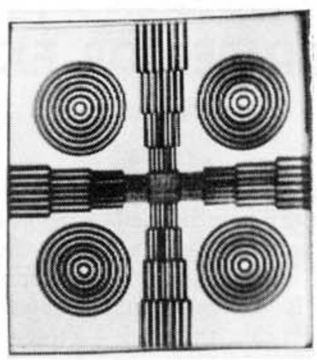
A NEW METHOD FOR TRANSMITTING
PICTURES BY RADIO . . .

A SLOW-SCAN T.V. SYSTEM FOR IMAGE TRANSMISSION

By Copthorne Macdonald, EE '58



The above pictures are actual photographs taken of images which were received during operation of the author's equipment.

There is an old saying that if you want to get a job done, give it to a busy man. Last fall an announcement was made in the Electrical Engineering student assembly inviting upperclassmen in E.E. to work on special projects of their own choosing and write a paper for entry in an AIEE Student Branch paper contest.

Copthorne Macdonald, who has been working 38 hours per week at Radio Station WVLK, Lexington, Kentucky, while maintaining a scholastic standing that puts him in the top 15 percent of his class, got busy immediately on an idea that was original with him. It concerned the reproduction of pictures at a distant point through radio transmission of signals originated by slowly scanning a photographic negative.

Coppie, as his friends call him, has also been able to devote time to activities in Eta Kappa Nu—the Electrical Engineering honor society of which he was chapter vice president—and Tau Beta Pi, the all-engineering honorary, of which he was chapter treasurer.

INTRODUCTION

For the past twenty years or so, the conventional wide band T.V. system and various mechanical scanning facsimile systems have been the only common methods of transmitting images by electrical means. Recently, however, another method has been used to transmit images over wire lines. Termed "slow-scan, or "slow-sweep" T.V., the method involves using television type pickup and reproduction devices with slow scanning rates to produce narrow bandwidth video signals.

Bell Telephone Laboratories' Picture-Phone" system uses a live pickup camera to generate the video signal, a magnetic storage drum to freeze the action, and special "Iatron" image storing cathode ray tubes to reproduce the image. A 60-line picture, 40-lines wide, is scanned once every 2 seconds and can be sent over ordinary phone lines.

Dage Electronics developed a system for use with "high fidelity" phone lines which are flat from 60 cps to 5,000 cps or higher. Both of these systems employ expensive components and, consequently, have not been widely used.

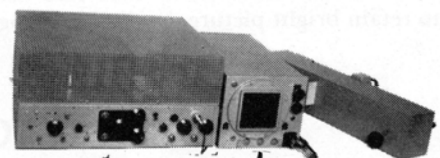
Upon reading about these "wired" systems the writer became intrigued with the possibility of utilizing the slow-scan prinicple for image transmission by radio. In September, 1957, he started the design and construction of a low-cost slow-scan T.V. system which is especially adapted to the transmission characteristics of the hundreds of thousands of commercial, police, citizens, amateur, and other two-way radio voice-communication circuits in operation today. This was undertaken as a personal project in an independent problem course at the University of Kentucky.

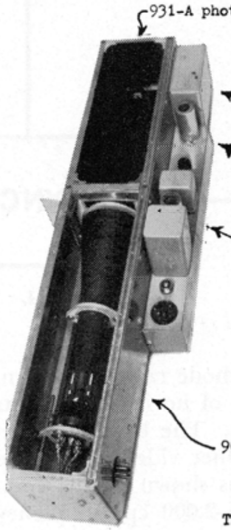
Briefly, the system uses a cathode ray tube flying-spot scanner to develop a 120-line picture, scanned once every 6 seconds from a slide embodying an inexpensive photographic negative. This picture actually has six times the detail of the reproduced image in the Bell "Picture-Phone" system. The video output of the scanner amplitude modulates a 2,000 cps carrier, resulting in an audio-frequency signal consisting of the 2,000 cps carrier and video sidebands extending both ways in frequency to 1,000 and 3,000 cps. This signal is then applied to the radio transmitter's modulator. At the receiving end, the audio frequency output of the radio receiver is processed, and the picture is presented on the screen of a low-cost electrostatically-deflected cathode ray tube with a long-persistence P7 phosphor.

The equipment was completed early in January, 1958, and "on-the-air" tests with the equipment were made. These proved to be quite successful, with system performance fulfilling design expectations. To the writer's knowledge this is the first slow-scan T.V. system designed and built for use with voice bandwidth radio communication circuits.

The widespread use of two-way mobile radio equipment suggests many possible uses for the system. For instance, a reporter for a newspaper or small T.V. station could take pictures with a Polaroid Land Camera, using the new positive-transparency film, and transmit the image almost immediately, through the mobile communications equipment in his car, to the newspaper office or T.V. station. Law enforcement agencies might also find use for the system in transmitting pictures of wanted criminals and other visual material directly, and simultaneously, to all squad cars, again using the Polaroid camera to make a transparency rapidly if the cost of a live camera is prohibitive.

While the system presents a less detailed image than conventioal facsimile, it is adequate for many purposes, and the system is superior to facsimile in certain other respects. This increases flexibility of operation by permitting rather rapid alternation of voice and picture transmission over the same circuit. This would, of course, be of vital importance in police or emergency radio where all transmissions must be kept short. Also, by presenting ten scans every minute instead of one every few minutes, it should be possibe to dodge the intermittent interference so prevalent in short-wave and VHF radio. Lower system cost is another advantage of the slow-scan T.V. system over conventional facsmile, which, in general, employs expensive mechanical drive systems having a speed accuracy of 1 part in 100,000.





THE FLYING SPOT SCANNER WITH COVER REMOVED

The slow-scan T.V. system uses inexpensive and readily available components. Furthermore, if cost is not a factor, a live pickup vidicon camera could easily be added to the system.

THE SYSTEM

Design Parameters

Number of lines: 120
Aspect ratio: 1:1 (square)
Vertical repetition rate: 6 seconds
Horizontal frequency: 20 cps
Modulation: Amplitude modulated 2,000 cps carrier. (White level 0-20% of max., Black level -50% to 75% of max., Sync level -max.)
Passband required: 1,000-3,000 cps
Synchronization: Maximum amplitude carrier bursts coinciding with retrace periods. (Approximately 0.015 second for vertical pulse and 0.0015 second for horizontal.)

Many possible combinations of sweep times, aspect ratios, and audio carrier frequencies were studied in an attempt to find the most suitable combination. The maximum possible vertical sweep time is limited to about 6 seconds because the brightness of the P7 phosphor on the receiver cathode ray tube face decays too rapidly to retain bright picture detail much longer than this. The 1:1 aspect ratio is a picture shape which makes efficient use of a round cathode ray tube screen, and does not favor the televising of horizontal objects as the usual 4:3 aspect ratio does. The bandwidth requirements of the flying-spot scanner video output are d.c. to approximately 1,000 cps as shown by the computations in the appendix. The 2,000 cps frequency was chosen because it permits the upper sideband to fall within the 300-3,000 cps passband considered representative of current radio communication practice, and provides at least two cycles of carrier for each cycle of modulating frequency.

Modulation polarity was selected with low level representing white and high level representing black for two reasons. First, the synchronizing pulses, being at the infra-black level, will blank the cathode ray tube retrace if the receiver retrace and sync. trigger time is less than the duration of the sync. pulse. Second, strong noise pulses appear black rather than infra-white as they would if high amplitude represented white.

Simple rectangular pulses lasting the duration of the retrace period permit synchronization of the receiver sweep oscillators. Since the vertical pulse is only about one-third the length of a scanning line, it is over well before the next horizontal sync. pulse starts. This avoids the need to serrate the vertical sync. pulse to prevent upsetting the horizontal sweep, as is necessary when the pulse is over one line in length.

Video Generator

The video generator consists of the flying-spot scanner and its associated circuitry as indicated by the block diagram in Figure 1.

The flying-spot scanner consists of a light-tight aluminum box with a 908-A cathode ray tube mounted at one end. The tube faces the other end where a 931-A photomultiplier tube is mounted so that light from the cathode ray tube will strike it. A slit in the side of the box directly in front of the cathode ray tube allows insertion of a slide, which consists of a #120 or #620 photographic negative mounted on a 3 by 5 inch cardboard frame. The slide is held in position in the scanner by its cardboard edges in such a manner that the transparent portion of the slide is in intimate contact contact with the glass face of the 908-A cathode ray tube. Thus, any light which appears on the surface of the 908-A passes through the photographic negative

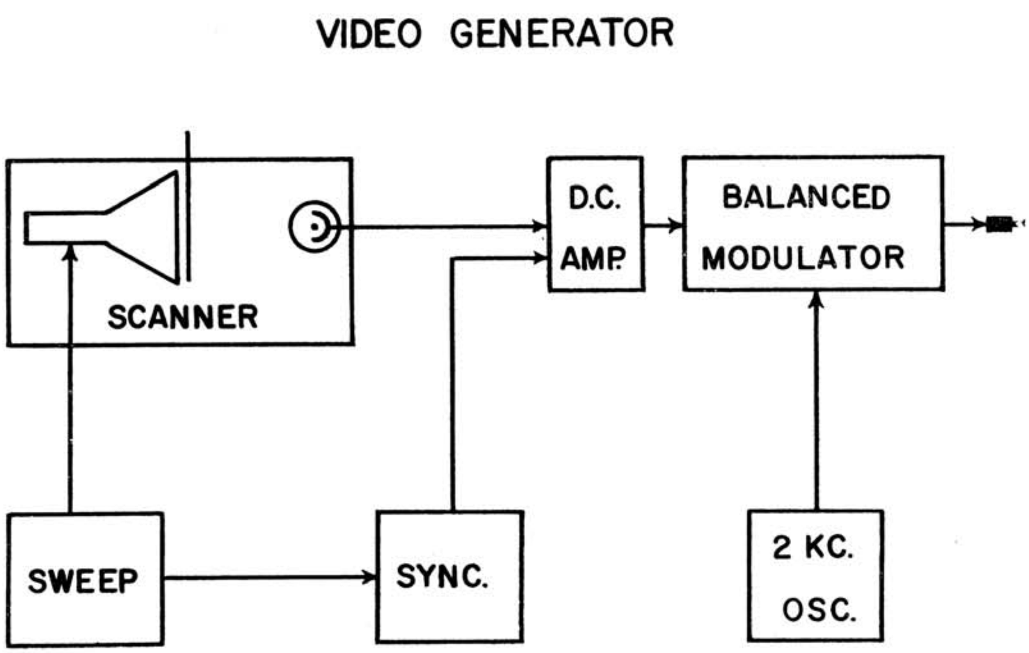


Figure 1. Video Generator

before it strikes the cathode of the photomultiplier tube, some 8 inches away.

In operation, a small bright spot on the cathode ray tube face is caused to sweep across the tube in raster fashion by the horizontal and vertical sweep voltages. The 908-A is a 3 inch electrostatically deflected tube with a P5 very short persistence screen, whose brightness decays to 1% of its original value in 10^{-5} second. The spot, therfore, remains a spot at the sweep frequencies used and does not leave a "tail" of undecayed brightness behind it as it sweeps across the tube. The spot faintly illuminates the cathode of the 931-A photomultiplier, and the intensity of the llumination is inversely proportional to the photographic density of the negative at a point directly in front of the spot. The small photocathode current is amplified approximately 40,000 times by the secondary-emission action of the dynodes. The voltage across the multiplier anode load resistor is, then, a video signal, whose instantaneous amplitude follows the variations in picture brightness as the negative is scanned.

Plate-coupled 6SN7 multivibrators are the heart of the sweep and sync. generation circuits. The 20 cps horizontal multivibrator is synchronized with the 60 cps power line, not only as a convenience in keeping its frequency constant, but to insure that any hum in the video will result only in variations in picture shading, not moving hum patterns. The vertical multivibrator with a period of about 6 seconds, is triggered by the horizontal oscillator during a horizontal retrace period. This insures that the vertical retrace will always occur at the beginning of a line, which is necessary for proper positioning of the vertical sync. pulse.

Sweep capacitors, charged through resistors from B+, are discharged during retrace preiods by current from the multivibrators, channeled through isolating diodes. The saw-tooth voltage developed across each capacitor is copuled directly to the grid of its associated sweep amplifier half a 6SN7. One of the horizontal and one of the vertical deflection electrodes of the 908-A are internally tied to the tube's anode which is returned to a positive centering potential. The other deflection electrodes are connected to the 6SN7 plates, putting the varying saw-tooth plate potential directly on the deflection electrodes.

The rectangular pulses developed by the multivibrators during the retrace periods are combined in a dual-diode "and" circuit to form a composite sync. signal. This signal is coupled to the photomultiplier load resistor where it is added to the video signal. The grid of a d.c. amplifier (triode half of a 6U8) is also connected to this point. Since the sync. pulses drive the triode beyond cut off, the output voltage consists of video during the sweep period, and of sync. pulses clipped to constant amplitude, during the retrace periods. The ratio of sync. level to video level is controlled by the cathode ray tube's brightness control, increased brightness raising the video level and reducing the ratio.

Since the video signal at this point has important components from d.c. to 1,000 cps, it is evident that it cannot be applied directly to the ordinary transmitter modulator which attenuates frequencies below about about 300 cps. To surmount this difficulty, the video is fed directly to the control grid of a 6AR8 sheet-beam tube used as a balanced modulator. This tube is essentially a miniature-beam tetrode with two plates and two deflection electrodes. In operation, the 2,000 cps output of an electron-coupled Hartley oscillator (pentode half of the 6U8) is applied push-pull to the deflection electrodes in the 6AR8. This causes the electron beam to be deflected back and forth from one plate to the other at the 2,000 cps rate. The beam current is controlled by the grid voltage and is therefore proportional to the level of the video signal. The output is taken from the plates through a push-pull transformer. The balanced push-pull connection prevents the original 0 to 1,000 cps video signal from appearing in the output, the only output being the varying-intensity 2,000 cps carrier and its sidebands. This output may be connected directly to a transmitter modulator, tape recorder, or wire line. It shoul dbe noted here that, although the image source is a photographic negative, signal polarities have been handled so that the transmitted image is positive, that is, clear negative is black level, dense area is white.

Video Receiver

The arrangement of the circuits used in the Video Receiver is shown in the block diagram form in Figure 2.

A three-stage audio-frequency amplifier, using a 6SL7 and a 6F6, amplifies the signal from a communications receiver, tape recorder, line or directly from the bideo generator, to a peak level of about 100 volts. This signal is coupled through an isolation transformer to a full-wave diode detector. The output of the detector is fed to the grid of the 5UP7 cathode ray tube through a low-pass filter which passes 0-1,000 cps without attenuation or excessive non-linear phase shift, but which effectively removes the ripple.

The 100 volt signal is also applied to an i-f type full-wave triode sync. separator which separates the sync. pulses from the composite signal. These pulses (actually a series of short pulses; one for each alternation of the 2,000 cps carrier) are amplified by the two halves of a 6SN7, one output going to synchronize the horizontal pulse is approximately 10 times as long as the horizontal multivibrator, the other to an R-C integrating circuit The vertical pulse is approximately 10 times as long as the horizontal pulse and the higher integrator output voltage, when driven by a vertical pulse, is sufficient to separate the vertical from the horizontal.

In conventional T.V., the vertical oscillator is brought into sync. by changing the oscillator frequency slightly. This could be a lengthly process with an oscillator that makes only one sweep every six seconds. To solve this problem the integrate dvertical-sync. pulse is used to fire an 884 thyratron. The 884 plate is directly connected to one of the multivibrator plates, providing positive triggering action during almost any part of the vertical sweep period.

In actuality, common sweep circuits are used for the 908-A and the 5UP7. The sync. arrangements are controlled by a send-receive switch which connects the sync. operations according to whether the unit is being used to transmit or to receive. The receiving amplifier and

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Slow-Scan T.V.

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detector circuits remain in operation during transmitting periods to permit visual mointoring of the transmitted picture. Since the retrace times on receive are the same as on transmit, and since an appreciable time is reguired for vertical sync. pulse integration, blanking of the receiver cathode ray tube is not assured. To insure blanking, a neon bulb relaxation oscillator, fired by the multivibrator plate voltage during retrace, is coupled to the receiver audio amplifier. The tone signal is amplified, detected, and fed to the cathode ray tube where the voltage extinguishes the beam for the entire retrace period.

VIDEO RECEIVER

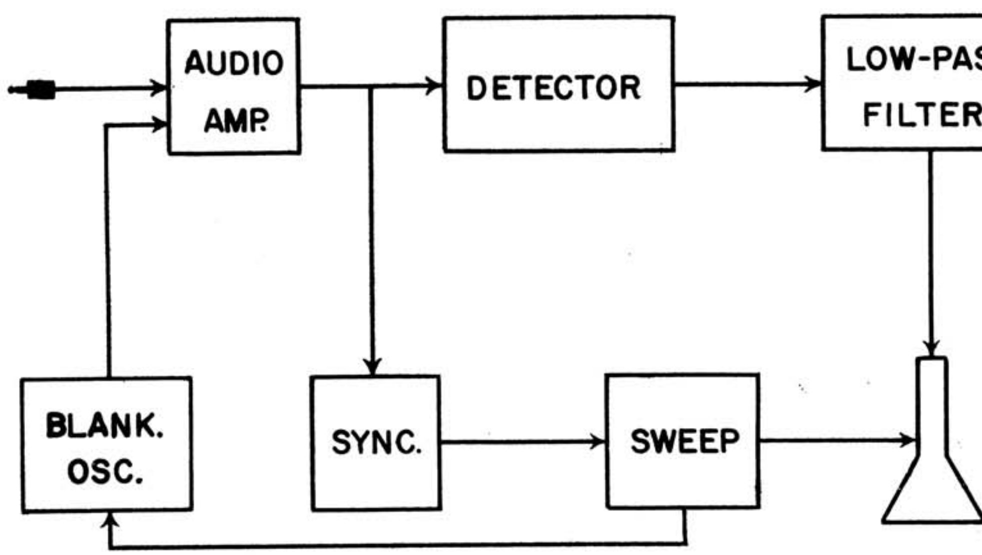


Figure 2. Video Receiver

Power Supply

A T.V. receiver-type power transformer is used with two 5U4's to provide 450 volt B plus and bias voltages. A VR-105 holds the bias constant at minus 105 volts. The modulator B plus is regulated with another VR-105. A scope power transformer, in connection with a 1B3 and an R-C filter, provides 1,850 volts for the 5UP7, 1,500 volts for the 908-A, and 650 volts for the 931-A. Photomultipliers are quite sensitive to voltage changes, so the dynode voltage is regulated by NE-2 neon bulbs connected between successive dynodes. This arrangement provides about 65 volts per dynode stage.

Tests

To facilitate testing, a tape recording of the signal has generally proved satisfactory. Even an inexpensive home recorder has adequate frequency response. The primary trouble is some skewing of the lines when recorded with an inexpensive tape recorder, and this is presumably caused by instantaneous speed variations during recording and playback. The effect is most apparent when long vertical lines are present in the picture, but it is almost unnoticeable in televising a human face. A properly adjusted professional-quality recorder will reproduce a picture indistinguishable from one obtained by the equipment used in a closed circuit system.

Short-wave air tests in the local area have been made and have proved to be quite satisfactory. A tape recording of the video generator output was aired on the 27-megacycle amateur band by amateur radio station K4KYY, one mile away and was received on a national NC-300 receiver at W4JP, the University of Kentucky's amateur station. The signal received over the one-mile path produced images equivalent to those obtained from the recorder directly, in spite of the fact that the overall frequency response (from picture gentrator through recorder, transmitter and communications receiver) was down 4 db at 3,000 cps compared with a 1,000 cps reference.

Long-distance air tests have not been attempted at the time of writing, but the cooperation of the Anchorage, Alaska, Amateur Radio Club in conducting tests has been requested.

CONCLUSION

A low-cost image transmission system, capable of transmitting images of moderate complexity over voice-communicatio ncircuits, has been designed, built, and successfully tested. Although not a universal substitute for conventional facsimile or T.V., the system is less disturbed by intermittent interference and is more adaptable to the alternation of picture and voice than is facsimile because of the relatively rapid rate of transmission. This, combined with its ability to utilize readily available narrow-band communication circuits, indicates that the system is potentially useful.

APPENDIX

Calculation of Required Video Bandwidth

Assumptions:

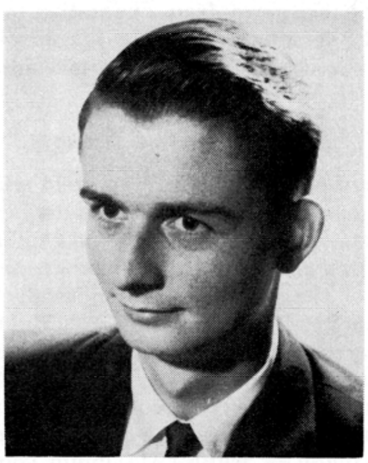
1. The actual vertical resolution is assumed to be about 83% of the 120 scanning lines, or 100 lines. Finite aperture size causes this reduction in vertical resolution. Test pattern tests on the completed system indicate that 100 lines is a reasonable value.
2. The horizontal resolution should be equal to the actual vertical resolution which, in this case, is 100 picture elements (alternate black and white segments).
3. The maximum required frequency is the fundamental frequency of the video signal which would be produced on scanning 100 alternate black and white segments at the normal sweep rate.

Calculation:

Active horizontal sweep time = nominal period − retrace time. Since each picture element represents one alternation of the maximum frequency:

$$f_{max} = \frac{\frac{1}{2} \text{ number of picture elements per line}}{\text{active horizontal sweep time}}$$

$$f_{max} = \frac{50}{0.0500 - 0.0015} = 1{,}030 \text{ cps}$$



"Coppie" MacDonald, Author of "Slow-Scan TV System"

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ENGINEERING TO THE RESCUE

The following exchange of letters recently ran in a Dayton newspaper:

To the Editor:

"Why does it get dark so early? And what about the low temperature?

"I sincerely believe the flights to outer space have left holes in our atmosphere. The light which lingered after sundown and the heat which makes life possible are seeping out those holes.

"We had better find ways to plug the holes we have already made or prepare to withstand the conditions of space right here on earth, once our atmosphere has all leaked out."

(Signed) ....

This letter brought the following reply:

To the Editor:

"Mr. ——— has raised a serious question about plugging sky holes. My company has been one of several engaged in developing sky plugs that will prevent light and heat from draining out of the atmosphere. Complete success has not been attained but we are confident that within the next year we will have the solution. Meanwhile the Russians are working on the problem and hope to gain the propaganda advantage of being first to solve it.

"There are two approaches to the solution: First to plug the holes and, second, to put the entire earth inside a giant self-sealing bag which would act somewhat like a tubeless tire. Such a bag would either be blown up around the earth using a few atomic bombs to create the pressure necessary to inflate it, or it would be suspended beneath a few satellites made for the purpose.

"Of course we are trying the suggested approach—making a sky plug to cover the holes torn in the top of the atmosphere by missiles. These plugs must be airtight and should be transparent. A lightweight material is preferable because sky plugs are lifted to a great altitude before being put into place. Glass is too heavy for this purpose, but plastics apparently will work.

"One of the factors making the job too difficult is that missiles and satellites usually leave jagged holes, and to provide an airtight seal, the holes must first be filled, a gasket made and a special plug designed to fit that particular hole.

"It would help if we had standard size missiles so that a single plug would do.

"Small missiles and off-course misiles sometimes leave holes that are difficult to find. These holes create a slow leak which we hope to correct once the new rocket-powered hole-seeker is perfected."

(Signed) ....