larger than the DBS dishes, such an antenna will produce a useful gain margin to compensate for path losses induced by rain, snow or other factors. **Figure 6.17** shows one example of a commercial antenna of this type. It is also possible to use a small surplus microwave dish. One of the first things you will need to do is to determine the focal length of the dish you have available. **Figure 6.18B** shows how you can calculate the focal length. First, measure the dish diameter in either English or metric units. Next, lay a straight edge (a board will do) across the center of the dish and measure the depth, at the center of the dish, using the same values you

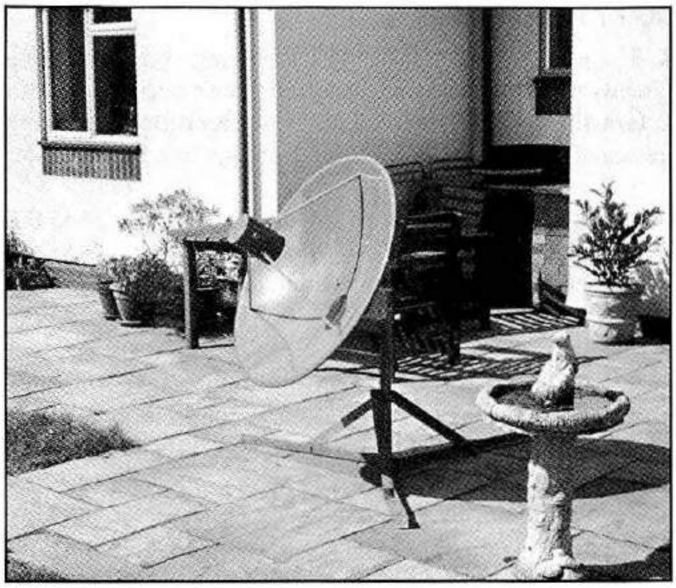


**Figure 6.17**. An example of a commercial WEFAX antenna system (courtesy of TimeStep). The best overall system consists of a dish antenna/reflector approximately 3 feet (~1 meter) in diameter equipped with a suitable feed at the focal point of the dish. This TimeStep system employs a cylindrical feed-horn similar to the home-built horn documented in Figure 6.18. Such an antenna can be permanently mounted on a wall or roof, locked on to the spacecraft of interest, or, as shown here, it can be set up temporarily on a tripod for portable operation where restrictions prohibit the permanent mounting of outside antennas.

used for the diameter. The focal length can then be calculated:

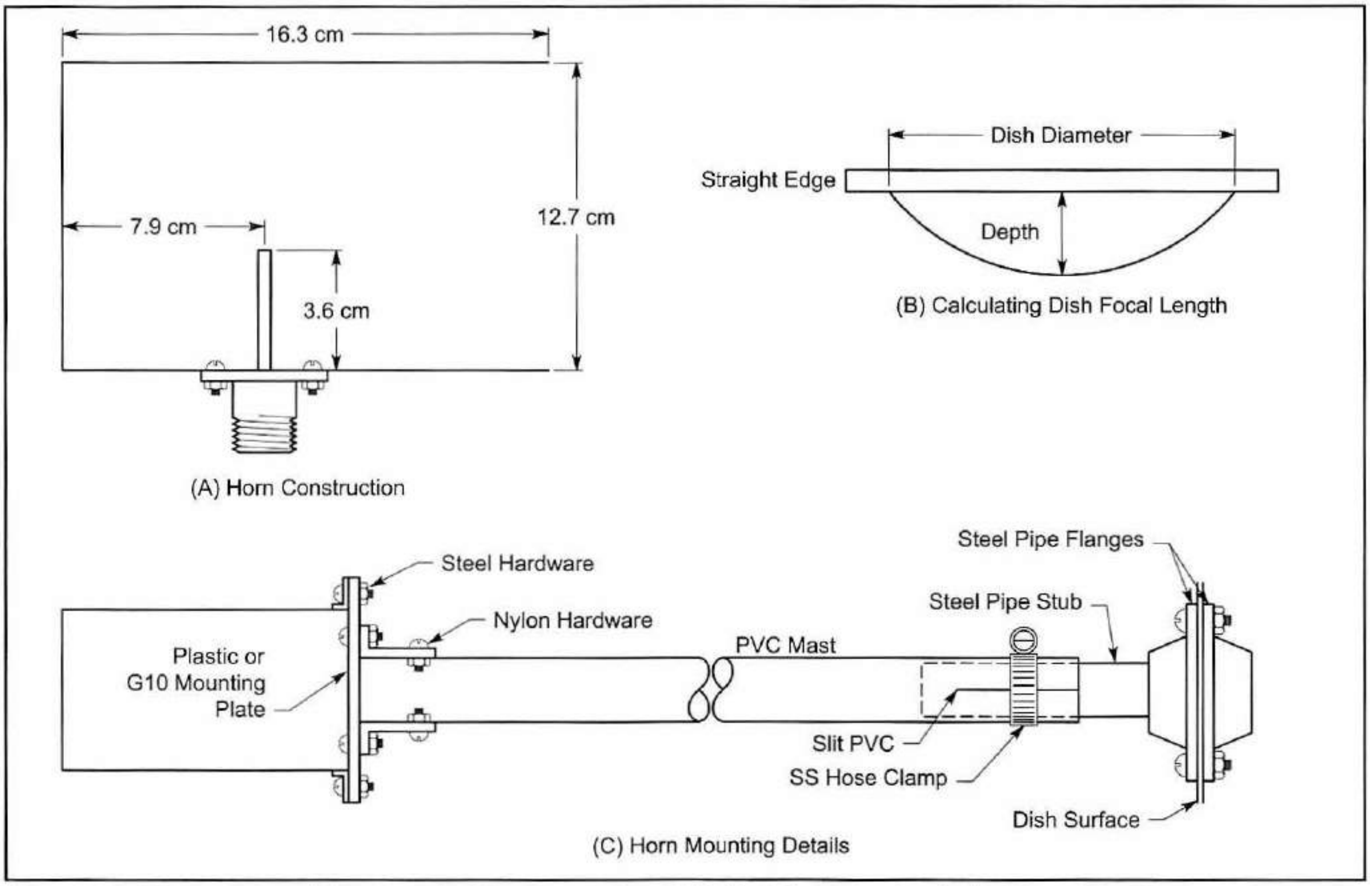
$$\mathbf{F = (0.5 \times D)^2/4 \times Y} \qquad (6\text{-}1)$$

Where F is the focal length, D is the dish diameter, and Y is the depth at the center of the dish.

### *HOME-BUILT FEED-HORN*

The next item we need is a suitable feed horn assembly to capture the RF energy reflected from the dish surface and couple it to the transmission line. Figure 6.18A shows the essential dimensions of a feed horn constructed from a **1 lb. 6 oz.** (**623 gram**) coffee can. You must use this size for the dimensions as shown!

1. Construction starts by obtaining some $^{5}/_{16}$ **in.** (**4 mm**) diameter brass tubing from a local hobby shop or hardware store. Cut a piece exactly **3.6 cm** long, slip it over the center-post of a **type N** female chassis connector, and solder the tubing in place.
2. Measure **7.9 cm** from the closed end of the coffee can, and center-punch and pilot-drill a hole. Drill it out to ¼ inch diameter and use a $^{5}/_{8}$ **inch** (**1.6 cm**) chassis punch to make a hole in the side of the can.
3. Use a wire brush to clean the pain from around the outside



(A) Horn Construction

(B) Calculating Dish Focal Length

(C) Horn Mounting Details

**Figure 6.18**. Using a surplus dish antenna for WEFAX reception. **[A]** Critical dimensions for the "coffee can" feed horn. **[B]** Set-up for measuring and calculating the focal length of a surplus dish. **[C]** Mounting the feed horn to the dish.

of the $^5/_8$ inch hole. Align the N connector (probe projecting into the can, and use a torch to solder the connector to the side of the can. Silver plated connectors should solder easily. If the connector is not silver-plated, use a file to expose the brass beneath the plating on the flange of the connector prior to soldering.

4. Use a wire brush to clean the paint off the area to be soldered and solder four small metal angle brackets, equally-spaced, around the open end of the horn.
5. Use tape to mask the probe and paint the inside and outside of the horn with several coats of exterior enamel (Rustoleum™ or similar type) to protect the horn from corrosion.

### MOUNTING THE FEED-HORN

Ideally, we want to mount the feed-horn aligned with the center of the dish, at a distance from the dish surface that will place the focal point approximately an inch inside the open end of the feed horn. We want to do so without obstructing the open end of the horn with any metal because all of the RF energy is passing through the opening, and any metal will result in a significant drop in signal level. The commercial dish in Figure 6.17 accomplishes the job by using mounting rods around the dish margin, but this is hard to do with a surplus dish where there is some uncertainty as to the precise focal length. Figure 6.18C shows a simple, center-mounting scheme that works well and costs very little. You will need the following items to fabricate this mount:

- Four nylon angle brackets and eight #4 nylon bolts and matching nuts. Some hardware stores will carry nylon hardware. If yours doesn't, try the local hobby shop.
- Four ¾-inch #6 stainless steel machine screws with matching stainless nylon locking nuts.
- A square piece of lucite or acrylic rigid plastic sheet slightly larger than the diameter of the horn — 13 inches square is about right. Alternatively, you could use a piece of unclad G10 printed circuit board stock.
- About 8 feet (2.5 meters) of 1 inch (2.54 cm) ID PVC plumbing pipe.
- 1 PVC pipe coupler to match your pipe.
- 1 can of PVC cement
- 12-inch (30 cm) length of 1-inch (2.54 cm) OD galvanized pipe, threaded on at least one end.
- Two galvanized pipe flanges to match your galvanized pipe
- Bolts and nuts to mount the pipe flanges.
- One stainless steel adjustable hose clamp that will slide over the end of your PVC pipe.

Now proceed as follows:

1. Center one of the flanges on the front or back of the dish and match-drill mounting holes through the dish surface.
2. Screw the pipe stub into one mounting flange and bolt the stub to the inside of the dish, using the second flange on the back of the dish as a back-up plate. Any excess bolt length, along with the nuts, should be on the back of the dish.
3. Place the open end of the horn on the plastic/G10 mounting plate, center, and drill four #6 holes through the plates using the angle brackets as a guide.
4. Cut a 12-inch (30 cm) length of PVC pipe. Make sure both ends are square.
5. Mount the four nylon brackets, equally-spaced, flush with one end of the PVC pipe, securing with #4 nylon hardware.
6. Center the bracket-end of the PVC pipe on the plastic/G10 mounting plate and drill four #4 holes, using the nylon brackets as a guide.
7. Mount the plastic/G10 plate to the bracket-end of the PVC pipe using #4 nylon hardware.
8. Use PVC cement to mount the PVC coupler to the free end PVC pipe segment
9. Mount the horn to the plastic/G10 mounting plate using #6 stainless hardware.
10. Now insert the remaining PVC pipe into the coupler but do not cement it in place. Take the calculated focal length for your dish and subtract 5 inches (13 cm).
11. Measure this distance from the face of the plastic/G10 mounting plate along the length of PVC tubing. Mark the tubing at that point, remove it from the coupler, and cut the tubing square at that point.
12. Use a hacksaw to cut 6-inch (15 cm) slits (at least four, equally spaced) at one end of the PVC pipe. Slide the slit end of the PVC pipe over the pipe stub at the center of the dish and secure hand-tight, using the stainless-steel clamp.
13. Insert the coupler with the horn in plate over the free end of the PVC pipe.
14. Move the PVC pile on the pipe stub in or out until the plastic/G10 mounting plate for the horn is located x inches from the dish surface, where X equals the calculated focal length of your dish minus 1 inch (2.5 cm).

At this point you can remove the coupler, the short PVC pipe, and the attached horn until you have the dish sited properly, aimed approximately at the spacecraft of interest, and are ready to check the signal level and make final adjustments.

### DISH MOUNTING

There are a great many ways to mount a surplus dish, depending upon how it is constructed and how heavy it might be. For several years I used a very heavy 3-foot (~1 m) dish that was simply attached to a simple wooden A-frame mount in the back yard. The key thing is that the dish must be secure, and you should be able to set it to the proper azimuth and elevation for the spacecraft of interest. One thing is absolutely vital: You must have a clear line-of-sight path to the point in the sky where the spacecraft is located. VHF APT signals can penetrate leaves and even wood frame buildings with tolerable losses; but at S-band (1691 MHz) frequencies, any obstruction — even a layer of tree leaves — can be serious or even fatal with respect to reception. Any of the commonly-available tracking programs (see Chapter 7) can generate the azimuth and elevation to any of the geostationary spacecraft within range of your station. You need to check out your property to see if there is a spot where it is practical to mount the antenna and get a clear "shot" at the satellite. Assuming you have a suitable spot, we will cover final alignment and adjustment of the antenna system after a discussion of the remaining system components.

## GEOSTATIONARY RECEIVERS

The typical WEFA receiving hardware consists of a remote LNA, located at the antenna, and a down-converter in the station to convert the 1691.0/1694.5 MHz signals down to the 137-138 MHz range for reception on your APT receiver. There are a few variations on this basic scheme, which I will discuss as we move along through the topics which follow.

### *WEFAX PREAMPLIFIERS*

Unless the down-converter can be mounted at the antenna, a remote LNA will be required. The reasons are basically the same as those discussed previously with respect to APT preamplifiers. In the case of WEFAX, however, the reasons are even more compelling given the very high losses of common transmission lines at 1691 MHz (see Table 6.1). Vendors such as TimeStep and Quorum offer suitable LNA's in weather-proof housings and the TimeStep model is illustrated in **Figure 6.19A**. As always, the most economical approach is to build your own; but that requires some experience with surface-mount components and good soldering skills. Downeast Microwave has a wide range of 1691 LNAs with kits starting in the $40-$50 range and wired and tested preamps, in cases, topping out in the $100-$120 range.

### *WEFAX DOWN-CONVERTERS*

One of the key specifications for any WEFAX down-converter is stability, since the signal must end up on an APT receiving frequency with enough accuracy that it is centered in the 45-50 kHz IF bandwidth. This can be a real challenge when the converter is mounted outside, given the seasonal temperature extremes typical of temperate latitudes. Quorum Corporation has an extensive line of down-converter products (an early model unit is illustrated in Figure 6.19B) that use crystal ovens to heat the crystal above any expected ambient temperature high, thus assuring stability over a very wide temperature range. The converter illustrated can be installed at the antenna (assuming it is protected from the weather), eliminating the need for a remote LNA. Another of their models is built into an active feed-assembly, which eliminates the need for building your own feed horn.

Most down-converters are best installed inside with the receiver, thus avoiding temperature extremes, not to mention weather. The RIG Shop page on the RIG Web site (**http://www.rig.org.uk/**) has several single and two-channel down-converters (produced by TimeStep and Dartcom) available to RIG members at attractive prices (typically 85-130 pounds sterling). Here in the US we need only a single channel converter that will take the 1691 MHz GOES frequency and output it at 137.50 MHz for reception using the APT receiver. European METEOSAT users have two frequencies available (1691.0 and 1694.5 MHz) and thus require a two-channel down-converter.

TimeStep has a very interesting product that basically integrates the down-converter and receiver electronics into a single package (Figure 6.19C). This eliminates the problem of coax switching between APT and WEFAX inputs (see Figure 6.10), since the output signal from the WEFAX receiver is the audio subcarrier signal. It also has the advantage that the internal IF circuits can use a somewhat narrower IF filter. (WEFAX deviation is somewhat less than that of the APT spacecraft and there is no Doppler frequency shift, thus improving the SNR of the system compared with a discrete down-converter/APT receiver combination.) The published noise figure of this system suggests the use of a remote LNA, with the WEFAX receiver located inside the station.

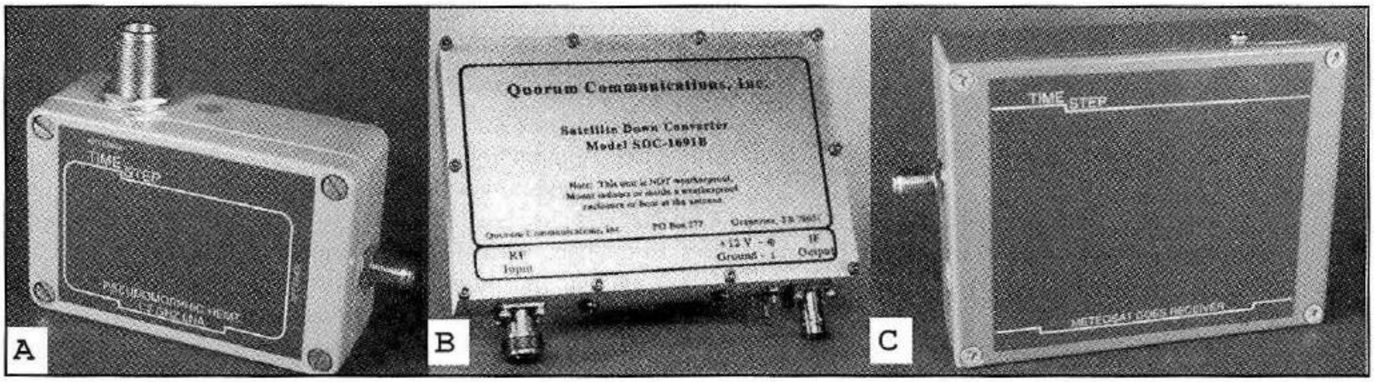


**Figure 6.19**. GOES/METEOSAT receiving hardware. **[A]** A remote preamplifier (LNA) mounted at the antenna feed is essential if there is any significant length of transmission line between the feed point and the down-converter/receiver. This TimeStep unit is housed in a weatherproof case, which simplifies installation. **[B]** A down-converter is used to convert the 1691.0/1694.5 MHz WEFAX signal to the 137-138 MHz range (typically 137.5 MHz) where the polar orbit satellite receiver can be used to demodulate the signal. This Quorum Communications converter features an internal crystal oven that maintains the stability of the local-oscillator frequency despite wide changes in ambient temperature. With a suitable weather-proof housing, this converter can be mounted at the antenna, in which case no preamplifier is required. If such a converter is installed inside with the receiver, a remote preamplifier will be required. **[C]** This TimeStep unit is unique in that it is a complete WEFAX receiver, incorporating the down-converter and IF receiver components. The output is an audio signal that can be routed directly to the image demodulator/interface.

### *FINAL WEFAX ANTENNA ALIGNMENT*

Once the WEFAX receiving system is operational, final alignment and adjustment of the WEFAX antenna system can be undertaken. You will need to know the "look angle" (azimuth and elevation) for the spacecraft you are interested in. Set the azimuth as closely as possible, using an accurate magnetic compass. The elevation can be preset using a magnetic protractor (aligned with the PVC mast in the case of our home-built antenna).

You will need a short length of quality RG58 foam coax (no more than 6 ft./2 m) with type N connectors at each end. Mount the horn to the central mast and attach one end of the cable to the connector on the horn and the other to the LNA or converter input. If using a remote LNA, the line back to the station should be a quality grade of RG8 foam with N connectors at either end. If your system has a down-converter at the antenna, RG58 cable will suffice for the run back to the station receiver. In practice, it is often easier to take the APT receiver and down-converter out to the antenna site. (Everything can be powered from a 12V battery for initial setup.) Otherwise, you will need to arrange some way that you can monitor the receiver output from the antenna site. This can be a long but temporary audio cable, or you can use CB or FRS hand-helds for temporary monitoring.

We will assume that the receiver is set to the proper frequency for the output of the down-converter and that everything is powered up. If you have done a careful job of setting up the antenna, you may hear the spacecraft right away. Since a WEFAX downlink handles over 300 images each day, it is likely to be transmitting at almost any time. If you don't hear any signal, make slow and careful sweeps in azimuth and elevation until you get some signal. At this point, proceed as follows:

1. Carefully optimize azimuth for the strongest possible signal (least noise)
2. Do the same with elevation
3. Now move the PVC pipe in and out on the pipe stub for the strongest possible signal. This step optimizes the horn position with respect to focal length.
4. Now rotate the PVC mast, without changing its position on the stub, again striving for the strongest possible signal. This step matches the polarization of the feed horn to the satellite polarization at your location.

The goal of these steps is to optimize the different variables (elevation, azimuth, focal length, and feed-horn polarization) to get the strongest possible signal. When working around the antenna, avoid blocking the horn opening or obscuring a significant portion of the dish area with your body as that will cause variations in the received signal level, complicating adjustment. If your receiver has a signal-strength meter or indicator (and most do not), you can probably forge through all the steps, going back through the series at least once to make sure that everything is optimized. Without a meter, you probably will get to a point where the signal is full-quieting, making it difficult to proceed further. In such a case, try obscuring the horn opening with a bit of aluminum foil, dropping the signal back to the point where useful noise is present. You can then proceed, obscuring the horn to a greater extent as needed with increases in the strength of the received signal. When you are through, you should have essentially a noise-free signal, at which point you can tighten the hose clamp to secure the PVC mast and proceed with all the details of finalizing your operational installation.

## PORTABLE/MOBILE OPTIONS

Up to this point I have talked about installing antennas as if there were no limits on your options. Today, in the real world, apartment living, restrictive deeds and covenants and a whole host of factors can intervene to restrict your antenna options. Where the look angles work out, temporary installation of antennas on apartment balconies or condominium patios is a real option. Most restrictions involve the permanent installation of antennas. If you bring the antennas out for discrete receiving sessions and then stow them away out of sight, you may well be able to receive plenty of interesting pictures. The TimeStep WEFAX antenna in Figure 6.17 shows how this might be done, and there is no reason why a temporary APT antenna could not be used in a similar manner. If you live in a condominium that has accessible attic space, an attic-mounted APT antenna could work well in the case of a wood-frame building.

So what if none of these options will work? Well, one solution is to take the entire satellite installation on the road. There are probably a number of open areas (parks, parking lots, etc.) that you might use as a temporary site for your satellite station. Modern RF gear is very compact and you can easily modify an APT antenna (or even a small WEFAX antenna) for easy portability, mounting it temporarily on a small mast attached to your vehicle. Since you will be using very short cable runs, inexpensive RG58 cable can be used without the expense and fuss of remote LNA's. A basic "on-the-road" APT station could consist of nothing more than:

- A portable APT antenna
- Antenna support mast
- Single short RG58 transmission line
- The APT receiver
- A sound card equipped laptop PC

The vehicle 12V electrical system will provide the needed power, and you can log images on a laptop for later viewing at home. It isn't a perfect substitute for a full-range home installation, but it can provide plenty of very good pictures. In fact, by getting "out of town" a bit, you may very well avoid potential sources of RF interference that could make life difficult at home. A similar system would work for vacation and business trips, allowing you to copy APT images from new areas — something you cannot do from a fixed station location.

Portable or mobile operations can have their own fascination and challenges in terms of packaging the system, optimizing and minimizing the various components, etc. The point is that you can succeed in setting up a worthwhile station under almost any conditions. You do need to be flexible and creative, but with modern equipment it can be done!

## TURN-KEY SYSTEMS

Virtually all the preceding discussion has been based on the premise that you will be assembling a station from discrete components. In fact, this is the way that amateurs approach most projects, acquiring gear here, building it there, mixing and matching until the system is complete. This approach lends itself to ready experimentation since, in one sense, you are never finished. If you build the station from pieces, it is easy to replace specific components, make modifications here and there, and otherwise "tinker" with your system, striving for continued improvement.

If you don't have the interest or patience to work incrementally but simply want to implement a station the way most people buy a stereo (one-stop shopping), that is an option. Virtually all of the major vendors of satellite ground station hardware offer turn-key systems. Many of these have been optimized to meet the needs of teachers and other educators, but there are individuals out there who would like to be up and running with minimal bother and uncertainty.

Most vendors will be happy to accommodate you with as much integration as you can afford. It is quite possible to order complete packages, which also include the display systems discussed in the next chapter, and simply wait for the UPS truck to deliver a collection of cartons that contain everything, down to the last cable and connector. If you have made yourself familiar with the individual station components, as described here, you are in an excellent position to do some comparison shopping for a turn-key package that will satisfy your needs and aspirations. Such systems typically will be more expensive, but in our fast-paced affluent world, convenience has acquired a considerable measure of value.

At this point, having described the basic RF components of a weather satellite ground station, the next chapter will be devoted to a more detailed examination of the various APT and WEFAX modes, computer-based image display and storage, and the day-to-day operation of your satellite installation.

## CHAPTER 7

# WEATHER SATELLITE INTERFACES AND STATION OPERATION

## INTRODUCTION

In the previous chapters we looked at the various requirements for setting up a basic receiving station for both polar-orbit/APT and geostationary spacecraft. In this chapter we basically will put that equipment to use, starting with image demodulation and interface requirements, followed by tracking, and finally, various considerations in the routine operation of a satellite ground station. The emphasis in the last section will be on automating your station for unattended image acquisition, some basic coverage on image processing, and some additional comments on portable/mobile station options. Please note that, as in the previous chapter, space limitations make it impossible to mention all possible vendors and models of satellite interface units. Your choice of interface probably will be based on a consideration of interface capabilities, software features, and price. As such, you should review offerings from advertisers in this volume and other commercial suppliers listed on the "Commercial Suppliers" page of the **Remote Imaging Group** Web site (**http://www.rig.org.uk/**). All vendors noted in the text are listed in the **Appendix**.

## IMAGE DEMODULATION AND INTERFACE OPTIONS

### *BASIC SIGNAL DEMODULATION*

As noted previously, the basic APT and WEFAX signal format is very simple. The signal consists of a 2400 Hz audio subcarrier that is amplitude modulated with the image luminance data. Signal modulation is linear, ranging from minimum amplitude (typically 4-6%) for black to maximum amplitude (95-100%) for white. An example of a basic weather satellite demodulator is shown in **Figure 7.1**. Any demodulator/interface must provide a minimum of three distinct functions:

- **Prefiltering, amplification, detection and post-detection filtering** to produce a baseband signal that swings from 0V (black) to 5V (white).
- **Analog to Digital (A/D) conversion of the baseband video** to digital form. Since all weather satellite image formats are monochrome, 8-bit coding (256 grayscale values) is adequate, resulting in a count value ranging from 0 for black to 255 for white.
- **Generation of an extremely accurate clock signal** for pixel sampling and other time-critical functions.

The circuit in Figure 7.1 accomplishes all of these functions and also provides for all the needed power supply voltages from a 12V source.

**Subcarrier Detection**. 2400 Hz subcarrier video is applied to **J1** and routed to a 10K **LEVEL** potentiometer. From this control the signal is routed through a **bandpass filter** stage (**U1D**) with a center-frequency of 2400 Hz and a bandwidth of 1.6 kHz. Despite its simplicity, this stage is quite effective in reducing the impact of noise falling outside of the video passband. From the bandpass filter the signal is routed to **U1C**, wired as a simple **gain block** with a fixed voltage gain of approximately 2.1. The gain block drives a precision full-wave detector comprised of **U1B** and **U1A**.

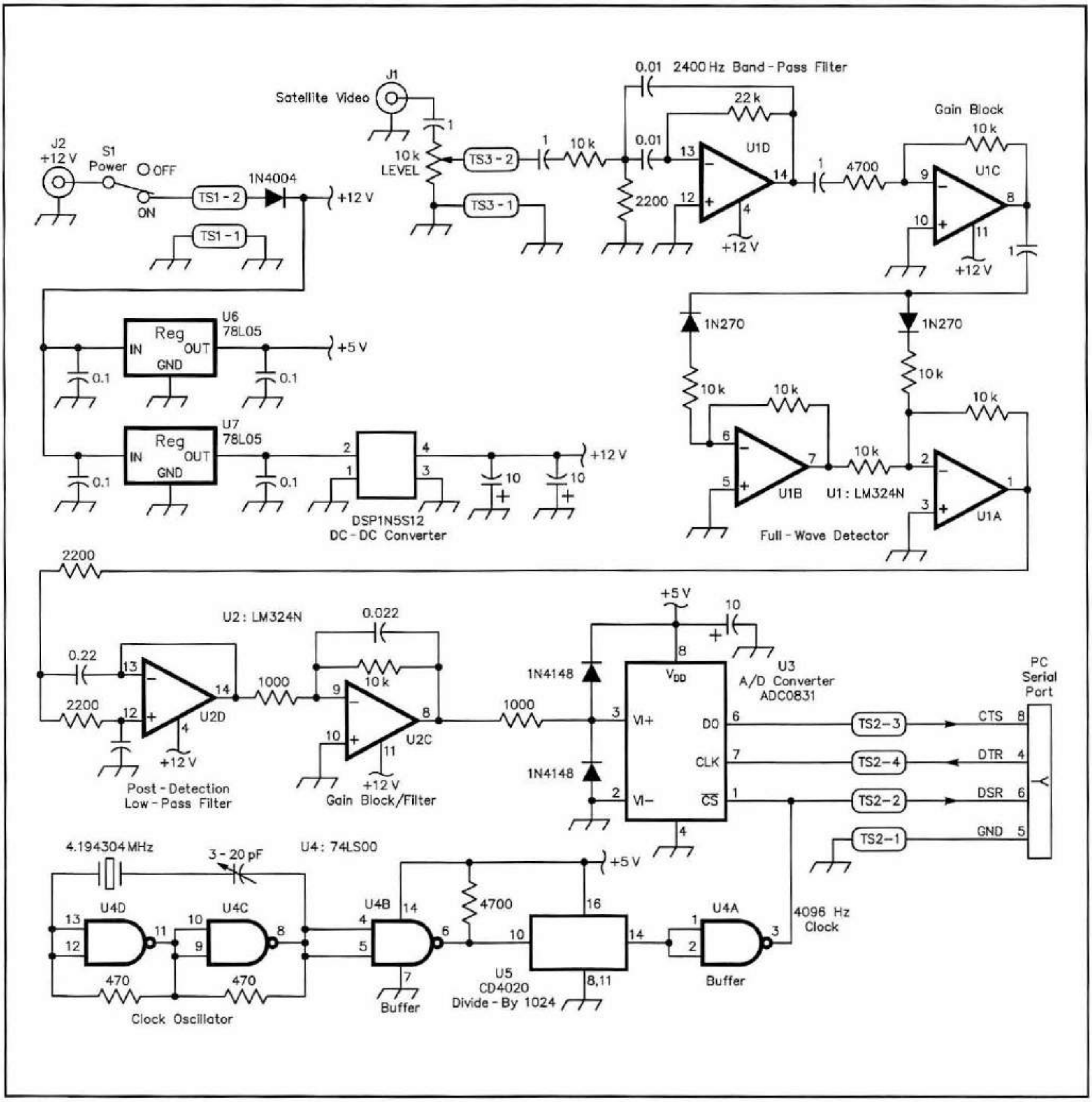


**Figure 7.1.** An example of a basic satellite interface. All fixed resistors are ¼ W 1% metal-film. Variable resistors are ¼ W pc-mount potentiometers. PF capacitors are variable trimmers. All other capacitor values are mF. Decimal values indicated 50V dipped mylar, the 1 mF capacitors are non-polarized 50V dipped mylar, and the 10 mF units are 16V dipped tantalum.

U1B is a unity-gain, inverting amplifier that inverts the negative-going subcarrier to a positive-going waveform. This positive-going signal is summed with the positive-going subcarrier signal in another unity-gain inverting amplifier (U1A). The output of **U1A** is a negative-going signal at 4800 Hz. Note that the use of the **1N270** germanium diodes at the input of U1B and U1A provides significantly better video linearity than the use of more common silicon diodes (such as the 1N4148). The next task is to remove the 4800 Hz component, leaving just the integrated DC component of the baseband video. This is accomplished by an active low-pass filter stage (**U2D**). The negative-going DC waveform is then routed to a final video stage (**U2C**) that provides three integrated functions:

- Inversion of the negative-going baseband signal to positive-going
- A fixed voltage gain of 10
- A small amount of additional post-detection filtering

In operation, the **LEVEL** control is adjusted so that subcarrier amplitude peaks (white) just reach 5V. At this point the baseband video signal is suitably conditioned for A/D conversion.

**Clock Signal**. Loading individual image pixels and other critical timing functions require an extremely accurate clock signal if the resulting image is to be precisely synchronized. The reference standard for the clock signal is a **4.194304 MHz** oscillator made up using a pair of NAND gates (**U4D** and **U4C**) and an inexpensive microprocessor crystal. A small trimmer capacitor in series with the crystal is used to set the oscillator to the exact frequency marked on the crystal. Without this provision, the images certainly would be slanted, given the normal variation in the crystal and other components. The 4.194304 MHz output of **U4C** is routed through a NAND gate (**U4B**) that functions as a buffer to isolate the oscillator stages from the counter stage, **U5**. The pull-up resistor on the output of **U4B** functions to interface the TTL levels at **U4B** with the CMOS input of the counter (**U5**). The counter is hard-wired to provide a divide-by-1024 function, resulting in 4096 Hz at the output pin (U5-14). This CMOS clock signal is buffered by another TTL NAND gate (U4A) and routed to an input bit from the host processor. The clock signal provides the system pixel clock and is used as a time reference for all other precision timing functions that might be required.

While the interface circuit illustrated in Figure 7.1 uses a crystal-referenced clock, other approaches can be used:

- Some interface units use a **phase-lock-loop (PLL)** clock circuit referenced to the 2400 Hz spacecraft subcarrier signal. This provides perfect synchronization without the need to trim the clock frequency, since the US TIROS/NOAA and WEFAX subcarrier signals are locked to the master time standards that control scanning (in the case of APT) or transmission (WEFAX). This approach has the advantage of eliminating the slight vertical curvature of the image display caused by Doppler frequency variations in the received signal when a crystal-referenced clock is used for display. WEFAX signals don't have this artifact since there is no Doppler frequency variation in the signals from geostationary spacecraft. Unfortunately, phase-locked clocks do not provide synchronization in the case of most Russian APT spacecraft, since the subcarrier signal is rarely locked to the master spacecraft clock.
- Some simple software control timing with simple **software timing loops**. Any of these programs require that you vary program timing constants until you get essentially vertical image display, due to the great variation in clock speeds (hence program execution) from one computer to another. Without something close to the proper timing constants, you are likely to get no useful display. After relatively tedious adjustment, the end result will be no better than achieved with the use of a crystal-referenced clock.
- It is also possible to derive timing from the **computer's clock**, although this will typically require calibration in software since the clock circuits operate near but rarely precisely on the nominal clock frequencies. Getting the proper correction constants is easier than achieving the same thing with timing loops, but it is still a tedious job and in the end no better than an external clock.
- Soundcard-based systems typically use the **relatively-precise sound card clock circuit on the card** for primary timing, and many of the programs have fairly simple (even automatic) routines to compensate for the relatively smaller frequency errors typical of sound card hardware. One advantage of some sound card software is that it can monitor the relative frequency of the NOAA or WEFAX subcarrier, correcting for Doppler distortion in these (but not Russian) spacecraft.

In general, the timing precision required for weather satellite display is significantly higher than that required for SSTV. Primarily, this is because the pictures require much longer periods for display because they have much higher resolution. Thus, any timing errors become compounded during the display interval.

**Analog to Digital Conversion**. The A/D conversion is accomplished by **U3**, a serial, 8-bit converter. Input diodes protect the A/D converter from negative or excessive positive voltage excursions. All A/D functions are controlled by just three I/O bits — a major advantage of using a serial A/D conversion. Since only three bits are required, a PC serial port is a reasonable way to connect between the interface and the computer. One bit is required to pull the **CS** pin (U3-1) **LOW**, enabling the chip and starting the A/D conversion. We can simplify the interface to the host computer by using the 4096 Hz CLK line to perform this function. In essence, each time the CLK line goes LOW, the A/D converter is enabled. Since the host computer needs access to the CLK line for timing purposes, one input I/O line (serial port line DSR) performs this function. Another processor I/O pint (Serial port line CTS and input) is used to monitor the **DO** pin (U3-6) of the converter to determine the logic state of each video bit as it is clocked out of the processor. Finally, a third output bit (serial port line DTR) is used to cycle the **CLK** input (U3-7), clocking out the 8 video bits in serial form.

**Power Supply**. The various integrated circuits used in this project require +12V, –12V, and +5V power supply voltages. The overall circuit is intended to be powered from the station +12V supply which is applied at **J2**, a coaxial power jack. The +12V DC is routed through the interface power switch and a series diode that protects the circuits should the power supply leads somehow be reversed. A single 78L05 integrated circuit regulator (**U6**) provides the required +5V directly from the +12V bus. A second 78L05 (**U7**) provides a regulated +5V to power a DC to DC converter that generates the –12V required for U1 and U2. **U7** is used to power the converter to provide some isolation to keep any noise generated by the converter from appearing on the other supply lines. The –12V output is filtered by a pair of 10 mF tantalum capacitors, again to minimize noise on the power bus. Noise reduction also mandates the liberal use of bypass capacitors throughout the circuit.

**Available Interface Options.** Interface circuits generally fall into three categories:

- External units that interface to the computer using parallel or high-speed serial ports
- Internal plug-in boards that are installed inside the computer
- Interfaces built around program-control of the computer sound card

**External interface** units such as the **PROsat** models from TimeStep (**Figure 7.2**) and the stand-alone MultiFax interface (**Figure 7.3**) are the most common interface units available. In most cases they are interfaced to the computer via an available serial or parallel port. Such an approach makes the type of bus irrelevant, in terms of a desktop system, and also permits the units to be used in conjunction with a suitable laptop or notebook computer. Moving the unit from one computer to another is also a trivial exercise, assuming the operating software is loaded on multiple machines.

All the various interface units that are currently available have the basic functions previously described. However, some incorporate a range of accessory functions (handling multiple receiver inputs for example) that may or may nor be important to your specific operating system or goals. Given the fact that for all but the simplest interfaces the resolution limit of your images is set by the APT or WEFAX format, your purchasing decision probably will be determined by the features offered by the support software. Each commercial interface is supported by proprietary software that can provide a large range of options beyond the basics of image display. Some of these features include (but are not necessarily limited to):

- **Support for input from an external GPS receiver**. A GPS input can precisely locate you station at any time, as well as supply atomic-clock grade time referencing for tracking and other functions.
- **Gridding of images**. With high-resolution tracking input and equally precise time data, the computer can insert geographic coordinates and political boundaries. This can be very helpful if cloud-cover obscures ground features you would normally use to reference your images.
- **Animation**. Multiple WEFAX images can be linked to show the movement of weather systems — precisely what you see on the evening news.
- **Thermal read-out**. Ground and cloud temperatures can be determined with considerable precision from properly-calibrated raw APT IR data.
- **False color display**. Despite the fact that the actual images you receive are grayscale, the computer can generate false-color images to emphasize temperature gradients (IR data) or provide the illusion of the color differences between land and water features. Since the color renderings are not inherent to the original image transmission, they are known as "false color" displays.
- **Image Processing**. The spacecraft sensors are designed to respond to a very wide range of temperature and light levels. On any given pass, image data will typically span only a small portion of the total dynamic range of the system. Depending upon the image format, time of day, and season of the year, images may appear too light, too dark, lacking in contrast, etc. Many programs have built-in image processing routines that permit you to optimize the image to meet your needs. Once images have been saved to disk files, assuming a standard graphics format has been used, almost any photo software package can be used to perform the same functions, often with a wider range of options. The subject of image processing will be touched upon later in the chapter.
- **Unattended operation**. Almost all software permits unattended acquisition of images, which is a very handy feature since most passes or transmissions are likely to occur when the typical amateur is at work, sleeping, or busy with other activities.

Some packages work in the DOS environment, but the vast majority of current software offerings are Windows-compatible to varying degrees. In the case of 32-bit operating systems (Windows 95 and later), you do need to look at the matter of Windows compatibility. Virtually all programs work with W95/98 and often NT. Later Windows releases can be problematic, a factor you should look into, depending upon your operating system.

Home-built interface projects are uncommon. I have attempted to fill this void by documenting a construction project for the interface circuit shown in Figure 7.1. The

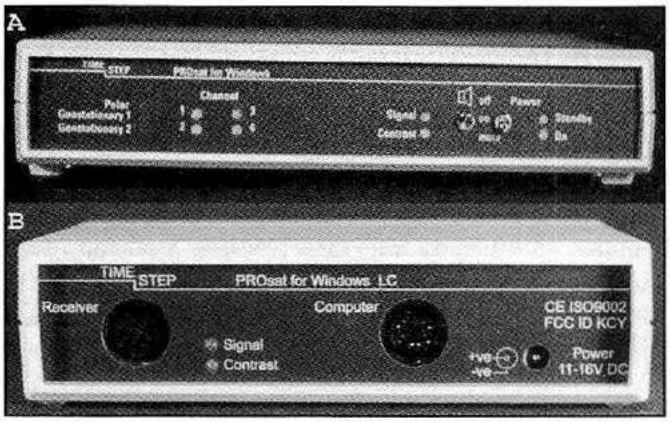


**Figure 7.2**. An example of two external interface units from TimeStep, Ltd. **[A]** is their top-end ***PROsat for Windows*** while **[B]** is the less-elaborate ***PROsat for Windows LC.*** Both units interface to the station computer, using a high-speed serial port.

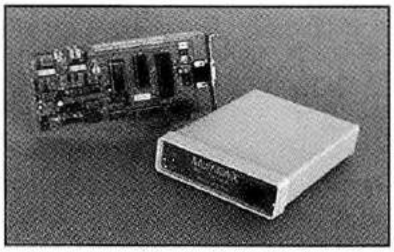


**Figure 7.3**. MultiFax, Inc. offers two similar interface circuits, supported by the same software package, but with two different form factors. One is an internal ISA bus card, while the other is an external unit that interfaces to the computer via a serial port.

project is included on the *ICH* CD-ROM as a complete construction package, including a complete parts list keyed to the DigiKey catalog, construction information, Gerber printed circuit board files, and a free software package. In addition, information is included on integrating the interface into the Hamtronics R139 receiver. Most of the APT images in this volume were obtained using this interface and software, operating in a completely unattended mode, an option that will be discussed further later in this chapter. One of the advantages of this particular package is that it will operate with virtually any PC, allowing a less capable machine to handle image acquisition 24 hours a day without losing images because your main computer system is being used for other jobs.

**Internal interface** boards were once quite common, but relatively few are currently available. One of these, marketed by MultiFax, is shown in Figure 7.3. These cards are quite convenient when using a display system based on a desk-top computer, since the interface is internal to the computer and thus doesn't take up space at the operating position. This approach also eliminates the need for an external power supply, since the computer supplies the necessary operating voltages. The connection between the receiver and the internal card is made using connectors on the card rear-mounting bracket, in common with other PC-compatible plug-in cards. Most of the boards that are still available are designed for use with the older **ISA** bus standard. Current computers tend to have few if any ISA slots, since the ISA architecture has been largely supplanted by the **PCI** bus, which supports faster I/O and the PC "plug-and-play" standard. If your computer has a spare ISA slot and you can locate one of these boards, it can provide excellent service.

A more complex implementation of the internal board approach was implemented by manufacturers such as Quorum, who marketed cards that included both the interface circuitry and a complete, synthesized APT receiver (**WEFAX Explorer** and related models). These were excellent products, providing a high-degree of station integration; but most have been discontinued with the decline of the ISA bus in favor of PCI architecture. Because the cards also contained the receiver circuits, they typically required a full-length AT ISA slot — even rarer in current computers. If you can locate one of these units and your computer has a full-length card slot, you should certainly consider using it.

### SOUNDCARD OPTIONS

As a complete DSP-based sound sub-system, a typical PC sound card has all the resources to function as a weather satellite interface. If you select this option, all that is required is a suitable program. Evolution of weather satellite sound card software is considerably behind what has been accomplished in SSTV in terms of the number of programs available, but there is an excellent program, ***WXSat***, that is widely used. WXSat was written by Christian Bock and is distributed as freeware for non-commercial use. A copy of **Version 2.59e** of this program is included on the *ICH* CD-ROM. ***WXSat*** has a number of very useful features, beyond basic image display, which will be noted in later sections. David Taylor has been doing some excellent software development in Scotland and his home page — with lots of software download options — can be reached through the **Members Pages** section of the RIG Web site (**http://www.rig.org.uk/**).

## APT AND WEFAX IMAGE FORMATS

Each of the APT and WEFAX spacecraft transmits its images in somewhat different formats; but there are basic similarities in subcarrier modulation, and most transmissions are at either 120 or 240 lines/minute. Your software is constructed to handle the different image formats, but it does help to understand how the images are organized so you can understand what you should be seeing. The details of the various APT and WEFAX formats will be briefly described in the sections which follow.

### TIROS/NOAA APT FORMAT

The basic line scan rate for TIROS/NOAA APT images is 120 lines/minute, so each line has a duration of 500 ms (**Figure 7.5**). In the case of a daylight pass, the first half of each line (250 ms) consists of thermal infra-red (IR) image data, while the second half (250 ms) is visible-light data. Despite differences in detail, the general organization of each line sub-segment is essentially the same.

**Sync Pulse**. Each sub-segment begins with a characteristic sync pulse, consisting of seven cycles of black to white subcarrier modulation. The two sync pulses do differ with respect to the frequency of the sync pulse train. The IR line sync pulse if 832 Hz while the visible pulse is 1040 Hz. If the system software is designed to detect the IR pulse, the result will be the display sequence shown in **Figure 7.4**. However, if the display is triggered by the 1040 Hz visible pulse, the line, as displayed, would appear to begin with visible light data, followed by IR. While both IR and visible light data can be displayed simultaneously, as shown in Figure 7.5, there are several display options, depending upon how the software handles the image sampling. For example, let's assume the software contains a routine to detect the 832 Hz IR line pulse and that the pixel clock operates at 4096 Hz (2048 cycles/APT line):

- **Simultaneous IR and Visible Display**. If the software detects the IR sync pulse, loads one pixel and each clock transition for a total of 2048, and then starts another line, the result will be the side-by-side display of IR and visible light data.
- **IR Data Only**. Alternatively, the software can detect the IR pulse, load image pixels for the next 1024 clock pulses, and then delay another 1024 pulses before starting again. In that case, only the IR image data will be displayed.
- **Visible Data Only**. In contrast, the software detects the IR pulse, delays for 1024 clock cycles, loads the next 1024 pixels, and then starts a new line, only the visible light data will be displayed.

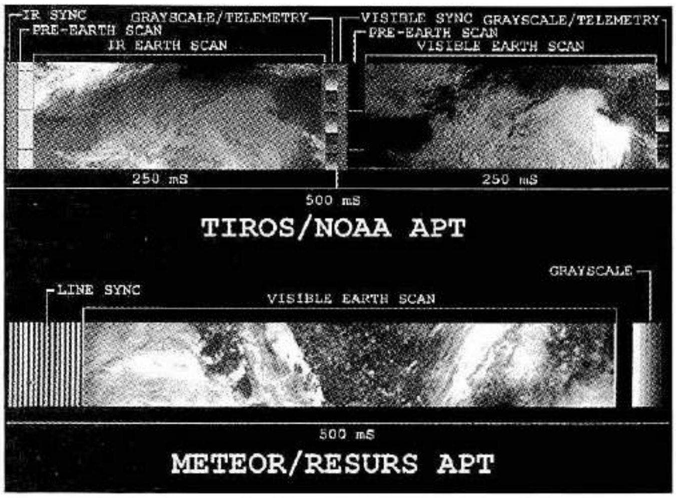


**Figure 7.4.** Basic organization of TIROS/NOAA and METEOR/RESURS APT images.

Most software will give you the option of simultaneous display if visible and IR data or the option to display just IR or just visible data.

**Pre-Earth Scan**. For a short interval prior to the actual Earth-scan, the sensors next will be scanning space beyond the horizon as seen by the spacecraft. The "Pre-Earth" interval looks quite different for IR or visible light data, and it lets you immediately determine which data you are viewing. Since space is cold, it will display as white in the thermal IR data but looks black in visible imagery. During the pre-Earth scan, the onboard computer inserts minute marks into the pre-Earth data. The minute marks are derived from the spacecraft master clock and consist of a set of black and white horizontal lines. The black line component shows up well in the white IR pre-Earth scan while the white line stands out in the visible-light equivalent. If you count the minute-markers in Figure 7.4, you will note that this short sample represents approximately 3 minutes of image data.

**Thermal Calibration/Telemetry**. The step-like grayscale display at the right edge of the IR readout includes thermal calibration data for the IR sensors (used when converting IR image brightness values to absolute temperature of objects in the image) and spacecraft telemetry information.

**Visible Sync Pulse**. The sync pulse that starts each visible line segment consists of a seven-pulse sequence at 1040 Hz.

**Visible Pre-Earth Scan**. As was the case with the IR data, the visible light sensors also scan a narrow view of space prior to the actual Earth-scan. In visible light this zone will appear black. Paired black and white minute-markers are inserted here as well, but in the case of visible light data, it is the white component of the minute-markers which is evident against the black background.

**Visible Earth Scan.** The orbits of US APT spacecraft bring them overhead relatively early in the morning and late in the afternoon — assuming the normal two operational spacecraft, so lighting conditions are highly variable, depending upon the season. In the height of summer, lighting conditions can be relatively uniform. In contrast, the low sun angles at high latitudes in the winter months can make visible light imagery somewhat marginal. At low latitudes there is comparatively little seasonal variation.

**Grayscale/Telemetry**. The step-like display at the far right of the visible light sequence represents sensor calibration and telemetry data.

It should be emphasized that the TIROS/NOAA spacecraft are transmitting APT data continuously, so there is no functional sub-division of the image into "frames". The vertical dimensions of the image are dependent upon how much of the image data from any particular pass was captured and displayed. The maximum amount of useable data can be obtained on an overhead or near-overhead pass where almost 14 minutes of image data could be displayed.

In practice, you will see two primary variants on this basic image structure. At night, the visible data are replaced by water vapor IR data, essentially resulting in side-by-side display of a pair of IR images. You will see some examples of this later in the chapter. The second variation concerns the direction of the satellite pass. When the spacecraft passes from north to south (a ***descending*** pass), geographic features will be displayed in a "normal" orientation with north at the top. However, if the spacecraft passes from south to north (an ***ascending*** pass), the image will appear to be upside-down. This is easily rectified by simply rotating the image. However, the overall orientation of the image with respect to the features just discussed will be different, depending upon whether the image was derived from an ascending or descending pass. In either case, all the features will be present, but they may appear to be placed differently with respect to the image. Systems that trigger on the visible (rather than IR) sync pulse will also appear to be structured slightly differently when displayed at the 120 lpm rate. It should also be noted that, given the very wide dynamic range of the TIROS/NOAA sensors, some image processing is always desirable to optimize the appearance of the image — a subject that will be discussed later in the chapter.

### *METEOR/RESURS APT FORMAT*

Typical Russian APT transmissions are similar to US APT data in some respects in that they employ essentially the same subcarrier modulation format and a 120 lpm continuous transmission format; but otherwise they are simpler in structure, since only daylight visible data are transmitted. Each image line begins with a wide line sync pulse (Figure 7.4), followed by the visible light earth scan, and ending with a mult-step grayscale display. In many cases, but not all, the narrow black zone immediately to the left of the grayscale is occupied by a narrow bar-code-like display that apparently contains spacecraft ID and telemetry data.

Some Russian spacecraft have included experimental IR imaging systems, but these are not operational; and most typically have not lasted long in the spacecraft that carry them. Most Russian METEOR/RESURS spacecraft simply shut down on the night side of the earth, turning on again as their orbits bring them back into sunlight. Ground controllers typically shut these spacecraft down if their orbits do not provide good lighting conditions. Since most of the 500 ms line is devoted to the visible imaging data, these spacecraft also have a higher effective resolution then comparable US satellites. The dynamic range of the image sensors appears to be strongly biased toward the bright end of the intensity range, and ground detail is poorly resolved (with respect to tonal resolution) during the summer months. These spacecraft are at their best during the winter months, as their orbits provide passes much closer to mid-day than do US APT spacecraft; and the imaging systems are superb in terms of resolving ice and snow features. Despite the fact that they are limited to daylight passes, the Russian APT spacecraft nicely complement the features of the US TIROS/NOAA spacecraft. Image processing is rarely required for typical pictures, although it may be used to bring out land/water boundaries in summer images to help with geographic orientation.

### *WEFAX FORMAT*

Unlike the polar-orbit spacecraft, which generate their images in real-time, WEFAX transmissions are formatted by the control stations on the ground and the geostationary spacecraft simply act as a relay — essentially a repeater in space. WEFAX images are also similar to other non-satellite image modes which we have examined in that they are transmitted as discrete frames. Subcarrier modulation is identical to the APT spacecraft and the images are transmitted at a 240 lpm rate (250 ms/line). A typical image will have 800 lines (200 seconds or 3 minutes and 20 seconds per frame), although the number of lines does vary with the specific product being transmitted. A typical WEFAX transmission has the following format:

**Start Tone**. The subcarrier is shifted between black and white limits at a 300 Hz rate for a total of 5 seconds — the so-called "start tone". The software uses this signal to initiate frame acquisition.

**Phase Interval**. This interval is designed to make it easy for the display system to synchronize with the upcoming frame transmission. The subcarrier is held at white level except for short intervals (~12 ms) and the 240 lpm rate, where the subcarrier drops to black level. These short "phasing pulses" represent line sync pulses and are easily detected, given the contrast in subcarrier level. The phasing interval lasts 15 seconds for US GOES and 5 seconds for the METEOSAT spacecraft. Once the phasing pulses have been detected, subsequent image display is typically done by reference to the interface clock.

**Frame Interval.** The phasing interval is followed by the actual transmission of the image data. As noted previously, a typical frame consists of 800 lines and thus requires 200 seconds for transmission and display.

**Stop Tone**. At the end of the frame, a short (typically 5-second) tone is transmitted. This tone is similar to the start tone, but the subcarrier is modulated at a 450 Hz rate.

Operational WEFAX spacecraft typically transmit over 300 images each day on a regular schedule, making it very simple to acquire just the pictures you want to see. Because WEFAX images are formatted by ground computers, image enhancement is rarely needed.

## APT SATELLITE TRACKING AND PREDICTION

With a functioning receiver and interface, the major operational problem is to know when you can expect to hear the various polar-orbit APT spacecraft. You can calculate this information manually, but most operators will use tracking and prediction software.

### *WINDOWS SOFTWARE*

The flashiest examples of satellite tracking programs are those designed to take advantage of the display capabilities of Windows-based PCs. Virtually all Windows tracking programs can be found listed, including download or purchasing links, through two Internet sources:

- T.S. Kelso's **Celestrak** Web site (**http://www.celestrak.com**) — just click on the **Software** link.
- The **AMSAT** (Amateur Satellite Corporation) Web site (**http://www.amsat.org**). Many of the Windows-based programs listed here are fund-raisers for AMSAT and there is usually a reasonable discount for AMSAT members.

These programs are too extensive to discuss in any detail, but all of them tend to share a few characteristics:

- The ability to simultaneously track a large number of spacecraft (200 or more in some cases)
- The ability to portray the current position of these spacecraft in a wide variety of ways, including:
  - Ground-track displayed on mercator projections (like the "wall" in NASA's Mission Control)
  - Ground track displayed on various global projections
  - Spacecraft position and track displayed against a local sky projection
- The ability to generate standard format serial tracking data to actuate el/az antenna tracking rotators.

These are generally quite spectacular programs and very impressive if you want to provide a compelling display for visitors to your station.

### *ORBITAL ELEMENTS*

In order to provide useful output, any tracking program must have accurate and current data with respect to a spacecraft's orbital parameters and position. All of this information, most commonly formatted as **Keplerian element** files, must be current. The actual position of a spacecraft and its orbital parameters are constantly being altered to small degrees by residual atmospheric friction, the variations in the Earth's gravitational and magnetic field, the gravitation "tug" of the moon, sun, and other planets, and a range of other, more minor factors. For greatest tracking accuracy, the Keplerian file data should be no more than a week or so out of date. If the data file is too far out of date, the predicted pass data for most spacecraft, but particularly those in relatively low orbits, will be meaningless.

I will discuss the structure of these files shortly, but the first-order problem is where to get a current version of these data. The answer, like the answer to so many questions these days, is via the Internet! Most satellite equipment vendors maintain FTP sites where you can download current element files, although there is some variation in how current the files from various sources actually are. One consistent source of current data is T.S. Kelso's **Celestrak** Web site (**http://www.celestrak.com**). What is nice about this site is that it provides several download options, each containing different collections of satellites. You will want to select the ***Weather*** option, since that file is limited to weather satellites. The file, which you will typically download as ***weather.txt***, will require some modification to eliminate extraneous spacecraft. That procedure is described in the section to follow.

### *DOS PASS SCHEDULING*

While impressive, the Windows-based programs are generally over-kill for a basic weather satellite station with a simple omni-directional antenna. The kind of information we require for a simple satellite ground station is much more basic — when will a specific spacecraft be above our horizon (the only time we can receive its signal), and how good will the pass be? That information is easily generated by a very nice DOS freeware program known as ***Pass Scheduler*** which also will operate under Windows. The program was written by T.S. Kelso and is available for download via his **Celestrak** Web site at **http://www.celestrak.com/software/tskelso-sw.html**.

Before getting into any detail with respect to using the program, it would be useful to do two things at the outset:

- **Make a directory for your tracking files**. From DOS, type **cd** and **<ENTER>** to get to the root directory. Type **md\sat** and **<ENTER>** to create a SAT directory.
- **Set your computer clock to GMT/UTC time**. Although most tracking programs accommodate the offset between your local time and **coordinated universal time** (UTC or the older GMT), all spacecraft operations are relative to UTC time. If you insist on juggling between that and local time, the result is sure to be confusion and errors. Much confusion can be avoided by setting your computer time and date to UTC. From DOS, type **time**, hit **<ENTER>** and then type the current UTC time (in 24-hour format, for example, 1:30 PM is 13:30:00) and hit **<ENTER>**. If the current UTC date is different from your present current date, change the date using the date option from DOS. It is possible to do all of this from the Windows desktop, and you may do it that way if it is easier for you. It is very important that the time entry is precise. Key in for the next full minute, wait for the precise time to arrive, and then hit **<ENTER>**. You should update the time every week or so for maximum accuracy unless your operating software uses **GPS** input, in which case you need not worry about time updates.

The file you will download (preferably to your new SAT directory), ***passcheduler.zip***, must be "un-zipped" at which point you will see the following files:

- ***passched.exe*** — this is the DOS program itself.
- ***passched.cfg*** — this is the primary program configuration file that you must edit to meet your needs as described below.
- ***home.obs*** — this information relates to your ground station location and must be edited as described below.
- ***noaa.tle*** — this is a sample Keplerian element file, a subject we will discuss shortly.
- ***passched.txt*** — information on how to get the Pass Update software, which you should not require.
- ***passupdt.txt*** — a text file describing the program functions and operation
- ***schedule.txt*** — this is a sample of the output data generated by the program.

Three files (***passched.cfg***, ***home.obs***, and a current Keplerian elements file) will need to be edited without making other, unwanted changes to the file contents or name. The easiest tool to use for this editing is the Notepad program that is supplied with Windows. If you haven't used this program before, you access it as follows:

1. Click on **Start** from the Desktop
2. Move the cursor to **Programs** in the new window
3. Move the cursor to **Accessories** in the new window, where it is probably the first selection listed
4. Move the cursor down the list on the new window and double-click on **Notepad**
5. Resize the program window to full-screen
6. Move the cursor to **File**
7. Click on **Open**
8. Change the **File Type** to **All Files**
9. Use the **Look in:** window to get to the directory with your tracking files
10. Double-click on the file you want to edit

When you are through with a specific file, simply use **File** and **Save** to save the file precisely as you have edited it. Note that if you close the current file, you will be back to the Desktop and you will have to go through all the steps above to work on another file. To avoid this, do not close but simply go to **File** and **Load** another file — it will replace the current one without the need to go through all the extra steps!

**Passched.cfg**. The essential pieces of this file are shown in **Table 7.1**. You should edit the left-side entries as shown. Basically, you are telling the system that you will have a zero-hour offset from UTC (line 1), you will not correct for daylight saving time (line 2), and that you will echo and save the satellite predictions (lines 3 and 4). The last two lines point to the resource files we will be editing in the next section.

**Home.obs**. This is the file that tells the program where your station is located — an essential set of data if the software is to determine when a spacecraft will be within range at your station. It is a simple, single-line file (**Table 7.2**) but it is important that you format the data carefully to avoid problems when you run the program. Latitude and longitude data are expressed in degrees and minutes (to two decimal places), much as you would get from a GPS receiver display. This, a latitude of 42°37.34 N would be entered as 42 37 34. If your latitude is less than 10 degrees, include a leading-edge zero. The same convention applies to longitude values less than 100 degrees. You can obtain your latitude and longitude from GPS receiver, many atlases, or from the local airport. If your longitude or latitude coordinates are in degrees, minutes, and seconds, simply divide the seconds by 60 and add the decimal value (rounded off to two places) to the minutes. Thus:

54°41' 28" N = 54°41.47 N (28/60 = 0.47)

The last entry is your elevation in meters (rounded to the nearest meter or even 10 meters is entirely adequate). Unless your topography is highly variable, an elevation obtained from the local airport or your Public Works department will be adequate. In the United States, elevation will probably be in feet. To convert the elevation to meters, divide by 3.28. For example, if your elevation is 2500 feet:

2500/3.28 = 762.195 = 760 meters

In this example I have rounded the value to the nearest 10 meters — more than sufficient accuracy.

### *KEPLERIAN ELEMENT FILES*

In a previous section we discussed where to obtain updated files of Keplerian orbital elements. If you choose the "Weather" option from T.S. Kelso's **Celestrak** Web site (**http://www.celestrak.com**), you will end up with a moderate-size text file (weather.txt) that contains element data for all weather-related spacecraft that are still in orbit. Some are irrelevant with respect to tracking (all the GOES and other geostationary spacecraft), while others are no longer active or not commonly available (such as the Ukrainian OKEAN/SICH spacecraft). While you could leave all of these in place, it is more work to sort through them each time you use the program. The easiest approach is to use Notepad to edit out spacecraft you do not intend to track. **Table 7.3** shows a sample of such an edited file. Note that the data for each spacecraft consists of three-lines — even though the format is referred to as two-line elements. The first line contains the spacecraft name, while the two remaining lines are made up of cryptic-looking numerical data. You want to cut out the three lines for any irrelevant spacecraft while leaving the three-line sets for the spacecraft you do wish to track. It is important when editing out unwanted spacecraft **that you do not alter the remaining files in any way**! When you have finished removing the lines you do not want, click **File** and then **Save As**, and save the file as **weather.tle**.

**Table 7.1.**

**Sample data from the PASSCHED.CFG configuration file for use with the *Pass Scheduler* program. See text for explanatory notes.**

```
0             % Time difference from UTC (hours)
N             % Allow for Daylight Savings Time
Y             % Echo satellite data
Y             % Echo schedule to disk file
              % Default drive for support files
              % Default directory for support files
HOME.OBS      % Default observer database
WEATHER.TLE   % Default satellite database
```

### *TAKING PASS SCHEDULER FOR A TEST DRIVE*

At this point you have all the files that you need to actually try the program. Proceed as follows, assuming you have installed the files in a \Sat directory. (Use your directory path if you have not.)

1. Click on **Start**, move mouse to **Programs**, scroll down and click on **MS-DOS Prompt** to get into DOS
2. Type **cd\Sat** and **<ENTER>** to get to your satellite directory
3. Type **passched** and **<ENTER>** to start the program
4. You should see the opening screen: key **<ENTER>** or any other key to move on...
5. The **Select observer database** prompt should be showing HOME.OBS as highlighted. If not, scroll to it with the keyboard arrow keys and key **<ENTER>**...
6. The next prompt will be **Select satellite database**. First you will be asked if you want to update the databases. Key <N> (no) because we already did that manually...
7. Next you should see a list of the various TLE files. In this case, you should see **NOAA.TLE** and **WEATHER.TLE**. **WEATHER.TLE** should be highlighted, but if not, scroll to it with the arrow keys and key **<ENTER>**...
8. Next you will see a listing of all the spacecraft in your WEATHER.TLE file. You can select as many as you wish — just highlight the desired file using the arrow keys and key **<ENTER>**. The selected file will be marked with an asterisk (*) on the list. For this demonstration I selected NOAA 14. When you have selected the last spacecraft you wish to track, key the **<ESC>** key.
9. The next prompt is **Specify the time interval of interest**. The first option in this area is the starting time. The default time and date for starting is always the current

**Table 7.2.**

**Required data for the HOME.OBS file when using the *Pass Scheduler* program. See text for an explanation of the entries.**

shapeTypeTAB0702.PCXbe852a13ea611e3fb00c75c7f8d4f501be852a13ea611e3fb00c75c7f8d4f501 day and time. You can over-type an alternate day/time for starting or just key **<ENTER>** to accept the default. For this demonstration I used the current day and time — 30 Jan 2002 at 0400 UTC.

10. Next you will be asked for a finish date and time. The default is 24 hours from the current date and time, but you can select any finish time-frame you wish. Keep in mind that going past a month or so is pushing the reliability of even fresh Keplerian element data. For this demonstration I selected the default 24-hour option of 31 Jan 2002 at 0400 UTC.
11. The next prompt is **Specify observing conditions**, which has three data entry options. The **Minimum elevation** represents the **smallest** value you want to accept for how high, in elevation, a particular pass will reach. The default is 10 degrees, which I selected for this demonstration. The second entry is the **Mask angle**, and you should select the default value of 0. Finally, there is the **Minimum duration**. Select the default value of 00 minutes.

While this seems like a lot of data entry, it is over in 20-30 seconds once you know the program. When user entry is complete, the program will scroll the satellite pass schedule on your screen and also write it to a disk file — **schedule.txt**. You can call up the file with a word processor (or Notepad) in the text mode and print it if you wish. **Table 7.4** shows the sample schedule file I generated to demonstrate the program. The schedule file is organized into three blocks. The first summarizes the data for the observing location and the time and elevation parameters you provided. The second major block repeats the Keplerian file data for the satellite(s) you selected, with one important addition. Note that on the far right of the first line a date and time has been inserted that was not present on the original Keplerian file. This is the date and time for the reference data for this spacecraft. Note that it is about two weeks old (relative to the date of the current schedule) and thus moderately fresh. If the offset between the reference and schedule dates stretches out much beyond three weeks, it's time to return to the Internet and get some fresh data. The reference date and time information can help you select a download site that updates Keplerian files frequently.

Finally, the third block is the actual satellite schedule (which can be very extensive if you selected several satellites and a wide time window). In this case, I was only interested in one satellite (NOAA 14) for a 24-hour period, so there are only five passes listed. Aside from the satellite name and date, there are three blocks of data for each pass:

- **RISE**. This is the time (hours, minutes, and seconds UTC) that the satellite will rise above your horizon. This is also known as **AoS** (**A**cquisition **o**f **S**ignal) since it is typically the earliest time you can expect to hear the spacecraft. The **Az** (azimuth) and **El** (elevation) values after **Rise** show the direction and elevation (always 0 for Rise or AOS) where the satellite will appear above the horizon.
- **ToC**. This is an acronym for Time of Culmination — a technical way of saying that the time, azimuth, and elevation listed represent the highest point in your sky that the pass will reach. The higher the elevation at ToC the better the pass will be in terms of both signal strength and pass duration.
- **SET**. This represents the time, azimuth, and elevation (again, always zero) where the spacecraft will set or drop below your local horizon. This is also known as **LOS** (**L**oss **o**f **S**ignal) since you can expect to lose the satellite signal as it drops below your horizon.

The best simple prediction of pass quality is the elevation at **ToC**. The first pass, starting at 11:12:00 UTC will reach 51 degrees and will be a pretty good one. The next two passes only reach 24 and 16 degrees, respectively; and I usually wouldn't bother with them. The fourth pass in our scheduling interval, starting at 22:38:46 UTC will reach 81 degrees elevation and should be excellent, while the final pass, reaching only 10 degrees, will be pretty poor. **The Minimum elevation** entry as the program boots is really asking how low you want to go in accepting passes with respect to elevation at **ToC**. When setting up for automatic operation (discussed later) I usually enter **35** degrees as the minimum elevation. That way, all passes listed must have a maximum elevation **(ToC)** of **at least 35 degrees** and thus can be expected to be pretty good. If I had done that for this demonstration, only the passes at 11:12:00 and 22:38:46 UTC would have been listed. The point is, the program lets you filter passes according to your own criteria and objective.

**Table 7.3.**

**A typical file of "two-line elements". This particular file contains data for six spacecraft. See text for an explanation of how to edit such files for use with the *Pass Scheduler* program.**

```
NOAA 12
1 21263U 91032A   02014.98364314  .00001103  00000-0  49431-3 0  4662
2 21263  98.5902   7.3164 0013753 104.1670 256.1037 14.24462142554310
METEOR 3-5
1 21655U 91056A   02013.92133165  .00000051  00000-0  10000-3 0  4542
2 21655  82.5562 321.8876 0014717 119.4773 240.7818 13.16949410500740
NOAA 14
1 23455U 94089A   02015.00785132  .00000587  00000-0  34017-3 0   330
2 23455  99.1891  17.8967 0008693 272.2018  87.8155 14.12953558363047
NOAA 15
1 25338U 98030A   02015.02796376  .00000654  00000-0  30437-3 0  5002
2 25338  98.5826  42.4075 0011247  43.8625 316.3444 14.23853681190934
RESURS O1-N4
1 25394U 98043A   02014.74453076  .00000745  00000-0  34748-3 0  1414
2 25394  98.6708  94.2759 0001262 156.2339 203.8899 14.23421301182640
METEOR-3M
1 27001U 01056A   02012.68076268  .00000138  00000-0  21472-3 0   262
2 27001  99.6479 247.4059 0014243 198.8186 161.2432 13.68144103  4512
```

The data from ***Pass Scheduler*** are not comprehensive enough to track the spacecraft with an el/az antenna rotor, but we don't need that kind of detail when using an omni-

**Table 7.4.**

**Output of the *Pass Scheduler* program for a single day's passes of the NOAA 14 spacecraft. See text for the interpretation of the information.**

```
Observing Site:   Mason, MI          Start time:  2002 Jan 30/0400
                  42 34 37 N         Stop time:  2002 Jan 31/0400
                  084 26 37 W        Min elevation:  10 degrees
                  300 meters AMSL    Mask angle:   0 degrees
-----------------------------------------------------------------
      NOTE: All times are Coordinated Universal Time (UTC)
-----------------------------------------------------------------
NOAA 14                                2002 Jan 15/0011
 1 23455U 94089A  02015.00785132 .00000587 00000-0 34017-3 0  330
 2 23455  99.1891  17.8967 0008693 272.2018  87.8155 14.12953558363047
--------------------------------------------------------------------------------------------------
Satellite   Date          Rise      Az    ToC    Az       El    Set   Az        El     Vis
--------------------------------------------------------------------------------------------------
NOAA 14     2002 Jan 30   111200    19    0      111950   100   51    112733    182    0
NOAA 14                   125301     2    0      130005   298   24    130707    233    0
NOAA 14                   10016    114    0      210644    58   16    211313      2    0
NOAA 14                   223846   166    0      224638   256   81    225435    345    0

NOAA 14     2002 Jan 31   002213   223    0      002804   273   10    003359    322    0
--------------------------------------------------------------------------------------------------
```

directional antenna. What we do need to know is when a specific spacecraft can be received and whether the pass is likely to be good enough to copy. ***Pass Scheduler*** does that with a high degree of accuracy and minimal complexity!

## LOCATING GEOSTATIONARY SPACECRAFT

Compared to the dynamic orbits of APT spacecraft, geostationary satellites such as GOES and METEOSAT are extremely easy to work with for the simple reason that they don't appear to move! They do orbit the Earth above the equator; but since their orbital period is precisely 24 hours, they stay in step with the rotating Earth below. Therefore, they remain over the same point on the equator and thus appear stationary in the sky when viewed from the Earth. Chapter 6 described the mechanics of aligning your geostationary satellite antenna but skipped how you get the azimuth and elevation data to begin with!

Most of the Windows-based tracking programs can handle geostationary spacecraft and thus will generate the required bearings. For those taking a simpler approach, there is a program on the *ICH* CD-ROM, ***geosat.exe***, that will give you bearings to start the antenna alignment procedure. To run this program, you must edit two lines of the ***geosat.dat*** file that is available with the alignment program. You can use Notepad to edit the file, the first ten lines of which are shown in **Table 7.5**. You will need to alter lines three and four to reflect the latitude and longitude of your station. Line #3 is the longitude data. (The value of **4234.07** that you see in Table 7.5 represents my latitude: 42 degrees 34.47 minutes North). You should substitute your latitude, using the same format. If you are located in the southern hemisphere, enter the latitude as a **negative** number. Line #4 is station longitude and uses the same format conventions. The program expects all latitude values to represent degrees West; so if you live in the eastern hemisphere, you will need to convert your normal degrees East coordinates to degrees West. Use the following equation:

$$W = 360 - E \tag{7-1}$$

where W is the latitude in degrees W and E is the latitude in degrees E.

To run the program from DOS, just type *geosat* and hit <ENTER>. The program will then display elevation and azimuth values for any of the geostationary weather satellites in range of your station. Once the values are displayed, hitting any key will return you to DOS.

## STATION OPERATION

### *SOURCES OF OPERATIONAL INFORMATION*

In the earlier discussion on tracking and scheduling, I noted that you edit the Keplerian element file so it contains only "active" spacecraft. So how do you know which of the many spacecraft in orbit are still transmitting pictures and what frequency they are using? The most authoritative information sources are the Web sites maintained by the governmental agencies that actually operate the spacecraft in session. These sites are designed to keep users up-to-date on the status of the various spacecraft sub-systems and operating frequencies. They are also excellent sources of information on future plans and programs for the various agencies.

- For the **US NOAA APT** and **GOES WEFAX** spacecraft, the most authoritative information source can be found at **http://www.noaasis.gov/NOAASIS/**. From this page there are links to all the status information you might require for both APT and WEFAX systems.
- Information on the **METEOSAT** spacecraft can be found at the EUMETSAT Web site at **http://www.eumetsat.de**.
- The Japanese meteorological agency, which operates the

**Table 7.5.**
**Contents of the *geosat.dat* file. See text for details of modifying this file for your location.**

```
7
HOME STATION
4234.07
8430.48
METEOSAT
0
0
GOES E
0
7500.00
```

**GMS** geostationary spacecraft, has a Japanese language Web site. Fortunately for non-Japanese speakers, Kochi University maintains a comprehensive English Web site at **http://www.kochi-u.ac.jp/index-e.html**.

- Comprehensive information on the Russian program is much less accessible. Useful information sometimes can be obtained from the Russian Space Research Institute site (**http://smis.iki.rssi.ru/**).

Many of the equipment vendors do provide update pages as does the RIG Web site (**http://www.rig.org.uk/**). At times these sources can be quite current; but they also can be considerably out-of-date. The later discussion on unattended operation contains some suggestions for simple techniques to determine whether specific spacecraft are active.

### *WORKING WITH TIROS/NOAA IR IMAGERY*

In operational terms, the various IR data channels of the TIROS/NOAA spacecraft must be considered the primary imaging system. IR data are available day or night and represent the prime data source for forecasting and other weather service activities. The IR sensors respond to thermal radiance differences in the various channels, and the apparent contrast or dynamic range of any scene is a function of the temperature gradients in the scene being imaged. At tropical latitudes, warm (or even hot in the case of deserts) ground and water temperatures contrast well against cooler cloud features; and the images may not look greatly different from how they would appear in visible light. At higher latitudes, however, there is a smaller thermal radiance gradient; and the image dynamic range/contrast is significantly reduced. The problem of limited dynamic range is at its worst during the winter months in general, especially as ground temperatures can be very low.

In the pre-computer age of amateur weather satellite activity, IR images incited little interest as they tended to be very light and "washed out", compared to the more interesting visible-light images. Today, with the availability of digital image processing, both IR and visible imagery are equally interesting. Some satellite software has built-in image processing functions, while other programs save the raw or primary image (typically with 8-bit coding/256 grayscale values). These you can use later as the subject of enhancement experiments, using the routines available in most photographic software packages.

During the day, a typical TIROS/NOAA line will include one visible-light and one thermal IR channel. At night, the visible channel will be replaced by water vapor IR data — probably the most challenging images you will ever deal with. **Figure 7.5A** shows a water vapor IR image from a pass almost directly over the author's station in Michigan. The problem with this image is highlighted by the pixel brightness histogram that appears immediately below the image. The histogram plots the relative number of image pixels over the 0 (black on the left) to 255 (white on the right) dynamic range. You can see that most of the pixels in the image occur in a very narrow peak near the white end of the contrast range. As a result, the image is very light with very little contrast. The appearance of this image can be enhanced greatly by "stretching" the pixel distribution so it covers a greater part of the total dynamic range. This is precisely what has been done in Figure 7.5B, where the same image is shown after the application of an image processing routine known as **equalization**. Note that the shape of the pixel distribution has not changed; but the whole distribution has been stretched from a narrow peak to a broader peak, covering approximately two-thirds of the total dynamic range. The result is an obvious increase in image contrast. Note that when the pixel distribution is stretched, we cannot increase the number of image pixel values (there being only so many in the original narrow peak), but we simply stretch them out over a greater portion of the potential dynamic range. Since there were about 32 different brightness values in the original peak, the discrete values of which are clearly evident in the stretched version (Figure 7.5B), the enhanced image still has comparatively little contouring.

It is very easy to "over-do" such enhancement. **Figure 7.7** shows a small segment of a water vapor IR image where the pixel distribution has been stretched across the entire

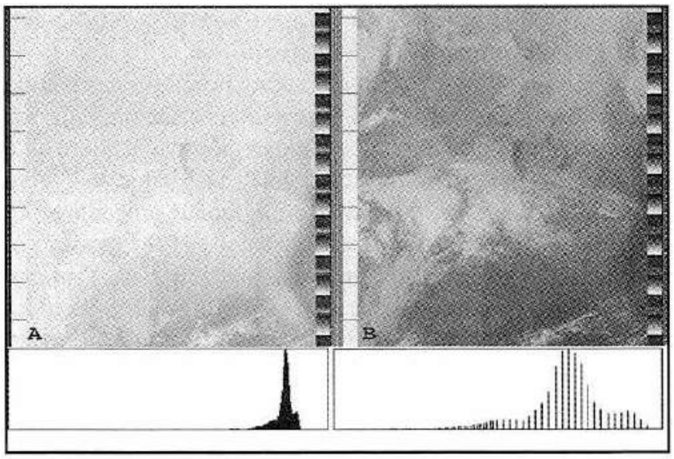


**Figure 7.5.** Of all the various APT products, water vapor IR has the smallest dynamic range, particularly during the winter months. **[A]** shows a water vapor IR image from a TIROS/NOAA pass. Immediately below this image is a histogram of the pixel brightness distribution (black on the left and white on the right) for the image. **[B]** shows the same image (with the pixel histogram below) after a moderate equalization image enhancement.

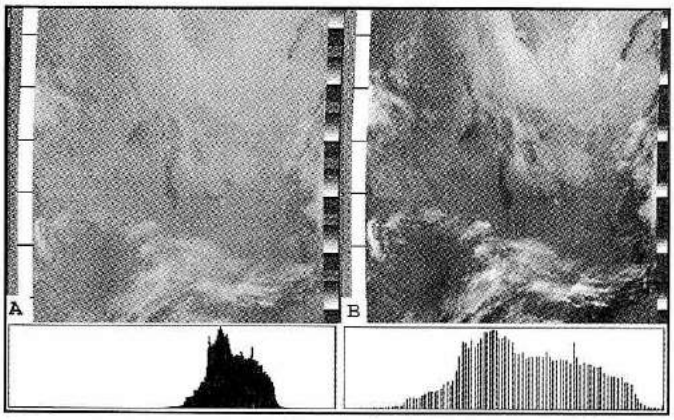


**Figure 7.6**. Typical thermal IR images have a wider dynamic range than water vapor IR, but the images still look washed out and tend to be biased toward the upper end of the dynamic range **[A]**. Moderate equalization enhancement **[B]** can transform them into pretty spectacular images. This was a near-overhead pass at the author's station, and the image coverage extends from the western Atlantic and east coast of the US and Canadian Maritimes across the Great Plains almost to the Rocky Mountains in the west. In the north-south axis, the image extends from the cloud-covered Gulf coast to the mouth of James Bay in the north. NOAA visible imagery is rarely useful during the winter months, so the ability to enhance IR images is a great asset.

dynamic range, yielding an image with very high contrast. Unfortunately, the image also looks terrible. In effect, the narrow peak of pixel values has been over-enhanced, amplifying every possible problem with the image. Enhancement artifacts, which can seriously detract from an image, can result from several factors:

- Small brightness artifacts resulting from the image sampling, particularly with DSP/sound card systems.
- Residual noise on the image, which can become very obvious with excessive image enhancement.
- Very low levels of 60 or 120 Hz "hum" on the receiver output which would not be obvious or even evident, with less extreme processing.
- The number of grayscale values will be limited, typically resulting in significant image contouring.

Thermal IR images typically require less drastic enhancement than equivalent water vapor images. **Figure 7.6A** shows typical raw thermal IR imagery. As you can see from the pixel histogram, the dynamic range of the image is considerably wider than was the case with thermal IR; but if you had to handle this image in the analog world, it would be disappointing. Although the raw image is low in contrast, there are some situations where you want to work with the original image data. Many of the available satellite programs have the capability to plot ground, water, and cloud temperatures directly from the raw image data. In many cases you can prepare false-color images showing temperature distributions, or you can point and click on specific points on the image and retrieve a temperature value. If you want to take advantage of such program features, you must use the raw image data. My general practice is to save a copy of the original image and then perform all image processing/enhancement experiments using a copy. Figure 7.6B shows the results of a modest equalization of the original image.

**Figure 7.7**. Image processing of water vapor IR images is as severe as anything you will encounter. As a result, any defects in your system are likely to be emphasized. The text discusses some of the enhancement effects and artifacts visible in this image sub-set.

### *VISIBLE-LIGHT IMAGERY*

TIROS/NOAA visible-light imagery suffers from two problems: limited dynamic range and seasonal lighting variations. The dynamic range problem is evident in **Figure 7.8A**, where the pixel histogram indicates that the image brightness range is only about 50% of the total dynamic range. In the days of analog image display, operators would simply increase the amplification in the video circuits, resulting in an image with the proper dynamic range. While this would work to display the visible light data, the effect was to compress the IR data, rendering the IR channel virtually useless. With today's digital options, the raw data are displayed and saved to preserve the original dynamic range of both the visible and IR data, after which the images can be optimized individually. In Figure 7.8B the pixel distribution has been stretched across the entire dynamic range, resulting in an image with excellent contrast.

The seasonal lighting problem is not as easy to solve. For operational reasons, the orbits of the TIROS/NOAA spacecraft are configured so that daylight passes occur somewhat early in the morning and late in the afternoon. During the summer months, when the sun is relatively high in the sky, the result tends to be well-lighted visible images, particularly in the case of the afternoon passes. In contrast, sun angles are low during the winter months and the light distribution is very uneven, especially at higher latitudes. There is no simple "fix" for this problem, and I tend to ignore NOAA visible imagery during the winter months. At low latitudes this is much less of a problem.

The Russian METEOR/RESURS spacecraft are designed to generate their visible light images during passes that are much closer to mid-day, minimizing the problems resulting from low solar illumination angles. As is evident by comparing **Figure 7.9A** with either 7.8A or 7.8B, METEOR/ RESURS summer imagery, while excellent in terms of overall contrast, does not do a good job of portraying land/ sea detail. However, their sensors are excellent at differentiating snow, ice and clouds; so winter imagery really can be quite spectacular. (See **Figures 7.10** and **7.11**.) The RESURS spacecraft do a better job in this respect than the older METEOR spacecraft; but, unless your program has an image gridding option, it can be hard to orient the cloud features you see in summer imagery. You can process the pictures to bring out useful land/sea detail (Figure 7.9B), but the results are useful only for orientation purposes as they tend not to be aesthetically pleasing. The Russian spacecraft images are significantly higher in resolution than equivalent NOAA APT images, and they are well worth following at any season of the year.

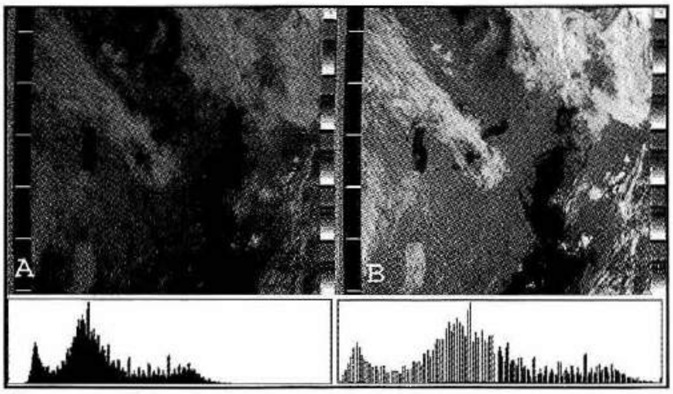


**Figure 7.8**. If the display contrast or level control is properly set to accommodate both visible and IR data (see text), TIROS/ NOAA visible-light images will always look too dark **[A]**, even with excellent lighting conditions. "Stretching" the pixel brightness distribution can produce an image with an excellent tonal range **[B]**.

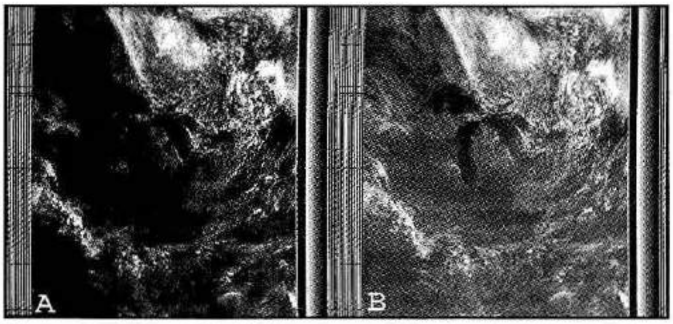


**Figure 7.9.** The visible-light sensors of the Russian METEOR/ RESURS spacecraft are at their best at the bright end of the dynamic range. During the summer months, they do an excellent job of depicting cloud cover **[A]**, but tonal gradations between land and water features are poorly displayed. This pass over the Great Lakes actually shows a faint outline of some of the lake features, but this is because of the distribution of thousands of small convective cumulus cloud cells over land and a lack of such cloud-cover over the lakes themselves. Rather severe image enhancement can be used to view land/water landmarks, but this often results in wide horizontal banding patterns **[B]** that reflect slight variations in the subcarrier black level.

### GEOSTATIONARY IMAGERY

If your major objective is simply to maximize the number of weather-satellite images/products you receive, monitoring WEFAX transmissions from the various geostationary spacecraft (GOES, METEOSAT, GMS, etc.) has a number of advantages:

- You don't have to determine when satellite passes will occur. If you are in range of one of these spacecraft, the spacecraft will be transmitting almost continuously according to a regular daily schedule. In other words, images of particular interest to you will be available at the same time every day, barring problems with the system.
- An extremely large number of images (300+) are transmitted each day from most operational spacecraft.
- All image products are gridded with both geographic boundaries and latitude/longitude lines, so orienting cloud features with specific geographic features is never a problem.

Figures 7.9 to **Figure 7.21** inclusive summarize some of the image products available through the GOES WEFAX program. A comparable range of products is available through METEOSAT, although that spacecraft features a different scheme for subdividing the Earth disk. In general, WEFAX image products fall into three broad categories:

- Images derived from the high-resolution Earth-disk imagery. This suite of images is dominated by IR products, primarily because uniform imagery is

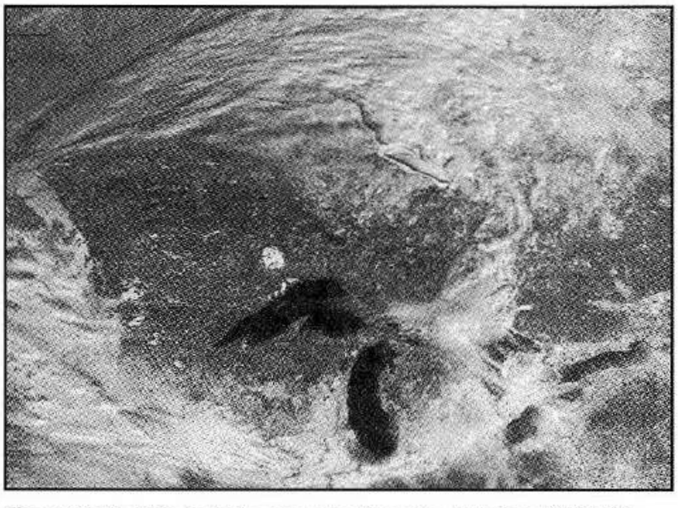


**Figure 7.10.** This is just a small portion of a Russian RESURS satellite pass over the Great Lakes during the winter. The Russian visible sensors are optimized to differentiate cloud and ice cover and often yield superb imagery. River valleys are clearly evident against snow-cover west and southwest of Lake Michigan, and the reduction in snow in the greater Chicago area is easily noted. Although the Great Lakes are ice-free, the bays on the north shore of Lake Superior are ice-covered, as is Lake Nipigon just to the north. The forested islands of Lake Nipigon can be seen, contrasting with the smooth, snow-covered ice on the lake. Thousands of snow-covered lakes are visible throughout southern Canada, including Lake Winnipeg to the extreme left of this image. Ice-covered James Bay is visible at the extreme northern edge, along with southern areas of Hudson's Bay.

available at all times of day. Visible images tend to be limited to a narrow mid-day interval where the Earth is evenly illuminated by the sun.

- Image mosaics, primarily polar views, compiled from polar-orbit HRPT data. The geostationary spacecraft have a poor perspective when imaging at high latitudes, and the polar mosaics tend to compensate for this.
- A wide range of weather charts

Because the WEFAX image are the products of ground-computer processing, they tend to be optimized with respect to contrast and dynamic range. As such, there is little need to subject them to any significant image enhancement.

### FALSE-COLOR DISPLAY

All weather satellite images are grayscale pictures, but many software routines have "false-color" display options available. These tend to fall into two categories. The first uses colors as a convenient way to differentiate temperature variations in IR image. The eye is much more sensitive to small color shifts compared with its ability to differentiate small grayscale differences. False-color represents a nice graphic approach to displaying thermal profiles.

A second and increasingly common false-color option is to be able to transform grayscale imagery, particularly visible light pictures, into pictures that look like color views. With these routines, clouds are portrayed in white and shades of gray, water features are blue, and land areas come out in greens or shades of green and brown. These colorizing routines are very popular and can be seen on many Web sites. In contrast, I am very stuffy and old-fashioned. They aren't color pictures to begin with and, at best, they can be transformed into a cartoon version of what the picture actually might look like from orbit. As a result of a lifetime doing serious photography, I like grayscale/B&W images, so I don't use these features. It's your station, so do with the pictures as you deem best!

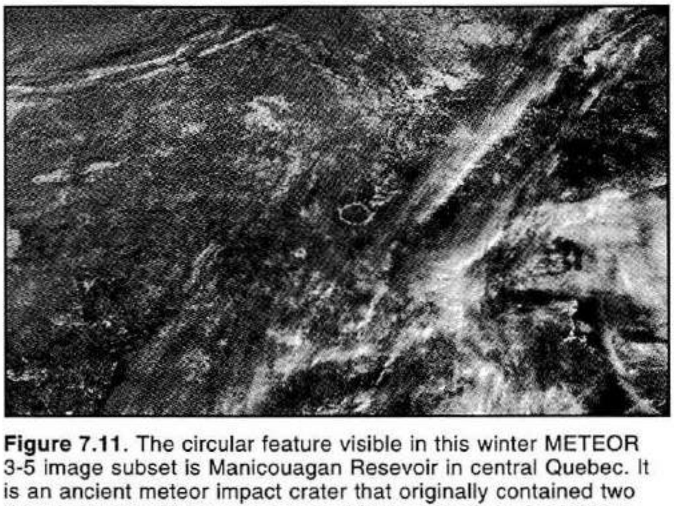


**Figure 7.11.** The circular feature visible in this winter METEOR 3-5 image subset is Manicouagan Resevoir in central Quebec. It is an ancient meteor impact crater that originally contained two river systems which were dammed for hydro-power, creating a circular lake. Bays, representing flooded tributaries leading into the lake, are evident on close examination.

### ARCHIVING IMAGES

Given the effort and investment required to set up a weather satellite ground station, there is a strong incentive to save images you have acquired. The practical problem is that these images result in very large files compared to any other image modes we have discussed up to this point. For example, a "typical" WEFAX image will be digitized at 1024 pixels/line and will consist of 800 lines. If we assume 8-bit

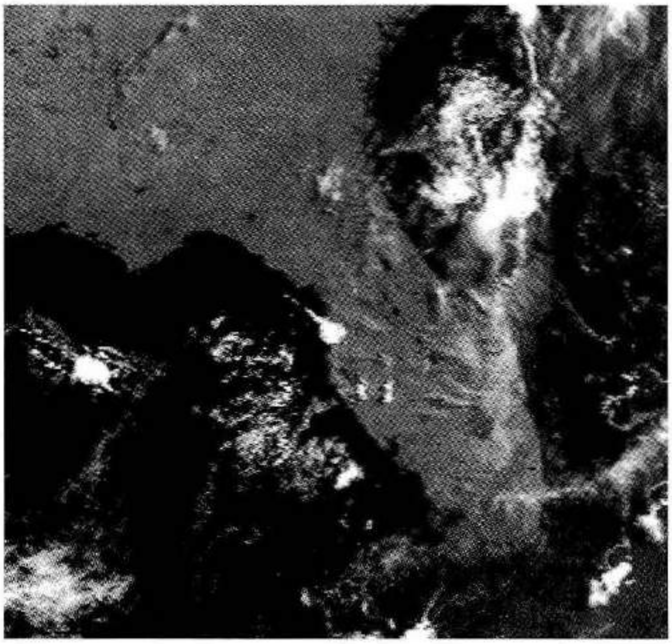


**Figure 7.12.** Numerous wildfires were burning in Florida at the time of this NOAA pass. This visible-light sub-set of the original image shows multiple smoke plumes angling off to the west-northwest in response to the prevailing winds.

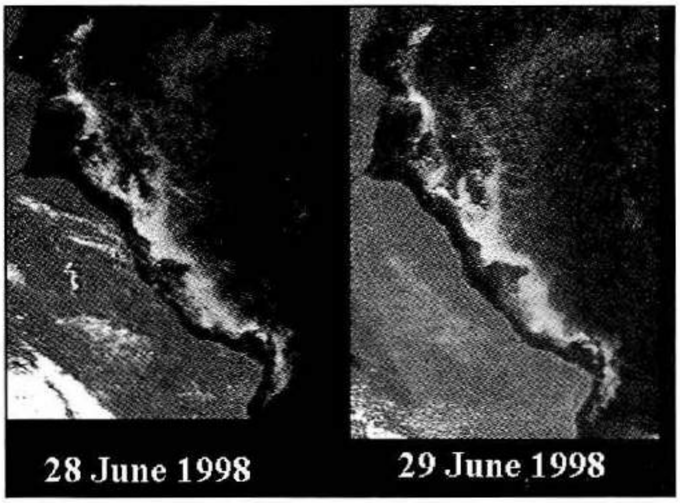


**Figure 7.13.** Differentiating sea ice from cloud-cover can be difficult. The answer is to look at passes on two successive days, where the cloud patterns will have been altered while ice distribution stays relatively constant. This is a set of visible-light NOAA image sub-sets showing the area north of Cape Churchill on the west coast of Hudson's Bay. The last remnants of the winter pack ice are off-shore in a complex drift of slabs and bergs.

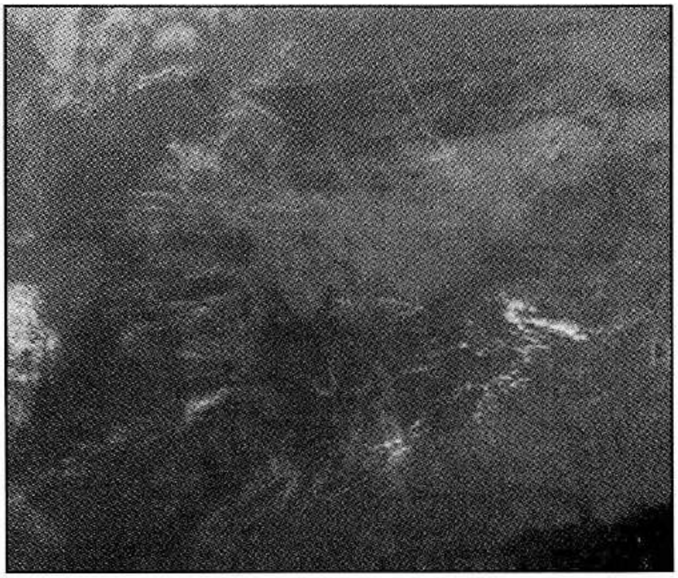


**Figure 7.14**. Careful examination of this NOAA IR image subset, covering the south-central region of the United States, reveals a fine network of straight lines, slightly lighter (colder) than the ground beneath. These represent contrails of jet aircraft, a relatively rare feature of weather satellite images.

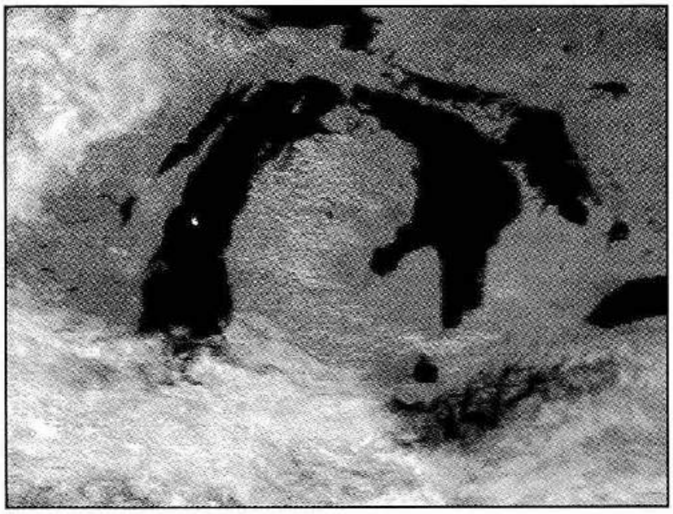


**Figure 7.15**. Every satellite pass can present a lesson in geography. Not many places are blessed with such obvious landmarks as the Great Lakes; but after a year or so of examining satellite images and comparing them with a good atlas, you will soon become an expert at recognizing features on the Earth below. Just a small piece of coastline seen through a gap in the clouds will be sufficient to orient the image and put the cloud formations into perspective. This is a small segment from a NOAA visible-light pass.

grayscale coding, the image file size will be:

**1024 × 800 = 819,200 bytes/image**

If you captured and stored each of the 300+ images transmitted daily by a GOES spacecraft, you would "use up" approximately 250 MB of hard-drive space each day! Polar orbit APT images are fewer in number, but the file size is much greater. For example, 10 minutes of a NOAA polar orbit pass (1200 image lines), digitized at 2048 pixels/line, would result in a file almost 2.5 MB in size. You certainly could acquire six to eight passes like this each day, which translates to 15-20 MB of hard-drive storage. If you save each pass of raw imagery and then proceed to do image enhancement on the copies, you can double the required disk capacity. Of course, the required hard-drive space can be reduced greatly by the use of compression formats such as JPEG; but I prefer to avoid any compression approaches that involve the loss of even a small amount of resolution.

The ideal archival medium when dealing with really large images is optical. Whatever images I copy on a given day are saved to a CD-RW disk in BMP (Windows bit-mapped) format. Most satellite software generates image file names based on the date and time of the start or image acquisition. For example, the *Image Communications Handbook (ICH)* Satellite program would save an image from August 13 and 18:55 UTC as:

**08131855.BMP**

Most programs use some variation on such a scheme. If I enhance any of my pictures, I save the enhanced version as a GIF file, using the same filename as the original. That way I can differentiate processed from raw data files without much thought. GIF files are compiled with loss-less compression. The major disadvantage of the GIF format is that it can only handle 256 "colors", but that is not a problem with satellite images with 8-bit (256 grayscale values) coding.

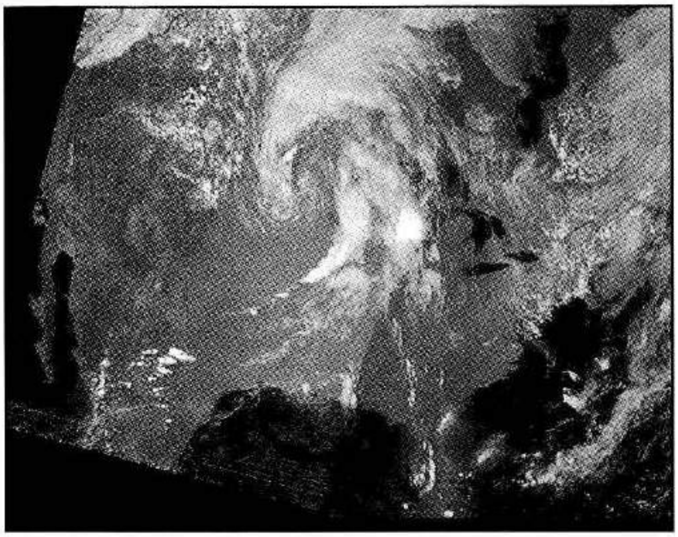


**Figure 7.16**. Sequential NOAA passes can be combined to produce a mosaic covering a larger area than any single pass. Here the computer has merged an eastern and a western NOAA pass (visible data) to produce an image covering almost all of North America from north of central Mexico. Both passes were logged with a simple turnstile omni-directional antenna array mounted in the author's attic.

I organize the CD-RW directory by year and month. Once the contents of the master CD-RW disk reach 600 MB or so, I write the entire contents of the disk to a CD-R disk that

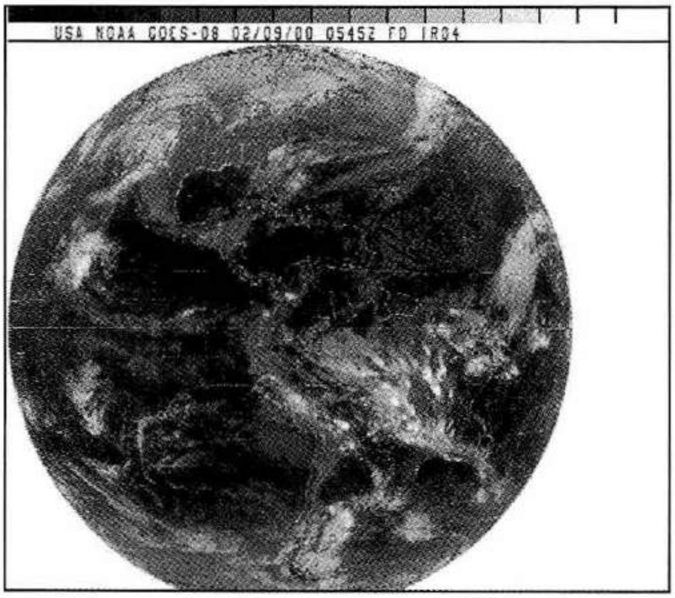


**Figure 7.17.** Full-disk images are transmitted as part of the daily GOES WEFAX schedule. While this picture (GOES E IR) has significantly less resolution than the original VAS source image, it does provide a nice overview. In order to provide greater resolution, the original full-disk VAS image is subdivided into various kinds of sectorized views for transmission via WEFAX. The thin horizontal line at the bottom of the image represents the beginning of the 450 Hz "stop tone" that signals the end of the WEFAX frame.

typically costs about $1.00. I can then erase the more expensive CD-RW disk and use it for new files.

### PRINTING IMAGES

Creating high-quality hard-copy images used to involve a significant amount of work in a home darkroom, but all of that is a thing of the past given the printing capabilities of modern computers. Any of the current crop of ink-jet or bubble-jet printers can produce prints that are quite acceptable, right up to essentially photographic quality, depending upon the software and the type of paper used. The larger the size of the printed image, the less printing artifacts will contribute to a reduction in final image resolution. I usually print most pictures at close to full-page format, even though ink costs are increased. Most weather satellite software has internal printing capabilities, as do all the various photographic software packages available. Treat the satellite images as if they were digital photo images when selecting your print options, and don't hesitate to experiment. Depending upon how your satellite software formats the image, the program you use to print it may recognize it as a grayscale image, or it may treat it like a 256-color image. Whenever possible, select grayscale printing as your option. Then it will be printed in a grayscale format, irrespective of how the printing software interprets the image. Of course, if you have colorized the image, you may wish to print it in color. If that is the case, select your printing parameters accordingly. Don't be afraid to experiment. Your satellite program may do a good job of printing pictures, but the image processing software that came with your scanner or digital camera may be even better!

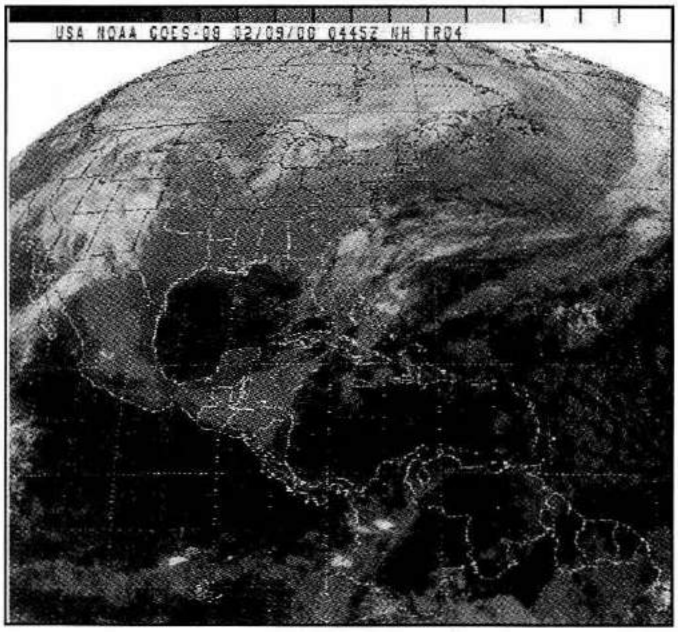


**Figure 7.18.** One very useful disk sub-sector is this view, from GOES E IR data, covering most of North America and northern South America.

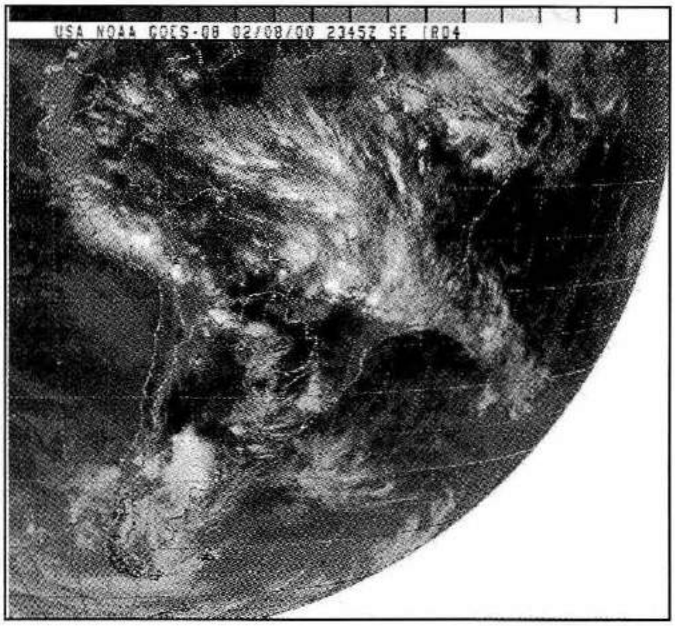


**Figure 7.19.** One standard GOES WEFAX product is a set of four equal quadrants of the full-Earth disk. This shows the SE IR quadrant of the Earth disk as imaged by GOES E, covering much of South America. The image quadrants overlap slightly in terms of coverage, and the four quads can be assembled in software to create a full-disk image with four times the resolution of the Earth as shown in Figure 7.17.

### UNATTENDED OPERATION

It is a sad fact of life that some of the best satellite passes occur at times of the day where you might be at work or

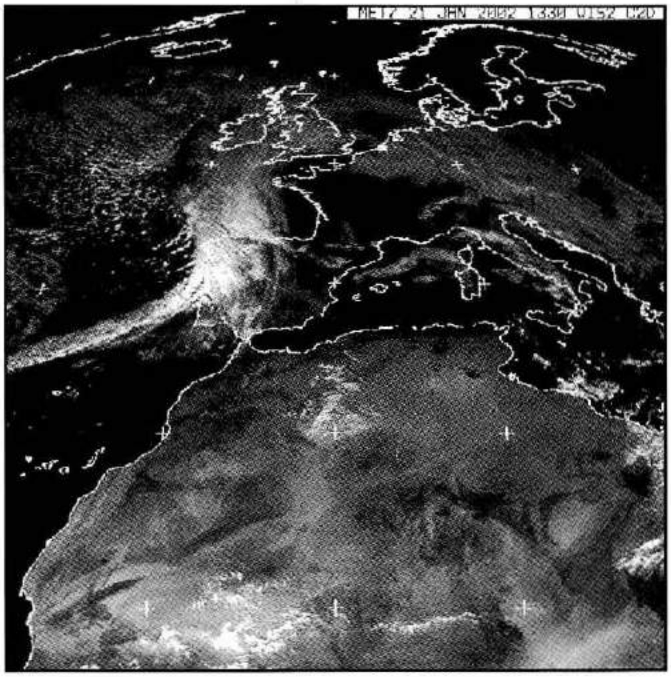


**Figure 7.20**. The European METEOSAT, located over the equator at 0° longitude, has its own daily WEFAX schedule. Selected METEOSAT WEFAX products are transmitted as part of the GOES daily schedule and vice versa. This particular frame covers Europe and North Africa.

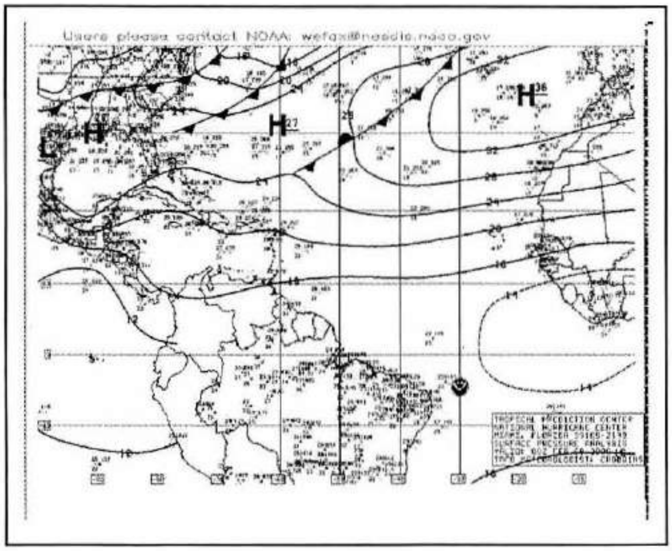


**Figure 7.21**. A relatively large number of weather charts are transmitted as part of the daily WEFAX schedule of the GOES spacecraft.

school. Fortunately, it is very easy to implement various levels of unattended operation. Many satellite software packages have their own internal orbital tracking software modules and can implement a variety of unattended operations. You need to check your software documentation to see what options you have.

Unattended operation also can be very easy if you are using Christian Bock's popular ***WXSat*** software (the program is on the CD-ROM packaged with this book) for Windows-equipped computers with a sound card. If your receiver can scan the various active spacecraft frequencies, simply let it scan and set WXSat for 120 LPM NOAA display. At the end of a day you will have lots of partial images on your hard-drive (from short, marginal passes), but you also will have the prime passes for any day. Of course, this approach can work even better if you build the tone-operated scan controller from Chapter 6. (This construction project is documented on the CD-ROM.) Then you won't have the receiver "hanging" on spurious signals that stop the normal carrier-operated scan control in most receivers. If you don't have a receiver that can scan, simply set up the receiver on the frequency of greatest interest to you. You will still get good pictures — just fewer of them.

A similar approach can be used tolog geostationary transmissions from GOES or METEOSAT, but you will end up with a very large number of pictures on your hard-drive each day. One simple modification that can be useful for WEFAX is to use a simple timer to activate a relay in series with the audio line between the receiver and the sound card. When the relay is off, no signal reaches the sound card and ***WXSat*** will not log images, no matter how many come along. When the timer activates the relay, any picture received will be saved until the timer opens the relay again. Some of the newer multi-even digital times will let you copy several blocks of images in any 24-hour period while ignoring pictures at other times.

The use of ***WXSat*** presupposes that you have a Windows-equipped computer available for unattended monitoring. One advantage of the *ICH* interface (Figure 7.1) and its software (included on the *ICH* CD-ROM) is that it will run on virtually any VGA-equipped computer. I have an old VGA laptop which isn't useful for much of anything in today's Windows environment. This computer is connected to the interface from Figure 7.1 and logs polar APT passes at all times, including moments like now where I am using the "big" computer for other purposes. The associated software has a very nice unattended mode that operates from files generated directly from the ***schedule.txt*** files discussed earlier in the section on satellite tracking and scheduling. While I could set it to copy everything, including marginal passes, I usually run it to log only the really good passes from each spacecraft, saving disk space and avoiding the need to delete lots of marginal files. **Figure 7.22** shows one sample of a full-day of passes using this software and interface.

Still another rationale for unattended operation is a school setting. If a basic satellite installation is in place at a school, the system can be set up to display images in a classroom (or piped off to a remote monitor in a hall display case, for example) without any significant monitoring by a teacher. No matter what your operating objectives, it is easy to accumulate far more satellite pictures than you can possibly work with!

### RECORDING SATELLITE PASSES

The WXSat program has the capability to record WAV sound-files for complete satellite passes. The CD-ROM contains several WAV files that can be used to align the *ICH* interface, and they were prepared using WXSat. These WAV files can be displayed using WXSat, or you can route them from the sound card out to any other interface for display. Since the recordings are digital, they will retain the precise timing required for quality display no matter how you use them.

If you are lucky enough to have a DAT (**D**igital **A**udio **T**ape) deck, you can also make precisely-timed recordings that can be replayed into any display system to generate pictures. Ordinary audio tape decks will not do well for a variety of reasons, chief among them being a lack of precise speed control during recording and playback. However, if you refer back to Chapter 5, you will see a description of how to use a video recorder to record SSTV images. Precisely the same technique will work well with weather satellite images.

### *UNCONVENTIONAL OPTIONS*

The previous chapter has some equipment options that can be considered if permanent antenna installation is impractical where you live. To that list of options we can add some items that emerge as a result of the possibilities for unattended operation. For example, you might well have a friend, perhaps another amateur, who lives in the country where antennas are not an issue. You might look at the possibility of setting up a very basic station (omni antenna and a simple receiver) along with one of the unattended or tape-recording options we have just discussed. You could then pick up recordings or disk files at intervals, doing any image processing and archival work on your computer at home, work, or school. Given the tremendous flexibility afforded by modern electronics and computers, there is a way to operate a weather satellite station in even the most restrictive environment. Your job is to think "out of the box" and come up with a solution that works for you!

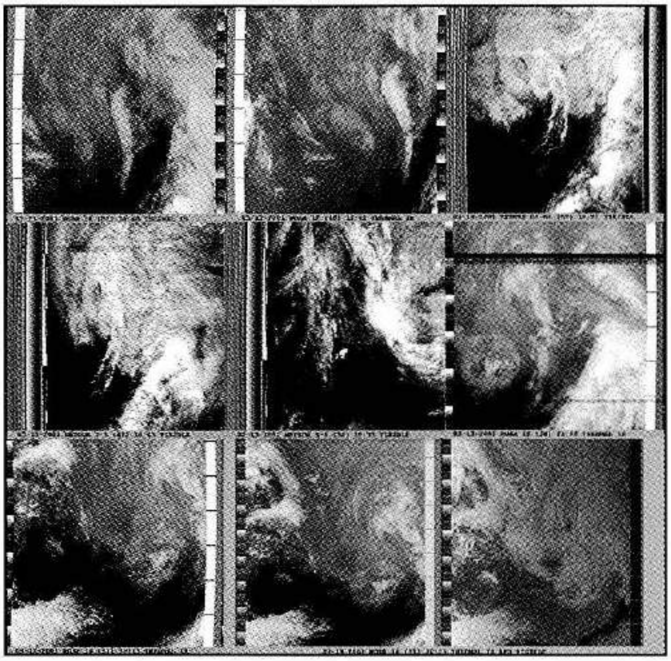


**Figure 7.22.** Simple approaches to station automation, mostly in software, can log images without operator intervention. Here is a day's "take" from a variety of NOAA and METEOR/RESURS APT spacecraft.

## CHAPTER 8

# SOME AMATEUR TELEVISION BASICS AND SETTING UP YOUR STATION

*In the next two chapters we are going to cover the equipping and operation of a basic Amateur Television (ATV) station. Although the majority of this chapter will deal with equipment options, we will begin with some basic TV-oriented technical details, followed by a brief discussion of what kind of range you can achieve with an ATV station under various operating conditions. Both of these topics are essential reading prior to making any equipment buying decisions.*

## A VERY BASIC LOOK AT NTSC TELEVISION

This section of the chapter has to walk a fine line. It would be very easy to err on the side of presenting too much technical detail. Given the very real limits on the space available for the discussion, we would end up with an inadequate mini-essay on television engineering that would make it appear that you have to be a technical wizard to operate ATV. In fact, this is one of the long-standing and very common misconceptions about ATV. That said, you will end up as chief engineer of your own television station; and you will have to understand some TV basics to operate your station properly and to understand the terms which will be tossed back and forth in your local ATV group. My goal will be to try to balance the technical content toward that end.

### *TELEVISION STANDARDS*

One of the first things you discover if you examine television from an international perspective is that there is no such thing as a "standard" TV mode. Commercial television, as we know it today, is the outgrowth of experiments in individual countries prior to WW II (see Chapter 1). By 1939, experimental transmission of medium-resolution TV pictures was happening in both the United States and Europe. Because of the bandwidth requirements for such signals, a topic we will return to shortly, these early experiments were occurring on VHF frequencies. The operating frequencies and the state-of-the-art (with respect to television reception and display) usually meant that the effective range of television signals was limited. This fact of life, coupled with competing commercial interests and healthy doses of national pride, meant that TV standards tended to evolve somewhat differently from one country to the next.

The Second World War restructured the power centers of Europe, leaving three main "players", the United States, Britain, and France, in terms of the post-war introduction of true broadcast television services. Television technology exploded in the post-war period, driven in part by technical advances brought about by the demands of war. By the early 1950s it was both technically and commercially feasible to consider the introduction of color television service. Given the relatively high cost of home TV equipment, a major consideration was to make the new color service compatible with existing monochrome (black-and-white) sets. Not surprisingly, there are various ways to accomplish this. Coupled with the differences that had already evolved in national television standards, this led to the appearance of three different international standards for broadcast television:

**NTSC** (**N**ational **T**elevision **S**ystem **C**ommittee). This standard is named for the US Committee that evaluated the various approaches to broadcast color service and made the recommendation that set the standard that would mandate the format of commercial TV transmissions for almost fifty years. Actually, the NTSC was convened twice. The first occasion was 1940-41, where the basic standards for broadcast television were formulated, and again in 1950-53. The latter involved the complex process of evaluating competing approaches for both compatible and non-compatible color television technologies. The extensive work of the NTSC provided the basis for almost all other color systems. NTSC television is the standard in North America, the Caribbean, Japan, and parts of South America.

**PAL** (**P**hase **A**lternate **L**ine). This format has somewhat higher resolution than NTSC (625 vs. 525 lines) and a different (and most would say a superior) approach to encoding the color data. It is the standard in Britain, most of Western Europe; and in terms of the number of countries using it, — it is the most common international television format.

**SECAM** (**SE**quential **C**oeleur **A**vec **M**emoire). The basic monochrome format is quite similar to PAL, but there are significant differences in color encoding. This standard was developed in France and is used in France, Belgium, and most other countries that were under post-war French colonial administration. Interestingly, when the Soviet Union introduced broadcast television both in the USSR and in the client states of Eastern Europe, they selected a variation of the SECAM format. This choice made it difficult for viewers on the eastern side of the Iron Curtain to receive PAL broadcasts from the neighboring nations along the western side of that very real post-war barrier.

The advent of communications satellites presented new challenges in terms of international dissemination of TV signals with significantly different formats. The problem was solved essentially with scan converters (often called time-base correctors in the industry). The evolution of amateur television in the US and Europe was dependent upon the availability of commercial television sets. Not surprisingly, amateur operations conformed to the existing national standards. Today, in the environment of a high degree of European economic integration, PAL dominates the ATV scene in Europe while NTSC is the standard in North America. The discussions that follow are based on NTSC technical standards and US/Canadian operations, although most of the broader principles apply to ATV in general. European readers will need to consult local organizations and groups for detailed technical data and the nature of regional ATV activity.

The commercial television landscape is changing again for the first time in fifty years. The impetus for change is the introduction of High-Definition Television (**HDTV**). This is going to present both challenges and opportunities to ATV operators, a subject I will discuss in Chapter 10.

### *NTSC VIDEO WAVEFORM*

The single most important technical aspect that you need to understand in a general way is the fundamental nature of the television waveform. The waveform that you would see if you connected the output of a monochrome camera or other video source is shown in **Figure 8.1A**. The signal would typically measure 1V peak-to-peak. Unfortunately, this is not what you would see if you looked at the modulated TV signal. In essence, if you put a simple detector/filter in the RF transmission line, the signal you would recover would be an inverted version of the camera waveform, as shown in Figure 8.1B. It is this version of the signal waveform, labeled with respect to relative-power, that will be the basis for our discussion.

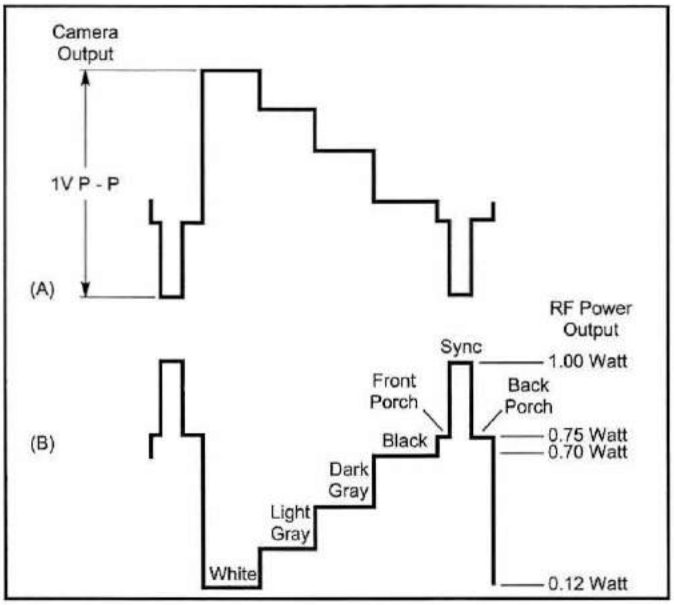


**Figure 8.1. [A]** View of one line of NTSC monochrome video as it might appear on an oscilloscope connected to the camera output. In this case the hypothetical video waveform consists of a four-step grayscale, running from white on the left to black on the right. The distinct negative-going pulses at each end of the display are the line (horizontal) sync pulses. Nominal camera output, according to industry standards, should be ~1V P-P, measured from the sync tips to white. **[B]** shows the same waveform, but inverted (with additional labeling) as you would see it if you detected the output of a properly modulated signal and displayed the signal on an oscilloscope or waveform monitor. If we assume the peak output of the transmitter is one watt, the sync tips should represent that peak power. The blanking pedestal, the front and back porches on either side of the sync pulses, should represent 75% of peak power or 0.75 W. The reference black level should be 70% of peak power (0.70 W) and white should be 12% of peak power or 0.12 W. The detected waveform should show proportional values, whatever the peak transmitter output, to produce a solidly-locked picture with good contrast range.

Both commercial and most ATV operations involve amplitude modulation (AM) of the RF carrier. Synchronization at the receiving end depends upon the ability of the receiver to extract the sync pulses that start each frame and line. A properly modulated signal will show maximum RF power (**100%**) for the duration of the sync pulses. The next power reference point in the signal is the base of the sync pulse — known as the **blanking pedestal** or simply the pedestal. The pedestal actually has two components, a short interval that occurs prior to the start of the line sync pulse (the **front porch**) and a slightly longer interval after the pulse known as the **back porch**. The blanking pedestal power level should be **75%** of peak power in a properly modulated signal. The difference between the 75% power level and the 100% sync level is the signal differential that is essential for reliable sync lock. We will return to this important 25%

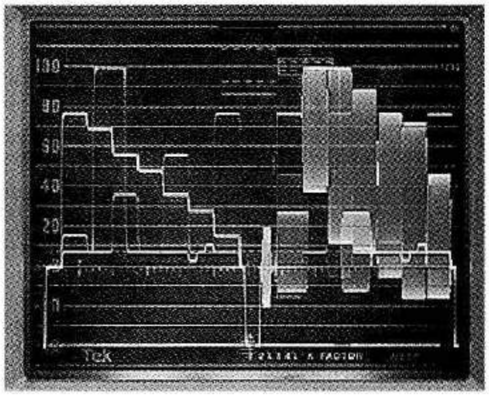


**Figure 8.2.** An NTSC color signal displayed on a Tektronics 17013 dual-filter waveform monitor. The left side of the trace shows the waveform with a 3.58 MHz trap in the line which essentially eliminates the color subcarrier signal. The trace represents the **luminance** (brightness) signal waveform and is essentially identical to Figure 8.1A. The trace on the right side represents the waveform with the trap out of the line. Thus the phase-modulated 3.58 MHz **chrominance** (color) subcarrier can be seen superimposed on the luminance waveform. Note that the magnitude of the chrominance signal has no relationship to the limits defining the luminance signal. The phase reference for the decoding of the chrominance data is the short **color burst** which can be seen superimposed on the back porch of the sync pulse at the center of the display.

power differential again and again, as few things are more critical for reliable ATV communications.

Slightly lower in power (**70%**), compared with the blanking pedestal, is the **reference black level.** Since both the blanking pedestal and sync pulse have a higher power level than black, the trace on the face of the receiver is "blacker than black". It is thus invisible during the retrace interval during which the scanning spot is reset for the next scanning line or next frame. Video brightness is referenced to the black power level, and the brightness values increase as power is reduced below the 70% level. The white end of the dynamic range is reached at **12%** of maximum power output — the **white level**. If the video modulator is overdriven, the white level can reach 0%, resulting in a distinctive distortion of the signal known a "whiting out". Proper transmitter adjustment requires that we observe the proper power levels with respect to sync, pedestal, and white level. Fortunately this can be accomplished without a lot of fancy test equipment, and the procedure will be discussed in detail later in this chapter.

The "black-and-white" waveform is pretty straightforward but quickly becomes more complicated when we add color. The system adopted by the NTSC was to use a subcarrier, riding along on the monochrome video information, to convey the color or chrominance data. The color subcarrier has a frequency of 3.58 MHz, and color data are modulated by changing the phase relationship of the subcarrier. Recovery of data from a phase-modulated signal requires that there be a phase reference signal. In the case of the color subcarrier, the phase reference is in the form of 7 cycles at 3.58 MHz inserted on the back porch of the blanking pedestal. This back porch reference pulse train is known as the **color burst.** If we were to observe a color NTSC signal as we did the monochrome signal in Figure 8.1, the signal would appear to be much more complex. This is because the phase-modulated color subcarrier (chrominance) signal would overlay the modulated monochrome (luminance) waveform (**Figure 8.2**). Modern oscilloscopes and TV waveform monitors have a variety of circuits and functions to evaluate both the luminance and chrominance signal levels. Since this subject is basic to both TV engineering and TV service, there is a huge body of technical literature on the subject, including lots of material on the Internet. There are plenty of information sources if you want to research the subject in greater depth. What must be kept in mind with respect to color is the matter of bandwidth. To transmit or receive a good color picture, all components at the transmitter and receiver end of the circuit must have sufficient bandwidth to pass the 3.58 MHz color subcarrier with minimal attenuation or phase distortion. Attenuation of the subcarrier can result in a loss of color while phase distortion can result in shifts in color values or the creation of color artifacts.

### *NTSC IMAGE STRUCTURE*

The line structure of an NTSC television signal has elements we have yet to encounter. In all the previous imaging modes, vertical scanning has been continuous. Once the frame begins, line scanning continues without interruption until the end of the frame. NTSC image lines are transmitted at a **15.75 kHz** rate, resulting in a line interval of ~63.492 microseconds (1,000,000/15,750). In 1/60 of a second (~16,666.66 microseconds) the vertical scanning moves from the top of the screen to the bottom. During that time interval, a total of **262.5** lines are scanned. The 262.5 scanning lines represent one scanning **field**. At the end of the field interval, the vertical scanning resets and starts again, scanning another 262.5 lines. Since the new field scan starts at the midpoint of a line, the new set of 262.5 lines is inserted *between* the first set of lines — a pattern known as **interlaced scanning**. A complete set of two 262.5-line fields thus represents a complete fast scan **frame**, requiring a total of 1/30 of a second. If the interlaced scanning works perfectly, the result is the transmission of a 525 line image in 1/30 of a second.

Interlaced scanning was a solution to a problem that began to emerge with experiments with higher resolution TV systems. It is perfectly feasible to used non-interlaced scanning and simply scan a 512 line image in 1/30 of a second. However, viewers almost always will perceive a degree of "flicker", resulting from the relatively slow scanning rate. Different viewers will respond to the flicker in different ways; but with most individuals, extended viewing of such a non-interlaced picture results in significant fatigue. With interlaced scanning, flicker and fatigue are virtually eliminated with no bandwidth penalty (see next section). It is interesting that most computer image formats, including those with a higher resolution that broadcast television, are non-interlaced. These modes avoid the flicker problem by using faster scanning rates, made possible because the signals are carried on a cable and not broadcast.

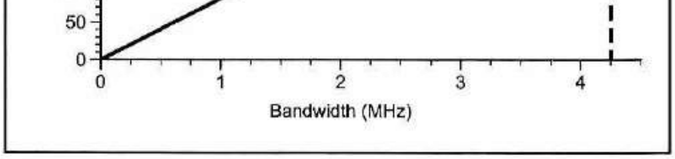
### NTSC VIDEO BANDWIDTH AND POWER SPECTRUM

Calculation of the bandwidth of an NTSC signal is relatively complex, involving the effective horizontal resolution of the video source, the image aspect ratio, the relationship between the theoretical line/pixel values and what is actually transmitted. **Figure 8.3** is a nomogram that plots bandwidth as a function of the number of scanning lines, taking these variables into account. In any case, the maximum video bandwidth is limited by FCC regulation to approximately 4.2 MHz, allowing "headroom" for the insertion of a FM sound subcarrier 4.5 MHz above the video carrier (a subject we will discuss in a later section). The combined video/sound signal thus has a combined bandwidth of slightly over 4.5 MHz. If this signal is used to AM modulate the video carrier, the resulting signal would have a total bandwidth of slightly over 9 MHz — a situation typical of most amateur ATV signals. Commercial broadcast stations have to be a bit more sophisticated in generating their signals as the FCC channel allocation is just 6 MHz for NTSC television signals. The fit is made possible by two technical tricks that are not commonly employed in ATV work:

- Instead of combining a 4.5 MHz FM subcarrier to produce the sound signal, broadcast stations use a second sound transmitter offset above the video carrier by 4.5 MHz. In this way, the sound signal does not appear on the lower sideband.
- Broadcast stations use an approach known as **vestigial sideband** or VSB. This involves the suppression (not elimination) of the lower sideband so it occupies less than 1 MHz.

The carrier of a broadcast signal is placed 1 MHz above the lower channel edge, the vestigial (lower) sideband is located below the carrier frequency, and the upper sideband, containing the video and sound modulation extends 4.5 MHz above the carrier frequency.

Although a TV signal is very wide compared with other modes, power distribution is not uniform across the occupied spectrum. Most of the sideband energy is distributed within 1 MHz of the carrier frequency, falling off rapidly beyond that point. Except for modest power peaks at 3.58 (color burst) and 4.5 MHz (sound subcarrier), the power density of the signal is such that there is comparatively little potential for serious interference to other stations, providing intermodulation products (IMD) are well-suppressed. It should be noted, however, that other signals within ±4.5 MHz of the TV carrier do have the potential to cause significant interference with respect to TV reception.



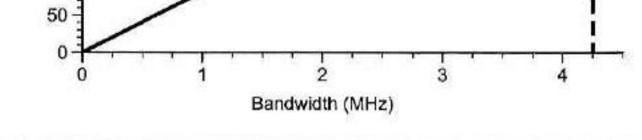


Figure 8.3. The relationship between the effective horizontal resolution (# LINES) and the bandwidth of an NTSC color signal. The dotted line at 345 lines represents the effective resolution of a typical color camera, resulting in a bandwidth of approximately 4.25 MHz.

### BANDS AND TRANSMISSION MODES

Due to the very wide bandwidth of ATV transmissions, NTSC television operation is restricted to UHF (70 and 33 cm) and microwave (23 cm and higher) on amateur bands. Of the bands available, 70 cm (420-450 MHz) is the most accessible, given the wide range of commercial equipment available, the relative ease of generating higher power levels if required, and the operating range that can be achieved. The 33 cm (902-928 MHz), 23 cm (1240-1300 MHz), and 13 cm (2390-2450 MHz) bands are used for point-to-point communications, particularly in metropolitan areas with high population density, but are most commonly employed as output or input frequencies for cross-band ATV repeaters. At one time or another virtually all our microwave bands have been used for ATV communications, and 10 GHz works particularly well for linking multi-site repeater installations. That said, most of our discussion will focus on 70 cm operations since this is, by far, the most popular (and populated) band for ATV.

To this point, all of our discussions have focused on AM modulation of the TV signal. This is the standard for commercial broadcast service and thus is compatible with the typical broadcast TV receiver. AM is the predominate mode for ATV operations, but the potential for FM TV has been studied to a considerable extent. FM modulation is used exclusively for commercial television satellite downlinks using 11 MHz channels with sound carried on a 6.58 MHz subcarrier. Most amateur experiments have used less deviation, and the amateur FM standard is based on 4 MHz deviation with 5.32 MHz sound subcarrier. The relative merits of AM vs. FM for TV transmission are summarized in **Figure 8.4**. At low signal levels the AM format has a significant advantage, but AM and FM become essentially equivalent at a signal level of approximately 7 microvolts. At still higher signal levels, FM has the edge and will deliver a snow-free picture at signal levels approximately –10 dB lower than an equivalent AM signal. FM ATV is also convenient when it comes to the use of power amplifiers, since a basic Class C amplifier — simple and efficient — is all that is required compared to the careful set-up of amplifiers for AM linear service. Although there are some manufacturers producing FM ATV equipment, FM has not caught on in the US for a number of reasons:

- **Cost**. FM ATV transmitters are significantly more complex than their AM equivalents. On the receiver

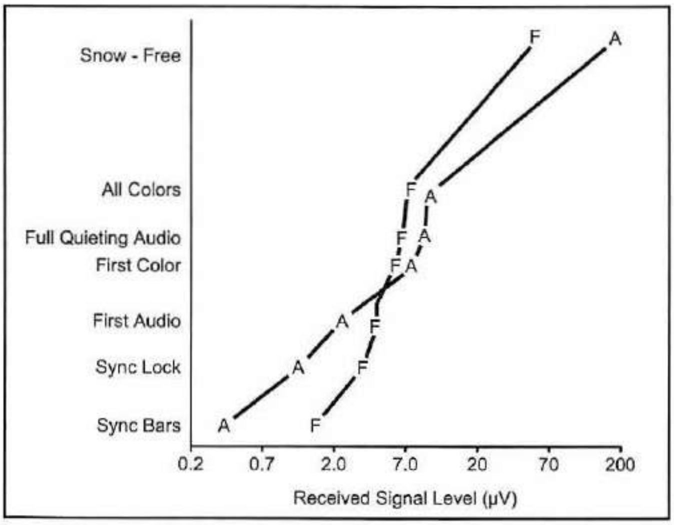


**Figure 8.4**. The relative effectiveness of AM [A] vs. FM [F] ATV under otherwise identical conditions. Note that AM has a distinct advantage when the signal is weak, but that the two modes are approximately equivalent at a received level of 7 microvolts. Above that level, the capture effect of FM is superior to that of AM, and the FM signal will achieve snow-free display at a significantly lower signal level.

side, a downconverter is used to drive an FM TV receiver unit with the detected video signal displayed on a TV monitor or TV set with either A/V inputs or an external RF modulator. All of this translates to significantly higher equipment costs.

**Bandwidth/Frequencies**. The US standard for FM ATV modulation is to use 4 MHz deviation with a sound subcarrier (–10 dB relative to the carrier) at 5.8 MHz above/below the carrier. The effective bandwidth of such a signal is approximately 20 MHz, so the 33 cm band is the lowest one practical for FM ATV operation here in the US, but 23 cm is probably a better choice given the available spectrum.

While FM ATV is comparatively little-used here in the US, other than repeater links and some operation in metropolitan areas, FM operation on 23 cm is the rule in Europe, where the 70 cm band is crowded to capacity and the 33 cm band is not available. Europe also has the advantage of relatively high population densities in a more restricted geographic setting. Increased use of 70 cm will certainly lead to more interest on the part of US amateurs in the potential of FM ATV operation.

## ATV EQUIPMENT OPTIONS

**Figure 8.5** provides a pictorial representation of the most basic equipment elements of a 70 cm ATV station. Each of these elements will be discussed in the sections which follow. As in previous chapters, I have attempted to reference some of the major equipment suppliers in North America, but you should not hesitate to investigate other sources. Also, as I noted earlier, the equipment emphasis here will be on 70 cm AM equipment. Many of the vendors I will reference have equipment for other bands and modes (FM ATV); and there certainly are other suppliers, particularly overseas.

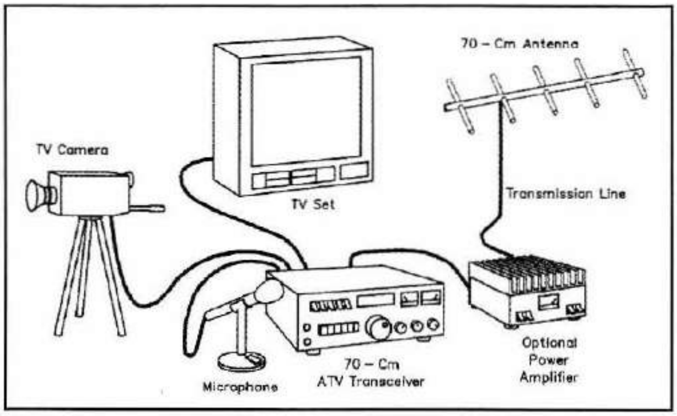


**Figure 8.5**. Basic equipment for a 70 cm ATV station.

### *ATV LINK ANALYSIS*

I am going to preface the equipment section by approaching the perennial question asked by every prospective ATV operator: "How far can I work on TV?" To start with, there are two different modes with respect to ATV operations. The first, and certainly most exciting, is the "band opening", where even modestly-equipped stations can complete contacts measured in hundreds of miles. We will discuss band openings and ATV DX in the next chapter; and, while it is exciting, these weather-driven events are like spices added to the main course of a dinner. The main course, representing 95% or more of typical ATV activity, is the fairly uniform propagation presented by 70 cm on a day-in- and-day-out basis. There will be days when the band is up a bit ("enhanced") and days when it is down a bit; but the variations, particularly with TV, are very modest compared to other modes on lower frequencies.

Day-to-day ATV operations must confront two major hurdles in defining the routine coverage that you can expect:

- **Bandwidth**. FM voice operations on 2 meters, the band and mode where most amateurs have some experience, uses peak deviations that result in an effective channel bandwidth of 15 kHz. In contrast, ATV signal bandwidth ranges from 6 to 9 MHz. If we take the low end of this possible range, an ATV signal will have an effective input power level at the receiving end that is **–26 dB** with respect to an FM voice signal with the same peak transmitter output! That is a huge starting deficit that cannot be avoided.
- **Frequency**. Everything else being equal, as we go higher in frequency, there is a gain deficit compared to lower-frequency signals with the same power and antenna gain. If we compared the world of 2 meters with the 70 cm band, that loss is in the range of another **–4.8 dB**!

These deficits are additive, such that an ATV signal starts with approximately a **–31 dB** disadvantage with respect to signal levels achieved on two meters using FM voice. Every equipment decision you make with respect to putting together your station feeds into the equation that will determine how well you see and are seen in your day-to-day ATV operations. To make this point and support the comments and suggestions later in this equipment section, I want to spend some time on a simple version of a "link analysis". Such an exercise can help predict station performance while, at the same time, highlighting the importance of all the "little details" in terms of equipment selection. Assuming line-of-sight conditions (no physical obstructions), a basic link analysis is a simple matter of adding all the positive factors and subtracting the losses for all the elements in the transmission and receiving system:

| INCREASE SIGNAL LEVEL (+) | DECREASE SIGNAL LEVEL(–) |
|---|---|
| Transmit Power Output | Transmit Line losses |
| Transmit Antenna Gain | Free-Space Path Loss |
| Receive Antenna Gain | Receive Line Losses |

If the goal is to maximize the signal at the receiving end, we need to maximize the three items in the positive column (power and antenna gains) and minimize the items we can in the negative column. The latter includes only the transmission line losses, since the free-space path loss (highlighted for emphasis) is entirely a matter of distance and frequency. Given the operating frequency (F in MHz) and the path distance (D in km), the free-space loss ($L_{fs}$ in dB) can be calculated:

$$L_{fs} = 32.4 + (20 \times \log(F)) + (20 \times \log(D)) \quad (8\text{-}1)$$

While all of these mathematical calculations are hard facts of life, most amateurs probably won't be happy doing them, especially again and again to play "what if" simulations. To get around this problem, I have written a simple DOS program (range.exe) that is available in the ATV directory of the *ICH* CD-ROM. The program lets you play with all of the variables (transmit power, antenna gains, line losses, and antenna heights) and come out with useful predictors of station performance. I will use results obtained from the program in several of the sections which follow to illustrate the importance of making optimum selections in assembling your station.

## ANTENNAS AND TRANSMISSION LINES

The basic principles for ATV antenna arrays are quite simple — use the biggest array you can manage, mounted as high as possible! Antennas can be a pretty complex subject, and many amateurs devote much of their time to experimenting with these fascinating and necessary gadgets. The antenna chapter of any recent edition of the *ARRL Handbook* or the book-length treatment in the *ARRL Antenna Book* are suitable starting points if you want to acquire a basic grounding in antenna theory. With respect to ATV operation at 70 cm, the most common antenna type in use is the **Yagi-Uda** array ("beam" or "Yagi"), named for the two Japanese engineers who first developed the design.

The fundamental design elements of Yagi antennas have been known for half a century. One very basic principle is that to achieve higher gain values (and directivity), you have to lengthen the boom and add more elements. In general, the longer the boom and the greater the number of elements, the higher the gain. However, designing such high-gain "long Yagis" was as much art as science. To optimize the performance of the antenna, the precise distance between different elements and the lengths of the elements themselves had to be varied, and each iteration had to be subject to careful evaluation on an antenna test range. Short Yagis could be optimized much more easily than long arrays, and seemingly small changes could greatly alter the matching properties of the array and its bandwidth, in addition to the expected changes in gain and pattern geometry.

One of the major advances in the 1990s was the development of antenna design software that let much of this "cut and try" work be done on the computer console, as opposed to in the workshop and on the antenna range. The result has been a whole new generation of high-gain arrays, both commercial and home-built, that actually perform as advertised! This work has made antenna selection or construction much easier for the new or experienced ATV operator.

While optimizing the **gain** of an antenna is critical to getting the best range and performance on the 70 cm band, it is not the only consideration. In general, as antennas get longer with more elements, the **bandwidth** of the antenna begins to get narrower. This is of little consequence for most operations, as long as the antenna is tuned to the part of the band where you want to operate; but it can be a problem with ATV. If we want maximum image resolution, the best possible color, and subcarrier sound, the antenna needs to have sufficient bandwidth to exhibit a "flat" (uniform) response over at least 6 MHz of the band; and even wider bandwidth is desirable to make frequency matching less critical. Antennas can be optimized for bandwidth, usually at the expense of some loss of gain; but that is almost an impossible task using "cut and try" techniques for long Yagis. Fortunately, that is precisely the kind of job for which antenna design software excels. The fruits of all of this technological development can be seen in the form of antennas that can be expected to yield solid and predictable results when used on ATV.

**Table 8.1** lists five commercially available Yagi designs for 70 cm that perform well in ATV service. The table is arranged in terms of an increasing number of elements (and thus boom length) and gain. Advertised gain values used to be a very contentious subject. The actual gain values achieved at VHF/UHF antenna measuring contests were often quite different (typically lower) than promotional hype might suggest. Today's promotion does a much better job of mirroring reality, in part because of the ease with which a specific antenna can be modeled in software and its performance parameters evaluated. The gain figures included in Table 8.1 may not be absolutely precise, but the patterns indicated in the table are in reasonable accord with boom length and the number of elements. The shorter antennas in the table (5 and 11-element arrays) are included because they are very practical for portable, emergency, or public service communications.

**Table 8.1**

Comparison of a set of commercial antennas for the 70 cm band that are suitable for use on ATV. Antenna gain specifications are derived from the manufacturers' promotional literature and are included for general information (see text). Vendors listed include M2 Antennas (M2), Cushcraft Corporation (CUSHCRAFT), and Directive Systems (DIRECTIVE). Contact information is available in the Appendix. (*) Cushcraft rates their antennas in dBi (gain referenced to an isotropic radiator), while most other vendors rate their antenna gain in dBd (gain relative to a reference dipole). In order to have comparable figures for claimed gain, the advertised gain for the 719B has been reduced by 2.15 dB, the theoretical gain of a reference dipole.

| MODEL | ELEMENTS | BOOM LEN. FT (CM) | GAIN (dBd) | VENDOR |
|---|---|---|---|---|
| 440-470-5W | 5 | 2.17 (66.1) | 7.8 | $M^2$ |
| 420-450-11 | 11 | 5.08 (154.9) | 11.3 | $M^2$ |
| 719B | 19 | 13.50 (411.5) | 13.4* | CUSHCRAFT |
| 440-21ATV | 21 | 14.50 (442.0) | 15.9 | $M^2$ |
| DSFO420-ATV | 25 | 17.25 (525.8) | 16.1 | DIRECTIVE |

We will look at specific signal coverage factors in Chapter 9, but it should come as no surprise that using higher gain antennas from further down on Table 8.1 will produce better results and are preferred if you have the space to mount and turn them. For example, if you were running a 2 W ATV exciter into the 7.8 dB 440-470-5W antenna of Table 8.1, your line-of-sight range for snow-free pictures, assuming moderate transmission line losses, would be about 13 miles when working a similarly-equipped station. If both of you were to switch to the higher-gain (15.9 dB) 440-21ATV Yagis, your line-of-sight range for snow-free pictures would increase to 36 miles! No matter how your station is configured and no matter what your site limitations, higher antenna gain is always preferable.

For those who might want to construct their own Yagi, recent editions of the *ARRL Handbook* have featured an excellent design by K1FO that is extremely well-regarded by the ATV fraternity. Design tables are provided to construct the antenna in any configuration from 15 elements (13.52 dBd gain, 7.8 ft (238 cm) boom) to 40 elements (18.65 dBd gain, 31 ft. (945 cm) boom). Engineering proper support for the longer versions of the antenna can be tricky, but the intermediate sizes work extremely well. The Directive Systems DSFO420-ATV is a commercial version of a 25-element K1FO Yagi.

### *MORE COMPLEX ANTENNA ARRAYS*

The experienced VHF/UHF operator may be tempted to start with even more complex arrays involving two or four long Yagis. This is the only practical way to achieve more gain once you have reached the 15-16 dBd point. I would suggest that newcomers to these frequencies select a single Yagi of adequate performance and get on the air. If your interests or requirements later suggest the need for more gain, more complex arrays can be constructed from multiple beams. Most of the commercial antenna vendors can supply two and four-port power dividers that make it a straightforward matter to combine Yagis, with due attention to achieving optimum spacing of the individual beams. Assuming minimal loss in the power dividers and interconnecting cables, the following gain figures might be expected by combining multiple 15 dBd long Yagi arrays:

| # Beams | Gain (dBd) |
|---|---|
| 1 | 15 |
| 2 | 18 |
| 4 | 21 |

### *POLARIZATION*

Antenna **polarization** primarily reflects the evolution of most local and regional ATV groups. In most areas, horizontal polarization is used, providing a good 20 dB isolation with respect to FM operations that are vertically polarized. However, some groups do use vertical polarization; so it is always a good idea to verify this basic fact before planning the mounting of your antenna(s). Newly forming ATV groups are urged to use horizontal polarization, both to preserve the potential to work out of the local area during band openings and for the isolation provided by cross-polarization when dealing with potential FM interference.

**Antenna Height** is a major factor in the decision as to where and how to mount your antenna. Having the array high enough to clear local trees is extremely useful. Foliage does a very effective job of absorbing 70 cm RF (even worse at 33 and 23 cm); and, if your antenna is located below the trees, you will notice a distinct drop in range during the summer months. Of course, clearing the local trees also assures that you will be well above local residential structures. The second factor contributed by antenna height, often erroneously referred to as "height gain", is an improvement in the line-of-sight (LOS) range. Given the nature of UHF and microwave propagation, the closer you can come to true LOS conditions over a given path, the better the signals. Assuming a smooth earth (not terribly likely!), the LOS distance (in miles) for various antenna heights (in feet) can be calculated by multiplying the height by 2 and taking the square root.

**Table 8.2** shows the calculated LOS distance for antenna heights of 10 to 100 feet in 10-foot increments, covering the range of typical tower heights. The table also contains LOS ranges for two unlikely height values (1000 and 100,000 feet) whose significance will become clearer in Chapter 9. In addition to the improvement your station can realize from greater antenna height, the benefits are additive when working other stations. For example, over a smooth earth, an antenna height of 50 feet has an LOS range of 10 miles (16.1 km). Any other station with a 50-foot antenna height will have the same LOS range; and two such stations up to 20 miles (32.2 km) distant, would enjoy a theoretical LOS path. When planning the development of an ATV station, the long-term goal should be to strive for the largest practical array as high as you can manage.

### *ANTENNA POSITIONING*

The relatively high gain of 70-cm arrays imposes a penalty in the form of rather narrow beamwidth in the vertical and horizontal planes. As a result, the antenna must be pointed at another station with reasonable accuracy to take advantage of the increased signal strength the antenna can provide. While antenna rotation can be handled manually when operating portable, home station operation will require an azimuth (directional) rotator. Fortunately, most single Yagis for 70 cm are light enough that a modest TV rotator will often serve. If you already have a tower and rotator, the usual practice is to mount the ATV array at the top of the existing antenna stack.

### *TRANSMISSION LINE*

In many ways, your choice of transmission line can be the most significant step you take in putting together your station. **Table 8.3** lists a series of transmission lines of varying quality. The cables at the bottom of the list (RG58 variants and solid RG8) are the lowest cost of any of the cables, they are universally available, and — unfortunately — they are completely unsuited for use on the 70 cm band. The 8214 and 9913 cables are available from most major amateur retail and mail-order outlets; and, while more costly, they are suitable for installations with moderate cable runs. The hardline and Heliax™ options are superior to anything lower on the list, but they are expensive (if purchased new) and may be harder to obtain.

What makes the difference with respect to comparing one cable type with another is the signal loss or attenuation. Some signal is lost when any cable is used, but the losses increase with the operating frequency. It is at 70 cm and higher where the differences between cable can be very significant, ranging from a high of about 12 dB/100 feet (30 meters) to a low of 0.8 dB. While the attenuation values tell the entire story, most amateurs don't have a good feeling for the magnitude of the logarithmic dB scale — especially with respect to attenuation. To help make this point, I have included a column in Table 8.3 that indicates the power output from a 100-foot (30-meter) length of each cable when driven by a 10-W transmitter. The worst cable in the table (RG58 solid) yields an output of just over half a watt compared to over 8 W for the best cables (7/8-inch hardline or Heliax™). You actually would derive more power from the 7/8 inch cables when driven by just 1 W than you would with 10 W driving to poorest cable! The best use of a long run of RG58 cable (the older the better) is as a high-quality 50-Ω dummy load!

**Table 8.2.**

Relationship between antenna height and line-of-sight (LOS) distance.

| HEIGHT Feet (Meters) | LOS Distance Miles (Km) |
|---|---|
| 10 (3.0) | 4.5 (7.2) |
| 20 (6.1) | 6.3 (10.1) |
| 30 (9.1) | 7.7 (12.4) |
| 40 (12.2) | 8.9 (14.3) |
| 50 (15.2) | 10.0 (16.09) |
| 60 (18.3) | 11.0 (17.7) |
| 70 (21.3) | 11.8 (19.0) |
| 80 (24.4) | 12.6 (20.3) |
| 90 (27.4) | 13.4 (21.6) |
| 100 (30.5) | 14.1 (22.7) |
| 1000 (304.8) | 44.7 (71.9) |
| 100,000 (30480) | 447.2 (719.5) |

If the power figures don't convince you of the value of good transmission line, the RANGE column of Table 8.3 shows just one of the results of a simulation run using the ATV Range program previously noted. The simulation was designed to show the impact of transmission line selection with a simple, entry-level ATV system with the following specifications at both ends of the circuit:

| | |
|---|---|
| **Antenna**: | 7.8 dBd Yagi |
| **Transmitter**: | 2 W peak |
| **Antenna Height**: | 25 feet (7.6 m) |
| **Transmission Line**: | 100 ft. (30 m) |

The LOS range in this case is 14 miles. Let's assume they are well situated and actually do enjoy line-of-sight conditions. If our two friends were foolish enough to use RG58 solid coax, their snow-free transmission/reception range would be just two miles! Although not shown on the table, the simulation also suggests that at 13 miles it would be a toss-up as to whether any video would be seen that would qualify as a "real" QSO. In short, our hapless amateurs would see virtually nothing! None of the readily-available cable is any prize, but the better ones do increase the snow-free range without the need to add anything else to the system. By the time they reached the use of 9913F cable in the two stations, they would receive snow-free pictures! Had they started out with the poorer coax, they well might have concluded that there was no future in ATV. The real beauty of using good cable is that it is still there, improving both

**Table 8.3.**

RF attenuation (450 MHz) for various transmission lines. The hardline cables (*) are 75 Ohm impedance and require matching networks as noted in the text. To emphasize the significance of the power loss values, the table also includes the peak RF power (POWER) delivered to the antenna, assuming a transmitter peak power output of 10 W and a 100 foot cable run. The RANGE column shows the predicted snow-free communications range for a pair of simple stations (see text) using 100 foot runs of each transmission line.

| CABLE TYPE | LOSS (dB/100Ft) | POWER (WATTS) | RANGE - SNOW-FREE MI [KM] | VENDOR |
|---|---|---|---|---|
| 7/8" Heliax™ | 0.80 | 8.33 | 23 [37] | Andrew |
| 7/8" hardline* | 0.95 | 8.08 | 23 [37] | CATV |
| 1/2" Heliax™ | 1.40 | 7.25 | 21 [34] | Andrew |
| 1/2" hardline* | 1.40 | 7.25 | 21 [34] | CATV |
| 9913F | 2.80 | 5.24 | 15 [24] | Belden |
| 8214 | 4.40 | 3.64 | 11 [18] | Belden |
| RG8 (solid) | 5.00 | 3.16 | 9 [15] | Various |
| RG58 (foam) | 7.10 | 1.95 | 6 [10] | Various |
| RG58 (solid) | 12.00 | 0.63 | 2 [3] | Various |

transmission and reception as you upgrade antennas, move the array higher, or add an accessory amplifier. Choosing good cable pays dividends for both the casual and serious ATV operator.

It is pretty obvious that the Heliax™ and hardline cables are your best options. Heliax is expensive when purchased new, but there is a chance that you can get new hardline (coaxial cable with a solid aluminum shield in place of the woven wire braid of more common cables). Hardline is used universally by cable television operators, and cut-off ends (up to a few hundred feet in length) are of little use to the cable company and often can be obtained free.

One problem with hardline is that the cable is stiff and can only be bent using a very generous radius. It is, however, perfect for runs to and up the tower. Lengths of a flexible low-loss coax (8214 or 9913F) then can be used to make the actual connection between the hardline and the antenna feed point and between the hardline and the equipment in the station.

The other problem with CATV hardline is that it has an impedance of 75 Ω while our equipment is designed for 50-52 Ω. A 75-Ω line can be matched to 50 Ω with a quarter-wave matching section having an impedance of 61.25 Ω (the square root of the product of the two impedance values to be matched); but that is not a stock value for coaxial line. A clever solution to the matching problem is a line of innovative connectors designed by Paul Darwactor (W8ZD) of ZD Engineering (see **Appendix**). The connector is a type N with a transition sleeve (with a conductor insert) machined to provide the 61.25 Ω matching sleeve between the end of the hardline and the 50-Ω N-connector. These devices are very reasonably priced and solve both the connector and matching problem presented by the amateur use of 75-Ω hardline.

If you choose not to use hardline, your best intermediate option is the use of 8214 and 9913F cables. Use the 8214 for relatively short runs (up to 50 feet) and the 9913F for longer runs. While much of this discussion has emphasized the use of low-loss cable options, there is a very limited role for RG58 cables (foam dielectric only) for short runs (up to a few feet) inside the shack. Connecting the output of an exciter/transceiver to a power amplifier is one place where such cable can be used. Another reasonable application is a portable or mobile installation where the total cable run is in the order of 10-15 feet (maximum of ~ 5 meters). Beyond such limited cabling tasks, all other transmission line runs should be the best cable you can acquire.

### *RF CONNECTORS*

Very little has been said about connectors at this point. There are really only two commonly available connector types suitable for use on 70 cm. **Type N** connectors should be used for 8214, 9913, and hardline/Heliax™ cable connections. For the relatively few occasions where RG58 cable is appropriate, use **BNC** connectors. Other commonly available connectors are not constant-impedance types and thus will produce impedance "bumps". This will increase your cable losses which can lead to instability and heating in the case of power amplifiers. For the same reason you *must completely avoid the use of cable adapters* that convert one connector type to another. These can work just fine at HF frequencies and may even work after a fashion on VHF, but they are completely unsuited for 70-cm and higher-frequency amateur bands.

One key to minimizing connector problems is to install them properly. Any edition of the *ARRL Handbook* or the *ARRL Antenna Book* will contain detailed specifications of N and BNC connectors along with detailed instructions on how to install them properly. If you are not sure about your ability to do the job, you may want to enlist the help of a more experienced amateur. Alternatively, many vendors selling cable will equip lengths of cable with connectors at a moderate additional charge. All connectors installed outside must be properly weather-sealed as any moisture in a transmission line will seriously degrade its performance. Type N connectors already have excellent weather-proof qualities (if installed correctly); but the careful application of putty-like sealing materials (Coax Seal™) finished off with several wraps of vinyl electrical tape can pay dividends in terms of a long, trouble-free service life.

## ATV TRANSMITTERS AND RECEIVERS

The basic RF equipment of any 70-cm ATV station consists of a common group of modules:

- **Downconverter** — converts an ATV signal in the 70-cm band to the frequency of an unused TV channel (typically 3 or 4) for reception on a standard broadcast television receiver.
- **Exciter** — a low-powered transmitter strip (typically 100 mW to 2-3 W) with an integral or external AM video modulator.
- **Sound** — capability to insert a 4.5 MHz FM sound subcarrier into the video modulator to permit sound reception via the TV set IF. In some cases, provisions may be made for narrow-band FM modulation of the video carrier.
- **Power Amplifier** — one or more stages of RF power amplification, typically in the AM linear mode, to increase the transmitter power output (from 10 W peak up to the legal power limit of 1500 W PEP).

Where stations will differ is in the packaging or integration of these modules. These elements can function as independent modules, providing the greatest flexibility and options for experimentation. Alternatively, the major pieces — downconverter, exciter, and sound subsystem (with the option of modest RF power amplification) — can be packaged in a single housing to create an ATV "transceiver". In the sections which follow, we will look at these different modules, as well as at some additional topics that go into rounding out a functional ATV station.

### *ATV RECEIVE CONVERTERS*

The acquisition of a stand-alone downconverter often serves as the first step in the decision to try ATV. With the relatively low-cost investment in a stand-alone converter, you can "look in" on local ATV activity. If you later move to a fully-packaged ATV transceiver, the downconverter is still available as an independent receiving system or can be loaned out to recruit new ATV operators. Most down-converters are fairly simple, consisting of a low-noise preamplifier stage (typically using a GAsFet device with a noise-figure below 1dB), a local oscillator circuit, and a mixer to convert ATV signals in the 70-cm range to an unused VHF TV channel (typically 3 or 4). Where the various converters differ is principally in the nature of the local oscillator, which can be either tunable or crystal-controlled.

**Tunable Downconverters.** These converters have a front-panel tuning dial that permits the unit to tune across the entire 420-450 MHz band. An example of a widely used tunable converter from PC Electronics is shown in **Figure 8.6A**. Both packaged and board-level converters of this type are available from PC Electronics and Communications Concepts. The primary advantage of the tunable converters is that they can receive ATV transmissions anywhere in the 70-cm band, and it is possible to adjust the tuning to minimize the impact of interference. PC Electronics provides the option of a switched local oscillator tuning range that permits TV signals to be tuned using the lower sideband, just in case local FM interference is a major problem. The tuning of these converters will shift slightly with warm-up or if the unit is subject to major temperature variations, but this is rarely a serious issue given the very wide bandwidth of TV transmissions.

**Crystal-controlled Converters**. The second major option is to use a converter with crystal-controlled local oscillator injection, much as you would for working narrow-band modes. Figure 8.6B shows a Hamtronics converter for ATV that is available as a kit or wired and tested. PC Electronics has crystal-controlled converters in their product line. Also, many of the home-built converter designs developed over the years could be modified for use on ATV by changing the local oscillator injection and retuning the output for channel 3 or 4. Downeast Microwave would be a preferred source if you wanted to try that route. The advantage of crystal control is that you don't have to worry about being tuned to the proper frequency; and, for this reason, crystal-controlled converters are the norm for repeater installations. The principle disadvantage is that you are limited to a single frequency unless you add additional crystals and some provision for switching the operating frequency. Here in Michigan I am located above the "A-line" (see Chapter 9). Our local ATV group has only one practical 70-cm frequency (439.25 MHz), so this is not a problem. In other areas, where more than one 70-cm frequency is in use, this would be a significant disadvantage.

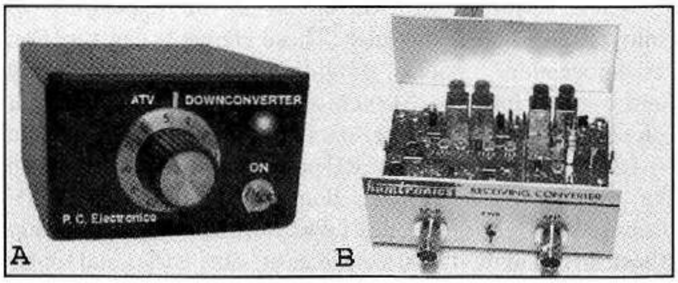


Figure 8.6. Stand-alone ATV downconverters come in two general configurations. **[A]** shows a tunable unit (a PC Electronics **TVC-46**), providing manual tuning of the entire 70 cm band with output on broadcast VHF channel 3 or 4. **[B]** is a crystal-controlled unit (Hamtronics **CC-432-9**) that converts signals on 439.25 to broadcast channel 3.

Almost any converter you select will have a reasonable front-end noise figure and good sensitivity. Just remember, based on our earlier antenna system discussions, that the converter performance likely will be limited by the combination of the antenna and transmission line you select. If you have strong local ATV stations, you may be able to copy pictures by hooking the converter to some sort of external antenna system, such as a UHF TV antenna. However, you will never appreciate its full potential unless you use a good 70-cm antenna and high-quality transmission line.

### *THE CABLE CHANNEL 60 OPTION*

If you have a cable-ready TV, it may be possible to copy local ATV activity without the use of a converter. Cable (not UHF) channel 60 corresponds to 439.25 MHz, the most common ATV simplex frequency. The biggest problem with this approach is that most cable-ready sets are designed for the cable environment, where signal levels are quite high. As a result, front-end sensitivity and noise figure tend to be unsatisfactory for serious ATV work. The better the antenna and transmission line, the better the potential performance, at least with respect to local activity. With a 70-cm pre-amp-lifier (see discussion in the later section on Preamplifiers) the performance can be comparable to conventional converter/TV set receiving systems. Actually, the comparatively poor sensitivity of cable-ready sets can be an advantage when monitoring your own transmitted signal. A really sensitive receiver will typically overload when a TV transmitter is operated in close proximity. Many cable-ready sets, tuned to channel 60 with a 75-Ω resistor across the TV antenna terminals, will do a much better job of showing how the transmitted signal actually looks.

### *ATV EXCITERS*

The typical ATV exciter consists of a low-powered 70-cm transmitter (crystal controlled) with video modulation applied to the final (and possibly driver) output stage. Vendors such as PC Electronics and Video Lynx sell small ATV transmitter boards that typically provide between 100 mW and 2-3 W of modulated output. Since these transmitter strips are intended for use on ATV, the required video modulation circuitry is typically included on the main PC board. If you need a simple, no-fuss ATV transmitter for 70 cm or other bands, such exciters can work very well. For many years I have used a 1.5 W PC Electronics KP-5 ATV transmitter on my ultralight aircraft (see Chapter 9), and it works very well.

For those who would like to customize their station options, it is perfectly feasible to use a small FM transmitter strip and add an external video modulator. Hamtronics offers two suitable transmitter options (one crystal-controlled and the other synthesized) in the 2-2.5 W range (**Figure 8.7**). Cannibalizing the transmit circuits of older crystal-controlled mobile rigs or handhelds is another option. The biggest advantage of using FM transmitters as your RF source is that it is easy to FM-modulate the carrier frequency. Receiving the FM modulated carrier (so-called **on-carrier audio**) typically requires a secondary receiver, but the advantage is that the FM voice signal on the carrier often can be copied when no useful video is received. (Remember that -26 dB video/audio signal differential discussed earlier.) In some areas, amateurs are experimenting with sending SSTV on the on-carrier FM signal while the carrier is also AM modulated with the TV signal. The on-carrier FM has no impact on ATV reception at the other end, although the AM modulation of the carrier does reduce the effective range of the on-carrier FM voice signal.

In order to use an FM transmitter board as a TV exciter you need one more item — a **video modulator**. In principle, a video modulator is quite simple. In effect, the most common type of modulator is simply a very fast voltage regulator that varies the voltage to the final output transistor(s) in step with the applied video waveform from the camera. In the real world the modulator has to meet some pretty exacting requirements:

- In must be capable of precise adjustment to set the white, black, pedestal, and sync levels.
- It must have a flat response from near DC to about 5 MHz to pass color and the sound subcarrier (if used).
- It must have low harmonic distortion to avoid unwanted phase shifts that would distort the color subcarrier.
- It must produce a very low level of intermodulation distortion (IMD) products in order to avoid interference of adjacent frequencies.

This last point is not widely appreciated, and many simple modulator designs are very "dirty" with respect to IMD. In the "old days" this might not have mattered too much with relatively few people using the 70-cm band. In contrast, today it is a critical issue since ATV operations share the band with weak-signal operators, digital communications, amateur communications satellites, and — of course — UHF FM. **Figure 8.8** shows a video modulator, designed by John Magliacane (KD2BD) that has none of the problems of a typical design. The series output transistor is a VHF power transistor. It has a flat response out past 20 MHz, less than 1% total harmonic distortion, and does not generate significant levels of IMD. A detailed technical description of the circuit can be found at **http://www.qsl.net/kd2bd/modulator.html**. A complete construction package in PDF format can be found on the *ICH* CD-ROM, including a technical description, parts list, printed-circuit board layout diagrams, and construction and set-up notes. This circuit is probably the best ATV video modulator I have run across over the years and is well-worth the modest effort needed to build it.

### *SOUND OPTIONS*

At first glance, the most obvious way to include voice capability in conjunction with video transmissions is to make use of the sound capabilities present in every TV set. In the broadcast service, sound is implemented by a separate aural (voice) FM transmitter operating 4.5 MHz above the video carrier. If one intends to implement TV sound, this is the most efficient and effective way to do so. Small FM exciter boards can be used to implement the aural link, but some modification will be required when using a standard narrow-band FM (NBFM) exciter. TV sound deviation is 25 kHz, compared to 5 kHz for NBFM. The FM modulator circuit will typically require some modification to increase the deviation closer to the standard 25 kHz.

Although the aural transmitter can have its own antenna system, this results in additional complexity with respect to an amateur installation. In practice, it is easier to combine the output of the video and aural exciters, so that the same antenna system will suffice for both. The simplest RF combiner is for each exciter to drive a ¼-wave length of 75-Ω transmission line. The common junction can be a standard T-connector (BNC) with the 50-Ω output connected to the common leg. The 75-Ω cable can be RG59 foam, and the length should be cut according to the velocity factor of the cable you use. A free-space ¼-wave is 17 cm, and typical RG59 foam coax will have a velocity factor of 0.66. The cable length for each leg, including connectors, would thus be 17 × 0.66 or 11.25 cm. The power output of the aural transmitter should be set to about –10 dB (essentially 1/10) relative to the peak power of the video

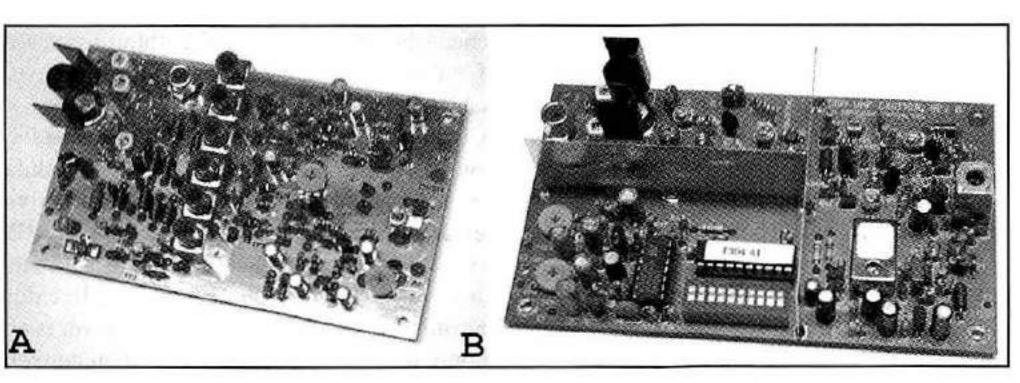


**Figure 8.7**. FM transmitter strips provide an excellent foundation for a low-powered ATV exciter. **[A]** Hamtronics **TA451** crystal-controlled exciter rated at 2 W peak output (available as a kit or wired and tested). **[B]** Hamtronics **T304-3** synthesized FM exciter (2-2.5 W). This model can be tuned to any frequency (5 kHz) in the 430 to 440 MHz range using the DIP switch visible at the center of the lower edge of the pc board. In this frequency range the board is only available in wired-and-tested form.

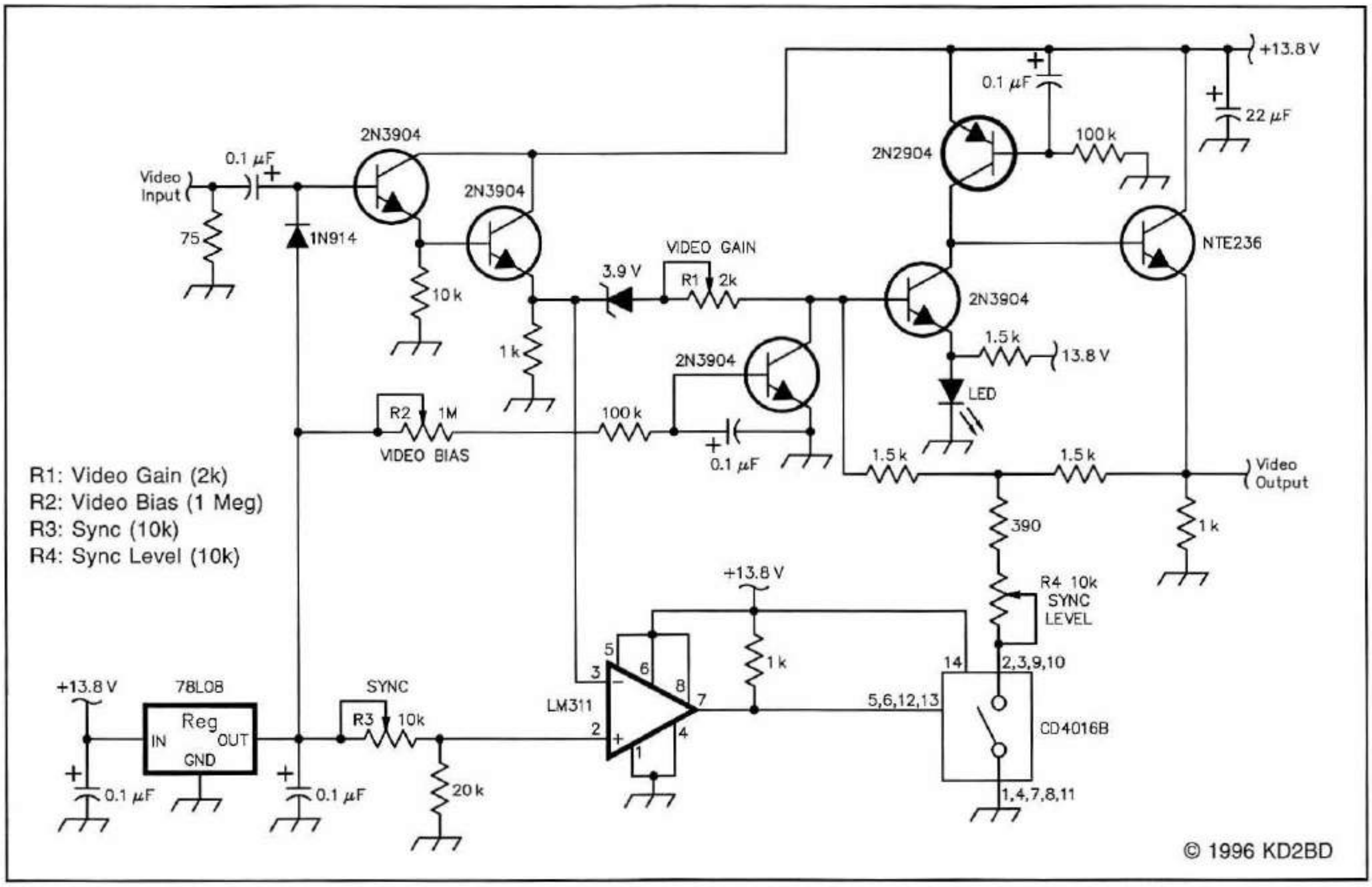


**Figure 8.8.** If an FM transmitter module is used as an ATV exciter, an external video modulator will be required. This circuit, designed by Mike Magliacane (KD2BD), while more complex than most, is an excellent choice if you want to generate a very high-quality signal with minimal IMD. (©1986, courtesy of KD2BD).

exciter. If the video exciter puts out 2 W peak, the aural subcarrier exciter would be set to produce 200 mW. The combined video/aural signal at the T-connector can be routed directly to the antenna for low-power operation if used to drive a linear amplifier (see later discussion) when more power is desired. Done properly, this approach will produce sound reception comparable to broadcast service, and typically you will get a reasonable voice signal even if the picture signal is quite weak.

Although the use of a separate aural transmitter represents best practice, most amateurs opt for the simpler approach of generating a 4.5 MHz aural subcarrier. Here an accurate 4.5 MHz carrier is frequency-modulated (25 kHz deviation). The signal is mixed with the AM video signal by injecting the subcarrier signal in the video modulator circuit. The level of the subcarrier signal is adjusted to set the subcarrier power level at 10-15 dB below that of the main video carrier. This approach, while simple, has two drawbacks:

- Since the subcarrier is injected via the video modulator, the 4.5 MHz sound will appear both 4.5 above and below the video carrier. This is not particularly efficient and makes the DSB AM video signal significantly wider than it has to be.
- Given problems with linearity and phase shift in most amateur modulators, recovery of the sound is not comparable to that seen with broadcast signals. Subcarrier sound typically will not be heard unless the ATV signal is moderately strong.

Even when reasonable results are obtained using the TV sound, the major practical problem with this approach is that most TV sets do not have the equivalent of a squelch circuit. Most day-to-day ATV operation has several stations transmitting in turn while you will be adjusting your high-gain (= directive) antenna to favor each in turn. The result is that the TV sound will be very noisy at times. Using the TV set as the audio link becomes completely impractical when two stations are attempting to make contact over a difficult path. Since you won't hear the subcarrier sound without some reasonable level of video, the sound channel simply doesn't work to coordinate a QSO.

Over the years, Don Miller (W9NTP) and others have advocated the use of on-carrier sound with direct NBFM modulation of the video carrier. There is no doubt about the effectiveness of on-carrier audio, but it does require a separate FM receiver tuned to the video carrier frequency. There is also the additional complexity of switching the receiver off-line during your ATV transmissions so that the NBFM receiver is not damaged. While on-carrier audio comes closer than conventional TV audio to producing a reliable voice link, relatively few ATV stations are equipped to use it.

For most groups the practical solution to the voice coordination problem is to use a different band and rig. Two meter FM generally has proven to be the most accessible option. Although active frequencies can vary in different parts of the country, 144.34 MHz is used widely as an ATV calling frequency and intercom. Ten W into a modest vertical will let a station work all other ATV operators in the area, no matter where the high-gain ATV array is pointed, and can be remarkably effective during band openings.

### *ATV TRANSCEIVERS*

An ATV "transceiver" is nothing more than a packaged combination of the modules we have discussed up to this point. **Figure 8.9** shows in block diagram form how the various pieces go together. The major advantage of an ATV transceiver is that it greatly reduces the "clutter" of a more modular set-up, and everything fits nicely into a compact enclosure. PC Electronics is one of the few sources for complete ATV transceivers, and their latest model is shown in **Figure 8.10**. The rugged, die-cast aluminum housing is perfect for the rough-and-tumble of portable operations. The latest version uses a synthesizer for transmitter frequency control, and all popular ATV frequencies can be selected from the front panel. The unit incorporates an internal power amplifier module, and its rated 20 W of peak output is a much more practical power level than units in the 0.1 to 2-W range. The unit has provisions for multiple video inputs, subcarrier sound (both microphone and line) and provisions for a remote T/R switch — often called "push-to-look" in ATV circles.

PC Electronics sells all the individual boards that make up the unit, and it would be quite practical for a new amateur on a tight budget to start with the essentials — the video exciter and converter boards — and add the remaining modules as budget permitted.

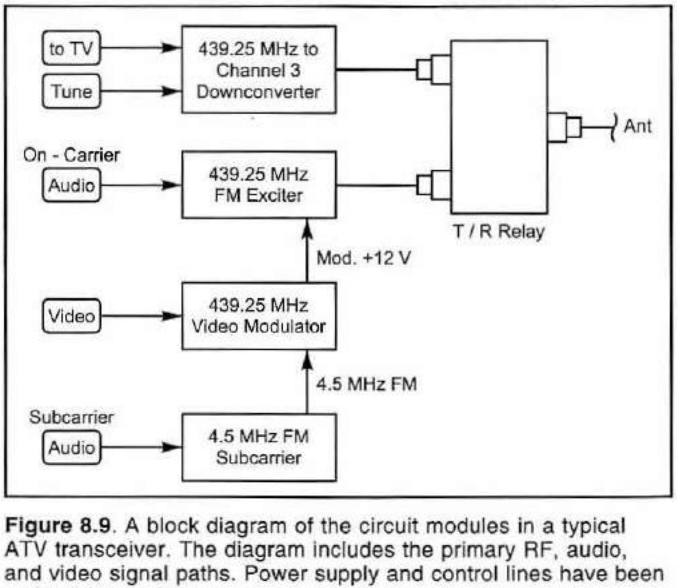


**Figure 8.9**. A block diagram of the circuit modules in a typical ATV transceiver. The diagram includes the primary RF, audio, and video signal paths. Power supply and control lines have been omitted for clarity.

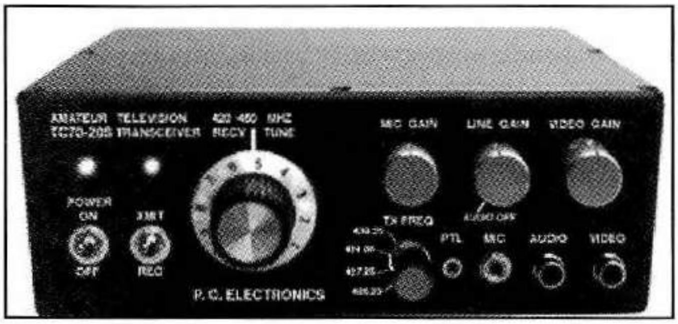


**Figure 8.10**. ATV transceivers contain an ATV downconverter, transmitter and video modulator, subcarrier sound generator, and even power amplifiers in one convenient package. This is the PC Electronics **TC70-20S**, that packages a complete 20 W (peak) synthesized ATV station (less TV and video source(s)), in a compact die-cast aluminum housing.

### *TELEVISION CAMERAS AND VIDEO SOURCES*

A television camera is obviously a key item for your ATV station. You probably will not have to buy one at the outset if your family has a camcorder. This will do just fine, but used camcorders can be picked up for very little at flea-markets and hamfests. When camcorders go bad, it is most likely to be the tape mechanisms; and some sales/service outlets may have units available that will serve well as cameras.

As compact as most camcorders are, I always found it a pain to try to find room for the camera and tripod while still providing a good field of view. Today there are a large number of truly miniature B&W and color cameras that can be purchased at very nominal cost. The Internet is littered with a large number of vendors for such cameras. However, I won't reference most of them as many promote their products for rather questionable applications; and others sell transmitting equipment that will operate on amateur bands, while not mentioning the "little" problem of getting a license. There is NO provision for license-free operation on amateur frequencies or on commercial broadcast channels. This is a subject I'll address at greater length at the beginning of the next chapter. PC Electronics markets a limited range of subminiature cameras, and ATV Research is a reputable outlet that handles just about every camera type available.

Amateur regulations require station identification at least every 10 minutes. You can meet the identification requirement by having a prominent callsign within the field of view of the TV camera in its normal operating position, in which case identification is virtually continuous. You also can identify the video transmission with call letters superimposed on normal camera video, or you can digitally generate ID slides and other materials. Intuitive Circuits markets a wide range of overlay modules, many of which are PC-programmable. There are modules that will do basic alphanumeric and color overlays, those that will overlay RS-232 data, and even some designed for real-time display of GPS data. These are simple devices to use because your camera video goes in on one port; and the video, with overlay imposed, goes out another. The options are quite diverse, and their Web site is worth a visit. Of course, there are ways to use a computer to generate video; but I will save that for the computer applications section near the end of this chapter.

### *TELEVISION SETS*

The selection of TV sets used to be simple — if it works and the family will let you take it, use it! Today there are plenty of sets to choose from, but there are a few things that need watching. A few of the key points are summarized below:

- **Cable-Ready**. If at all possible, use a cable-ready set. This will give you the option of monitoring your signal on cable channel 60 (439.25 MHz), and with a preamp such a set will serve as a general band monitor.
- **Screen Size**. Large-screen sets are really only comfortable to view at a distance. Given the economics of mass production, the least expensive color sets are those with a 13-inch screen. This is a bit large for use right at the operating position; but such sets can be wall-mounted, especially since all current production TVs come with remotes. I prefer 9 inches for general station use. Five-inch sets are also very nice but tend to be a bit pricey compared to larger screen sizes.
- **DC Operation**. Many small-screen sets have the capability to operate from a 12-V DC power source. This is an excellent option for portable or emergency use.
- **Blue Screen**. One of the features common in contemporary television sets is the "blue screen". If a given television channel has a weak signal (or no signal at all), the microprocessor switches in a blue screen so the customer doesn't have to watch a screen filled with "snow" (noise). The blue screen display makes it impossible to search for weak signals. In some sets the blue screen feature can be turned on or off, and this is what you should look for. If the blue screen feature cannot be disabled, the set is unsuited for serious ATV use.

There are a wide range of miniature TV sets with LCD screens that are a bit delicate for day-to-day use but which may serve when using a light portable installation. It also would be practical to build one of these small sets into an ATV transceiver, resulting in a portable package that would only require the addition of a micro-TV camera, microphone, and small antenna for portable use.

### *REMOTE PREAMPLIFIERS*

In discussing weather satellite receiving systems in Chapter 5, I indicated it was standard practice to employ remote RF preamplifiers at the antenna to overcome the problem of transmission line losses. Given the impact of line losses on reception at 70 cm, one might well ask if remote preamplifiers could mitigate the line loss problem. The answer is definitely "Yes," but there are complications in using remote preamplifiers in a system where the transmission line and antenna also will be used for transmitting. Let me start by emphasizing that there is rarely any benefit to adding a preamplifier to the equipment inside your station. Most converters already employ low-noise GAsFet front-ends, and additional preamplification probably will not make much of an improvement in front-end noise figure. What will be degraded is the dynamic range of your receiver, which will be reflected in greater potential for interference and possible signal overload in the case of nearby ATV stations. To be useful, a preamplifier has to be installed as close as possible to the antenna so as to negate the effect of transmission line losses on the received signal. In order to function at the antenna, the preamp has to solve two problems:

- **Weatherproofing**. The module obviously has to be protected from the weather. This can range from simple vented plastic or metal boxes to more elaborate sealed enclosures.
- **Preamplifier Switching**. A remote ATV preamplifier must have the capability of switching off-line when transmitting, otherwise the unit would be destroyed. Some units employ internal RF sensing to implement the switching while others are switched remotely from the station.

The switching function must be completely automatic (and fail-safe), otherwise you will forget at some point and destroy a perfectly good (and relatively expensive) preamplifier. Advanced Receiver Research (**Figure 8.11**) and Mirage both manufacture remote preamplifiers with the choice of RF or remote switching. Different models are rated with respect to the RF power that can be by-passed safely. In the case of units that are switched via RF sensing, it is important to observe the minimum power specifications. One model from the Advanced Receiver Research line has a 25-W power rating and will switch when driven by a signal as low as 500 mW. In contrast, the 160-W model requires a minimum of 5 W to trigger switching. If you were to connect a 2-W ATV exciter to the transmission line, the 160-W preamplifier probably would be destroyed. If you want to employ RF switching, you must be sure that you will never apply RF power below the switching sensitivity threshold.

If the preamplifiers are switched remotely, then the transmit power level is not an issue. It is important that the remote switching sequence protect the preamplifier from RF damage. A simple relay actuation can cause a problem if RF levels on the transmission line rise prior to completion of bypass-switching in or around the preamplifier. To avoid this, you should employ a T/R sequencing circuit that will actuate the transmitter only after a time delay sufficient to assure bypass-switching at the remote preamplifier. T/R sequences are widely employed in weak-signal microwave work, and Downeast Microwave has circuits that will do the job.

The least expensive option, in monetary terms, is the home-built conversion of a basic RF preamplifier such as those offered by Downeast Microwave or Hamtronics. You will need to fabricate a weather-shielded case (with adequate venting) and work up a reliable system to bypass the transmitted RF. One way or another, a remote preamplifier can make a

**Figure 8.11**. Mast-mounted preamplifiers can eliminate the impact of transmission line losses when receiving pictures. Such a preamplifier must be protected from the effects of weather, and some provision must be made to safely switch the unit off-line when transmitting. This particular unit is an Advanced Receiver Research Model **MSP450VDG-160**. It features a weatherproof aluminum housing and an integral bracket for mounting to either the antenna mast or boom. It includes RF switching circuits to automatically take the preamplifier out of the line during a transmission. A minimum of 5 W of RF is required to switch this particular model, which can handle up to 160 W on 70 cm.

significant improvement in your reception, particularly if you are not using hardline or Heliax transmission line.

### *RF POWER AMPLIFIERS*

While you can (and probably will) make useful ATV contacts with a low-powered exciter, if you spend any time with the **RANGE** program (included on the *ICH* CD-ROM), the benefits of increased power are readily apparent, both with respect to increasing your "snow-free" local coverage (or at least improving your signal) and the increased potential to work distant stations when the band is "open".

The simplest approach is the use of a basic 70-cm "brick" as a linear amplifier (**Figure 8.12**). "Brick" is the term applied to solid-state amplifiers, using either discrete components or hybrid power modules, housed in a simple metal cabinet with a heat sink on the top. Most of these are designed to operate directly from a nominal 13.6V DC power supply. Installation is simple as the typical brick has an input and output connector for RF, a switch to turn it on or off, and possibly a few switches for other functions. Although most models have provisions for external T/R switching, they are operated more commonly by using internal RF sensing circuits that switch the amplifier in-line whenever RF drive is detected at the input. Such amplifiers are universally employed for FM work on VHF and UHF bands and are also used for CW and SSB where power levels up to about 100 W (peak) are required. Amplifiers designed for use on SSB usually are biased to provide class AB linear service.

A quick search of vendors' catalogs will show that there is no shortage of available amplifiers in the 10-100 W range, including dual-band amplifiers (2 meters/70 cm) designed for use with the popular two-band FM and multi-mode transceivers. However, finding an amplifier that will do a good job on 70-cm ATV is a bit more complex. First, most of the available units are designed primarily for FM use (Class C) and thus are not a good choice. The second problem, particularly important in the case of relatively high-power amplifiers (50-100W), concerns some fundamental issues of solid-state RF power amplifier design. A 70-cm power amplifier will employ power transistors that provide a significant amount of power gain in the 420-450 MHz range.

Unfortunately, any transistor that will provide good gain at these frequencies will provide even more gain at lower frequencies — particularly in the HF range. There is so much gain available that, without provisions to suppress low-frequency feedback, it is quite possible for the amplifier to break into low-frequency "parasitic" oscillation. Such oscillation can destroy the transistors and will certainly generate high levels of interference even if the finals survive! To solve this problem, designers employ negative feedback circuits in the HF range to suppress such "parasitics" and permit the stable operation of the amplifier. Stated succinctly, the problem is that our modulated ATV signal contains important low-frequency components — the actual video waveform! Many high-power amplifiers, when driven by an ATV signal, will be subject to several possible problems:

- **Poor video response**, including loss or distortion of the picture color, as a result of the suppression circuit networks.
- **Damage** to the suppression circuit components, followed in short order by damage to the amplifier (or high levels of spurious emissions) with the onset of parasitic oscillation.

"Conversion" of high-power solid-state amplifiers for ATV use often involves the removal of existing parasitic suppression networks, as well as the addition of new components that achieve the same end without degrading ATV performance. The ATV section of the *ICH* CD-ROM includes a number of ATV Application Notes by Tom O'Hara (W6ORG) of PC Electronics. One of these covers conversion of the Mirage D-1010 amplifier. **Table 8.4** lists

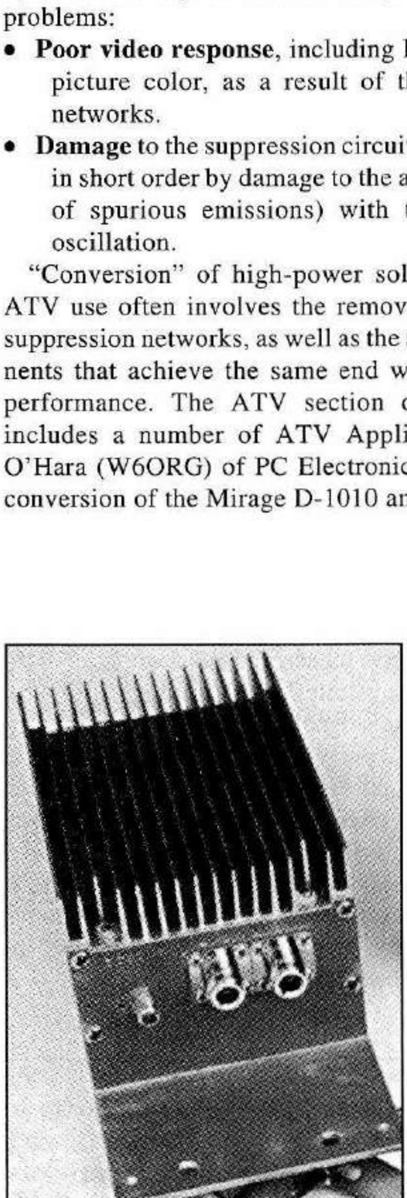


**Figure 8.12.** Solid-state "brick" amplifiers provide an excellent way to boost your transmitter power, provided you understand how to set them up properly (see text). This unit, the RLA-70 mast-mount amplifier formerly marketed by AEA, is illustrated because it used an interesting approach to overcoming the high transmission line losses common on 70 cm. The entire power amplifier and a low-noise preamplifier were housed in an enclosure designed to be mounted at the antenna. The unit was powered through the transmission line and ran 50 W PEP output. It typically delivered a stronger signal than a 100-W amplifier located in the shack. With a bit of ingenuity, almost any solid-state amplifier can be adapted for mast-mounting.

several models of Mirage amplifiers that have proven effective in ATV service. Mirage also has been responsive to the needs of the ATV community in providing variants of their D-100 and D-1010 amplifiers with the ATV modifications made at the factory. These models have an ATVN suffix, with the ATV designation indicating the ATV modifications and the N indicating the use of BNC connectors.

One complicating factor is that Mirage was recently purchased by MFJ Enterprises. The Mirage offices and production were moved to Starkville, MS, the location of MFJ's facilities. I recently purchased one of the current production D-1010ATVN amplifiers that ultimately posed a few questions. The amplifier itself (and the manual) indicated that the unit was the ATV variant, but the manual described some (not all) of the modifications required to use the unit on ATV! At the same time, the schematic appeared to show the converted circuit with all of the required modifications. I ended up opening the amplifier and doing a point-by-point comparison between the unit and the schematic, and it turned out that the amplifier was properly modified.

Obviously, standard units can be modified according to Tom's Application Notes. In that case, however, test the unit first with unmodulated RF drive to verify all the basic amplifier functions prior to making the modifications. Making the changes probably will void any warranty coverage, so you do want to check it out before you start cutting and soldering! It is also worth noting that the Model D-100 amplifiers (2 W in/ 82 W out) is basically a D-1010 (10W in/82W out) with the input attenuator pad removed. Thus, if you get your hands on a 1010, you can convert it for use with a low-powered (1-2W) exciter. Again, it would be prudent to test it thoroughly prior to making the modifications. If you feel uncertain about making any of these circuit revisions, you probably can get assistance from someone locally who is already on ATV or who is familiar with VHF and UHF amplifiers.

All solid-state "bricks" have another problem in ATV service — something known as **sync compression**. **Figure 8.13** shows the input/output power curve for a hypothetical amplifier. If the input/output function were truly linear (a straight line), the power ratios of the driving signal would be preserved in the output signal. In fact, the input/output function is non-linear, in that power goes up with input drive at a higher rate at low power than at high power. What this means is that the amplifier has to be driven harder for each incremental increase in output power as you get closer to the maximum rated output of the unit. In short, the I/O function is a curve! In fact, the input/output function of most real-world bricks is even worse than the hypothetical example shown here.

**Table 8.4**

Selected Mirage solid-state amplifiers that perform well in ATV linear AM service.

| MIRAGE MODEL# | PEAK INPUT (W) | PEAK OUTPUT (W) |
|---|---|---|
| D-15-N | 1 | 15 |
| D-26-N | 2 | 60 |
| D-100-ATVN | 2 | 82 |
| D-1010-ATVN | 10 | 82 |

This non-linearity has no real impact in CW or FM service. For SSB the result is equivalent to adding some RF speech-processing, giving a bit of added readability to the sideband signal. That same non-linearity is a serious matter on ATV. Let's assume that the amplifier is driven by a properly adjusted ATV signal with exactly 1 W peak output during the sync pulses (SYNC IN). Since the drive signal is assumed to be properly modulated, the pedestal power level will be 0.75 W (PEDESTAL IN) — 75% of peak output power. If we look at the output power distribution, we see +10 W out for the sync pulses (SYNC OUT), but 8.4 W out for the pedestal level (PEDESTAL OUT). Because of the non-linear input/ output response, the pedestal is now 84% of peak output instead of 75%! Unless this signal is very strong, it will not lock up. (The image will roll vertically and tear horizontally.) The contrast will appear excessive because the other video reference power levels have also been distorted. This is called **sync compression** because the result is the same as if you had compressed or suppressed the sync amplitude relative to the rest of the waveform.

It is possible to adjust the exciter to minimize this problem, but the solution requires that you be able to access the video modulator. For the average ATV operator, the job can be done very simply if you have or can borrow an accurate UHF wattmeter (such as a Bird) with slugs appropriate to the output power of the amplifier. Connect the wattmeter in line and connect the amplifier output to a UHF dummy load (best) or the antenna (when you won't cause interference):

1. Disconnect the camera or video source from the video input of the modulator/exciter.
2. Key the exciter and monitor the power output from the amplifier.

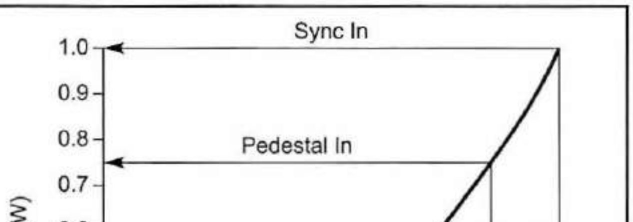


Figure 8.13. Most solid-state amplifiers, despite attempts to bias them for linear operation, have a non-linear input/output power curve. Without predistortion of the input waveform, the result will be sync compression, resulting in an unstable picture (see text).

3. Advance the PEDESTAL control on the modulator (R2 in Figure 8.8 or check your manual for a commercial video exciter or transceiver) so the power output **increases**.
4. Observe the **maximum** power output you can obtain. This is the **peak** or **sync** power level.
5. Retard the PEDESTAL control until the indicated power output is **60% of the peak** or sync power and leave the control at that setting.

At this point you can un-key the transmitter, reconnect the camera or other video source, and check the signal on the air with another ATV operator. Your own monitor probably will overload, so you need to check it at a distance. The signal should be stable with respect to sync and show good contrast. Have the other station reorient his antenna and confirm that the signal stays solidly locked as it gets progressively noisy (snowy). If you leave the wattmeter in-line, the power you observe — sometimes referred to as "average video" — will be significantly lower than for pedestal setting; and it probably will vary between bright (lower power) and dark (higher power) material. The average power level has no real analytical significance (other than to prove that the amplifier is operating), and most operators will take the wattmeter off-line to minimize the need for additional cables and connectors. While this "solves" the sync compression problem, you also will have to readjust the PEDESTAL control if you want to use the exciter "barefoot" for portable operation. The construction project for the ND2BD video modulator (Figure 8.8), contained on the *ICH* CD-ROM, incorporates two pedestal controls and a simple switching arrangement to set the modulator up for service with either the exciter alone or the exciter and an amplifier.

The "brick" I chose to illustrate in Figure 8.12 is the VLA-50, originally manufactured by AEA but out of production for a number of years. The reason for illustrating this particular model is that it employed a strategy that can be duplicated by adventurous amateurs. The power amplifier, along with an integral low-noise preamplifier, was designed to be mounted at the antenna, essentially eliminating line losses as a factor in both transmitting and receiving. If you were to package a Mirage D-24-N (Table 8.4) so it could operate at the antenna, you could generate a signal with a peak output of 60 W. Assuming you had 3 dB of transmission line losses, this would represent more power at the antenna than you could obtain using a D-1010ATVN operating in the shack (82W peak –3dB = 41W). Obviously, some innovative packaging can improve the effectiveness of your station significantly!

If you are going to use a basic solid-state amplifier, I would urge that you go to the higher end of the output power range, if for no other reason than that is the most cost-effective approach. If you need more than the 80-100 W that can be delivered by a solid-state "brick", the only real solution is a tube-type amplifier. Numerous tube power amplifiers for 70 cm have been described in *QST* over the years, and many of these have appeared in previous editions of the *ARRL Handbook*. Construction of such an amplifier can be very rewarding, although parts procurement will be your biggest practical hurdle. There are two serious aspects of a high-power tube amplifier (from several hundred W to 1.5 KW PEP) that should be noted:

- **RF Exposure Limits**. In the process of tuning such amplifiers or working in proximity to high gain antennas, it is very easy to exceed RF exposure limits if you don't follow accepted procedures and recognize the issues. The RF exposure guidelines and technical data can be found in any current edition of the *ARRL Handbook*. It is now a legal requirement, as well as plain common sense, to follow accepted guidelines with respect to RF exposure at various frequencies and power levels. In particular, high-powered amplifiers should be operated only with all shields and covers in place. Additionally, high-gain antennas must be sited to eliminate the possibility of excessive RF exposure. This generally means that if you run very high power, you should have a tower or other support that keeps the antenna pattern well above adjacent structures.
- **High Voltage Hazards.** High-power tube amplifiers operate at plate potentials of several thousand volts. Proper amplifier design includes the incorporation of interlocks and other approaches to minimizing any potential high-voltage hazard. Those of us who were weaned on the technology of vacuum tubes tend to have a built-in set of responses when working around power supplies and amplifiers; and, with all that, a careless moment can lead to severe high-voltage burns *and even electrocution*. If you are part of the younger generation, where 12V power supplies have been the norm, you need to do some reading and talk with older amateurs about the things you can do to eliminate HV risks. Those risks can be eliminated, not just minimized; but you need to know what you are doing.

If budget is not the major issue, Henry Radio makes an excellent line of high-powered amplifiers for the 70-cm band. Some modifications are required to optimize performance on ATV (see an article by Henry Ruh, KB9FO, in the October 1989 issue of *Amateur Television Quarterly*, pp. 28-29), but it is entirely practical to run up to the 1.5 KW PEP legal power limit. While such power levels have a certain allure, the vast majority of ATV operators work both local and DX contacts using power levels in the 50-100 W range. You needn't "go the limit" to enjoy all the fun and challenges the mode has to offer.

## COMPUTER OPTIONS

Of all the various image communications modes, ATV might seem the one least relevant to the use of computer technology. There has not been major interest among ATV operators in using computers, but that is on the verge of change. The first factor driving that change is a proliferation of consumer products that integrate television and computers. The second factor is longer term and tied into the introduction of HDTV — something I will discuss in Chapter 10.

**The Computer as a Video Source**. While the VGA/

SVGA output of a computer is not compatible with NTSC television, using the computer as a television signal source is a relatively simple problem of real-time scan conversion. A number of companies have developed such products, and Focus Enhancements probably has the majority of the market share for VGA to NTSC scan converters. Some of these products are targeted at business while others are more consumer-oriented. One of their products that I use almost every day is the **Micro XGA**. This is a small module, about the size of a package of cigarettes, which can handle both PC and Macintosh video, converting it to broadcast-standard NTSC television. The VGA video output of the computer basically loops through the scan converter, with no impact on the computer display. Internally, the scan converter senses the video mode in use and performs the operations necessary for the conversion process. It does that job flawlessly and, in terms of computer use, you would never know it was there. However, whatever is being displayed on the computer monitor is now available at the NTSC output (PAL versions are also available) of the module. That video signal can be displayed on a TV monitor, routed to a VCR, or used to drive an ATV transmitter. I use this capability, along with Microsoft Power Point™, to be able to transmit anything from station ID slides to actual slide shows. It also provides the means to use a Webcam or digital camera as a live video source, further increasing my video options.

**The Computer as a Television Receiver**. Given the amount of time people spend at their computers, it was probably inevitable that hardware and software would appear that would permit them to watch TV at the same time. One of these products is **WinTV** from Hauppauge Computer Works. WinTV is essentially a computer-operated TV receiver that uses the computer's own monitor for the image display. There are versions of the product that install externally to the computer via a USB port, or you can get a PCI bus card that installs inside your system. Either way, you then can watch TV via an antenna or cable connection to the rear of the unit; or NTSC video can be viewed via standard video line or S-video inputs. The product works so well that I probably could retire the TV set at my operating position!

My primary use for the gadget is making "snapshots" of ATV pictures, using the integral frame-grabbing functions inherent in the WinTV software. Preserving records of ATV contacts always has been somewhat difficult. It is possible to videotape what you are watching, but there is an unavoidable loss of quality when you do so — and DX signals give the poorest results of all. It is also possible to take photographs off the TV display, but that requires that you have a camera on-hand at all times, just in case something special happens. With WinTV, I can capture as many 640 × 480 images as I want, then pick and choose those I wish to save. Many of the pictures in Chapter 9 were derived using this system. Since the computer is there anyway, it is convenient to be able to use it to capture stills or even live video sequences.

One of the nice things about ATV is that you can start with a very basic station, adding capabilities as your interest and finances dictate. The majority of active ATV operators have stations very much along the lines of Figure 8.5. At the other end of the spectrum are amateurs running the legal limit with stations that look more like a broadcast television installation. Simple or complex, the reason for putting together a station is to have some fun. It is the fun and excitement of ATV operation that will be the focus of the next chapter.

## CHAPTER 9

# ATV OPERATIONS

## INTRODUCTION

There are lots of stereotypes about ATV, some of which we have already dealt with in the previous chapter. No, you don't have to be a technical wizard to operate your own TV station; and no, it doesn't cost a lot of money to set up and operate that station. In this chapter we will be addressing the final stereotype — the idea that you will go through all the effort to set up a station and then be stuck working stations on the other side of town. In fact, the world of ATV has three very distinct dimensions, and one of these is local. If we assume average topography, most of your day-to-day operations will involve communicating with other stations within a 20-30 mile radius. Your operating area may be a bit larger if you run high power and large, high antenna arrays; or it may be smaller if you run low power or have hills and other immovable objects to deal with. That's not a bad situation at all, since I happen to like the other ATVers inside my little circle. Very large numbers of amateurs operate 2-meter FM day after day; and they don't have a problem with communicating with the same people, not to mention all those folks who check into 75-meter nets day in and day out. The fact is that ATV is a challenge, and that sense of overcoming obstacles is shared by all your fellow ATV operators. We belong to a very special group of amateurs, and that fellowship simply adds to the pleasure of our on-the-air encounters.

While ATV does have a local dimension most of the time, Mother Nature has her surprises in the form of tropospheric band openings that can open your ATV horizons out to several hundred miles. These openings can last half an hour or extend over a day or more. While certain features of the weather map may suggest that something is going to happen, most openings arrive unannounced and are all the more exciting for that reason.

The third dimension of ATV is remote sensing. By using ATV technology, we can go places and see things that are quite out of the ordinary. You can ride a balloon to the edge of space or sit in the cockpit of a radio-controlled airplane. Through the magic of ultra-miniature TV gear you can be entertained, educated, or thrilled. In short, there is nothing else in Amateur Radio quite like ATV, and that's what keeps us coming back for more. In this chapter we will look at the range of activities you can enjoy once you've assembled your first TV station. You will talk with guys on the other side of town, but that's just for openers!

### *AMATEUR RADIO LICENSE*

I am going to bring up a subject that has not been raised in earlier discussions — the business of getting an Amateur Radio license. You don't need a license if all you plan to do is receive images. This covers all aspects of satellite operations, as well as the reception of SSTV or ATV pictures on any band. You can also build and experiment (closed-circuit) with narrow-band TV gear without a license. Where a license is almost always required is any activity that involves transmission of voice and pictures on any of the bands that are included in the Amateur Radio service. The reason for bringing the subject up in this chapter is the current "wireless video" craze, exemplified by the ads that you will see posted on Internet Web sites for businesses that promote wireless equipment. Let me start by saying that there is wireless video equipment that can be operated license-free. Most of the legitimate equipment operates in the 2400 MHz range at extremely low power. At best, you can expect a range of up to several hundred feet. In effect, you could have video "contacts" within your own house or possibly with a friend next door, but that's the limit. Such equipment (operated under Part 15 of the FCC regulations) cannot be modified in any way, and that includes connecting the transmitter to a more effective antenna system.

So what about operation on other frequencies? There is one kind of operation that can be eliminated without much discussion and that is unlicensed transmission on *any* commercial TV channel. There are companies that promote equipment for putting a TV signal on an "unused" local TV channel, with the implication that because the transmitter is low-powered and the channel is not in use, that such operations are legal. They are *not* legal, and any such operation could subject you to significant fines and legal action on the part of the FCC.

There are other possible frequencies where video would be permitted under Part 15; but the bottom line is that radiated power from legal devices is in the microwatt range in almost all cases, and that is not enough power to maintain contact over any meaningful distance. I have seen ads for "license-free" 10-30 milliwatt transmitters for the 70-cm band promoting ranges of ¼ mile or more with amplifier options to extend the range "up to 10 miles"! All such operation is illegal without an Amateur Radio license, and any fines or other sanctions will fall on the operator of the equipment. If you are discovered by a local Amateur Radio operator, you *will* be turned into the FCC. Amateur Radio operators have two faces. One is all smiles and welcome to those who are interested in getting a license and participating in this pastime that we love so well. However, the other face is implacable and very unfriendly; and that is the face encountered by anyone who tries to use the amateur bands for unlicensed operation.

So if this license is so special, it must be hard to get, right? Hardly! Recent changes in the Amateur Radio service make it easier than ever to get a license. The most basic license category is the Technician license. There is no Morse code test, and all you have to do is pass a very basic 35-question multiple choice exam. With a Technician "ticket" you can legally operate ATV on any of the bands from 70 cm on up, not to mention SSTV on 6, 2, and 1¼ meters. In fact, you will have all amateur privileges on any of those bands. Upgrading your license category to get operating privileges on the HF bands is slightly more demanding, but the fact that there are plenty of elementary and middle school students operating on HF shows that it isn't all that hard.

Where do you start your quest for an Amateur Radio license? The first step is to find an Amateur Radio club in your area. Check the ARRL Web site (**http://www.arrl.org**) to locate a local or regional club and read about the various license requirements. The League publishes study manuals for all license categories, and local clubs periodically run classes and coordinate license examinations. It's easy, simple, and highly rewarding. Your license is your "ticket" to a lifetime of enjoyment, good fellowship, and fascinating exploration via Amateur Radio.

### *IS THERE ALREADY ATV ACTIVITY IN YOUR AREA?*

The more densely populated your region, the greater the probability that there is already ATV activity. There are several routes that you can take to determine if there is activity and what it will take to join in:

- **Internet Sites** — A multitude of ATV-related sites can be found on the Internet, and most have links to regional ATV web pages of sites maintained by ATV repeaters.
- **Local Radio Clubs** — If there is ATV activity in your area, members of your local radio club may be part of the action or can point you to an ATV contact-person.
- **VHF and UHF Repeaters** — Ask around on the local repeaters. If there is activity, you will be pointed in the right direction.
- **ATV Calling Frequencies** — Most local ATV groups use a 2-meter FM frequency for audio communications and coordination. 144.34 MHz is widely used, but it is possible another frequency may be in use in your area. Internet sites can help. Monitoring the regional 2-meter "intercom" frequency can hook you up with a local operator.
- **ARRL Repeater Directory** — The ARRL *Repeater Directory*, available from the ARRL (**http://www.arrl.org**) lists most active ATV repeaters.

Your "search" will return one of three possibilities which will determine your next step.

1. **There is a Local or Regional ATV Repeater**. This is very good news as it means there is probably a sizable ATV population in the area. Jump to the ATV REPEATERS section of this chapter to determine if and how you can monitor the repeater output. If you are too far away for that to be practical, there is probably some regional activity on the fringes of the repeater coverage area; so check out the POINT-TO-POINT section later in the chapter.
2. **There is Local or Regional Activity but No ATV Repeater**. If this is the case, you need to check out the POINT-TO-POINT section of this chapter.
3. **There Appears to be No Local or Regional Activity**. This looks discouraging but need not be necessarily. See the next section below.

### *BE AN ATV PIONEER*

Your ATV prospects may seem pretty dim if there is no local activity, but the picture is actually brighter than you might think. If there were local stations active on ATV, you still would have to assemble your first basic ATV station and get it on the air. With no local activity, you face the same task except that you have to persuade at least one other amateur to take the plunge with you. The greater Lansing, Michigan, area has a viable ATV group of about eight stations. In contrast, if you could time-warp back to the mid-1970s there was no one on ATV. That's when Mike Schmidtendorff (WB8JXF) and I built some solid-state 1-W transmitter strips, got our hands on a pair of crystal-controlled converters, and home-built our video modulators. We were about 10 miles apart and initial pictures were only in the P2 range, but we gradually hiked them up to P5 with continued tweaking of the system. In the movie "Field of Dreams," Kevin Costner is encouraged to build his baseball field because, *"If you build it, they will come."* Much the same philosophy applies with respect to ATV. Activity encourages activity; and in a very short time we were joined by Andy (W8AHY), Jeff (WB8RJY), and a number of other pioneers of the mid-Michigan ATV scene.

What is important, if you intend to pioneer ATV in your area, is to select one or more fellow amateurs whose stations you have a real chance of being able to work. At most realistic antenna heights, line-of-sight is going to be somewhere between 15 and 20 miles over relatively flat terrain. You want to try to stay within that range, and closer would definitely be better. Topography is all-important. Back in the 1960s, I was trying to work WB2INC over a 12-mile path in northern New Jersey. That would be a local ATV QSO in Michigan, but we had the Ramapo Mountains to deal with. Working that path, even with modern equipment, would be a lost cause. Choose a partner who is as close to line-of-sight as you can manage and use the **RANGE** program in the *ICH* CD-ROM (packaged with this book) to estimate what it will take to work that path. Today, blessed by 40 years of hindsight, I'd work with someone up or down the valley and not try to fight the mountains. Better yet, were I actually back at the old homestead, I would pack the entire ATV station up on top of those mountains — an impossible dream back in the early 1960s — and really have some fun! That, however, is a subject we'll reserve for later in the chapter.

## STATION NOTES

Modern ATV activity tends to break down into three distinct modes:

- Working through repeaters
- Day-in and day-out, point-to-point communications within your local geographic area
- Specialized activities that are enhanced by the use of ATV

I will discuss each of these in later sections of this chapter, but first I'll cover a few more miscellaneous aspects of your station set-up and operation that were not touched on in the previous chapter.

### *ATV "P" SIGNAL REPORTING SYSTEM*

If you start watching or listening to ATV activity, one of the first mysterious things you will hear is the signal reports — "You're P5 here", or "You're between P3 and P4", and the like. These arcane terms are in reference to the "P" (picture) reporting system that has evolved over the years. The system is a subjective way to evaluate how well an ATV signal is being received. **Figure 9.1** is one attempt to illustrate the P reporting scale, and you will find others on various Internet sites. It is important to emphasize that the reporting system is subjective; it forces you to make a judgment call. In fact, you don't really need pictures to illustrate the system as it is pretty straightforward:

**P5**: The image has no snow or other visible noise artifacts.
**P4**: The picture is very good but slight noise effects (snow) can be noted.
**P3**: A nice solid image but snow is obvious.
**P2**: A stable image but there is a lot of snow.
**P1**: "Sync bars" can be seen imbedded in noise but there is no useful image detail.

The **P** component of the report is typically modified by additional comments with respect to color and sync stability. For example:

The picture is P3 with good color.
Your picture is P4 with intermittent color.
The picture is P4 to P5 but it is rolling vertically.

As a general "rule of thumb", a gain or loss of 6 dB will move you up or down the scale by one P-unit. In practice it

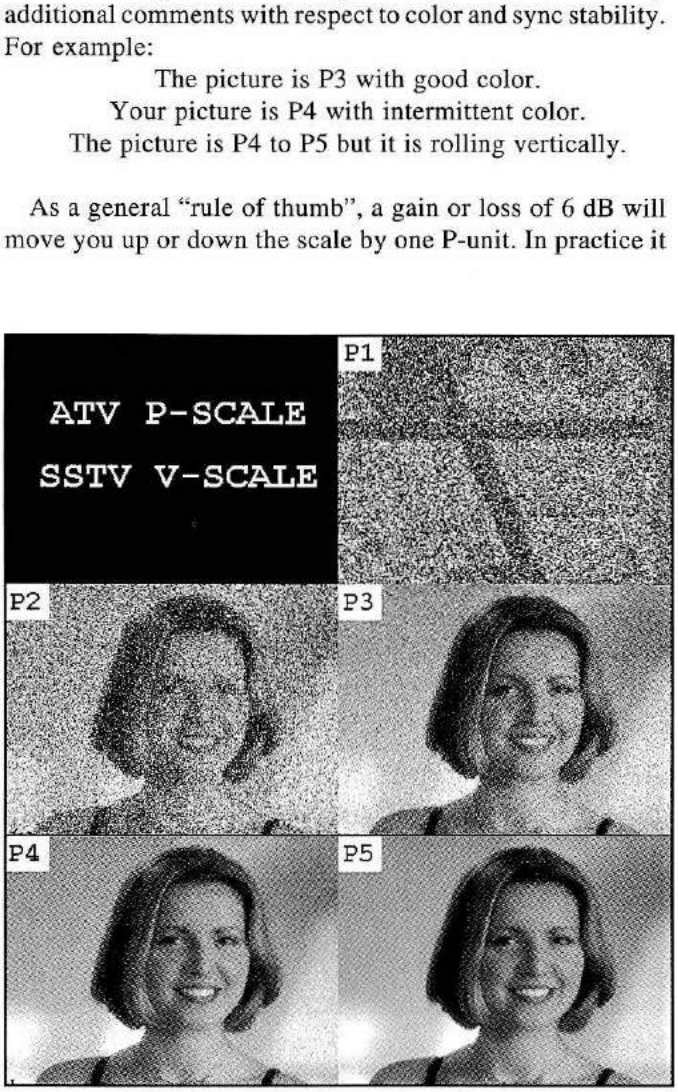


**Figure 9.1**. The ATV P-scale is a subjective system for assessing received signal strength. Here the author has subjected his daughter Molly to varying noise levels to illustrate the steps between P1 (high levels of noise, faint sync bars, no useful video) through P5 (noise/snow free). If the signal is properly modulated with no unwanted supresion of the color subcarrier, color will usually start appearing between P2 and P3. Essentially the same scale is used for SSTV signal reports, but the system is called the V-scale. In the case of SSTV, color will be present at all steps on the V-scale.

is rarely that simple. ATV signals often present a "threshold effect" in the sense that image quality can increase significantly from the P1 level up through P3 or so, but getting rid of the last trace of noise may require a more significant increase in signal strength.

Assuming you are working a well-equipped station and you get pretty consistent reports, there are only a few options for improving the signal:

- Increase the gain of your antenna system.
- Increase the height of your antenna to assure that you clear local obstacle such as trees or buildings.
- Reduce the transmission line losses by using a higher quality cable or eliminating unneeded line from the system
- Increase your transmitter power output.

Again, the **RANGE** program can be a useful predictor of the improvements you can expect by playing with the different pieces of your station. While a "perfect" **P5** picture may seem a reasonable goal, that isn't always possible. (See comments and examples in the later POINT-TO-POINT section of this chapter). Foliage, rain, or snow all can act to impact picture quality; but, in general, line-of-sight (LOS) and near-LOS propagation is remarkably consistent on 70 cm. It is pretty common to have mediocre results when you first put your station on the air (**Figure 9.2A**). You probably are in a hurry to get everything hooked up, you may be running low power, and you probably are not yet taking all the cautionary statements in the previous chapter very seriously. If you do pay attention to the guidelines in Chapter 8 and the advice you will get from fellow ATV operators, you probably will be able to "tweak" the various elements of your system to get another one P-unit — or even two — of improvement over your initial efforts (Figure 9.2B).

### *STATION LIGHTING*

One of the delightful things about an ATV contact is the sense you get of almost being there with the person at the other end of the path. A few weeks back I was receiving very poor audio reports from a new HTX-252 2-meter transceiver. The problem seemed focused on the microphone. After a few minutes of trying all sorts of tricks, I temporarily fixed the problem by slipping a sock over the microphone. At the moment, the local ATV crowd is getting its kicks by watching me talk to a sock! The point is, you will be spending a lot of your time on live camera and you want to optimize the picture you send out. In most cases, that is a combination of camera positioning and lighting.

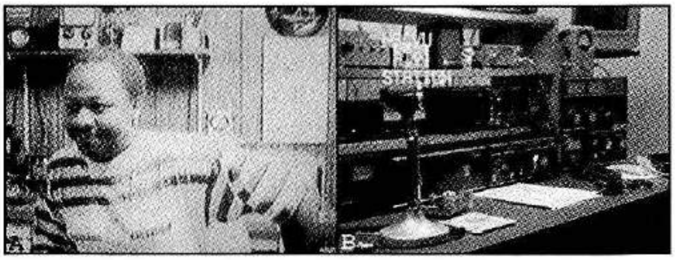


**Figure 9.2.** When you first get your station on the air, it is quite possible you will be disappointed since signals may be less that ideal. In most cases this is due to the fact that you are in a hurry to get on the air and may have cut some corners. **[A]** shows a picture from Roger (N9CVU) taken about 10 years ago when Ralph pulled some old ATV gear out of the closet to get back on the air. He used a simple 6-element Yagi and a length of cheap coax. The result was a P3 picture, despite the fact that Roger has a top-flight station and was running 100 W over the 12-mile path. **[B]** is a current image, frame-grabbed from one of Roger's transmissions at the same power level. This picture is P5, courtesy of a 13-element Yagi and some 9913 coax. ATV is a mode where it is worth taking time to optimize your installation.

In the "old days", camera positioning was a problem as the cameras were relatively large and heavy and usually needed a substantial tripod. Finding a spot to put the cumbersome camera and still get a good view of the operating position was a problem. Now we can work with cameras that are so small that you can lose track of them if you're not careful. This, combined with the wide-angle lenses that are available (or the use of the zoom option if you are using the family camcorder) greatly simplifies the business of camera placement. It should be possible to put the camera in a spot where it gets a good view of you and the surrounding equipment. Of course if you want to lounge in a comfortable chair, surrounded by plastic plants like some morning talk show celebrity, you can do that too!

Once you have decided where to place the camera, lighting becomes the major issue. Modern cameras are so sensitive that it is tempting to use them without additional lighting, but that rarely produces optimal results. The first problem with too little light is the signal-to-noise ratio (SNR) of the camera video output. With ample light, most modern cameras will produce a video signal with a 40-45 dB SNR. It is the camera noise floor that sets the limit for what constitutes a P5 image when signals are strong. If you take the same camera and use it with less light, the automatic gain control (AGC) circuits will drive the gain higher and the SNR will be degraded. This will have the effect of making your signal look noisier than it actually is. The noise in this case is contributed by the camera, but the end result is the same as if the SNR or the received signal had been reduced. The solution is to let the camera operate with adequate light.

Really good lighting is more than just shining some light on the scene. In the case of ATV (or slow-scan if you are doing some frame-grabbing from the TV camera) the goal is to get a pleasing balance between the lighting on your features and the background areas behind you. That usually requires experimenting with different light sources, intensities, and positions, depending upon the primary light sources that are already there. If you will be operating during daylight hours, it is very important to avoid strong back-lighting from a window. If you want the window in the scene, you will have to compensate with more frontal fill-lighting to get a balanced response from the camera. Almost certainly this will mean that the light set-up during daylight hours will be different from what you will use at night. In most cases, you should monitor the camera output directly to develop the best lighting scheme, as watching your transmitted signal will generally be unsatisfactory. **Figure 9.3** is a nice example

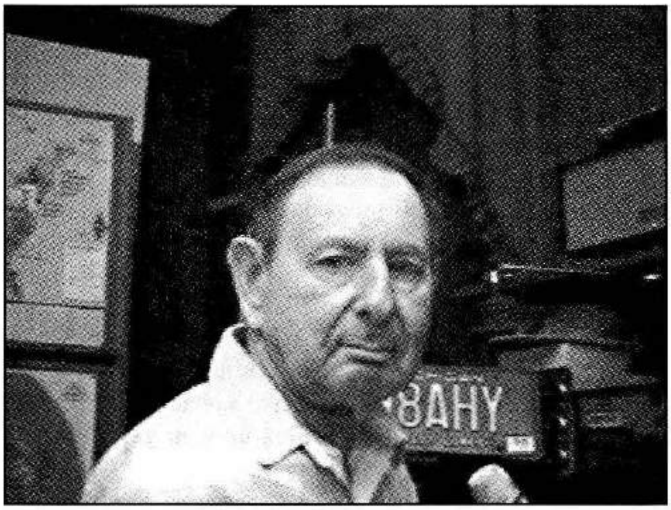


**Figure 9.3.** Adequate and balanced lighting is a key ingredient in generating a good "live" picture. This is Andy, W8AHY, one of the "old-timers" on the mid-Michigan ATV scene. If you can't work Andy you either forgot to turn the gear on or failed to connect the coax! Note the Amateur Radio license plate it the background. As long as it is relatively easy to see, such a callsign can meet the FCC requirement for station identification.

of good lighting from a transmission by Andy, W8AHY.

### *OTHER PICTURE SOURCES*

**Off-the-Air Video** — It is quite feasible to set up a VCR to receive a broadcast TV station and route the VCR video output to the input of your TV transmitter. In most cases doing so is a **violation of FCC regulations and an infringement of the copyrights** connected to the broadcast material. The single exception permitted by the FCC is the retransmission of NASA Select video feeds, which most commonly handle shuttle launches, mission operations, shuttle landings, and operations aboard the International Space Station (ISS). Many ATV stations are equipped to retransmit NASA video, as are most ATV repeaters.

**Still Pictures** — As noted in the previous chapter, a computer, equipped with a VGA to NTSC converter, is an ideal way to transmit still images. If you operate SSTV, there is no reason why your slow-scan image library cannot also be used for ATV. Video clips, webcam output, or any other computer image source are potential ATV material.

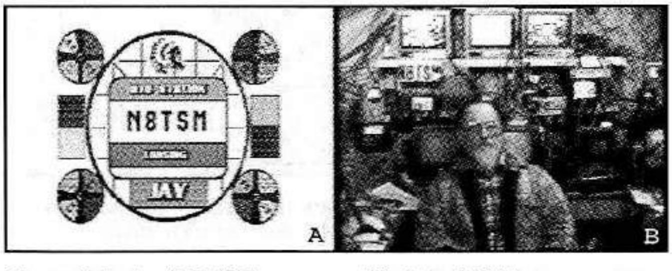


**Figure 9.4.** Jay (N8TSM) uses a solid state ROM image source to generate test patterns and ID-slides **[A]** in addition to a "live" camera **[B]**. The ID-slides meet the requirement for station identification and work very well during band openings.

**Video Tapes** — Taped material in any format can be transmitted by simply routing the video output of the tape system to the video input of your transmitter. Any non-commercial video you or others have produced is potentially useable, but motion pictures or other copyrighted material cannot be used.

**Figure 9.4** illustrates a good example of a station ID-slide, in addition to a "live" camara shot. In considering what material you might use in addition to the basic "live camera" output, give some thought to the **RIQ** criteria discussed in Chapter 5:

**R**elevance
**I**nterest
**Q**uality

One of the reasons why some of the operations covered in the SPECIALIZED ACTIVITIES (later in this chapter) are so popular is that they are activities relevant to the operators involved and have a very high general interest potential. Of course, most of them are a lot of fun as well! By their nature, image quality may suffer a bit at times, but quality takes a back seat if the other two criteria are met.

### *ATV FREQUENCIES AND THE INFAMOUS A-LINE*

So how wide is the 70-cm band in the United States? The "safe" answer is that it extends from 420 to 450 MHz. Within this 30 MHz are four generally recognized ATV frequencies: **426.25**, **427.25**, **434.00**, and **439.25** MHz with the last one being the most commonly used throughout the US In most places, frequencies at the low end of the band might be used for repeater inputs or outputs or to permit two simultaneous ATV contacts within the 70-cm band. This set of four frequencies has been carefully worked out over the years to minimize both the potential of ATV to disrupt other amateur communications on the band and to protect ATV operations from interference. Given the fact that 70 cm is becoming more crowded each day, I strongly advise not operating on other frequencies, even if they seem to be free of activity.

Unfortunately, there are places in the US where for specific reasons the band is actually not as wide as 30 MHz. A careful reading of Part 97 of the FCC regulations (the rules governing the Amateur Radio service) will indicate that there are restrictions on 70-cm operations in some parts of the country, usually in close proximity to military or research installations. The most wide-spread "restricted area" is a strip extending from coast to coast, somewhat south of the Canadian border. In Canada there are other services assigned below 430 MHz; and, to protect those services, the FCC confines US 70-cm operations to 430-450 MHz. The southern boundary of this protection zone is known as **Line A** in the FCC regulations or the **A-line** in amateur references to the boundary. Above the A-line you cannot operate below 430 MHz — no exceptions. The ARRL publishes a compendium of the Part 97 regulations which includes a map that shows the location of the A-line. While the map is useful, if there is any chance that you might be located north of the line, you need to know precisely how the line is defined in the regulations:

1. A great-circle track from **Aberdeen, Washington** to a point located at **48°N** and **120°W**.
2. From end-point #1 (aove) eastward along latitude **48°N** to its intersection with longitude **95°W**.
3. A great-circle route from end-point #2 (above) to the southern-most point of **Duluth, Minnesota**.
4. A great-circle route from end-point #3 (above) to a point **45°N** and **85°W**.
5. From end-point #4 (above) south along longitude **85°W** to the intersection of latitude **41°N**.
6. Eastward along latitude **41°N** to the intersection with longitude **82°W**.
7. A great-circle course from end-point #6 (above) to the southern-most point of **Bangor, Maine**.
8. A great-circle route from end-point #7 (above) to the southern-most point of **Searsport, Maine**.

If you are located north of the A-line (as we are here in central Michigan), you effectively have only one possible ATV operating frequency on the 70-cm band: 439.25 MHz. It isn't good practice to try to operate higher in the band because that will cause problems with the ever-growing number of UHF repeaters between 440 and 450 MHz. So why can't 434.00 MHz be used? Well, although 434 MHz is seemingly well above 430 MHz, we have to recognize the very wide nature of the ATV signal. A double-sideband AM TV signal with a 4.5 MHz FM audio subcarrier will have sidebands that extend below 430 MHz, thus constituting illegal operation. It is possible to configure a station to operate at 434.00 MHz above Line A, but the following steps would be required:

- Either eliminate the use of a 4.5 MHz sound subcarrier, or employ a separate sound transmitter 4.5 MHz above the video carrier to eliminate the 4.5 MHz lower sideband component.
- Use a vestigial sideband filter to suppress as much as possible of the lower sideband. This filter would have to be placed in the transmission line between the final amplifier and the antenna.

As we shall see shortly, stations above the A-line have restricted options with respect to ATV repeaters.

## ATV REPEATERS

If there is a local ATV repeater in range of your station (**Figure 9.5**), you are assured of a pre-existing active ATV group; and the repeater can make your first contacts a lot easier to come by.

### *IS THE REPEATER WITHIN RANGE?*

This is the key question, for if you can't see it or get into it, you will have to operate as if it weren't there. It is common for active ATV repeaters to maintain an Internet web page, and one of the items often included is a signal coverage map (**Figure 9.6**). These maps tend to be pretty accurate in terms of general terrain features, but your location could be impacted by features such as tall buildings that cannot be accounted for on a general map. These coverage maps attempt not only to show the area from which you should receive the repeater, but what signal strength or picture quality you should expect. In general, for reasons that will become clear shortly, if you can receive the repeater, you can access it. If the coverage map suggests that you should be able to see the machine, then it is worth proceeding. If the map suggests that you wouldn't be able to receive a picture, you should probably move on to the POINT-TO-POINT section. It is worth noting that while you might not be able to see/access the repeater from your home QTH, it is always possible that you could do so on occasion by virtue of band openings or by operating mobile or portable from a suitable location. The rest of this section will assume that you are close enough to the repeater to receive a picture that is worth the effort you will expend in setting up your gear.

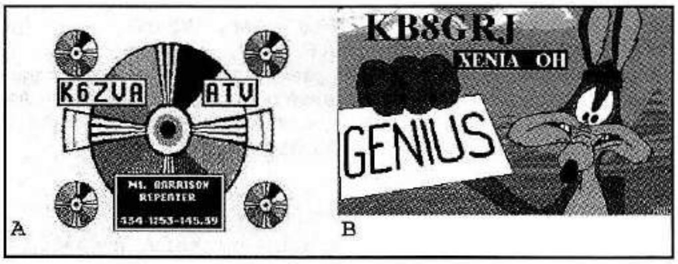


**Figure 9.5**. If you are within range of an ATV repeater, watching your first ATV and completing your first television contact will be pretty simple. **[A]** shows one of the ID screens for the K6ZVA Mt. Harrison ATV repeater in southern Idaho. **[B]** is the ATV machine in Xenia, Ohio.

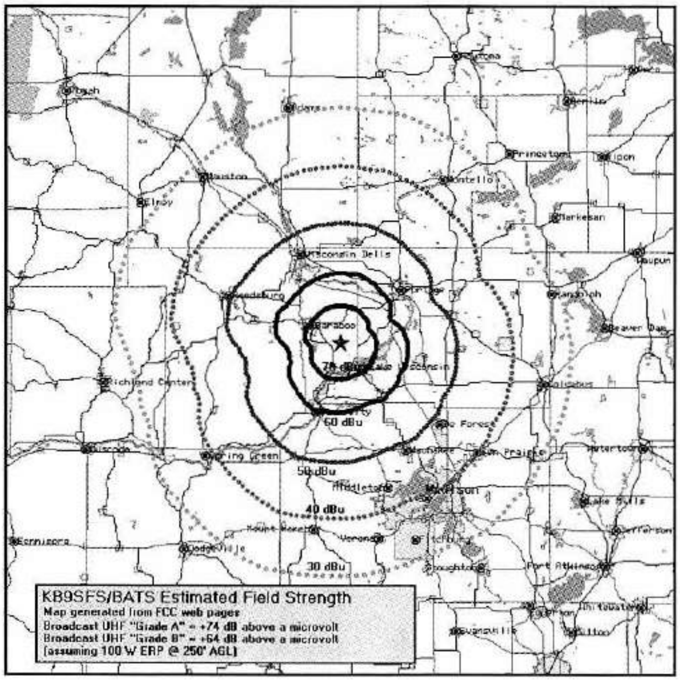


**Figure 9.6**. Many ATV repeaters are featured on Internet web pages and the information available often includes maps to estimate the coverage area of the repeater. This is a map showing such data for the Baraboo Amateur Television Society repeater (KB9SFS) in Wisconsin. Such maps can now be generated in software using digital terrain data and are typically very reliable.

### TYPES OF ATV REPEATERS

ATV repeaters have two distinctly different configurations, and you need to know which type you are dealing with. **In-band** repeaters have both their input and output on the same band — in most cases 70 cm. In-band repeaters are a technical challenge because it is very difficult to get adequate isolation between the repeater's transmitter and receiver. One very good way to solve the problem is to have the receiver and transmitter at different sites, connecting them via a microwave link. However, most repeater groups have enough trouble finding one good site and maintaining the installation; so, split-site systems are not that common. The typical in-band 70 cm machine will use frequencies at opposite ends of the band to help achieve the needed isolation. Unfortunately, groups located above the A-line don't have this option.

Given the increasing problems of frequency coordination on 70 cm, not to mention the A-line issues, an alternative to the in-band machine is a **cross-band** repeater. With this configuration the input is usually on 70 cm (often 439.25 MHz), with the output on the 33, 23, or 13-cm band. This makes it much easier to isolate the receiver and transmitter; and as an added "bonus", you typically can monitor your signal at the repeater output while transmitting on the input frequency. This is a real plus in terms of optimizing your signal, and you can't do that with an in-band system.

You never get something for nothing, particularly with ATV, and there are some down-sides to a cross-band system. The first concerns equipment. You typically will have to get an antenna, converter, and transmission line to implement reception on the output frequency/band. Vendors such as P.C. Electronics stock everything you would need, so finding the equipment isn't a problem. The added cost isn't really that much, especially since many operators with access to an in-band machine usually will set up an independent receiving system, complete with an antenna locked on the receiver site, to monitor the repeater output. This lets you watch the repeater output (assuming you are not transmitting) no matter where your "big antenna" is pointed.

The second problem is more serious since it deals with the laws of physics. You will remember that in the path-loss equation we discussed in the previous chapter, the loss was a function (among other things) of the logarithm of the frequency. This means that path losses will be higher as we move up in frequency, and the differences are not trivial. If we assume a path where the 70-cm signal is just P5 with the same power output and antenna gain, the following additional path loss will be observed if we move up in frequency:

| BAND | ADDED LOSS (dB) | P-REPORT |
|---|---|---|
| 70 cm | 0 | P5 |
| 33 cm | 6.2 | P4 |
| 23 cm | 9 | P3+ |
| 13 cm | 14.3 | P2 |

As indicated, the increased path losses equate to a poorer signal as we move up the frequency spectrum. The losses can be countered with a combination of increased power and antenna gain, but that is rarely practical. It becomes substantially more difficult to generate significant power on the higher-frequency bands, and increasing antenna gain significantly for an omnidirectional system is difficult. In short, you pay for the benefits of a cross-band repeater with a reduction in coverage area.

### SETTING UP TO RECEIVE

The output of the repeater probably will be vertically polarized, regardless of the output frequency. For this reason alone, you most likely will want a separate antenna for the repeater output. The antenna can be mounted to the tower or other support without the use of the main antenna rotor. Once the antenna alignment is complete, it can be tightened up and will work no matter where your main 70-cm array might be pointed. If the system operates cross-band, transmission line losses will be significantly higher than on 70 cm, so you typically have two options:

1. Use relatively expensive low-loss cable
2. Install a preamp for the output band frequency. Because you will not be transmitting with the antenna, the preamp does not have to have the capability to bypass the transmitted signal.

If I were setting up for use with a repeater, I probably would use a second TV set dedicated to monitoring the repeater output. That way I would be able to operate in any direction on 70 cm and not miss the action if someone came on through the repeater.

### ACCESSING THE REPEATER

Once your transmitter is up and running, getting into the repeater simply requires that you point your primary antenna system in the proper direction and transmit. Most repeaters key their output signal in response to the presence of horizontal sync pulses on the signal at the input frequency. In the case of a cross-band system, if you get a reasonable signal from the repeater, getting into the system should be routine. As noted earlier, a cross-band system lets you monitor your signal and make adjustments even if no other stations are available to give you a report. In the case of an in-band system, you will need other stations to evaluate your signal quality.

### BELLS AND WHISTLES

Once the basic repeater functions are working, ATV repeater systems tend to evolve to add additional features:

- A range of test patterns or other output displays
- Re-transmission of NASA video feeds during Shuttle missions
- The ability to transmit weather radar or other severe-weather data
- The ability to switch in one or more remote cameras at the repeater site or elsewhere.
- The ability to receive the FM "intercom" frequency and

retransmit it as subcarrier sound on the primary video output

- The addition of ATV inputs on other bands
- Links to other regional repeaters

Because some of these options have educational value or a high level of interest to the general public (Space Shuttle video for example), it is often desirable to promote the availability of the repeater output signal to showcase Amateur Radio and TV and to promote Amateur Radio as a community resource. Public access is particularly easy for 70-cm systems, since cable-ready TVs and simple UHF antennas often will suffice for reception in the primary output coverage area.

### *DON'T GET TOO FOCUSED*

ATV repeaters make it easy to get on, and the repeater naturally becomes the central focus of local ATV activity. The problem is that a repeater can become so easy to use that you lose sight of the opportunity to work stations outside of the repeater coverage area. In fact, it is not uncommon for operators to go entirely to fixed antenna systems and split-frequency operation in the case of cross-band systems. This provides the ultimate in convenience in terms of operating through the repeater, but it becomes almost impossible to work anyone else should the 70-cm band open up.

## POINT-TO-POINT COMMUNICATIONS

Most ATV operation involves a local group of enthusiasts who simply communicate point-to-point. While most of the communications are of a local nature, there is a potential DX component; so, we will discuss both possibilities.

### *THE LOCAL ATV GROUP*

Local ATV contacts are complicated by a basic constraint — the relatively narrow beamwidth of the high-gain antennas that is needed to achieve good signal levels. If you are pointed at one local station, it is quite possible that other local stations may have trouble seeing you or the station you are working. The key to holding roundtable contacts is the VHF intercom frequency. In effect, the group is in constant voice communication, but pictures are "passed around" in the sense that all operators are constantly adjusting their antennas to favor one operator or another as the session proceeds. What makes this work is the use of omnidirectional antennas on the VHF band — typically 2 meters. If you are monitoring for activity, it makes little sense to depend on the television set. Instead, you listen on the 2-meter calling frequency. In order to maximize the opportunities for recognizing when the band might be open, it is useful to use an intercom frequency compatible with practice within your larger region. This also makes it easier for potential ATV operators to locate your group.

Just having a reasonable number of ATV-equipped stations doesn't necessarily translate to a lot of on-the-air activity unless you take steps to promote it. One useful strategy is to have at least one "ATV Night" each week. It doesn't have to be a formal net, but simply an agreed-upon time when stations will try to get on. This also makes life easier for those who might be interested in trying to "look in" for the first time. A few other options also can help to maintain activity. As just one example, you may want to work on a simple "phone tree" that would be put into operation should the band open up, when a mobile operator is passing through, or if anything else out-of-the-ordinary occurs. A second useful technique is to make use of e-mail. Most ATV operators have e-mail, and it can be a convenient way of keeping the group updated on special activities. For example, one of our "local" operators is Bryan, KC8LMI. Bryan likes to get out on the road with his portable ATV system (see **Figure 9.13** also referenced under the subtitle "Mobile and Portable Operation"), stopping off at hilltops and other prime sites. Since he is a young man, he depends upon one of his parents to do the driving chores and thus doesn't always know exactly when he'll be able to manage one of his roving expeditions. He uses e-mail to keep the local group up-to-date on what he will be doing and has yet to fire up from some remote site and discover that no one is on!

Once you get on the air, you will quickly discover how the local patterns of activity and topography will define your normal operating range. Some paths may be difficult for you, based on your specific location and site factors, while other stations may have no problem. One example of this can be seen in **Figure 9.7**. Bruce (KA8YXX) and Bryan (KC8LMI) operate from Pleasant Lake, Michigan, about 10 miles from my station in Mason. Between our two stations there is a complex of glacial features resulting in hills that rise up to several hundred feet above average terrain. They aren't enough to block the signals, but they do knock the signal levels down to the P3-P4 range. There really isn't anything that can be done to improve the path, so we just accept it as a fact of life. In contrast, other local stations (**Figure 9.8**) actually may be farther away, yet we enjoy P5 signal levels. In the same vein, other local stations have the good fortune not to have those same hills between themselves and Bruce and Bryan and thus get P5 signal reports.

The results you achieve very definitely will depend upon your having done your homework in terms of optimizing your station (**Figure 9.9**). As I write this, it is late winter in Michigan; and Jim, K8UHF, has just gotten back on the air after an absence of several years. Jim lives in Dimondale, Michigan, within sight of Roger's (N9CVU) tower. Roger puts in a great P5 signal at my location (Figure 9.8), but Jim is somewhere between P1 and P2 on most evenings. He has a good antenna, but because it's still winter, the antenna is mounted on a mast in his yard, fed by about 100 feet of very aged coax! That will change come spring, but until then Jim is limited to working stations that are very local.

Although local propagation on 70 cm is remarkably constant from day to day, there is variation. Some days signals are definitely down a bit. Sometimes the cause is obvious — heavy snow or rainfall for example — but other times there is no obvious cause. In contrast, there will be times where signals are definitely above average in quality. (VHF and UHF operators use the term "enhancement" to describe the better-than-normal signal levels.) Such enhanced band con-

**Figure 9.7**. An ATV family. **[A]** An off-the-screen photo of Bruce, KA8ZXX, taken about 1990. **[B]** Bruce's son Bryan, KC8LMI, mans the ATV operating position in 2002. This particular image shows Bruce in the background. He is rarely seen from the home station these days, but is still active, spending his time contructing miniature ATV installations that he puts in the R/C model airplanes and helicopters that he and Bryan fly. Bruce's wife, Linda, is also a radio amateur (KB8EMA), and, while she doesn't operate ATV, she drives son Bryan around on his portable ATV expeditions (see Figure 9.13).

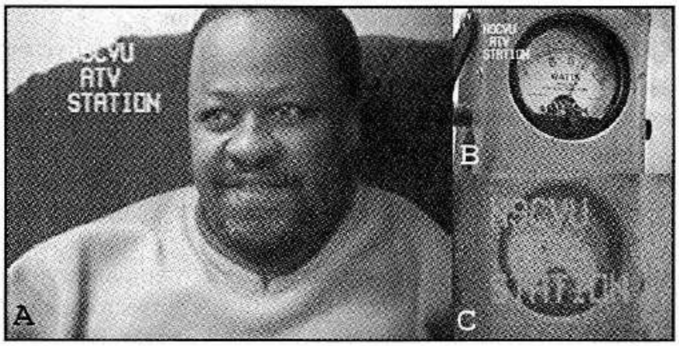


**Figure 9.8**. Roger, N9CVU, has been on ATV in the Central Michigan area for over 12 years **[A]**. He was running approximately 100 W peak power over a 13-mile path when the author frame-grabbed this picture. His trusty Bird wattmeter **[B]** is a common subject for his in-shack camera. While browsing the Southern Illinois ATV Groups web-site (see text) for some good examples of DX, Ralph ran across a familiar sight **[C]**. Here is Roger's wattmeter as received by Bob (K9UVY) in Mt. Vernon, Illinois — a distance of **373 miles/612km**! Roger has refined his station over the years and is ready to take advantage of any 70 cm band openings.

ditions can let you work a bit further than normal and are welcome when they occur. Of course, there are times when the band does something profoundly different — a real band opening! That's where the fun really starts — a subject we will discuss in the next section.

A local ATV group has a natural cycle of activity that is directly related to the number of active operators. In the greater Lansing area the local group has ranged from as few as three to a dozen or more in the past 15 years. Some operators may disappear for a few years due to family issues or other projects that catch their fancy; and, of course, people will move away or even become Silent Keys. The key to sustaining local activity is to maintain a high degree of interest and actively recruit new operators. The recruitment effort essentially requires missionary activity:

- Any activity (such as public service work) that puts ATV in the spotlight can recruit other amateurs into the ATV ranks and even serve as an inducement for new people to become involved in Amateur Radio
- Never pass up the opportunity to give demonstrations at local club meetings. Although videotapes of contacts are useful, arranging for some live TV — while requiring more effort — has a greater impact.
- Set up an Internet Web site and keep it current. Lots of pictures will make it more interesting; and, since lots of young people surf the Net, it is a great Amateur Radio recruiting tool.
- Stay in touch with the local media outlets such as newspapers and TV stations. They almost always have a local-interest agenda, and there are times when they will really be hard up for material. A story about a bunch of local "hams" communicating via television can help their programming and be an excellent showcase for local activity.
- Get involved in one or more of the specialized activities I will discuss in the next section. All of them are highly interesting and can focus the energy of the local ATV group toward common goals.

The future of both ATV and Amateur Radio in general is absolutely dependent upon our ability to recruit people from each new generation. Historically, one of the biggest attractions of our community is our ability to communicate to the far corners of the globe. In this age of universal Internet access, that allure is not as compelling as it might once have been. At the same time, the Internet is breeding a whole generation of young people who are essentially communicators. They simply need to learn that Amateur Radio is a more interesting and rewarding way to communicate. ATV has an inherent fascination that can help engage people, both young an old, in the magic of what Amateur Radio represents. The key to using ATV as a recruiting tool is to stop keeping it a secret. If everybody in your area, amateur and non-amateur alike, knows what you are doing, your ATV group will never shrink below critical mass!

### *THE DX CONNECTION*

The common near-line-of-sight properties of propagation on 70 cm means that ATV activity is sustained on a day-to-day basis by local activity. The signal from your highly directive antenna will shoot straight out into space 99% of that time, but that other 1% has some interesting potential. Unlike the "short wave" HF bands, UHF waves are not significantly effected by the different levels of the ionosphere, so we don't encounter classic HF "skip" conditions". However, at VHF and higher frequencies, the radio wave can be impacted by weather conditions that would be absolutely transparent to HF signals. Air masses of different temperatures, occurring as part of temperature inversions or along frontal systems, can act as a tube or "duct", bending VHF and higher frequencies so that significant signals can be propagated for many hundreds of miles — well beyond the range you might normally encounter. This mode, known as **tropospheric ducting** or simply "tropo", has the potential to let you communicate via ATV well beyond your normal

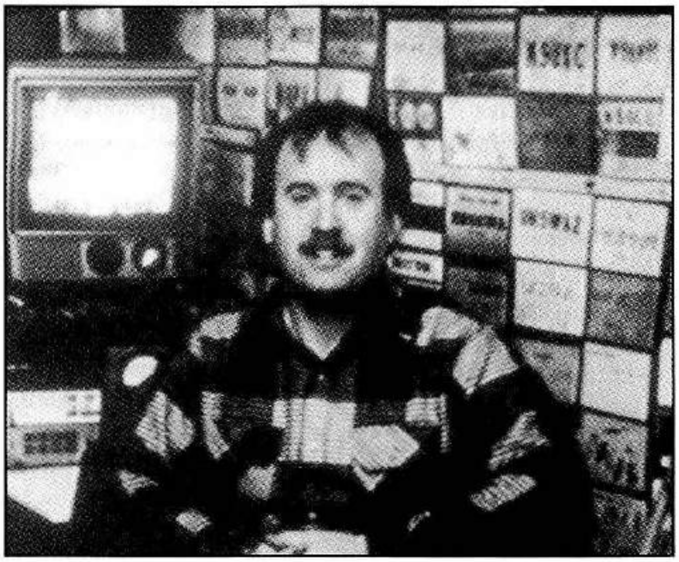


**Figure 9.9.** An ATV QSO is like visiting another amateur face to face. Here is a 1 W transmission from Jeff, WB8RJY, over a path of about three miles back about 1990. Jeff has an excellent location and was able to get by with a small antenna off the side of the tower. The antenna may have been small, but he took excellent advantage of every bit of available power by using a Heliax™ cable run from the shack.

RF horizon. How this type of propagation is expressed can vary from region to region; but here in the Midwest we expect such band openings — especially during the summer and fall, but they can occur any time. The key is to recognize when the band is really open and then to be prepared to take advantage of the situation. Just monitoring the local ATV frequency won't do (since everyone is using very directive antenna arrays), but there are good ways to spot band openings on 70 cm:

- Monitor the 2-meter intercom frequency. Tropo ducts are strange animals and may not impact 2 meters and 70 cm equally, but typically they do. Hearing strange voices and callsigns on your 2-meter frequency is a sure sign that something is up. That, by the way, is why you want to use an intercom frequency that is common throughout your region.
- Use a scanner to check out known VHF and UHF beacons.
- Monitor the low end of the UHF broadcast range and keep a list of UHF stations in different parts of your region. When you start seeing stations instead of snow, that's your invitation to an opening.
- Monitor local FM repeaters. When things begin to go crazy on the frequency, an opening may be in progress.
- Even if you are a couch potato glued to the cable or satellite TV, make it a point to check out some of the local UHF stations at the low end of the UHF band during breaks in the program. When you start to see beating or co-channel interference, the band is getting active.

All right, the band is active and your early warning system might even suggest the favored direction. So what do you do next? If you can work the stations on 2 meters, then give them a call. The problem we face here in Michigan is that although we are tucked in between some beautiful lakes, this isn't the first place that our neighbors start looking for ATV activity. Ohio, Indiana, and Illinois stations tend to be working stations on a general east-west axis, with the result that their high gain antennas are not pointed in our direction. Our job is to get their attention, and that's where 2 meters comes in.

For routine local work, I have suggested the use of an omnidirectional vertical on 2 meters. If your antenna has significant gain, you may be able to break in on more distant 2-meter contacts, but this may be difficult. Here I would recommend a modest beam (3-4 elements), oriented for vertical polarization on the same mast as your ATV array. The reason to use a modest beam (and moderate power) is that you don't want the frustration of being able to talk to stations you cannot work on TV, yet you do need to attract attention.

Once you are attempting a DX contact on video, it sometimes takes a bit of finesse to complete a QSO. Here are a few hints and generalizations that can help:

- If both of you are running similar power, irrespective of other differences in your station, link reciprocity will assure that the other station should see you with about the same signal quality that you are receiving — go for it!
- If you are running more power than the other station, you should put in a better signal than the one you are seeing — go for it!
- If you are running relatively lower power, you have your work cut out for you. If the DX station is very strong, you probably will make the QSO; but your signal report may not be outstanding. If there is a big power differential and the DX station is P3 or P4, you have to play the band. Watch signal levels — there is almost always QSB (fading) on a tropo path. Watch the other signal; and as the signal starts to peak, have the other station switch to receive and give it a shot. Sometimes, by taking advantage of a few seconds at the top of a QSB cycle you can make a contact that would not have been possible given the average signal level.
- Have something handy which is easy to recognize. The universal standard for a TV QSO is that both stations be able to read callsigns or other print or see something else clearly recognizable. Your normal in-shack camera may not provide an optimum image for such recognition. Have some very obvious ID posters handy and switch to a live-camera view if time and conditions justify it. Don't depend on color differences for your ID slides as color may not be present on your signal. Big, blocky white letters on a black background work quite well.

Working tropo ATV DX out to 200-400 miles (330-660 km) is perfectly within the capabilities of the average ATV station. Other than the log entries, most ATV stations do not compile pictures of their DX contacts, so showing you good examples here proved to be difficult. One very good collection of DX ATV images is maintained on the Web site of the Southern Illinois ATV Group (SILATVG) that you can find at **http://members.tripod/silatvg**. Many of the pictures on the site were photographed or captured by Bob, K9UVY in Mt. Vernon, Illinois. **Figure 9.10** features a small selection of Bob's photographic trophies.

The "ultimate" ATV DX has yet to be determined, but some of the marks already on file will be difficult to match. In terms of one-way reception on 70 cm, how about KC6CCC in southern California receiving pictures in 1994 from KH6HME, operating from the Mauna Loa volcano in Hawaii — a distance of 2518 miles/4041 km (**Figure 9.11A**)? While I haven't talked much about ATV on the higher UHF and microwave bands, plenty of opportunities exist to push the envelope on these bands, although some pretty significant marks have already been set. This includes an excellent contact between F1AAM/EA5 on the east coast of Spain and HB9AFO/I5 who worked across 630 miles/1031 km of the western Mediterranean using FM ATV on the 10 GHz band (Figure 9.11B, C). The next time someone jokes about working across town on ATV, you might want to tell him how big that town can be! It is no accident that some of the longest UHF and microwave ATV records represent over-water paths. Tropospheric ducting does the bending in terms of the signal, but that is all for naught if a mountain gets in the way or the mountains break the continuity of the duct. Really long paths are likely to be conquered over water for just those reasons.

**Figure 9.10**. Actual image samples of ATV DX are hard to come by (for reasons that are discussed in the text). The Web site of the Southern Illinois ATV Group (**SILATVG**) has some excellent examples, including this collection as received by K9UVY in Mt. Vernon, Illinois. This midwest tropo-DX sampler includes **[A]** K4VXP—205 mi/337km, **[B]** KA9QFL—195 mi/320km, **[C]** W4HTB—162mi/266km, **[D]** W8RVH—289mi/475km, **[E]** W8ZCF—249mi/409km, **[F]** WA8ZAH—253mi/415km, **[G]** The WR0J ATV repeater—314 mi/516km, and **[H]** W9NTP—193 mi/317km.

So far we have talked about local ATV communications and the DX possibilities, but we still haven't touched on the strange, wonderful, or simply useful things you can accomplish on ATV. It's about time we investigated some of those possibilities.

## SPECIALIZED ACTIVITIES

### *PUBLIC SERVICE AND EDUCATION*

Amateur Radio has a long record of contributions in the public service area, and ATV is no exception. Every local ATV group should be looking at how they can contribute to the local or district efforts of **ARES** (**A**mateur **R**adio **E**mergency **S**ervice). ARES coordinates nationwide at all levels, making the resources of Amateur Radio available to managers and response and relief organizations in the event of significant disasters. The ARRL Web site (**http://www.arrl.org**) can point to ways to get involved. One of the aspects of ATV that can be of use with respect to emergency commu-

**Figure 9.11**. With just a bit of patience and luck, working tropo DX over paths of several hundred miles is well-within the capabilities of typical ATV stations. Getting to the top of the ATV DX pyramid takes skill, perseverance, and luck. The current one-way DX record on 70 cm **[A]** is 2518 miles (4041 km)! KC6CCC in southern California received this picture from KH6HME, operating from the Mauna Loa volcano in Hawaii. KC6CCC was using a modest 14 dB Yagi, 50 feet of 9913 coax, and a standard 70 cm ATV converter. (Photo by KC6CCC) The microwave bands are attractive targets for ATV distance records, but even there you will have your work cut out for you! The current distance record on 10 GHz/3 cm is held by F1AAM/EA5 **[B]** on the east coast of Spain, working HB9AFO/I5 **[C]** on the western coast of Italy. The path was via ducting over the eastern Mediterranean for a distance of 630 miles (1031 km). One-meter dishes and 12 W amplifiers were used at both ends of this record-breaking QSO. Photo [A] by KC6CCC, photos [B] and [C] by HB9AFO.

nications is providing mobile and portable facilities for critical video links during and after an emergency or disaster. Some aspects of mobile and portable operation are covered briefly in a later section, but you do need to check out and refine your mobile and portable capabilities under less stressful conditions. Other public service activities can help you test those capabilities while simultaneously demonstrating Amateur Radio to a wider public. For many years the Southern California ATV group provided ATV support for the annual Tournament of Roses Parade. Every year, dozens of ATV groups contribute support on a smaller scale for the many walk, ride, and run fundraisers conducted for worthy causes in all areas of the country. The ARRL also has resources available to assist in such public service activities.

Education is another area where in recent decades Amateur Radio has been working to make a significant contribution. Science and technical education are priority areas for most school systems these days, and this is an area where Amateur Radio is a perfect fit. Many locales have annual Science Days where activities are planned at shopping malls or other sites. These and similar events are excellent opportunities to demonstrate ATV and attract potential new operators at the same time. The efforts you make don't have to be on a monumental scale to have real impact. In many cases, just getting into the schools is a good first step (see **Figure 9.12**). Public service work is fun, educational, and beneficial to both your community and Amateur Radio in general. The next time a local amateur faces the Zoning Board in an antenna dispute, it would help a lot if all the official players had a positive image of what we do!

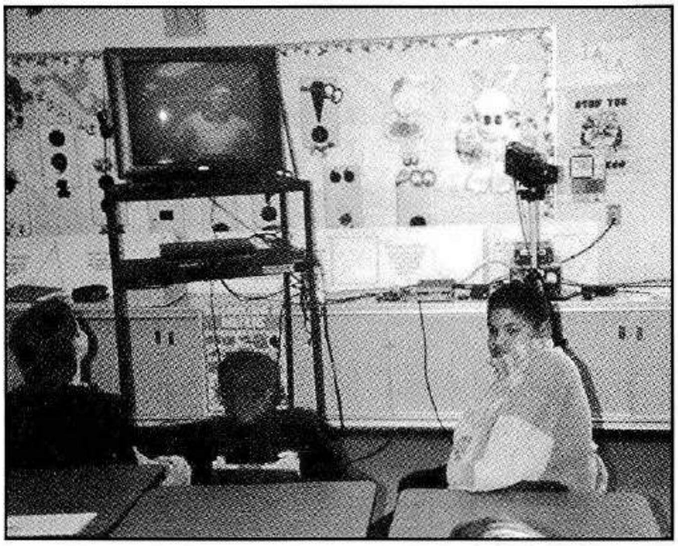


**Figure 9.12.** Here is a photo from Mrs. Plater's 5th Grade classroom at Harley Franks Elementary School in Lansing, Michigan, where Jim Hein (K8UHF/ex. WD8BDL) was in ATV contact with Mark Lynch (KB8LKC). Mark was set up in Mrs. Drake's 5th Grade classroom at Lansing's North Elementary School. The school to school ATV link was held as part of the Lansing School District's Science Week and showcased Amateur Radio as the students from the two schools shared their experiences over the air. Perhaps the most lasting lesson was that television isn't just something you watch – it can also be something you do! Photo by K8UHF.

### *MOBILE AND PORTABLE OPERATION*

When I became involved in ATV back in the early 1960s, the gear was built with tubes, and a station could fill up an entire rack. The idea of taking that kind of installation anywhere was ludicrous. Today I can package a complete ATV station in a briefcase, and mobile operation is entirely feasible. However, there are state motor vehicle laws that limit the scope of how you can configure and operate a mobile ATV installation. Most states prohibit the operation of a motor vehicle in which the driver can watch a television set while the vehicle is in motion. What's more, most troopers are likely to raise an objection if they pull you over and find a car filled with loose equipment items that could shift around when the vehicle is in motion or take on lethal velocities in the event of a crash. All mobile equipment should be firmly mounted, and the driver should not be able to watch the TV screen from the driver's seat. You cannot expect long-range contacts when operating from the car (unless you happen to be up in the mountains); but mobile capability is excellent in terms of emergency operations, and it can be a lot of fun on vacations — if you operate with the vehicle safely off the road!

Portable operation also has a role in emergency communications, but it also gives you the chance to operate from spots where you can make contacts that would not be possible from the home station. Most microwave DX records, not to mention less spectacular contacts, are made using portable equipment. Figure 9.13 (referenced previously under the subheading "The Local ATV Group") shows Bryan's (KC8LMI) portable installation that he takes hilltopping at every opportunity. Portable operation is an excellent option if you have a very poor ATV location or face restrictions with respect to the antennas you can erect. I expect that if I were still operating from northern New

**Figure 9.13.** **[A]** Bryan, KC8LMI, enjoys taking his ATV station on road trips around central Michigan, trying his hand at portable operation. The entire station, including a 100 W Mirage amplifier, is packaged in a custom wooden rack shown here. The aluminum enclosure on the left side of the rack is a vestigial sideband filter for 439.25 MHz. Bryan often finds himself on hilltops next to both commercial and amateur repeaters. The filter reduces the chance that he will cause interference, particularly to 70 cm systems, and also helps protect his ATV converter from overload. **[B]** Bryan's mother, Linda (KB8EMA) is a great sport and drives him on these expeditions. The truck has a mast that supports a K1FO Yagi at heights between 5 and 15 feet.

Jersey, I would be doing a lot of ATV work from the top of the local mountains!

### *BALLOON LAUNCHES*

One of the more exciting ATV options that has emerged in the last decade or so is using weather balloons to loft ATV gear into near-space. At altitudes of 100,000 feet (35,000 m), line-of-sight ranges exceed 300 miles, permitting Amateurs over a wide area to monitor the balloon transmissions (usually on 439.25 MHz). Getting a good picture from the balloon package is not always as easy as it might seem, particularly when the path length is measured in hundreds of miles. Run the **RANGE** program from the *ICH* CD-ROM and you will see why. With power outputs of 1 – 2 W and negligible antenna gain, you really have to keep line losses down and antenna gain up to get a good picture at maximum altitude and range.

A successful balloon project is fascinating (see **Figure 9.14**), but it is a highly technical exercise that requires the coordinated contribution of some talented people. Some of the technical issues and resources are referenced in the balloon discussion in the SSTV operations chapter (Chapter 5, Specialized TV Operations, SSTV At the Edge of Space, Page 5.16). It is precisely the group nature of the effort that makes a balloon launch an excellent activity to galvanize a local or regional ATV group. More than "book-learning" is involved; and should your group get interested in such a project, it would be a good idea for a few key people to apprentice with an established operation for a couple of launches.

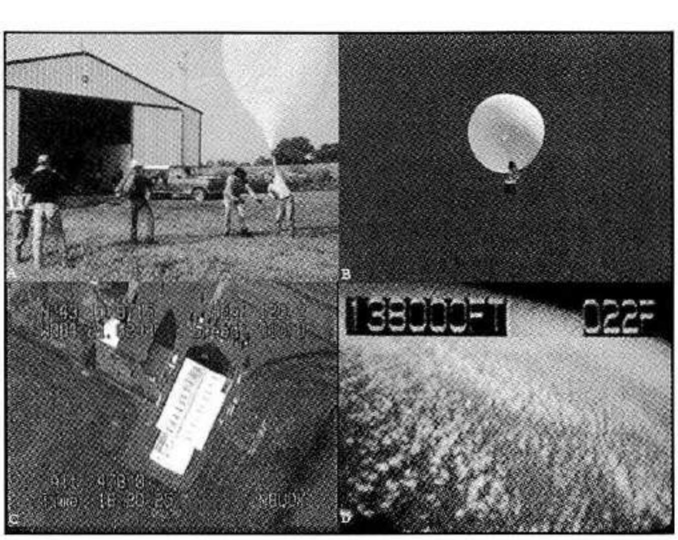


**Figure 9.14**. ATV balloon lauches provide an excellent opportunity to showcase ATV and demonstrate the cabilities of a local amateur group to carry out demanding projects. **[A]** Launching a delicate helium-filled weather balloon takes experience. Here the balloon "wranglers" of the Kansas Near Space Project get the job done (photo by KD4STH). **[B]** The Mabel-1 balloon, launched by N8UDK and the Detroit Amateur Television Society, gets started toward its rendevous with near-Earth space. **[C]** ATV view from Mabel-1 shortly after launch. Telemetry information, including GPS data, is overlaid onto the camera video. (Photos B and C by N8UDK). **[D]** Carrying out a successful ballon project is a demanding task, but the ATV views from the edge of space make it all worthwhile! Getting snow-free images at maximum altitude and range is not as simple as it might seem, a subject discussed in the text.

### *ATV IN SPACE*

Balloons naturally bring up the subject of ATV-equipped satellites or the possibility of ATV operations from the space station. In fact, there has been successful ATV communication via the Space Shuttle as part of the old SAREX program, but the results were marginal and NASA had little interest in flying additional hardware. The problem is simply excessive path losses, coupled with the wide bandwidth of the signals. It is like the balloon problem, magnified by a factor of ten! There are still those who hope for ATV capability from the International Space Station (ISS), but you can't ignore the laws of physics. Only extremely well-equipped ATV stations could be expected to be able to work the ISS; and results, like those with the Shuttle, would be marginal. The near future of image communication with the ISS is slow-scan TV (see Chapter 5). Perhaps a next generation of ATV standards, involving a significant reduction in bandwidth (see discussion in Chapter 10), will change that – but not yet.

### *ATV AND MODEL VEHICLES*

Any young person who ever has built a flying model airplane certainly has dreamed about what it would be like to be small enough to actually fly in that new creation. Well, with modern, miniaturized ATV gear that dream can become reality. The last time I checked, ATV gear had been shoehorned into model planes, helicopters, rockets, cars, kites, tethered balloons, model railroad trains, and model boats and submarines. **Figure 9.15** provides some idea of the results that can be obtained. Almost any recent visitor to the world-famous Dayton Hamvention certainly has noticed the ATV-equipped model blimp that cruises the exhibit halls, providing an aerial view of the crowd. ATV offers a unique way to combine two or more different hobbies and is an excellent vehicle for attracting modelers to Amateur Radio. This kind of activity has universal appeal and, like portable operations, can get you out of the station and into the fresh air. In fact, a good portable station is a real asset for such activities. The model builders tend to focus on how to make everything work at the model end and then short-change the receiving end in order to try out everything. Most areas have a local R/C flying site, so you may want to visit and see if anyone is interested in a joint project. What is just as likely is that you will get captured by the model-building hobby, but there is no harm in that! W6ORG, who operates PC Electronics, has written an excellent application note on ATV in models; and the .PDF file is available on the *ICH* CD-ROM.

### *ATV IN AIRCRAFT*

If ATV will work in model aircraft, how about the real thing? The answer is a definite YES, and W6ORG has another application note on the subject which is also

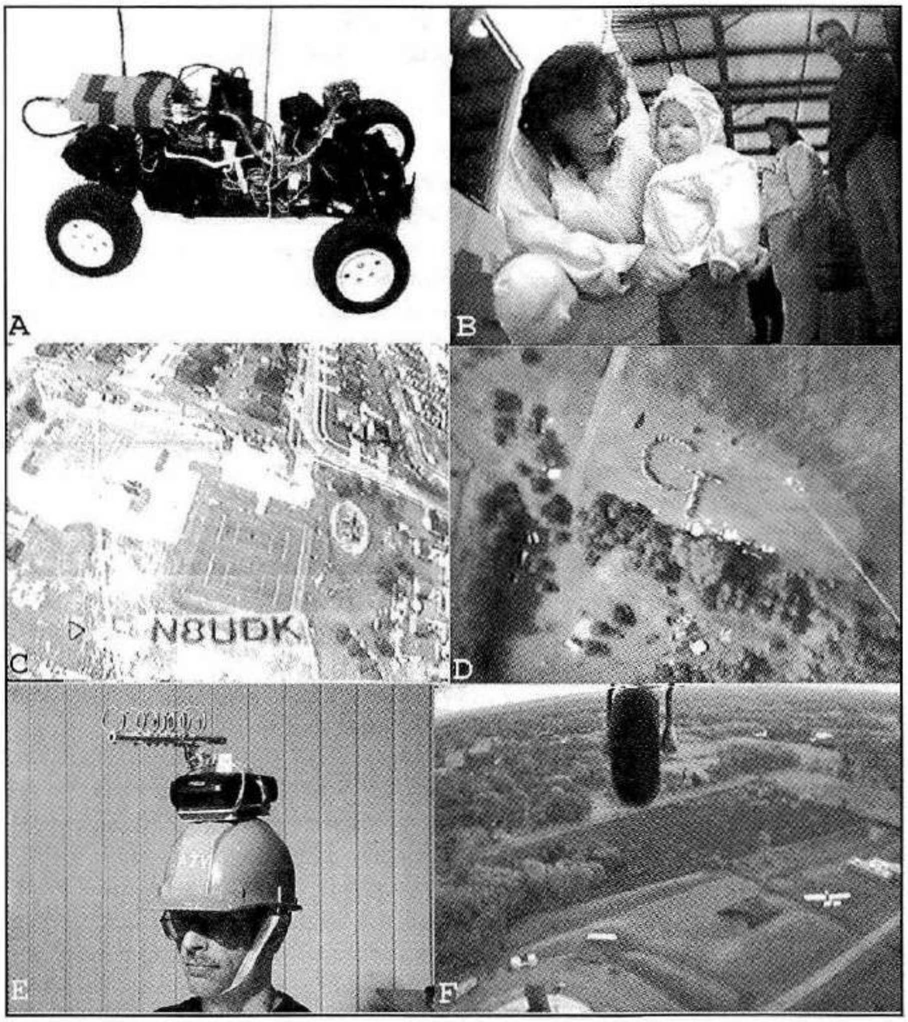


**Figure 9.15**. Planes, trains, and automobiles! The compact nature of modern ATV gear makes it possible to install equipment almost anywhere. Chris (N8UDK) and his friends in the Detroit Amateur Television Society have tried everything from balloons to high-powered rockets. **[A]** An ATV-equipped radio-controlled model car (Jeff, N8QPJ) gets noticed wherever it is run, providing an excellent view of curious spectators **[B]**. Lofting the ATV gear in a large kite (N8UDK and N8QPJ) results in an excellent image of the ground below **[C]**. Chris is seriously involved in high-powered rocketry and set up an ATV-equipped tethered balloon to provide a unique perspective of the rocket launches **[D]**. Chris and Jeff collaborated on a 2.4 GHz R/C aircraft package that provided some unique challenges. Since the 13 cm signal was not very strong, reliable tracking using a gain antenna was a requirement. Since the pilot has to watch the aircraft, mounting a loop Yagi and downconverter on a helmet provided automatic tracking **[E]**. The result was crystal-clear reception in-flight, including this rare shot that shows another aircraft in close formation **[F]**.

available on the *ICH* CD-ROM. This can be far more complex than either model or mobile installations due to the fact that the FAA has very specific rules about the things you can append to aircraft of different types and how they can be used. If you can work out an installation that satisfies the pilot, the FAA, and the common-sense dictates of flight safety, a private aircraft can represent a mobile installation with excellent potential, compared to the relatively poor results from most automotive installations.

Ultralight aircraft aren't configured to permit two-way ATV work, but they can provide a platform for relaying in-flight pictures. **Figure 9.16** shows some of the results I have obtained with a 1.5 W P.C. Electronics transmitter and a helmet-cam using my ultralight gyroplane. While ultralights have fewer constraints than conventional aircraft, the Law of Gravity still rules; and any such installation must be configured so that nothing can fall off. (There are people and property on the ground!) Flight safety cannot be compromised under any conceivable set of conditions. Although it sounds like common sense, the pilot has to concentrate on flying and leave the ATV gear to work on its own. That isn't a big issue compared to building a balloon package that will function at 100,000 feet.

### *BUILDING AN ATV REPEATER*

Probably the premier specialized activity for any individual or ATV group is the construction of an ATV repeater. The repeaters all over the world testify to the feasibility of such a project, but it is easy to underestimate the effort. Such a project will require concentrated effort on the part of a significant number of people and will typically cost $3000 or more if done properly. The successful realization of an ATV repeater project can really boost local ATV activity. However, if you commit time and money and fail to bring it off, it can have just the opposite effect. Treating the subject in any detail is far beyond the scope of this book, but I have provided yet another of W6ORG's ATV application notes in the form of an analysis of what is entailed in a typical repeater project. Tom's company, P.C. Electronics, probably has provided the key components for more repeaters in this country than anyone else; and he knows what's needed to make such a project work!

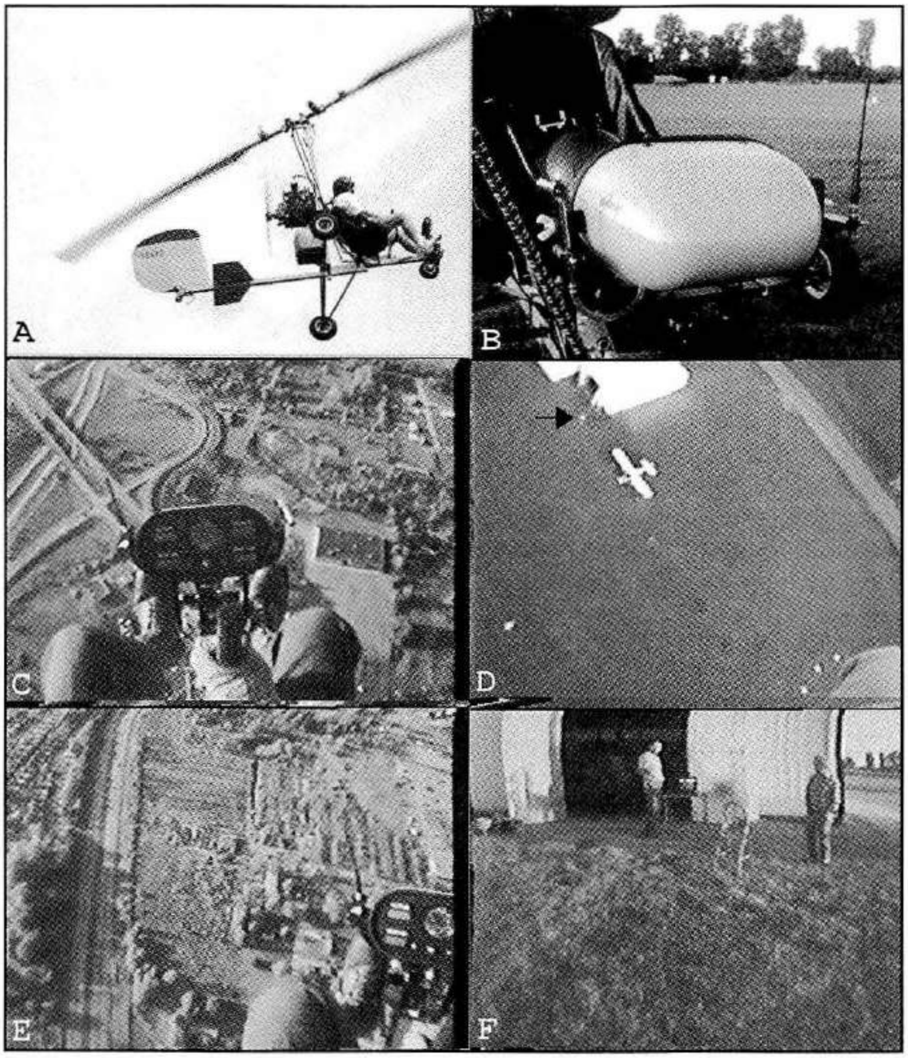


**Figure 9.16.** **[A]** The author's original-design ultralight autogyro. The instrument pod **[B]** is equipped with a BNC mounting jack that permits a variety of antennas to be used. In this case, the UHF "rubber duck" antenna is mounted for an ATV flight. Such an antenna would not normally be considered very useful for ATV, expecially with a 1.5 W transmitter, but if you get it 500 to 1000 feet (150-300 meters) in the air, it can be very effective. **[C]** A view of the Mason (Michigan) highway interchange, several miles from the airport. **[D]** The author makes a pass over the grass-strip airport where their gyroplane is based. The arrow points to a faint spot — the author's flying partner, Don Chubb, who is tracking the flight with a small 6-element Yagi. **[E]** Flying along local rivers and two-track roads in the country is typically a solitary experience, but in this case the helmet cam gives folks on the ground the same view seen by the pilot. **[F]** Pulling up to the hangar after a landing catches a candid view of the ground crew. Don is in the open doorway, next to the table with the TV set and recording gear. A cable-ready set, tuned to channel 60, was used to acquire the signal as far out as 10 miles, providing the Yagi was oriented vertically to match the vertically-polarized signal from the ultralight.

I hope I have managed to convey some of the excitement and potential of ATV. I started my personal image communications quest with ATV almost four decades ago, and I'm still active with the mode. Perhaps it is appropriate that we have come close to the end of our image communications journey in the context of this book. However, we aren't quite through yet, for it's time to polish off the crystal ball and see what the future might hold for the many image-related activities in Amateur Radio. That will be the subject of our final chapter.

## CHAPTER 10

# WHAT THE FUTURE HOLDS

Back in Chapter 1, I alluded to magic mirrors and crystal balls as mythological approaches to seeing at a distance. In a sense, we have come full-circle, for this final chapter is all about crystal balls in the sense of trying to assess what the future of amateur image communications might have in store. At best, crystal balls are low-resolution devices that work best if you don't try to peer too far into the future. The one thing that is certain with respect to developments in the immediate future is that they will be dominated by digital technology. Most of this volume has dealt with digital manipulation of inherently analog image formats. More and more, the near future appears to be a world where digital devices will be used increasingly to handle digital formats. In effect, the digital revolution in the hamshack is only partially complete, and the digital trends we are seeing now will only intensify and proliferate as time goes by.

This chapter, the shortest and least detailed so far, will parallel the organization of the book as a whole, focusing on trends in the area of narrow-band TV, slow-scan-TV, weather satellites, and amateur television. That said, it is important to recognize that these distinctions will continue to blur and may become essentially meaningless within a relatively short time. To illustrate what I mean, let's look at the wide range of digital modes, many of which didn't even exist a few years ago, now available using the PC and sound card. When operating these modes required a dedicated TNC and appropriate firmware, the distinctions between them had significance, but those days are past. These days on HF you are likely to watch another operator type, "I operate digital modes here...", meaning whatever of the many choices matches conditions and strikes his or her fancy. Switching from one mode to another is virtually seamless, and you can switch in the middle of a QSO if that's what you want. New modes and variants are appearing all the time, and all are equally accessible. The term "digital modes" is now an umbrella that encompasses a rich array of options that used to require considerable specialization.

We are fast approaching that situation with respect to image communications. I always will tinker with hardware, but the essence of my ability to handle narrow-band TV, slow-scan, and weather satellites resides in the computer. The same image library serves all these options and the many modes encompassed by each of them. Right now, the only major "stand-alone" mode is ATV, and even there the computer is becoming an increasingly valuable tool. In the not-to-distant future, ATV also will reside under the computer umbrella for reasons we will discuss shortly.

So what does the crystal ball say about that near future? For one thing, there will be far fewer hardware boxes to deal with. A master computer, a lot faster and more powerful than those available today, will be the center-piece of the typical amateur station. It will operate your rig(s) — which will probably be under the table or otherwise tucked away — and with it you will have the option of communicating via voice, digital modes, or images; perhaps more than one at the same time! To many "old timers" this looks like the ultimate "appliance station," and they may bemoan the fact that "nobody builds anymore". Well, they do and they will, but the venue has changed. There always will be those who experiment with new hardware, for that is often the only way to tackle new frontiers; but most of the "builders" will be constructing new modes in software, not hardware. As just one example, Peter Martinez (G3PLX) "built" PSK-31 and the software to use it just as surely as the pioneers who constructed the first "superhet" receivers or laid the foundations for single-sideband. Seeing the value of what Peter had created, other amateurs "built" new software or incorporated the mode into existing software in the same way that new hardware designs proliferate after every breakthrough in technology. The future holds endless opportunities for "home-brew" experimentation, but most of that effort will be in the software, not hardware, arena. That said, let's look at some pretty predictable areas of development and change with respect to our major areas of image communications.

## NARROW-BAND TELEVISION

A major aspect of NBTV activity will continue to be the rediscovery and exploration of the early days of mechanical television. This activity parallels the vintage radio movement and is both valuable, in terms of the preservation of our history, and extremely interesting. The real challenge, however, is operationalizing NBTV on the amateur bands to a greater extent than has been realized yet.

NBTV images are low-resolution, but they are full-motion television and can fill a niche that is presently vacant in the area of image communications. The fascination inherent in watching these matchbook-sized images cannot be conveyed adequately in words. I would suggest that anyone interested, visit one of Erwin Meyvaert's (ON1AIJ) web pages (**http://users.pandora.be/ON1AIJ/english.htm**) to watch two simultaneous full-motion image displays. Just a few weeks ago I sent such images across my basement workshop using a micro-power wide-band FM transmitter (~200 kHz bandwidth) on 440 MHz. It won't be long before the system is ready for a real on-the-air test. As it stands, the signal has at least a 15 dB advantage over conventional ATV, and that alone is worth the effort of seeing how well it works in practice!

As interesting as sending WBFM NBTV might be, the future is, not surprisingly, in the digital realm. With sampling and some basic real-time compression, the signal well might be suited for on-carrier modulation of the ATV signal. On paths where ATV signal strength was marginal, or the other station's antenna is pointed in another direction, you still would have the option of watching the "little" picture! To this point, efforts to shoe-horn NBTV signals into voice-channel bandwidth mostly have been limited to reducing the frame rate; but with image compression there is no reason why something very close to full-motion capability could not be realized using standard FM and SSB equipment.

## SLOW-SCAN TELEVISION

In the near term, we can expect continued development of new modes within the existing SSTV signal parameters. For example, one major gap in the present mode structure has been the lack of a medium-resolution (320 × 240/256) monochrome mode. Such a mode would be extremely useful for routine image exchanges where time is at a premium. Nick Fedoseev (UT2UZ) recently has incorporated SSTV into his multi-mode ***MixW32*** program — a concrete example of the unifying trend alluded to at the start of this chapter. Nick has included a new 43-second monochrome mode (see **Figure 10.1**) that probably will see wider use, particularly if it is included in dedicated SSTV programs. If you would like more information on ***MixW32***, you can access Nick's web page at **http://tav.kiev.ua/~nick/my-ham-soft.htm**. The program covers virtually all digital modes (including CW) and is steadily adding imaging capabilities.

While the standard analog SSTV formats, plus new ones that are sure to arise, will serve us for many years to come, digital techniques are creating new options at both ends of the slow-scan video spectrum. One area of activity involves new low-resolution options. While medium and high-resolution color pictures are nice, NBTV shows that it doesn't take a lot of pixels to generate a useful thumbnail image of the person at the other end of a QSO. Skip Tyler (KH6TY), co-author (along with Nick Fedoseev, UT2UZ) of the very widely-used ***DigiPan*** PSK software, already has done some useful work in developing software to send low-resolution images via PSK-31. PSK is one of the hottest modes around at the moment, and with a bandwidth under 100 Hz it gets rave reviews in terms of its ability to produce excellent long-haul contacts at QRP power levels. Skip's initial experiments were not intended to be terribly sophisticated, but only to evaluate the concept. Simple 60 × 80 pixel thumbnail images (see **Figure 10.2**) were simply converted to 4800 byte text files for transmission and reception — a process that requires 8 minutes. The receiving station would then convert the received text file back to the

**Figure 10.1**. An off-the-air example of the new 43-second medium resolution monochrome SSTV format incorporated into the multi-mode MixW software.

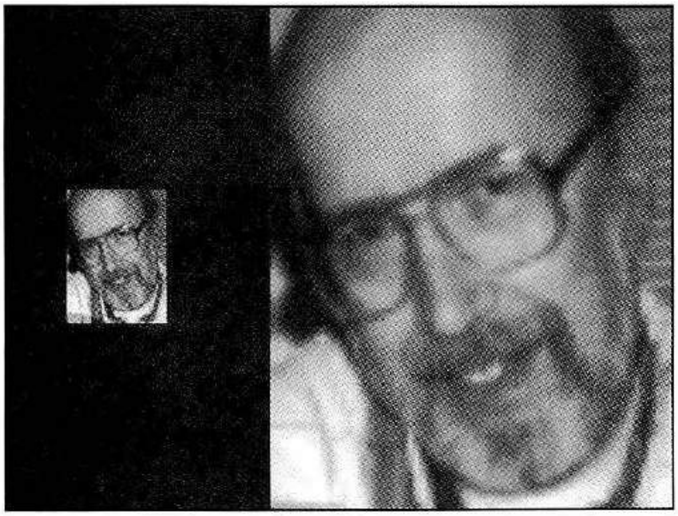


**Figure 10.2**. Transmitting thumbnail images using PSK. On the left is a 60 x 80 image formatted for transmission using PSK-31. A digital enlargement of the same image is shown on the right. The image is clearly lacking in detail when enlarged, but at its original size is more than adequate to serve as a thumbnail portrait of the operator. Initial experiments simply transmitted such images as 4800-character text files, but work is now underway to handle the images directly within the popular ***Digipan*** PSK program (see text).

60 × 80 image format. Despite the long transmission times, the results have been quite encouraging. The next step, currently underway, is to implement the image handling routines within a future release of the ***DigiPan*** software. With direct transmission of the image data within ***DigiPan***, Skip expects a frame time of approximately 1.5 minutes. Right now the "brag file", listing all the equipment in use, is a standard part of any PSK QSO; and there is no reason why a thumbnail image of the operator can't become just as common. Given some agreement with respect to standards, I see no reason why an "image box" could not be a universal component on every PSK software "control panel".

At the other end of the SSTV spectrum are ongoing experiments with the implementation of digital formats. The most significant work to date is that of Barry Sanderson (KB9VAK) in the development of a high-resolution digital SSTV format that features very short transmission time. The format is complex, involving a total of eight simultaneous audio subcarriers, each of which is phase-modulated to nine possible values. The format incorporates two levels of Reed-Solomon coding with extensive error-correction capabilities. A complete description of the technique and the results of on-the-air testing can be found at **http://www.svs.net/wyman/examples/hdsstv/index.html#tl1**. The approach permits the transmission of error-free image files (see **Figure 10.3**) under conditions where conventional analog SSTV formats are extremely marginal. In addition to the long-haul HF testing shown in Figure 10.3, the mode has also been used through the AO-29 amateur communications satellite, where conventional SSTV is very challenging. I have not illustrated the results of those tests since you can expect an error-free image file (Figure 10.3B) to look the same no matter how it is transmitted!

The KB9VAK digital system is still experimental as several pieces of software are required. **Figure 10.4** summarizes the present elements and processes required. The image to be transmitted is encoded off-line as a **.WAV** audio file. The audio file is then transmitted using standard SSB or FM voice equipment. At the receiving end, the audio output of the receiver is recorded as a **.WAV** audio file which is then decoded off-line to produce the received image file. At present, the off-line coding and decoding steps typically take longer than the 30+ seconds required to actually transmit the image. Present experiments are aimed at optimizing the degree of error correction implemented in the various mode options.

One possible goal is to implement the KB9VAK approach in a single software package that can be used by the average SSTV operator. Whether that happens or not is, at one level, irrelevant. These experiments, involving the transmission of error-free, full-color images in very short time frames, compared with analog techniques, clearly point to the direction of future SSTV development. As such experiments mature into operational software products, the result will be better images with more efficient use of our most precious resource — the RF spectrum.

## WEATHER SATELLITES

While the pace of development in the amateur imaging arena is internally driven, weather satellite experimenters march to tunes determined by the governmental agencies

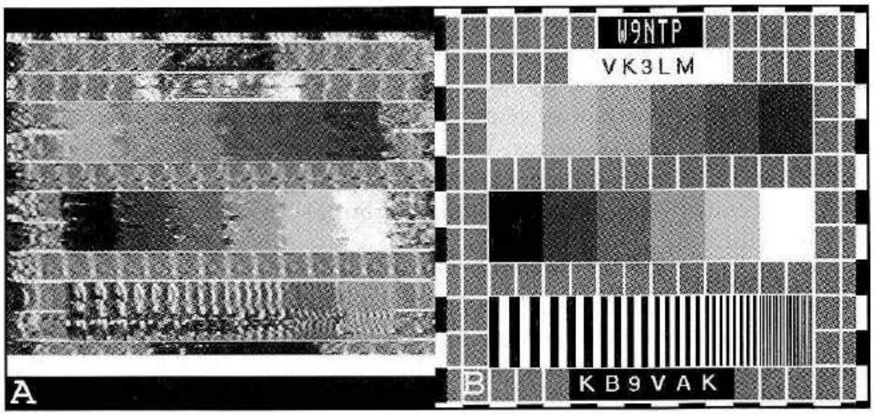


**Figure 10.3**. High-resolution digital slow scan experiments using a digital modulation format developed by KB9VAK (see text). **[A]** A Robot 36 color image as received by W9NTP from VK3LM on 20 meters. **[B]** A few minutes later, the experimental digital image (of significantly higher resolution) was transmitted over the same path in 30.5 seconds. While the system is still experimental, the potential for future development of digital SSTV technology is quite clear.

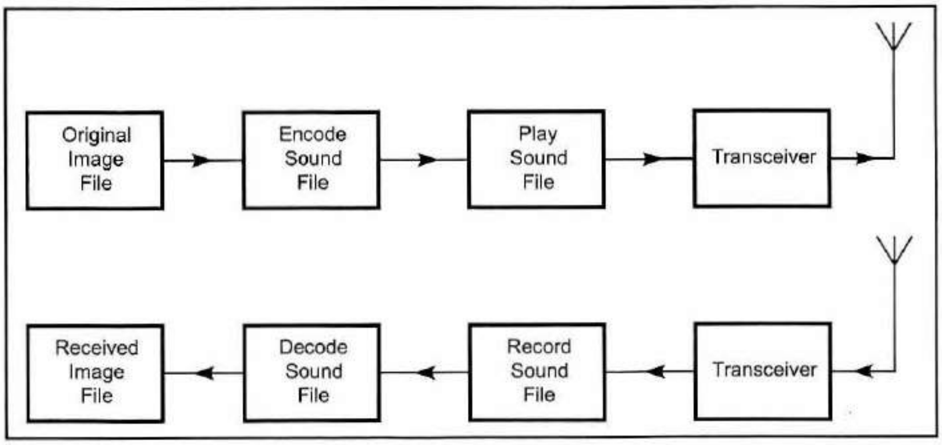


**Figure 10.4.** Basic elements and operations in the on-air tests of the KB9VAK digital SSTV format.

responsible for building, launching, and maintaining the global network of polar-orbit and geostationary spacecraft. The earliest operational spacecraft of the 1960s employed analog data acquisition and transmission systems. As newer spacecraft came on-line, employing ever more-sophisticated digital systems, dissemination of satellite imagery branched into two distinct paths. The "high-end" products were essentially digital in nature (HRPT on the TIROS/NOAA polar orbiters and VAS on the GOES geostationary spacecraft) and intended for governmental, research, and commercial use. Amateurs have developed the techniques to access these data, but the number of experimenters has been limited. As a legacy of the earlier analog technology, analog dissemination has been continued (APT in the case of polar-orbiters and WEFAX from the geostationary spacecraft) to serve the needs of the much larger "low-end" user community of which most amateurs are a part. The march of technology has a certain inexorable pace, and the time has arrived for the transition to full-digital service from the various categories of environmental satellites.

The current inventory of APT-equipped NOAA spacecraft will be depleted with the launch of NOAA-N, currently scheduled for June of 2004. This should assure the availability of current TIROS/NOAA APT products well-past mid-decade. As part of the transition to all-digital services, a **Joint Polar-orbiting Operational Satellite System** (JPS) is being forged with the cooperation of the National Oceanic and Atmospheric Administration (**NOAA**) and the European Organization for the Exploitation of Meteorological Satellites (**EUMETSAT**). As part of this effort, the Europeans will launch their first polar-orbit weather satellite, METOPS-1 (**Figure 10.5**) in late 2005. Two additional METOPS spacecraft are planned; and since each has a projected operational lifetime of five years, service spanning the second decade of the 21st Century is expected. The first of the new-generation NOAA spacecraft (NOAA N) is expected to come on-line in 2008. Specifications for the next-generation spacecraft have not been finalized, but expectations are that low-resolution products will be digital in nature and that a much wider range of products will be available. It is unlikely that the current frequency assignments in the 137-138 MHz satellite band will be adequate, but the picture is presently unclear. It does appear that current APT services will be available through the end of the decade and possibly beyond. Part of the uncertainty is due to a lack of information about Russian plans for future polar-orbit spacecraft. The onset of digital products from polar orbiters can be expected to induce a flurry of amateur activity to develop hardware and software to take advantage of these products, based on the assumption that they will continue to be freely disseminated to the international user community. It is generally anticipated that this will be the case.

The digital transition with respect to geostationary products is already on a fast-track. NOAA plans to replace the current analog WEFAX services from the GOES spacecraft by sometime in late 2004. The replacement format already has been codified in the form of the **LRIT** (**L**ow-**R**ate **I**nformation **T**ransmission) standard. LRIT transmissions will continue to be made at 1691 MHz, which means that existing antennas and downconverters still will be useful, but receivers with digital demodulators and the software to process the LRIT products will be required. A complete LRIT presentation in PDF format can be downloaded at **http://noaasis.noaa.gov/WEFAX/pdf-files/LRIT1_5.zip**. Similar trends can be expected in Europe as the current generation of METEOSAT spacecraft are replaced with the new and more capable MSG series satellites. Given the inventiveness exhibited by the amateur weather satellite fraternity, the development of suitable receivers and demodulation software can be expected.

One new aspect of meteorological remote sensing is the role of the International Space Station (ISS). The ISS is certainly a potential site for the installation of a number of possible systems for monitoring the Earth's environment and resources. What form such installations will take is far from certain, but the possibilities only add to the fascination as to what the future will bring!

## FAST-SCAN TELEVISION

It is in the area of ATV that we can expect to see some of the most profound changes in the not-to-distant future. In part, this is because ATV, particularly in North America, has not been especially innovative. There has been plenty of

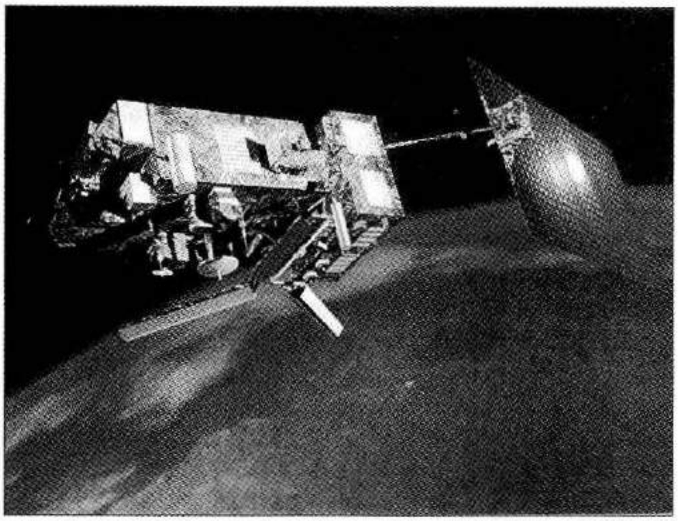


**Figure 10.5**. Artist's conception of the European **Metops** polar orbit spacecraft intended to bridge the gap between the last of the TIROS/NOAA series and the introduction of the next generation of digital environmental spacecraft. Photograph courtesy of Eumetsat.

work in the development of RF hardware, but virtually nothing with respect to imaging formats. In large part this has been a result of the fact that ATV has operated in a consumer environment saturated by NTSC broadcast-standard hardware. In an environment that mass-produces color receivers and cameras that often can be had in the $100 range, this is to be expected. What has made ATV appealing, despite the need for specialized transmitters and down-converters, is the fact that the "hard parts", in the form of TV receivers and cameras, were universally available.

While the short-term outlook for conventional ATV is bright, the long-term situation is quite different. Put bluntly, *ATV operations based on NTSC (or PAL) broadcast standards have no real viability much past the end of the current decade*! This may seem like a harsh assessment, but it is really a call to look seriously at what trends are viable in terms of future development and growth. Let's start with the basis for the assessment itself and then look at where we should be going. The assessment is based on two issues:

- Equipment availability
- Spectrum management

Each of these presents an insurmountable barrier to "business as usual", and I will briefly highlight the issues in the sections which follow.

### *EQUIPMENT AVAILABILITY*

We are on the verge of the single greatest technological change since the introduction of commercial television broadcasting. That change is the FCC mandated shift from NTSC to DTV (Digital Television) for the television broadcast service. This means that the NTSC format is no longer the U.S broadcast standard. What has replaced it is a set of 18 (so far) digital TV formats that fall under the umbrella of the ATSC (Advanced Television Standards Committee) "standard". The 18 formats range from HDTV (**H**igh-**R**esolution **D**igital **T**elevision) with up to 1125 lines of 1920 pixels down to a number of modes essentially equivalent in resolution to closed circuit NTSC. The image aspect ratio can vary from 16:9 to 4:3, frame rates cover ranges from 60 down to 24 frames/second, with both interlaced and non-interlaced (progressive) scan formats. Unlike the rigid specifications inherent in the NTSC analog world, all this flexibility is possible because digital circuits are expected to recognize and cope with the various formats. The new commercial broadcast channels are 30 MHz wide (to accommodate a single HDTV signal), or the station can choose to transmit up to six channels of SDTV (Standard Digital TV) within the channel allocation. Because the signal is digital, assuming a threshold signal level, snow, ghosts, and color shifts will be artifacts of our analog past.

Reception of these new formats will not be possible with older NTSC receivers. The new DTV sets are either completely self-contained or can be configured using a set-top receiver/converter (**Figure 10.6A**) in conjunction with a DTV monitor (Figure 10.6B). DTV channels are already operating in all the major US TV markets; and by the end of 2006, all NTSC broadcasting will cease in the US So where does this leave millions of NTSC television sets? The answer is that essentially they are obsolete. The lifetime of newer equipment will be extended by the fact that the set-top DTV converters will typically output NTSC video, and folks want to use their NTSC camcorders for as long as they keep operating. However, the large-scale manufacturing of NTSC equipment will cease; and it is impossible to imagine sustaining ATV on the basis of essentially obsolete surplus equipment.

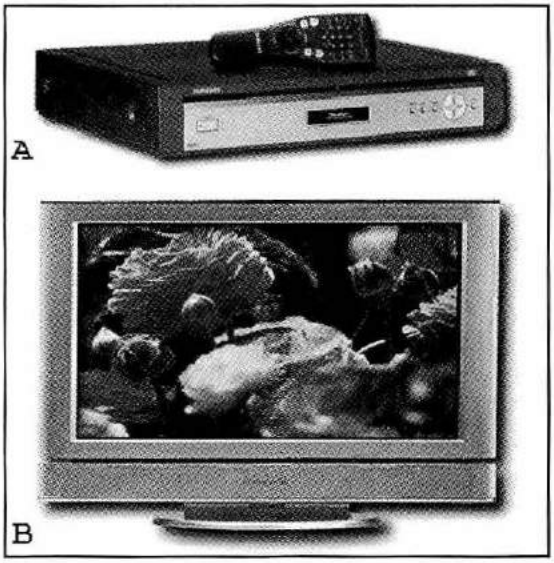


**Figure 10.6**. Digital television components. **[A]** A Samsung set-top multi-function converter. This unit can decode and format any of the 18 approved ATSC digital modes for display on a digital television monitor and can also downconvert the digital formats for NTSC display on older analog TV sets. **[B]** An example of a full-function DTV monitor. This is a Panasonic LCD monitor, with a 16:9 aspect ratio screen, capable of displaying any of the ATSC formats using an outboard converter, such as the Samsung unit shown above.

### *SPECTRUM MANAGEMENT*

When our small group in northern New Jersey first put our puny ATV signals on the 70 cm band, I cannot recall our ever encountering any other amateur signals in any mode. Today the situation is profoundly different and ATV is competing for spectrum with a host of other users. In most areas of the country, where the band is a full 30 MHz wide (420-450 MHz), it is still possible to reach reasonable operating accommodations between the various users; but interference with ATV operations is becoming more common and more severe. Despite spectrum availability, the band is filling up fast. In Europe, where the band is not as wide as it is here, spectrum usage has reached the point where most ATV operations have moved up to 23 and even 13 cm. The only reason this works at all is the relatively high population density.

As the operating frequency is increased, path losses increase disproportionately. Compared to 70 cm, the path loss for any link on 23 cm is increased by over 9 dB, rising to over 14 dB additional loss at 13 cm. Transmission line losses are also significantly higher and it is more difficult to generate reasonable levels of RF power. Increased antenna gain is easy to achieve, but at the expense of considerable directivity, making it difficult to construct effective repeater antenna systems with anything approaching uniform coverage.

Here in North America, where distance and low population densities are a more common factor, the use of 23 and 13 cm is only practical in the immediate vicinity of significant metropolitan areas. Long-haul point-to-point work greatly benefits from the use of 70 cm, with its inherent advantage with respect to path loss and a host of technical factors. Unfortunately, it is this band than is acquiring a larger population. In the decade ahead, it will become increasingly difficult to support a relatively small number of operators requiring 6-9 MHz of spectrum in the face of other, equally legitimate claims for spectrum usage.

### *FUTURE DIRECTIONS*

Given the technological changes in broadcast television, there are only three possible trajectories for future development and they are far from being equal:

1. **Do Nothing and Stay with the NTSC Standard**. This is a superficially easy option that essentially involves business as usual. Unfortunately, such an approach will ultimately fail. You cannot sustain growth or even maintain numbers if you are dependent on obsolete equipment that will become increasingly difficult and expensive to acquire. What is more, staying with the NTSC standard will not solve the spectrum management issues. Defending ATV's "right" to significant blocks of spectrum will, in fact, become increasing indefensible given the fact that other useful and even superior options are available.
2. **Adopt a Broadcast DTV Standard**. It would be possible to adopt some of the SDTV subsets of the ATSC standard, but there are several practical problems. First, the commercial equipment designed to display such images will be considerably more expensive than the present NTSC equipment; and it is likely to be a number of years before prices drop to the point where most amateurs could consider dedicating such gear to their ATV operation. Equally important, the SDTV mode options all require a 6 MHz channel bandwidth, which does nothing to ease the problem of spectrum congestion. Given the development effort that would be required, it would seem that the disadvantages of such a project would greatly outweigh potential benefits.
3. **Develop Amateur Digital Standards**. Amateur Radio is a communications, not an entertainment service. Given the changes sweeping the TV broadcast industry, this may well be an opportune time to break from broadcast standards with respect to ATV and craft a television option better suited to the needs and objectives of the Amateur Radio service. Properly conceived, such an effort can eliminate dependence on expensive DTV equipment, address the issue of responsible spectrum usage, and bring ATV closer to the amateur mainstream in terms of equipment requirements.

If we suspend parochial perspectives and make the assumption that a full-motion television standard has a place in Amateur Radio, it is clear that the third option listed above has a great deal of potential.

### *A NEW LOOK AT ATV POSSIBILITIES*

With respect to audio quality, amateurs have never really attempted to emulate the "audio resolution" of broadcast radio services. We basically employ modulation standards that strike a compromise between quality and spectrum bandwidth. We certainly can apply the same perspective in looking at the possibilities for amateur television standards. As just one example, I have included a sample medium-resolution (320 × 240) SSTV image in **Figure 10.7**. This

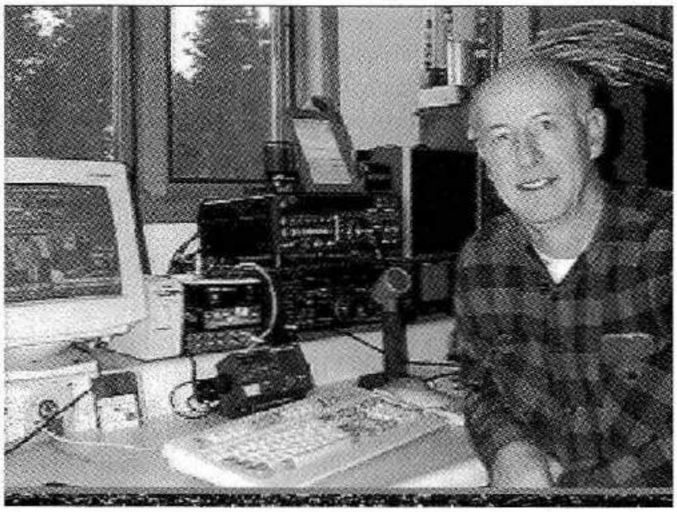


**Figure 10.7**. An example of a 320 x 240 SSTV image transmitted on 15 meters by W0LMD in Colorado and received by the author in Michigan. The original image was transmitted in 24-bit color but is displayed here as an 8-bit grayscale image. An ATV image standard based on images of this resolution would have a significantly lower bandwidth than the current NTSC standard.

particular image of Robert Suding (W0LMD), sitting at his operating position, demonstrates the detail that can be achieved using modest resolution in conjunction with digital image display. The fact is, you rarely will see a picture this good using ATV, despite the theoretical resolution inherent in the NTSC standards. If pictures of this resolution were transmitted at a 15 Hz frame rate and displayed on a computer monitor, the resulting images typically would exceed anything you could achieve using NTSC video. Even with the relatively low frame rate, the image would have no significant "flicker" because the computer scans the image in memory at 60-70 times each second, even though the entire image is being updated at a 15 Hz rate. Implemented properly, the colors in such an image would greatly exceed current broadcast standards as a result of greater color bit depth and saturation. A 24-bit color image with a frame rate of 15 Hz would have a baseband video bandwidth of about 1.6 MHz, compared to 3-4 MHz with NTSC video. If we transmitted a monochrome image at the same rate, the video bandwidth would fall to about 500 kHz! Even if we employed analog modulation, the resulting signal would have significantly lower RF channel bandwidth than a comparable NTSC signal!

One reason why ATV operators have not seriously considered alternative standards is that the new mode would have few practitioners if everybody had to build color receivers and cameras in order to operate. These considerations don't have to restrict our thinking in the current digital environment. New signal formats might require some basic receiver RF and detection elements, but the computer would provide a color display inherently superior to that of an NTSC color receiver. Mode-specific color cameras would not be required, since the computer can perform scan conversion in real-time from any video source (NTSC camera, DVD video, etc.). It is impossible to predict what such standards should look like, but we are certainly at a point in time where we should start to initiate discussions on the subject.

### *DIGITAL ATV*

While analog implementation of any new standards would result in a system with performance advantages relative to our present NTSC system, I already have alluded to the role of computer technology at the camera and display ends of the system. If we are willing to examine the possibility of converting the entire TV system to digital, we could realize additional advantages:

- **Bandwidth Compression** — In the analog world signals have inherent bandwidth characteristics. If you attempt to restrict the signal bandwidth by filtering or other means, you will lose information and effective resolution. In the digital world, image signals can be compressed in a variety of ways that result in little or no loss of resolution. We have discussed compression earlier in the context of still images, where the object of compression is to reduce the effective file size of an image. In the case of video images, the effect is to reduce the required channel bandwidth. The most widespread compression "families" for video are the various **MPEG** (**M**oving **P**icture **E**xperts **G**roup) standards that underpin much of out current video technology. This includes computer video, direct-broadcast satellite technology, and the ubiquitous DVD. Video compression holds the key to reducing ATV bandwidth to a point where the mode has long-term viability on bands such as 70 cm.
- **Error Correction** — Image "snow" (noise), ghosting (multi-path) and other artifacts are all symptomatic of the ways in which an analog signal can be degraded over a specific path. In a digital television system, the basic structure image is known with certainty. In addition, if previous frames have been decoded successfully, certain attributes of the next frame can be predicted, depending on how fast the image content has been changing. Artifacts such as noise and multipath also have predictable characteristics to varying degrees. All of this information can be applied in a process known as "error correction". In effect, images can be "repaired" in real time. As long as a digital signal exceeds a basic detection threshold in terms of signal-to-noise ratio (SNR), it can be displayed free of any of the artifacts that can plague an analog signal path.
- **Color** — In the analog world, the ability to display color is proportional to the SNR and the effectiveness of the video modulator at the transmitter. In ATV this translates to the fact that reasonable color requires a moderately good signal. Phase shifts and other non-linearities anywhere in the system can degrade the color component of the signal or result in shifts in color values. Since color is a numerical attribute in a digital video system, if the signal can be demodulated at all, there is no reason not to expect the signal to exhibit all of its original color characteristics.

It is obvious that digital image standards can have some very distinct advantages over comparable analog formats, but the North American ATV community has very little experience dealing with digital video. Fortunately, European amateurs, particularly in Germany and Holland, have been experimenting with digital ATV since the late 1990s.

**Figure 10.8** shows a block diagram of the basic elements of a digital TV system. At the transmission end, the video typically is encoded using available MPEG hardware chipsets. The transmitter follows common amateur practice except for the use of digital phase-modulation. The modulation and associated filtering is typically done at low power levels (a few milliwatts) and the signal is then heterodyned to the final operating frequency and amplified to the desired power level. At the receiving end the RF signal is converted to an IF frequency, digitally detected, and converted back to the native video format by an MPEG decoder. Many of the German and Dutch experimenters have been using set-top DBS satellite decoders as they contain the MPEG decoding hardware and firmware. It is also worth noting that virtually all modern computers incorporate MPEG decoders to handle DVD discs and other streaming video formats.

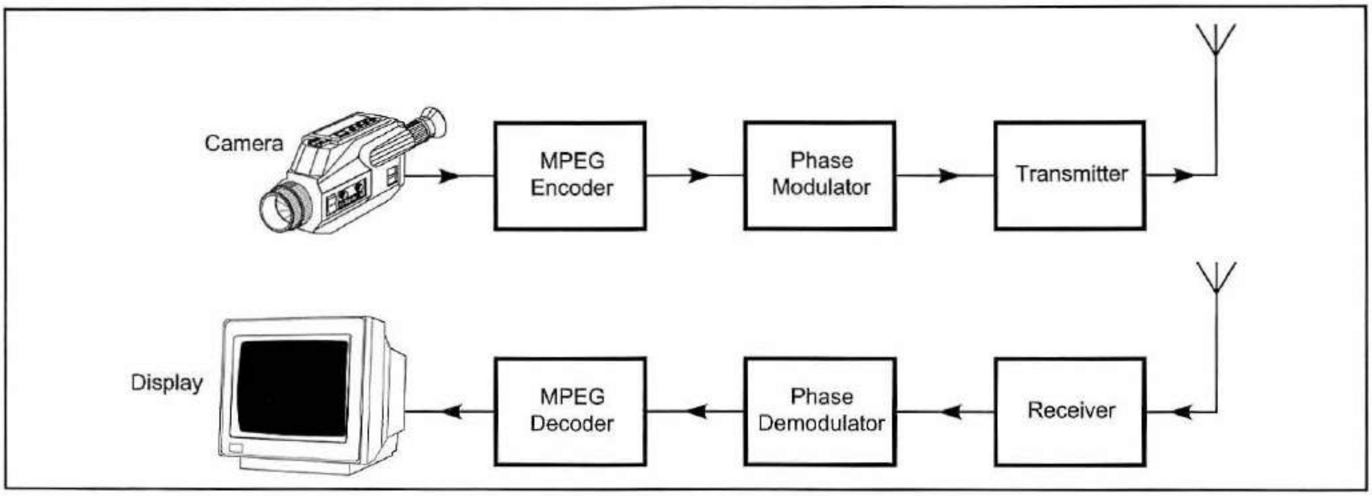


**Figure 10.8.** Basic elements in current digital amateur television experiments in Germany and the Netherlands.

There are a number of Internet web pages on the subject of Digital ATV. A good starting point, with a reasonable amount of English content, is a Web site set up by Uwe Kraus (DJ8DW), one of the pioneers in DATV (**http://darc.de/distrikte/g/datv/datvindex.html**). If you don't mind testing your high school or college German skills or exploring the mysteries of Dutch, there are additional sites with a lot of technical content that eases the burden of translation:

**http://www.d-atv.de/**

**http://www.atvrepeater.com/DATV/tv_a_nr_118.htm**

Results of even some of the earliest experiments have been very impressive, including, for example, the successful transmission of digital video and sound over a 100 km (60 mile) path using a 15 W 434 MHz transmitter, 15 dB antennas at each end of the circuit, and an RF bandwidth of under 2 MHz! No matter what band is employed, a digital signal should be equally robust in comparison with analog formats. DATV is definitely gathering momentum in Europe, and it is a technology that we in North America would benefit from exploring.

## SUMMARY

It is obvious that radio amateurs have a long and significant history of involvement in image communications. Much of this history has involved relatively small pockets of activity outside of the amateur mainstream. The ascendancy of digital computers, more than any other single factor, is changing that pattern and transforming amateur image communications into a set of accessible options that can be employed by everyone. Most of our current imaging options will be with us for years to come, but the future holds challenges that will result in new and even more effective ways to communicate with pictures. It is perhaps appropriate to end with the modest set of quotations that opened the first chapter of this Handbook:

> *A picture's meaning can express ten thousand words.*
> Chinese Proverb

> *As soon as there is general recognition of the fact that a radio receiver need no longer be blind, the acceptance of television is inevitable.*
> Zworykin and Morton, 1940

> *Hams should be seen as well as heard.*
> Don Miller, W9NTP

In fact, our radios can see. Taking advantage of that fact and the potential it represents can be one of the factors helping to define and galvanize the growth and development of Amateur Radio in this new century.

# GLOSSARY

Listed below are selected terms and working definitions relevant to various aspects of image communications. General terms with respect to basic electronics, computers, and Amateur Radio are not included. *The ARRL Handbook* is an essential reference for anyone interested in Amateur Radio and is suggested in cases where the reader requires working or detailed definitions in these areas.

**A/D** — Analog to Digital conversion: circuits and/or software to convert analog voltages (from an image waveform, for example) to numerical values for computer or digital processing.

**advanced very-high resolution radiometer** — see **AVHRR**

**AM** — Amplitude Modulation: the process of transmitting voice or image information by varying the amplitude or power of the audio or radio-frequency carrier

**amplitude modulation** — see **AM**

**AOS** — Acquisition of Signal: the time when you can expect to hear a signal from a spacecraft as it rises above the local horizon.

**ATSC** — Advanced Television Systems Committee: the group that defined the set of standards and formats for the digital television formats now being implemented in the Broadcast Television Service. See **DTV**.

**AVHRR** — Advanced Very-high Resolution Radiometer: the mechanical/optical scanning system used for primary image acquisition by the US TIROS/NOAA polar orbit spacecraft.

**analog** — a data format involving signal levels that vary continuously over a defined range.

**APT** — Automatic Picture Transmission: the general term applied to the various low to medium-resolution images that are transmitted in real-time by polar-orbit weather satellites.

**aspect ratio** — the ratio of the width of an image format to its height.

**azimuth** — the geographic direction to which an antenna must be aimed in order to track a spacecraft at any moment. The term may also be used in the context of a terrestrial path, in which case the azimuth is the great-circle bearing between the receiving and transmitting stations.

**back porch** — see **blanking**

**bandwidth** — the audio or radio-frequency spectrum required for a given image format or other signal.

**black level** — the signal level amplitude that corresponds to the black end of the video dynamic range.

**blanking** — a "blacker-than-black" signal level that assures that the scanning trace cannot be seen as it is reset to scan another line or frame. In conventional television this is often referred to as the **blanking pedestal**, consisting of two segments — the **front porch** that precedes the vertical sync pulse and the **back porch** that follows the sync pulse.

**BMP** — bitmap image format: the native (default) uncompressed image format used by the Windows operating system.

**cathode ray tube** — a specialized electron tube, employing a phosphor-coated screen, used for image display. The classic TV "picture tube", used in most television sets and computer monitors, is an example of such a tube.

**chrominance** — that portion of an image signal that represents the primary color data. In the case of NTSC television, the chrominance data are represented by phase modulation of the 3.58 MHz color subcarrier.

**color analysis** — the process of extracting the color or luminance data from an image as part of formatting a color image for transmission.

**color burst** — seven cycles of a 3.58 MHz subcarrier signal located on the back porch (see **blanking**) of an NTSC color TV signal waveform.

**color subcarrier** — the modulated 3.58 MHz component of an NTSC color television signal that is used to convey the color or luminance image data.

**color synthesis** — the process of recovering the color or luminance data as part of the process of reconstructing and displaying a color image.

**compression** — various digital techniques to reduce the bandwidth, transmission rate, or file size of an image.

**CRT** — see **cathode ray tube**

**D/A** — Digital to Analog conversion: the circuits and/or software to convert digital image data to analog form, typically for display.

**deflection** — the circuits or other components controlling the vertical and horizontal "sweep" signals that move the scanning beam of a cathode ray tube image display.

**demodulator** — the circuits that recover the data from a modulated audio or radio-frequency carrier.

**digital** — the processing or storage of data as discrete numerical values as opposed to the continuously variable levels characteristic of analog signal formats.

**digital signal processing** — the manipulation or processing of audio or radio-frequency data in digital as opposed to analog form. The computer sound card is essentially a DSP system for handling audio data.

**downconverter** — a circuit for converting a radio-frequency signal to a lower frequency range for demodulation or other processing.

**DSP** — see **digital signal processing**

**DTV** — Digital **Television**: most commonly applied to a series of 16 digital formats (including **HDTV** or **H**igh-resolution **D**igital **T**elevision) that will comprise the default commercial broadcast TV standards in the United States. DTV is already being implemented across the country, and all current TV channels using the current NTSC format will cease operation in 2006.

**electrostatic deflection** — changing the location of the scanning spot on the face of a cathode ray tube using high-voltage signals applied to internal deflection plates. Most oscilloscopes employ electrostatic CRTs.

**elevation** — (1) the angle, referenced to the horizon, of an antenna tracking a spacecraft at any given moment. (2) The vertical displacement, relative to mean sea level, of a station located on the surface of the earth.

**equatorial orbit** — a spacecraft orbit where the orbital track is located directly above the equator.

**EUMETSAT** — the multi-national European organization with operational responsibility for European weather satellites.

**FM** — Frequency **M**odulation: the process of transmitting voice or image information by varying the frequency of the audio or radio-frequency carrier.

**frame** — a complete set of scanning lines (or pixel rows) that comprises an electronic image.

**frame grabber** — a device for capturing a television signal in digital form.

**frame sequential color** — the transmission of a color image by transmitting the red, green, and blue luminance data as a sequence of complete primary color frames. The three luminance frames are then combined, typically in digital memory, to create the color image on the display system.

**frequency modulation** — see **FM**

**front porch** — see **blanking**

**geostationary** — a specialized circular satellite orbit where the orbital track is oriented over the equator, the spacecraft moves in the direction of the Earth's axial rotation, and the orbital altitude (~22,700 miles or 37,000 km) is such that the orbital period equals the time required for the Earth to complete a single rotation on its axis. Under these exacting conditions, the spacecraft will maintain the same location over the equator and thus, from the ground, will maintain a constant bearing with respect to elevation and azimuth.

**GIF** — **G**raphics **I**nterchange **F**ormat: a loss-less image compression format developed by CompuServe. GIF images are limited to 256 color values and are thus primarily used for monochrome/grayscale images.

**GOES** — **G**eostationary **O**perational **E**nvironmental **S**atellite: the operational geostationary spacecraft operated by the United States.

**GMS** — **G**eostationary **M**eteorological **S**atellite: a geostationary equivalent of the GOES spacecraft operated by the Japanese government.

**GOMS** — **G**eostationary **O**perational **M**eteorological **S**atellite: A geostationary spacecraft, similar to GOES, developed by the Soviet Union and now operated by the Russian Federation. GOMS has yet to reach true operational status.

**HDTV** — see **DTV**

**HRPT** — **H**igh-**R**esolution **P**icture **T**ransmission: The primary operational imaging system of the US TIROS/NOAA polar orbit spacecraft.

**interlaced scanning** — a scanning pattern, designed to reduced perceived flicker in broadcast television systems, in which the complete image frame is actually made up from two sequentially-scanned fields. The timing of the sequential scanning is such that the lines of the second field are interspersed between the lines of the first field.

**IR** — **I**nfra-**R**ed: image formats based on the use of heat radiation as opposed to visible light. Depending upon the IR wavelengths used to make up the image (all IR radiation has a longer wavelength than visible light) cloud cover, ground and sea-surface temperatures, and atmospheric water vapor content can be assessed day or night.

**ISS** — **I**nternational **S**pace **S**tation

**Joint Polar-orbiting Operational Satellite System** — see **JPS**

**JPEG** — **J**oint **P**hotographic **E**xperts **G**roup: A set of digital compression standards (involving variable degrees of image loss) for still imagery.

**JPS** — a cooperative program involving NOAA (US) and EUMETSAT (Europe) for management of polar-orbit satellite systems through the middle of the first decade of the 21st Century.

**Keplerian elements** — sets of numerical parameters for satellite orbits that provide updated reference data for use by satellite tracking programs.

**limiter** — high-gain circuit elements designed to remove any amplitude variations in an FM signal format prior to detection. Limiter circuits are universally used in FM receivers and as one of the early stages in the processing of SSTV and high-frequency facsimile images, which employ a frequency-modulated audio subcarrier.

**line-of-sight** — see second definition under **LOS**

**line sequential color** — the transmission of color images as data in sets of three sequential lines, each line representing luminance data for a different primary color (typically red, green, and blue). The three lines of primary color data are then integrated, usually in digital memory, to reconstruct one line of color image data for display.

**link analysis** — an engineering analysis of the signal levels expected over a specific signal path. A link analysis takes into account the power output of the transmitter, transmission line losses, antenna gain, free-space path loss, receiver antenna gain, receiver transmission line losses, and the noise-floor or minimum received power threshold of the receiver. Accurate link analysis is only possible over line-of-sight signal paths.

**LOS** — (1) **L**oss **o**f **S**ignal: the time at which a receiving station can expect to lose the signal from a satellite/spacecraft as in drops below the local horizon. (2) **L**ine-**o**f-**S**ight: a radio-frequency or optical path where a signal is not blocked by the earth or other significant objects. Given the high radio frequencies used by spacecraft, reception of such signals is only possible when the spacecraft is above the local horizon.

**LRIT** — **L**ow-rate **I**nformation **T**ransmission: a standardized digital transmission format that will replace the WEFAX signals currently transmitted by US GOES geostationary spacecraft.

**luminance** — that portion of an image signal which conveys the primary data with respect to the brightness level of successive pixels. In an NTSC television signal, luminance data are represented by the amplitude modulation of the video carrier.

**magnetic deflection** — the use of magnetic fields, typically applied by a deflection yoke located around the neck of a cathode ray tube, to control the scanning beam that creates the display image. Most TV sets and computer monitors employ magnetic deflection.

**METEOR** — the primary operational polar orbit weather satellites developed by the Soviet Union and now operated by the Russian Federation.

**METOPS** — A transitional series of polar-orbit meteorological satellites, designed and operated by the European EUMETSAT agency, which will provide a significant amount of the polar-orbit satellite data from the mid-2000s to the late 2010s.

**METSAT** — **Met**eorological **Sat**ellite: the operational geostationary spacecraft operated by a consortium of European nations.

**mirror drum** — a drum, containing a number of carefully positioned mirrors (one mirror for each image scan line) used for both image pick-up and image display in some mechanical television systems.

**mirror screw** — a helical arrangement of thin mirrors (one mirror segment for each image scan line) used for image display in some mechanical television systems.

**MPEG** — **M**otion **P**icture **E**xperts **G**roup: a set of digital image compression formats/standards for moving images.

**Nipkow disk** — a flat disk, perforated with a spiral series of holes (one hole for each image line) along the outer edge, used for image pick-up or display in some mechanical television systems.

**NOAA** — (1) **N**ational **O**ceanic and **A**tmospheric **A**dministration: the US governmental agency with responsibility for operation of the polar-orbit and geostationary meteorological satellite systems. (2) The acronym applied to U.S. polar-orbit meteorological spacecraft once they reach orbit.

**NTSC** — **N**ational **T**elevision **S**ystems **C**ommittee: (1) The committee that set the standards for both monochrome and color broadcast television. See also **ATSC**. (2) An acronym for the combined monochrome/color signal format for broadcast television in North America and selected other countries. See also **DTV**.

**orbital elements** — see **Keplerian elements**.

**PAL** — **P**hase **A**lternate **L**ine: the most common broadcast color television format in western Europe.

**path loss** — the total reduction in signal power (in dB) over a free-space path. Total path loss is a function of the operating frequency and the length of the path.

**picture element** — for analytical purposes, the smallest spatial component in the scanning or display of an image. Image resolution is directly related to the number of picture elements. If the size of a picture element is large relative to total image size, the image will be made up of a relatively small number of picture elements and thus have relatively poor resolution. If the size of a picture element is small relative to total image size, the image will consist of a large number of picture elements and thus demonstrate better resolution.

**pixel** — see **picture element**

**pixel sequential color** — a color transmission/display system based on the sequential transmission of primary color data (typically red, green, and blue) in the form of a sequence of three image pixels. The chrominance data for the three primary color pixels are integrated (typically in digital memory) to produce a single color display pixel. NTSC broadcast television uses basically this technique with an analog implementation.

**polar orbit** — a satellite orbit where the orbital track passes over the north and south geographic poles with each orbital revolution. The term is loosely applied to low-orbit weather satellites since the orbits have a high inclination that takes them comparatively close to but not directly over the geographic poles.

**polarization** — the orientation with which radio waves are propagated through space. The polarization of a transmitted wave is a function of the physical orientation of any antenna elements and the phase relationships with which they are driven.

**primary color(s)** — the subset of colors used to synthesize a full-color image. In conventional and slow-scan television, the primary colors are red, green, and blue.

**progressive scanning** — a scanning sequence in which all image lines are scanned sequentially to display the complete image frame. Computer monitors typically use progressive scanning, in contrast to the **interlaced scanning** employed in NTSC broadcast television.

**raster** — the pattern of scanning lines developed on the face of a cathode ray tube during the display of one image frame.

**resolution** — the ability to resolve spatial or tonal detail in a given image format.

**RESURS** — the most recent series of operational polar-orbit weather satellites operated by the Russian Federation. Based on their image output, the RESURS spacecraft appear to be derivatives of the earlier METEOR satellites.

**retrace** — the time interval during which a scanning beam is returned to either the start of a line or the start of a frame. See **blanking**.

**Robot** — used in reference to both SSTV equipment and image modes (mostly color) developed by Robot Research, Inc. of San Diego, CA. The company no longer manufactures Amateur SSTV equipment.

**scan converter** — a device, usually incorporating digital storage technology, to take an image transmitted in one format and display it on a device designed for a different image format. SSTV scan converters, where SSTV images are displayed on NTSC or computer monitors is one example of such technology. Virtually all computer display of amateur image communications modes employs the principle of scan conversion.

**scanning disk** — see **Nipkow disk**

**SDTV** — see **DTV**

**SECAM** — **SE**quential **C**oeleur **A**vec **M**emoire: a broadcast color TV format developed in France. A variant of SECAM was developed in the Soviet Union and was widely used in eastern-bloc nations during the Cold War.

**sound card** — generic term for the ***Sound Blaster***™-compatible computer bus-cards that are widely used as the basis for the sound capability of PC-compatible computers. In most cases, such cards are essentially DSP sound subsystems developed around specific chipsets.

**synchronization** — the various means employed to assure that the display of an image is kept precisely "in-step" with the scanning and transmission of the image at the transmitter end of the circuit. Proper synchronization typically requires that the receiving system be able to detect the precise time that the image frame and each individual line starts and that the image data are processed at precisely the proper rate and with the proper geometric organization.

**televisor** — term for any mechanical television display device.

**TIROS** — **T**elevision **I**nfra-**R**ed **O**perational **S**atellite: generic prelaunch acronym for the U.S. polar orbit meteorological satellites. The spacecraft are re-named with a NOAA designation once they reach orbit.

**tracking** — the process of keeping a ground receiving antenna pointed at a spacecraft as it moves from horizon to horizon. Accurate tracking requires a source of current satellite orbital elements, tracking software (or a mechanical plotting board), and a means to adjust the elevation and azimuth of the receiving antenna throughout the pass.

**VAS** — see **VISSR**

**VISSR** — **V**isible and **I**nfra-red **S**pin-**S**can **R**adiometer: mechanical/optical high-resolution scanning system used for primary image acquisition by the GOES geostationary weather satellites. The system uses the spacecraft spin for line scanning and a high-resolution mirror stepping system for frame scanning. The most recent version of this instrument is known as **VAS** or **V**ertical **A**tmospheric **S**ounder. All these instruments are multi-spectral, gathering data simultaneously at multiple visible and IR wavelengths.

**visible** — refers to sensors or images acquired using visible light wavelengths as opposed to infra-red (IR) wavelengths. Visible-light imagery is only available during daylight hours or passes, while IR data can be used day or night.

**WEFAX** — an acronym derived from Weather Facsimile. It describes the format used to relay a wide range ground-processed image products that are relayed back through the various geostationary spacecraft. These products include sub-sectors of the full-disk image data obtained by the spacecraft, mosaics of polar-orbit imagery, and a wide range of weather charts.

**white level** — the white end of the video dynamic range in any image transmission format. The difference between white and black levels defines the video dynamic range of the mode.

# APPENDIX

## GROUPS, ASSOCIATIONS, AND INFORMATION SOURCES

***Amateur Television Quarterly***
Web: **www.hampubs.com**
Phone: 815-398-2683
Postal: Harlan Technologies
5931 Alma Drive
Rockford, IL 61108-2409
USA

**American Radio Relay League, Inc. (ARRL)**
Web: **www.arrl.org**
Phone: 860-594-0200
Postal: 225 Main Street
Newington, CT 06111-1494
USA

**Benelux NBTV Website (ON1AIJ)**
Web: **users.pandora.be/ON1AIJ/english.htm**
Phone: NA
Postal: NA

**Dave Jones CQ SSTV Web site**
Web: **www.tima.com/~djones/**
Phone: NA
Postal: NA

**Experimental Television Society (ETS)**
Web: **pyanczer.home.mindspring.com/Tour/**
Phone: 314-822-1748
Postal: c/o Peter Yanczer
835 Bricken Place
Warson Woods, MO 63122-1613
USA

***Image Communications Handbook*–Web site**
Web: **taggart.glg.msu.edu/ICH/ICH.htm**
Phone: NA
Postal: NA

**International Visual Communications Association**
Web: **www.mindspring.com/~sstv/**
Phone: NA
Postal: See Web site for membership contact information:

**Narrow-Band Television Association (NBTVA)**
Web: **www.nbtv.wyenet.co.uk/**
Phone: NA
Postal: See Web site for current membership secretary

**Remote Imaging Group (RIG)**
Web: **www.rig.org.uk/**
Phone: NA
Postal: see Web site for current membership secretary.

## VENDORS

**Absolute Value Systems**
Web: **www.ultranet.com/~sstv/**
Phone: 978-256-6907
Postal: 115 Stedman Street
Chelmsford, MA 01824-1823
USA

**Advanced Receiver Research, Inc.**
Web: **www.advancedreceiver.com**
Phone: 860-485-0310
Postal: Box 1242
Burlington, CT 06013
USA

**ATV Research, Inc.**
Web: **www.atvresearch.com**
Phone: 402-987-3771
Postal: 1301 Broadway
PO Box 620
Dakota City, NE 68731-0620
USA

**Black Cat Systems**
Web: **www.blackcatsystems.com**
Phone: 240-282-5904 (fax)
Postal: 4708 Trail Court
PO Box 2293
Westminster, MD 21158
USA

**BUX CommCo**
Web: **www.packetradio.com/psk31.htm**
Phone: NA
Postal: 115 Luenburg Drive
Evington, VA 24550-1702
USA

**Communications Concepts, Inc. (CCI)**
Web: **www.communication-concepts.com**
Phone: 937-426-8600
Postal: 508 Millstone Drive
Beavercreek, OH 45434-5840
USA

**CombiTech**
Web: **www.mscan.com**
Phone: +31-118-601665
Postal: PO Box 8041
NL-4330EA Middelburg
The Netherlands

**Cushcraft Corporation**
Web: **www.cushcraft.com**
Phone: 603-627-7877
Postal: PO Box 4680
Manchester, NH 03108
USA

**Directive Systems**
Web: **www.directivesystems.com**
Phone: 207-658-7758
Postal: 177 Dixon Road
Lebanon, ME 04027
USA

**Down East Microwave, Inc.**
Web: **www.downeastmicrowave.com**
Phone: 908-996-3584
Postal: 954 Rte. 519
Frenchtown, NJ 08825
USA

**FOCUS Enhancements, Inc.**
Web: **www.focusinfo.com**
Phone: 408-866-8300
Postal: 1370 Dell Avenue
Campbell, CA 95008
USA

**Fontana Software**
Web: **www.roy1.com**
Phone: +39-011-9058124 (fax)
Postal: Str. Ricchiardo
21-CAP 10040 - Cumiano (TO)
Italy

**GSHPC**
Web: **ourworld.compuserve.com/homepages/dl4saw**
Phone: +49-0721-47-53-19
Postal: Mark Hann
Am Zuendhuetle 7a
D-76228 Karlsruhe
Germany

**Hamtronics, Inc.**
Web: **www.hamtronics.com**
Phone: 585-392-9430
Postal: 65 Moul Road
Hilton, NY 14468-9535
USA

**Harlan Technologies**
Web: **www.hampubs.com/sstvwith.htm**
Phone: 815-398-2683
Postal: 5931 Alma Drive
Rockford, IL 61108
USA

**Hauppauge Computer Works, Inc.**
Web: **www.haupauge.com**
Phone: 631-434-1600
Postal: 91 Cabot Court
Hauppauge, NY 11788-3706
USA

**Henry Radio, Inc.**
Web: **www.henryradio.com**
Phone: 800-877-7979
Postal: 2050 S. Bundy Drive
Los Angeles, CA 90025
USA

**Intuitive Circuits, LLC**
Web: **www.icircuits.com**
Phone: 248-524-1918
Postal: 2275 Brinston Avenue
Troy, MI 48083
USA

**M$^2$ Antenna Systems, Inc.**
Web: **www.m2inc.com**
Phone: 559-432-8873
Postal: 4402 N. Selland
Fresno, CA 93722
USA

**MFJ Enterprises, Inc.**
Web: **www.mfjenterprises.com**
Phone: 662-323-5869
Postal: 300 Industrial Park Road
Starkville, MS 39759
USA

**Mirage, Inc.**
Web: **www.mirageamp.com**
Phone: 662-323-8287
Postal: 300 Industrial Park Road
Starkville, MS 39759
USA

**MultiFAX, Inc.**
Web: **www.multi-fax.com**
Phone: 585-425-8759
Postal: 30 Steele Road
Victor, NY 14564
USA

**P. C. Electronics**
Web: **www.hamtv.com**
Phone: 626-447-4565
Postal: 2522 Paxson Lane
Arcadia, CA 91007-8537
USA

**Silicon Pixels, Inc.**
Web: **www.siliconpixels.com**
Phone: 509-961-3780
Postal: PO Box 579
Selah, WA 98942
USA

**Tigertronics, Inc.**
Web: **www.tigertronics.com/sl_main.htm**
Phone: 541-474-6700
Postal: PO Box 5210
Grants Pass, OR 97527
USA

**TimeStep Ltd.**
Web: **www.time-step.com**
Phone: +44-1440-820040
Postal: PO Box 2001
Newmarket CB8 8XB
England

**VideoLynx**
Web: **www.transmitvideo.com**
Phone: 240-602-1082
Postal: 19910 Bramble Bush Drive
Gaithersburg, MD 20879
USA

**West Mountain Radio, Inc.**
Web: **www.westmountainradio.com**
Phone: 203-853-8080
Postal: 18 Sheehan Avenue
Norwalk, CT 06854
USA

**WinPix32**
Web: **homepage.ntlworld.com/winpix**
Phone: +44-1279-420-755
E-mail: Winpix@ntlworld.com

**Woodhouse Communications, Inc.**
Web: **www.view2earth.com**
Phone: 616-226-8873
Postal: PO Box 73
Plainwell, MI 49080-0073
USA

**WRASSE electronic, GmbH**
Web: **www.sstv.org**
Phone: +49-43-13-25-28
Postal: Kronsberg 10
D-24161 Altenholz
Germany

# INDEX

# ABOUT THE ARRL

The seed for Amateur Radio was planted in the 1890s, when Guglielmo Marconi began his experiments in wireless telegraphy. Soon he was joined by dozens, then hundreds, of others who were enthusiastic about sending and receiving messages through the air–some with a commercial interest, but others solely out of a love for this new communications medium. The United States government began licensing Amateur Radio operators in 1912.

By 1914, there were thousands of Amateur Radio operators–hams–in the United States. Hiram Percy Maxim, a leading Hartford, Connecticut, inventor and industrialist saw the need for an organization to band together this fledgling group of radio experimenters. In May 1914 he founded the American Radio Relay League (ARRL) to meet that need.

Today ARRL, with approximately 170,000 members, is the largest not-for-profit organization of radio amateurs in the United States. The ARRL is a not-for-profit organization that:

- promotes interest in Amateur Radio communications and experimentation
- represents US radio amateurs in legislative matters, and
- maintains fraternalism and a high standard of conduct among Amateur Radio operators.

At ARRL headquarters in the Hartford suburb of Newington, the staff helps serve the needs of members. ARRL is also International Secretariat for the International Amateur Radio Union, which is made up of similar societies in 150 countries around the world.

ARRL publishes the monthly journal *QST*, as well as newsletters and many publications covering all aspects of Amateur Radio. Its headquarters station, W1AW, transmits bulletins of interest to radio amateurs and Morse code practice sessions. The ARRL also coordinates an extensive field organization, which includes volunteers who provide technical information for radio amateurs and public-service activities. In addition, ARRL represents US amateurs with the Federal Communications Commission and other government agencies in the US and abroad.

Membership in ARRL means much more than receiving QST each month. In addition to the services already described, ARRL offers membership services on a personal level, such as the ARRL Volunteer Examiner Coordinator Program and a QSL bureau.

Full ARRL membership (available only to licensed radio amateurs) gives you a voice in how the affairs of the organization are governed. ARRL policy is set by a Board of Directors (one from each of 15 Divisions). Each year, one-third of the ARRL Board of Directors stands for election by the full members they represent. The day-to-day operation of ARRL HQ is managed by an Executive Vice president and his staff.

No matter what aspect of Amateur Radio attracts you, ARRL membership is relevant and important. There would be no Amateur Radio as we know it today were it not for the ARRL. We would be happy to welcome you as a member! (An Amateur Radio license is not required for Associate membership.) For more information about ARRL and answers to any questions you may have about Amateur Radio, write or call:

ARRL–The national association for Amateur Radio
225 Main Street
Newington CT 06111-1494
Voice: 860-594-0200
Fax: 860-594-0259
E-mail: **hq@arrl.org**
Internet: **www.arrl.org/**
Prospective new amateurs call (toll-free):
**800-32-NEW HAM** (800-326-3942)
You can also contact us via e-mail at **newham@arrl.org**
or check out *ARRLWeb* at **http://www.arrl.org/**

# NOTES

# NOTES

# NOTES

# NOTES

# FEEDBACK

Please use this form to give us your comments on this book and what you'd like to see in future editions, or e-mail us at **pubsfdbk@arrl.org** (publications feedback). If you use e-mail, please include your name, call, e-mail address and the book title, edition and printing in the body of your message. Also indicate whether or not you are an ARRL member.

Where did you purchase this book?
☐ From ARRL directly ☐ From an ARRL dealer

Is there a dealer who carries ARRL publications within:
☐ 5 miles ☐ 15 miles ☐ 30 miles of your location? ☐ Not sure.

License class:
☐ Novice ☐ Technician ☐ Technician with code ☐ General ☐ Advanced ☐ Amateur Extra

---

Name ARRL member? ☐ Life ☐ Annual ☐ No

______________________________ Call Sign ______________

Daytime Phone ( ) ______________________ Age ______________

Address ______________________________________________

City, State/Province, ZIP/Postal Code ____________________

If licensed, how long? ______________ e-mail address: ______________

Other hobbies ______________________________

______________________________

Occupation ______________________________

| | |
|---|---|
| **For ARRL use only** | **ICH** |
| Edition | 1 2 3 4 5 6 7 8 9 10 11 |
| Printing | 1 2 3 4 5 6 7 8 9 10 11 |

From ______________________________

______________________________

______________________________

Please affix postage. Post Office will not deliver without postage.

EDITOR, IMAGE COMMUNICATIONS HANDBOOK
ARRL—THE NATIONAL ASSOCIATION FOR AMATEUR RADIO
225 MAIN STREET
NEWINGTON CT 06111-1494

– – – – – – – – – – – – – – – – – please fold and tape – – – – – – – – – – – – – – – – –

# Explore the possibilities of using Amateur Radio to **see and talk with other hams!**

Gone are the days when image communications were regarded as difficult and expensive. Today, using personal computers, widely available software, and gear many hams already own, it's easier than ever to start enjoying the imaging modes. Common Webcams have even made it possible to dispense with a standard TV camera in the amateur television (ATV) station!

Use this **Handbook** to introduce yourself to a whole new range of activities — **using Amateur Radio for image communications.**

- **History of image communications**
- **Basic imaging principles and concepts**
- **Equipment and operation of several modes, including...**

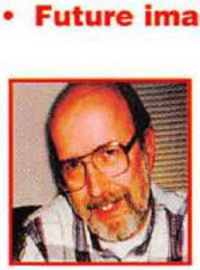
**Narrow-Band Television (NBTV)** "Looking forward while looking back..." — NBTV experimenters use modern techniques to generate the flickering images that once dominated the mechanical television systems of the 1920s and '30s.

**Amateur Television (ATV)** — the use of broadcast-standard cameras and receivers to provide two-way medium-resolution, full-motion television, typically in color, on the 70 cm and higher-frequency amateur bands.

**Slow-Scan Television (SSTV)** — the transmission of medium to relatively high-resolution still images, both gray-scale and color, using standard amateur voice equipment (SSB, AM, FM) on any bands (HF through microwaves) where voice transmissions are authorized.

**Facsimile (Fax)** — the transmission of very high-resolution images, typically gray-scale, on amateur bands where voice operations are authorized. Fax techniques are commonly used to receive the extremely detailed images transmitted by both polar-orbit and geostationary weather satellites.

- **Future imaging approaches and techniques**



**Dr. Ralph E. Taggart, WB8DQT**, ventured into image communications with the construction of a complete Amateur Television (ATV) station, including the TV camera, in 1963. His first published Amateur Radio article (in the mid-'60s) was a video modulator that appeared in the old ***Amateur Television Experimenter.*** Ralph did pioneering work in SSTV at Michigan State, including the development of an analog technique for transmitting and receiving color images. Among the more notable achievements of his work with the Michigan State Amateur Radio Club station, W8SH, were the first transmission of color SSTV images and the first two-way color SSTV contact. He co-authored, with Don Miller, W9NTP, the ***Slow Scan Television Handbook*** (1972) and authored the ***Weather Satellite Handbook*** (1976, and now in its 5th edition through ARRL). Ralph has written many articles on ATV, SSTV, weather satellites, and other Amateur Radio projects for ***QST***, ***73 Magazine***, and ***Ham Radio Magazine***.

Published by:
**ARRL** *The national association for AMATEUR RADIO*
**ARRLWeb: www.arrl.org/**
**225 Main Street, Newington, CT 06111-1494**

ISBN 0-87259-861-6
52595 >
EAN
9 780872 598614
ISBN: 0-87259-861-6 ARRL Order No. 8616