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SLOW SCAN TV: INTRODUCTION AND BASIC PRINCIPLES

You are about to enter the wonderful world of amateur slow scan television. Imagine yourself sitting in front of a radio receiver with a slow scan television monitor plugged into the headphone jack. The screen shows SMØBUO in Stockholm operating his rig from his lakeside cabin. You turn your dial to another frequency on the 20 meter band and observe WØLMD exchanging circuit diagrams with W4TB in North Carolina. These things are now possible with slow scan televsion. It has not always been this way, so let us turn the slow scan history pages back a few years to see how it all began.

In 1958, Copthorne Macdonald, a young engineering student at the University of Kentucky, began an investigation into the possibility of reducing the bandwidth of a wideband television signal to such a narrow spectrum width that it could be sent over a voice communication system. This meant that a 3 MHz television signal had to be reduced to 3 kHz signal – a 1000 to 1 reduction in bandwidth! Macdonald eventually designed a television system that met these requirements. This system used an AM subcarrier, with picture information transmitted as amplitude variations of a continuous tone of constant frequency. The old 11 meter band was used to transmit test pictures since that was the only HF band authorized for picture transmission. The AM subcarrier system proved successful, and circuit details were published in August, September *QST* (1958). Unfortunately, before the slow scan pioneers of that period could build equipment, the 11 meter band was allocated to the Citizen Band Service.

Slow scan television was now limited to frequencies of 50 MHz and above. However, under special authorization from the FCC, it was possible for Cop to perform tests on 10 meters for short periods of time. It was during one of these test periods that Cop WA2BCW, by transmitting "blind" over a period of 30 days, was successful in sending pictures across the Atlantic Ocean to John Plowman G3AST. These tests, and the pictures received in England, were described in March *QST* (1960).

Their imaginations sparked by the transatlantic tests, other amateurs soon began to explore SSTV. Soon, a small group of SSTV enthusiasts were exchanging SSTV audio tapes, and investigating a variety of circuits and standards. An FM subcarrier system was developed (January, February

Fig. I-1. Picture of W9CNW, sent from W9NTP to VK3AHR, 10,000 miles, on 20m. 2.5kHz bandwidth.

QST 1961), and it proved superior to the AM subcarrier system due to its greater immunity to interference from QRM and fading. Since none of the early experimenters were close enough geographically to exchange pictures on the 6 meter band, tests were confined to closed circuit systems, tape exchanges or transmission over phone lines.

During this time the slow scan enthusiasts were attempting to get slow scan (SSTV) permitted on the HF bands. Petition after petition was written, but no FCC action resulted. Macdonald, now WAØNLQ, enlisted the help of several hams in Washington and succeeded in getting a special test period set up at the Rocky Mountain ARRL Convention in Colorado to test the possibility of interference to other hams. W3LJV, W7FEN, WAØNLQ, W9NTP, and WØITB participated in these tests, and for three days visitors at the convention saw themselves on slow scan television either going out over the air or their image being returned over the air from far-off places via retransmitted tape-recorded pictures. It was hoped that other amateurs would hear the signals, form an opinion about their nature and interference potential and let their feelings be known through proper channels. It was during this test that the well-known picture of W9CNW, Figure I-1, was recorded in Australia by VK3AHR with the scheduling help of W9TCT. This test was described in September 1966 *QST*.

As a result of the Rocky Mountain Convention tests, Macdonald convinced both the Navy and the FCC to authorize special SSTV tests on the HF bands. The primary goals of these tests were twofold: to improve the techniques and equipment developed for STTV, and to provide visual communications for personnel wintering over at McMurdo Sound, Antarctica. Fifteen stateside amateurs were authorized to participate in these special tests and Macdonald provided a camera and monitor to KC4USA/NØICE for use in Antarctica. Despite erratic propagation conditions, excellent pictures were often exchanged between Antarctica and the States, some of which were shown in *QST* Feb. 1967, page 77. It is interesting to note that the Navy to this day continues to support the development and use of slow scan, and has recently authorized W4ABY/NØAAJ and W4UMF/NØXTV to exchange SSTV pictures with the *S.S. Hope*.

An FCC proposal of rulemaking permitting SSTV operation on the HF bands was published in November, 1967 *QST* with one month allowed for reply. After this reply period, several amateurs – W2PMV, W9VZL/3, WAØNLQ and W9NTP – went to Washington to review the 30 letters of opposition. Very few of these letters were strong in their criticism, but some letters expressed fears that needed to be studied and resolved. After eight hours of study and discussion these amateurs spent that evening at the home of W9VZL/3 where they wrote answers to the criticisms. This small group felt sure that a slow scan television allocation was just around the corner.

At this time incentive licensing was getting quite a bit of attention by the ham world, ARRL, and the FCC. After about a year with no FCC slow scan television action, fears began to grow again. By making inquiry through the proper channels, we were told that SSTV would be a part of the incentive licensing proposal. The rest is history.

During the summer of 1968, while on a mobile DXpedition to Central America, one of your authors heard the famous words from W7FEN: "Slow scan is authorized on HF." That is how it all came about. Those of you who now enjoy the luxury of operating your slow scan gear have these early pioneers to thank. Copthorne Macdonald is the inventor, and by his persistent interest finally perfected the system and obtained FCC action to use it.

Slow scan television can be transmitted in all of the advanced and extra portions of the amateur bands. Its bandwidth is confined to that of a voice station which is interpreted to be 3 kHz for single sideband transmission. The 160 meter band is excluded but all the phone portion of 10 meters and VHF and UHF can be used by General and higher classes of amateur licensees. It is of interest that SSTV received more band allocation from the FCC than any of the petitions ever requested.

This is the history of slow scan television. Today hundreds of amateurs throughout the world – in Russia, England, Sweden, Italy, Greece, South Africa, Colombia, Venezuela, Guadeloupe, Puerto Rico, Nicaragua, Canada, Alaska, Hawaii, New Zealand, Australia, Japan, Brazil, Southwest Africa, Belgium, Germany, the continental United States, a total of 28 countries – routinely exchange pictorial information via slow scan television on the 80 through 10 meter bands. And what started as a senior project for a young undergraduate student at the University of Kentucky is now one of the most exciting communications modes within the amateur service.

Basic Principles of Slow Scan TV

Let us explore this new amateur television that was specifically designed by hams for picture transmission on the high frequency bands. Instead of 3 MHz being available for ATV, as in UHF, we are restricted to a 3 kHz voice bandwidth in the HF amateur bands. The bandwidth of a conventional television signal must be reduced by a factor of over 1000 for slow scan. It becomes obvious that both the horizontal and vertical frame rate must be reduced to as low a frequency as possible in order to reduce the bandwidth from 3 MHz to 3 kHz. Resolution of the picture is a prime consideration in choosing the standards Home television viewers may feel that all 525 lines of commercial TV are needed for good TV pictures, but with narrow i-f's, poorly adjusted interlace and other deteriorating factors the actual resolution of a home television receiver is reduced to about 250 lines. As an example, 80 lines per MHz is the computation formula used for estimating the resolution of a 3 MHz i-f system. This is a resolution of only 240 lines. If we now consider that viewing will be done on a small cathode ray tube (available radar tubes), the tube screen size becomes a limiting factor due to beam focus. Everything being taken into consideration, 120 lines were chosen as the maximum number of lines for slow scan TV. It will be shown later that if 240 resolution lines are desired, they can be transmitted in an interlaced format for increased resolution, but such a picture cannot be viewed directly and must be photographed for the increased resolution to be realized in practice.

The vertical frame rate should be as slow as possible consistent with the storage time of the viewing tube. As far as the average ham is concerned, this means the use of a surplus P7 phosphor radar tube since available storage tubes are prohibitively expensive. Tests run over several years showed that 10 seconds was the maximum time of a frame that would permit viewing the frame on a P7 tube with a viewing hood in a normally lighted room.

It is a real advantage to use a horizontal line frequency that is related to the power line frequency. After sampling many viewer opinions and running laboratory tests it appeared that 15 Hz (i.e., 60 Hz divided by 4) was a good choice. 120 lines at 15 lines per second gives an eight-second vertical frame rate. Since these standards have been used by slow scanners in all 60 Hz power countries, it is hoped that they will be maintained indefinitely.

One thing that remains to be demonstrated is the video bandwidth of the slow scan system. Since an aspect ratio of 1:1 seems the most desirable to fit a round radar cathode ray tube, the horizontal resolution should equal the vertical resolution. There are 120 lines division in the vertical direction; therefore, there should be 120 division in the horizontal direction. This is shown in Fig. 1-1. For simplicity assume that every other spot is black alternated with white spots If these spots

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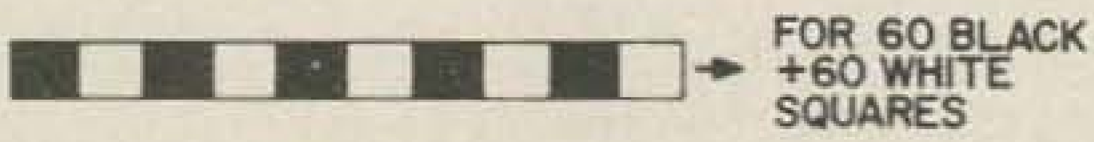


Fig. 1-1. One line of slow scan TV.

are scanned, the output will be a square wave which is formed out of one black and one white spot. This waveform generates 60 complete square waves or cycles in 1/15 second or 60 x 15 = 900 Hz. This means that the maximum video bandwidth is approximately 900 Hz. This analysis is approximate, but is adequate for easy comprehension.

All that remains to be shown is the requirements of the sync pulse standards. We now have a 120 line picture being generated every eight seconds which generates a bandwidth of 900 Hz. Each line must be locked or synced, and each eight-second frame must be locked or synced. In order to choose the proper length sync pulse consideration must be given to the composite spectrum (sync, pulse and video) and how it is combined to be transmitted with good fidelity.

It has been shown that a video bandwidth of 900 Hz, is adequate to reproduce the slow scan 120 line picture. Since the line rate and frame rate is extremely low frequency, a great amount of the video energy is near zero frequency. This means that amplifiers and modulation devices must operate near the dc level. This, of course is impossible since phase shift and drift would cause much deterioration in the picture. The problem can be avoided if the 900 Hz video is modulated on to a subcarrier placed within the 3 kHz FCC allocation for slow scan televison.

This subcarrier is placed at 1500 Hz. In the early days of slow scan, the subcarrier was amplitude-modulated, but extensive testing proved that AM noise created many problems. At that time, it was decided to go

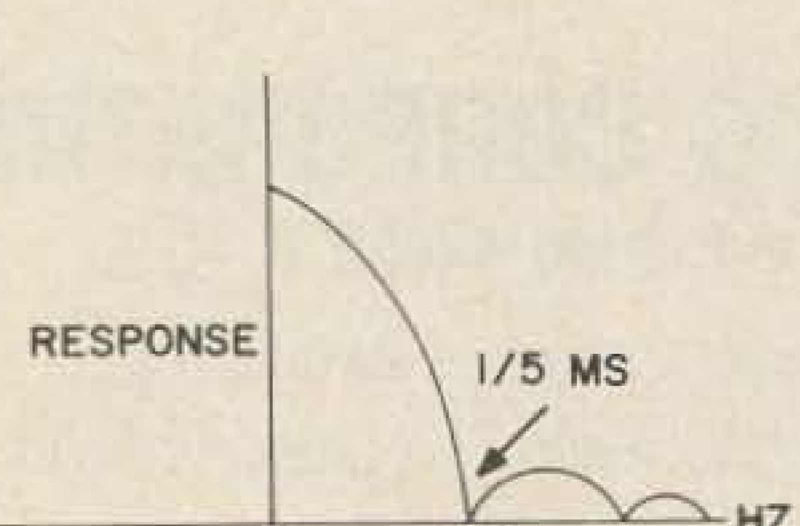


Fig. 1-2. Spectrum of video sync pulse.

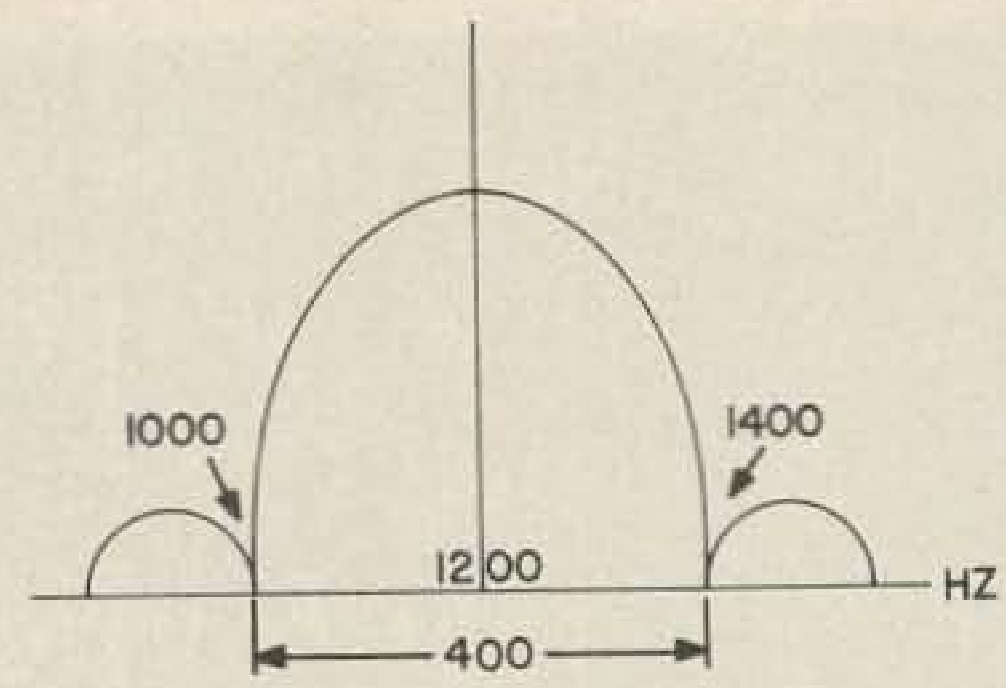


Fig. 1-3. Subcarrier spectrum of video sync pulse.

to an FM subcarrier. Today, the subcarrier operates at 1500 Hz for black video and increases in frequency to 2300 Hz for white video. These frequencies were chosen due to extensive experience with FM subcarrier facsimile transmission.

The sync frequency of 1200 Hz was chosen and represents blacker than black so that the raster is blanked during retrace. In order to separate the spectrum of the sync pulse as much as possible, the length of the pulse is made five milliseconds. Analysis showed that a five-millisecond pulse has a base video bandwidth of 200 Hz as shown in Fig. 1-2. When the sync pulse is modulated or gated on to a 1200 Hz sinewave, the bandwidth is 400 Hz, centered around 1200 Hz as shown in Fig. 1-3. Note that the major part of the sync spectrum does not fall into the major part of the video spectrum which swings upward from 1500 Hz. Finally, the vertical sync pulse is made much wider than the horizontal sync pulse in order to integrate or separate the two pulses. The vertical pulse was made 30 milliseconds long or about ½ a horizontal line. There are some who feel that this pulse should be made a bit longer. This would provide a better vertical sync pulse separation and noise immunity. Most monitors will tolerate longer vertical pulses so there is some room for experimentation on this point.

Let us review the standards for slow scan television:

	60 Hz Areas	50 Hz Areas
Horizontal line rate	15 Hz (60/4)	16 2/3 Hz (50/3
Vertical frame rate	1/8 Hz	1/7.2 Hz
Horizontal pulse width	5 milliseconds	5 milliseconds
Vertical pulse width	30 milliseonds	30 milliseconds
Sync subcarrier frequency	1200 Hz	1200 Hz
Black frequency	1500 Hz	1500 Hz
White frequency	2300 Hz	2300 Hz
Overall transmission BW (SSB)	3000 Hz	3000 Hz

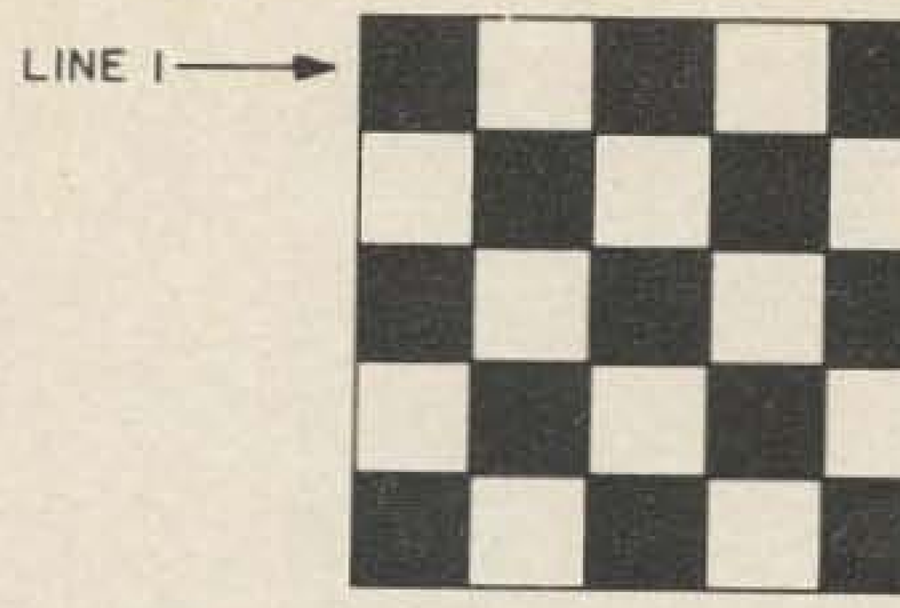


Fig. 1-4. Checkerboard pattern for slow scan transmission. The video signal and sync signals are shown in Fig. 1-5.

As a visual example of pattern generation, consider the following black and white SSTV transmission (shown in Fig. 1-4).

The video and sync signals are shown in Fig. 1-5.

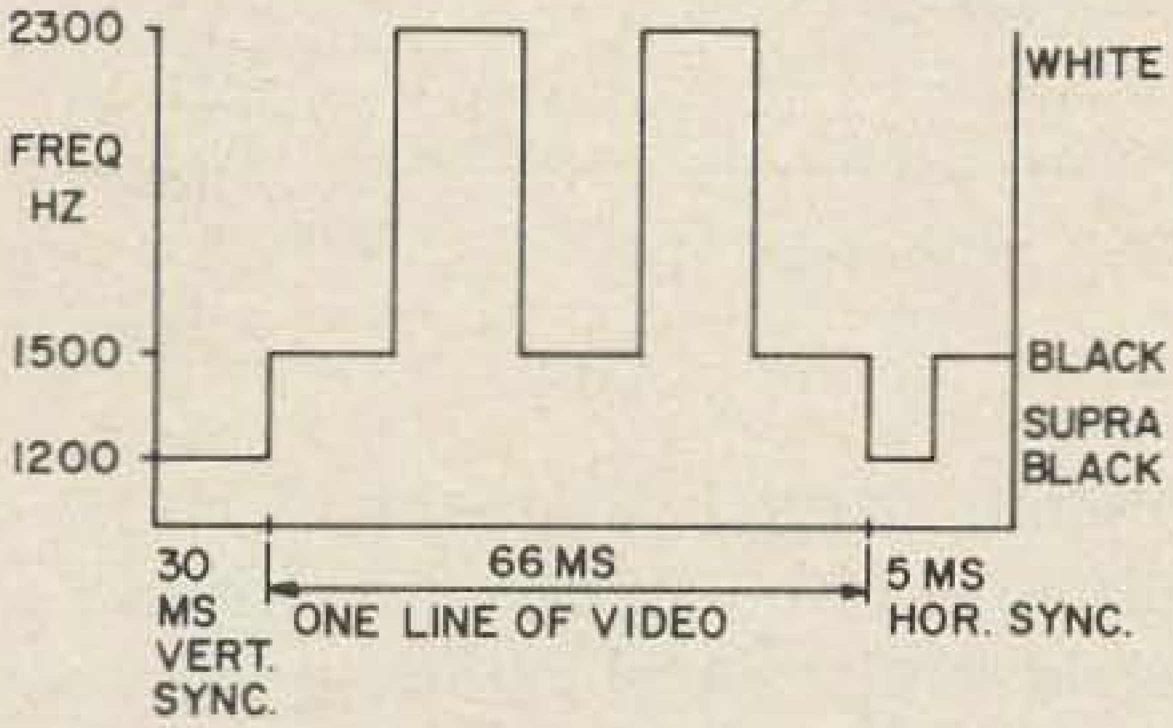


Fig. 1-5. One line of composite sync and base video.

The composite FM subcarrier signal is shown in Fig. 1-6. The composite video signal consists of a midrange audio tone ranging from 1200 to 2300 Hz and is processed in the transmitter and receiver just like a voice signal. If you doubt that a quality picture can have such a restricted bandwidth, visit a slow canner and watch pictures produced from an inexpensive cassette recorder operation at 1 7/8 r.p.s.

Most important in a slow scan television station is the monitor. The photograph of the original slow scan electrostatic monitor is shown in Fig. 1-7. This Macdonald monitor was described in March 1964 *QST* and this design has become the most reproduced piece of slow scan gear design ever published. This monitor has become the workhorse of slow scan TV, and it is still a favorite by slow scanners who prefer working with tubes.

Fig. 1-7. Photograph of original Macdonald monitor (see March 1964 QST).

The principle of all slow scan monitors is the same. Since the audio signal coming from the headphone jack of a radio receiver is audio FM, some means of FM detection must be used. A limiter is required to help eliminate much of the AM noise and QRM that is present on the HF bands. This limiter passes the clipped signal to an audio discriminator. This discriminator can be designed in several ways. The original Macdonald monitor uses a single-sided discriminator, but later in this book several other types of discriminators are described.

The discriminator changes the FM audio signal to an AM signal. It is important to note that the waveform is still made up of the subcarrier centered at about 1500 Hz. In order to recover the 1200 Hz sync signal a tuned circuit sync discriminator can be used to accentuate its amplitude so that the vertical and horizontal sync pulses can be recovered by threshold detectors.

These AM subcarrier signals will require rectification in order to produce the base

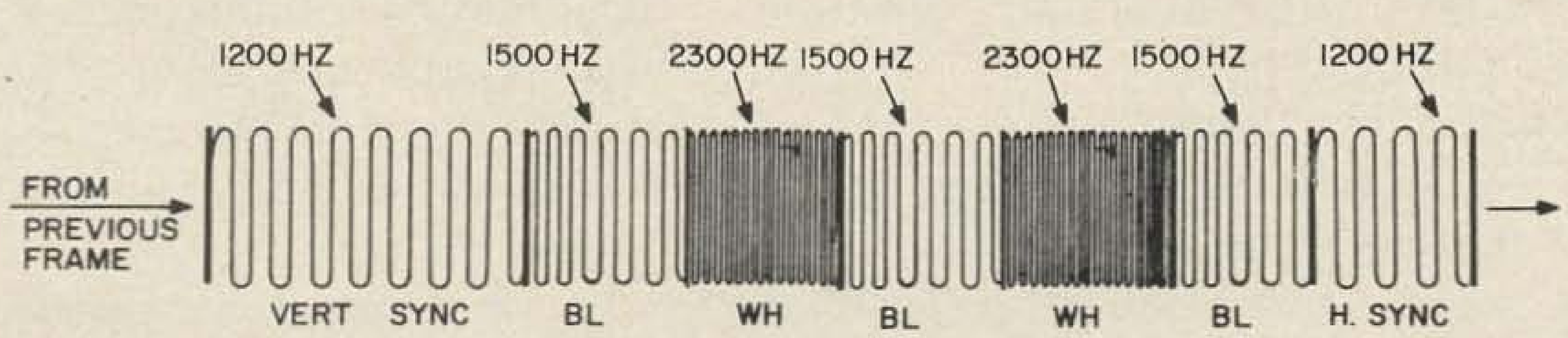


Fig. 1-6. Composite FM subcarrier modulated with composite sync and video. The composite video signal consists of a midrange audio tone ranging from 1200 to 2300 Hz and is processed in the transmitter and receiver just like a voice signal. If you doubt that a quality picture can have such a restricted bandwidth, visit a slow scanner and watch pictures produced from an inexpensive cassette recorder operating at 1 7/8 l.p.s.

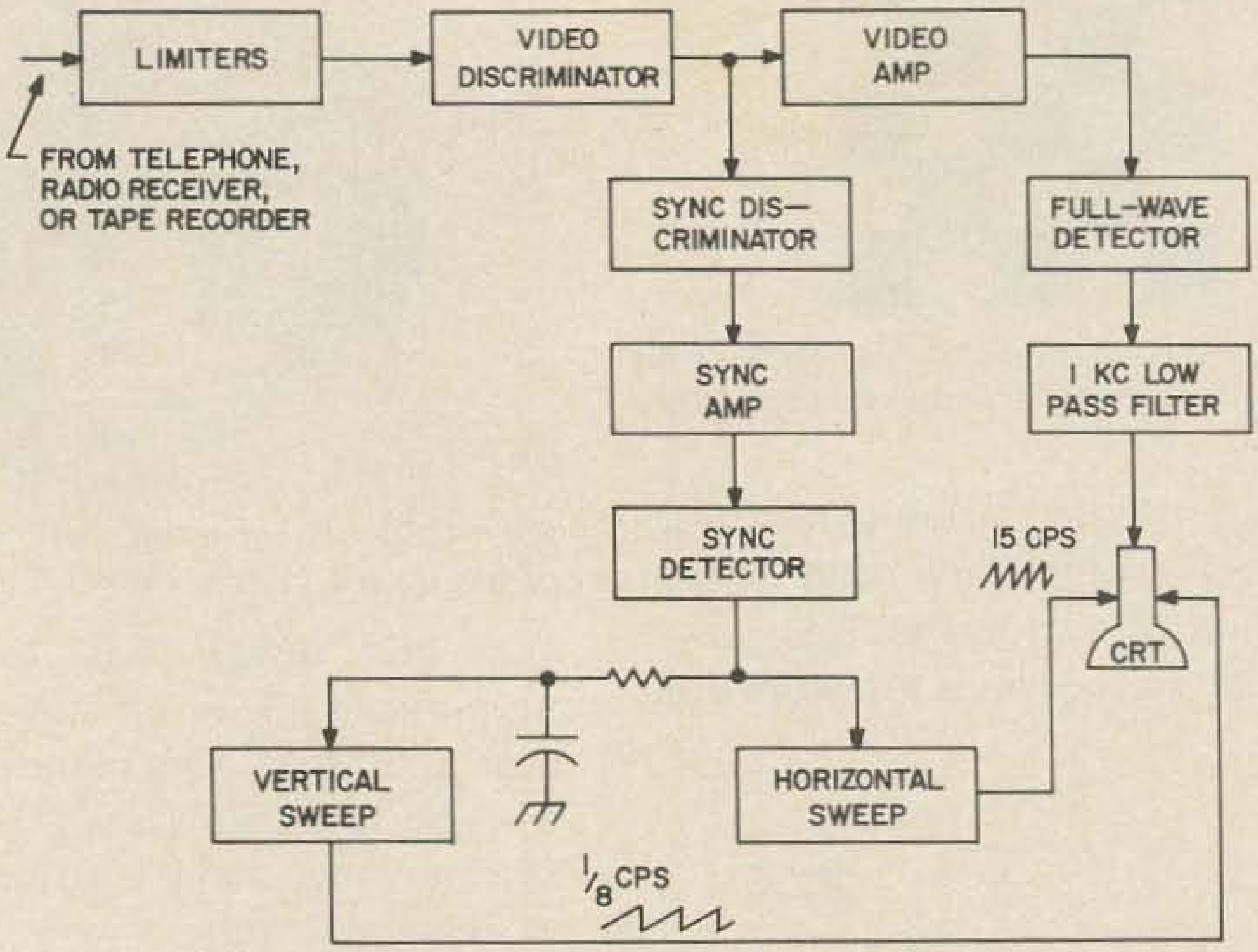


Fig. 1-8. Block diagram of a slow scan TV monitor.

video and sync signals that were generated by the slow scan camera or flying spot scanner. Usually full wave rectification is to be preferred since the low pass filter following the sync and video detector can more easily filter the subcarrier components if they have been doubled in frequency by full wave rectification.

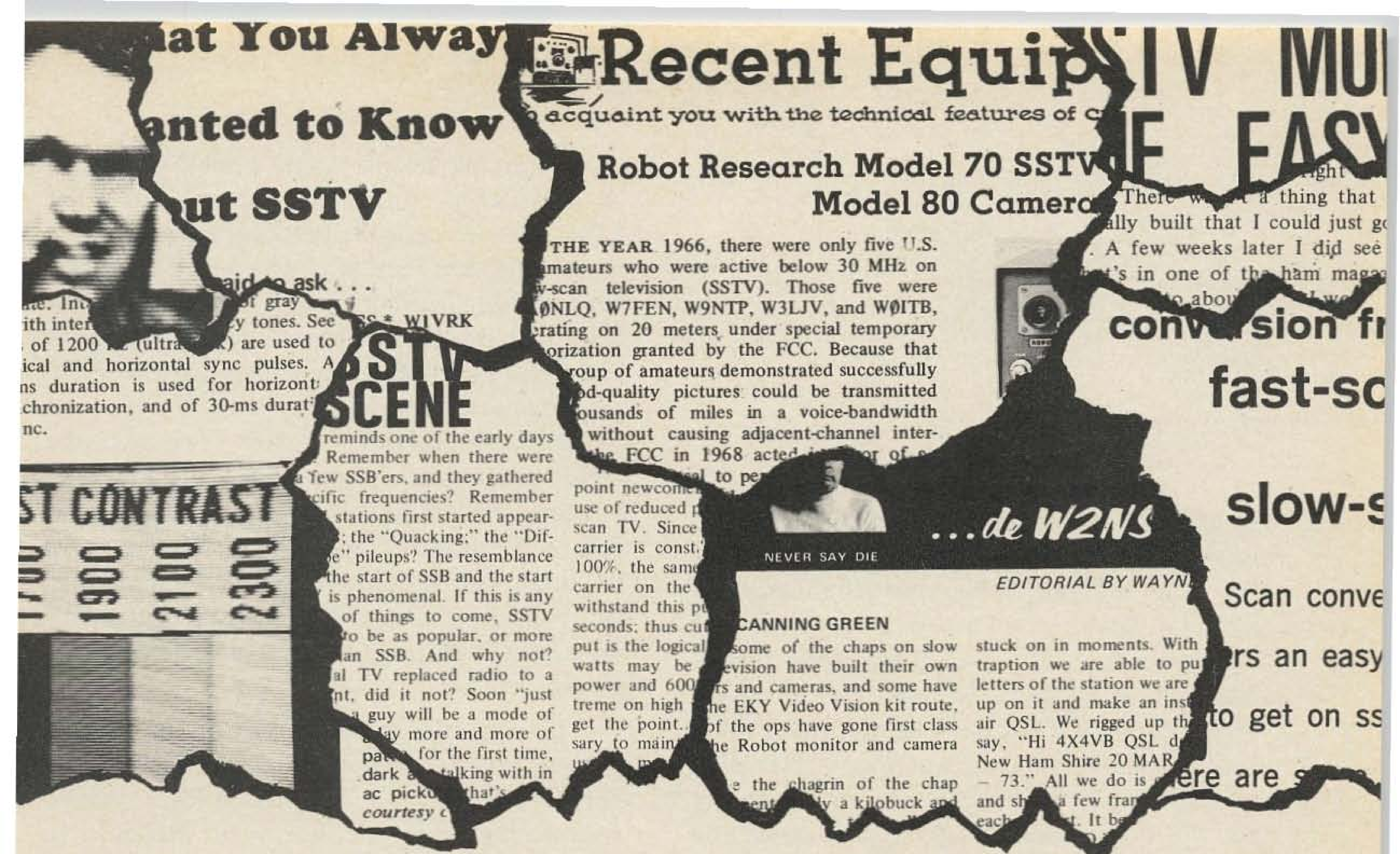
Finally the deflection circuit (whether it is electrostatic or magnetic) is controlled by the recovered sync pulses to produce a raster on the cathode ray tube. The recovered and filtered video is now applied to the Z axis of the cathode ray tube to produce a slow scan picture. A block diagram of the slow scan monitor is shown in Fig. 1-8.

The generation of a slow scan television picture can be done in several ways. The simplest method for the transmission of slides, photographs, and circuit diagrams is the flying spot scanner. There are two designs of the flying spot scanner shown in later chapters of this book.

To utilize the flying spot camera to produce TV signals from film negatives or positives, it is necessary to generate a raster. A raster results when a sawtooth electrical signal is connected to the horizontal and vertical plates of a cathode ray tube. The two sawtooth voltages applied to the horizontal and vertical plates differ in frequency; so for one cycle of vertical deflection, several hundred deflections occur in the horizontal direction. The grid of the cathode ray tube is adjusted to produce a constant brightness spot on the face of the tube. The overall result is a white illuminated square or rectangle on the face of the tube made up of several hundred very nearly horizontal lines.

A flying spot raster on a home TV set can be produced by turning the contrast control fully counterclockwise until no trace of picture results. The brightness control is then adjusted clockwise until a white constant brightness rectangle results. This image is called a flying spot raster. A similar white rectangle is produced for slow scan television, but from different frequency sawtooth voltages. How do we produce a TV signal from this raster? It is important to remember that the raster has been synchronized in both horizontal and vertical directions by a timing circuit that starts the beginning of each sweep. The flying spot or beam is therefore in a precise location on the face of the cathode ray tube at any instant of time.

If a transparent negative or opaque positive picture is placed directly on or near the face of the tube, the light that passes through the transparency or that is reflected from the opaque photograph will be modulated by the density of the



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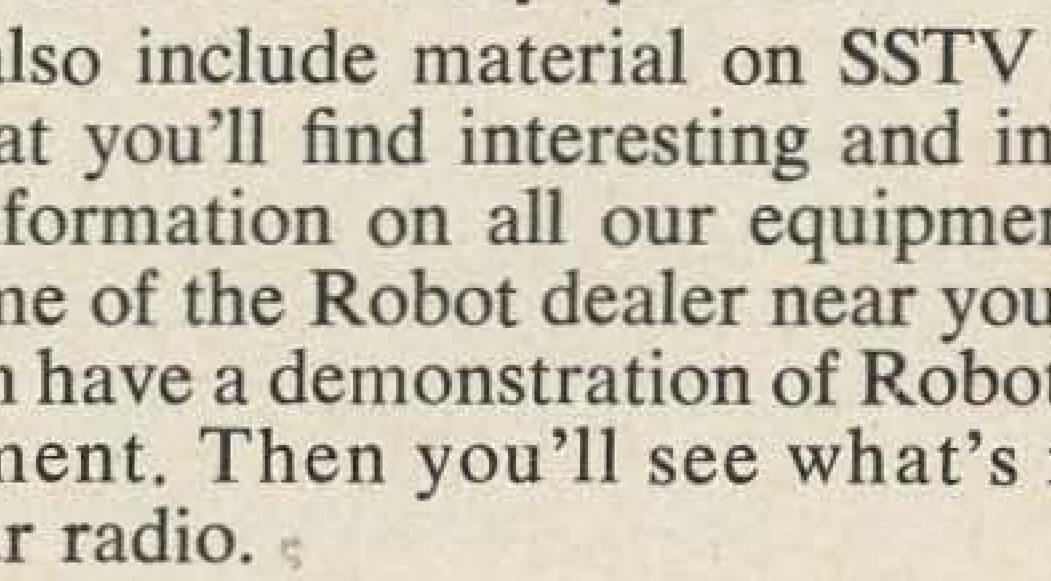

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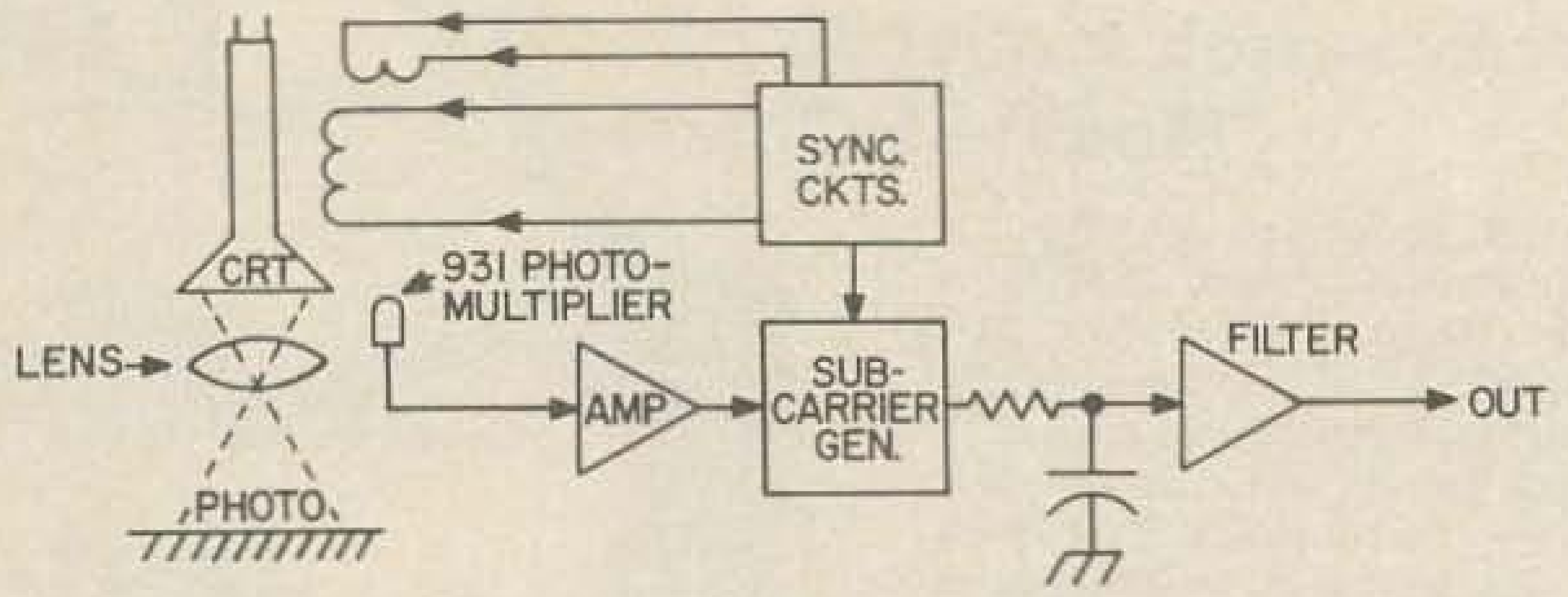

Fig. 1-9. Simple magnetic flying spot scanner.

photograph. It is now possible to place a light sensitive device (photo-multiplier) in the front of the tube, and the resulting electrical signal called video is synchronized automatically with the flying spot raster. The pulse sync signal is combined or added to the video to produce a signal that can be used to paint a picture on the screen of a distant TV set. It is important to remember that the sync signal always occurs when the beam flys back to its start during retrace; therefore, the video is not affected. A block diagram is shown in Fig. 1-9.

The principle of the flying spot scanner is useful for both fast and slow scan. Commercial TV stations have used FSS for advertising breaks. In the case of slow scan, the TV signal must be further processed before transmission. The video frequencies are so low that a subcarrier is needed to help the transmitter pass the slow scan video.

The slow scan enthusiast has several very good live cameras to choose from. Originally when Macdonald designed the shuttered 7290 slow scan camera, vidicons were given out by Westinghouse for experimental uses. Slow scan has grown greatly since it has become FCC-authorized in the Advanced and Extra class amateur phone segments.

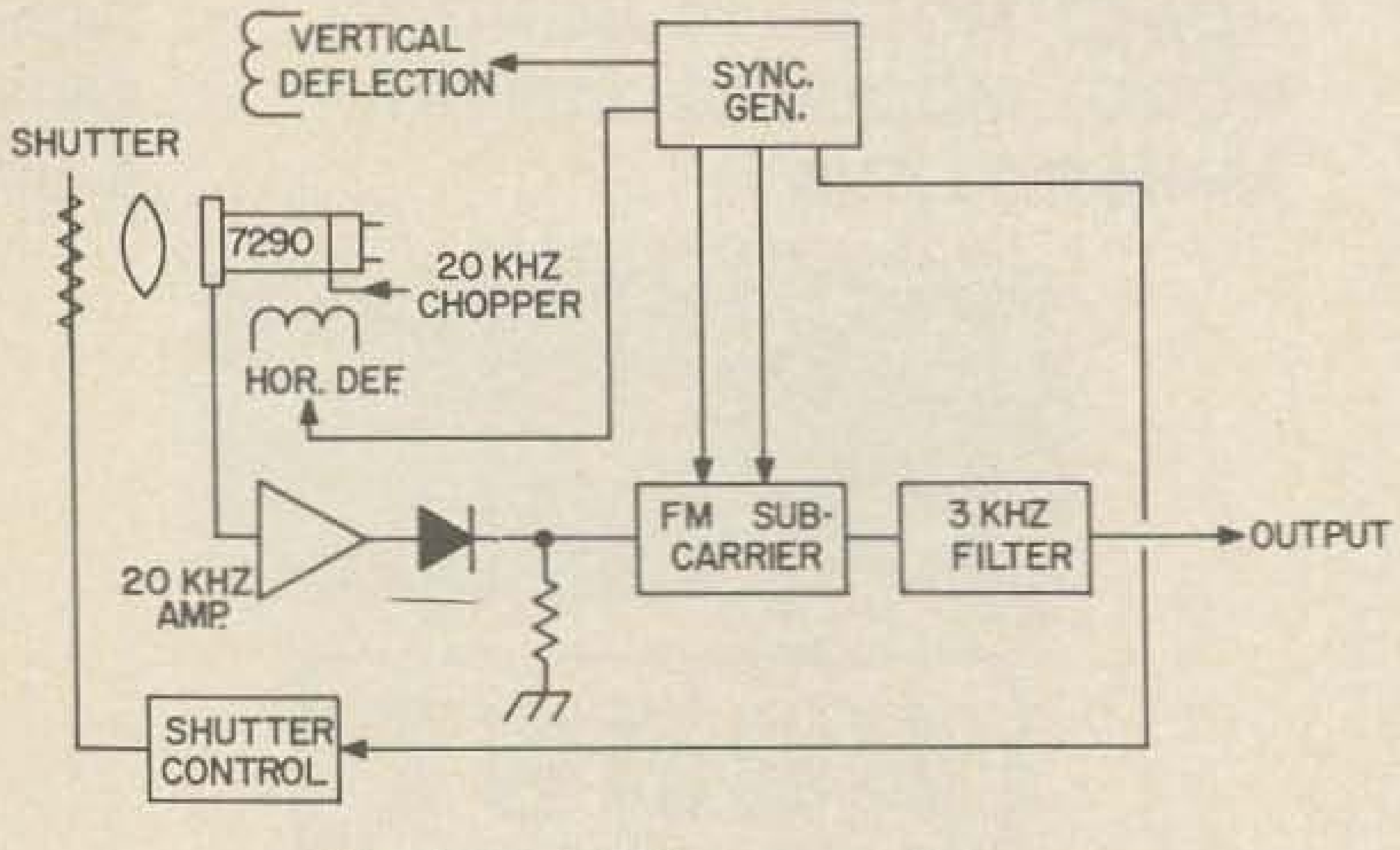

Fig. 1-10. 7290 shuttered camera.

Free vidicons are no longer available but can be purchased from the same source for $100. This price is far below the selling price of this vidicon for commercial use. The slow scan 7290 vidicon target can hold an electrical image for several seconds once it has been exposed to an image. In the 7290 SS camera shown in Fig. 1-10, an electrically-operated shutter exposes the target for about 1/30 second and then the image is electrically scanned for the next eight seconds. Similar to flying spot scanners, the vidicon beam must be swept in horizontal and vertical directions by the 15 Hz and 1/8 Hz sawtooth voltages to produce video.

The signal from the 7290 vidicon target is a very low frequency audio signal and requires much amplification. Audio frequencies near dc are very difficult to amplify because of limitations of coupling and by-pass capacitors, so a technique of chopping is used to electrically change the signal into an ac wave. A 20 kHz sine wave applied to the vidicon grid will turn the scanning beam off and on at this rate so that the small target signal can be amplified as a 20 kHz signal. Once the amplification is completed, the 20 kHz signal is rectified and the resulting signal is the amplified low frequency video or audio signal desired.

The vidicon is provided with the dc operating potentials usually needed and provision is made to blank the vertical and horizontal beam during retrace.

Due to the lack of 7290 vidicons, early slow scan pioneers tried to substitute ordinary fast scan vidicons such as the 7735A and 7038. Contrary to the opinion of those acquainted with the chemical and electrical make-up of these tubes, some slow scan hams were able to get reasonable pictures with *open shutter* operation. K7YZZ and WB8DQT have investigated this type of picture generation thoroughly, and have provided many good pictures on the slow scan net.

About this same time slow scan hams in Europe (such as SMØBUO) were successful in using plumbicons in the Macdonald circuit in the open shutter mode. This proved to be very successful and hams such as W4YHC,

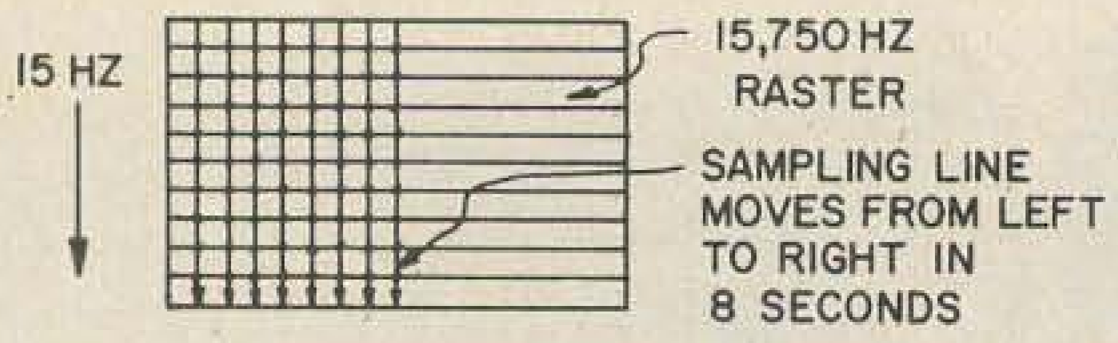

Fig. 1-11. Sampling method of producing a slow scan picture.

W7ABW WØLMD, and others have produced some excellent pictures using the Phillips plumbicon. These tubes are available as pull-outs from color cameras here in American and are available at TV stations in some parts of the country. Plumbicons, with their relatively high target resistivity are quite effective at slow scanning rates and represent an excellent alternative to the 7290 in the open shutter mode. Last but not least comes what the authors consider to be the best type of slow scan camera – the sampling camera. All of the above cameras (with the exception of the 7290 camera) require open shutter and therefore the subject being televised must remain nearly immobile for the eight seconds. In practice this is not very difficult and contributes to some of the fascination of slow scan TV in which special effects can be staged.

In principle a sampling camera operates like sampling oscilloscopes. The operating principle is based on the fact that the picture being sampled does not change over the length of time that it takes to sample moving fast scan frames. In this case, the time is eight seconds. Assume that a fast scan camera is operating with the following standards: vertical frame rate – 15 Hz, and horizontal line rate – 15,750 Hz. Note that a normal fast scan camera operates with a 60 Hz field or frame rate!

It is assumed that the video will be sampled at every line crossing as shown in Fig. 1-11.

By slowly moving the sampling point to the right at a 1/8 Hz rate, 120 vertical lines are formed. A slow scan sampled picture is generated in this way. This picture is on its side and the electrical signal needs to be filtered, but it is identical to slow scan pictures produced in other ways.

From a circuit designer's viewpoint, the functions that need to be generated in a sampling camera are as follows:

1. a 15 Hz sawtooth sweep voltage locked to 60 Hz mains.

2. A 1/8 Hz sawtooth, preferably locked to 60 Hz mains or to the 15 kHz horizontal sweep voltage.

3. A 15 kHz sawtooth to sweep the fast scan raster. This sweep does not necessarily need to be locked to other time bases and is available from the fast scan camera.

4. A circuit that provides the timing necessary to do the sampling that moves in time across the raster.

A block diagram is shown in Fig. 1-11.

Part II, next month, will cover popular SSTV circuits.

. . .W9NTP & WB8DQT

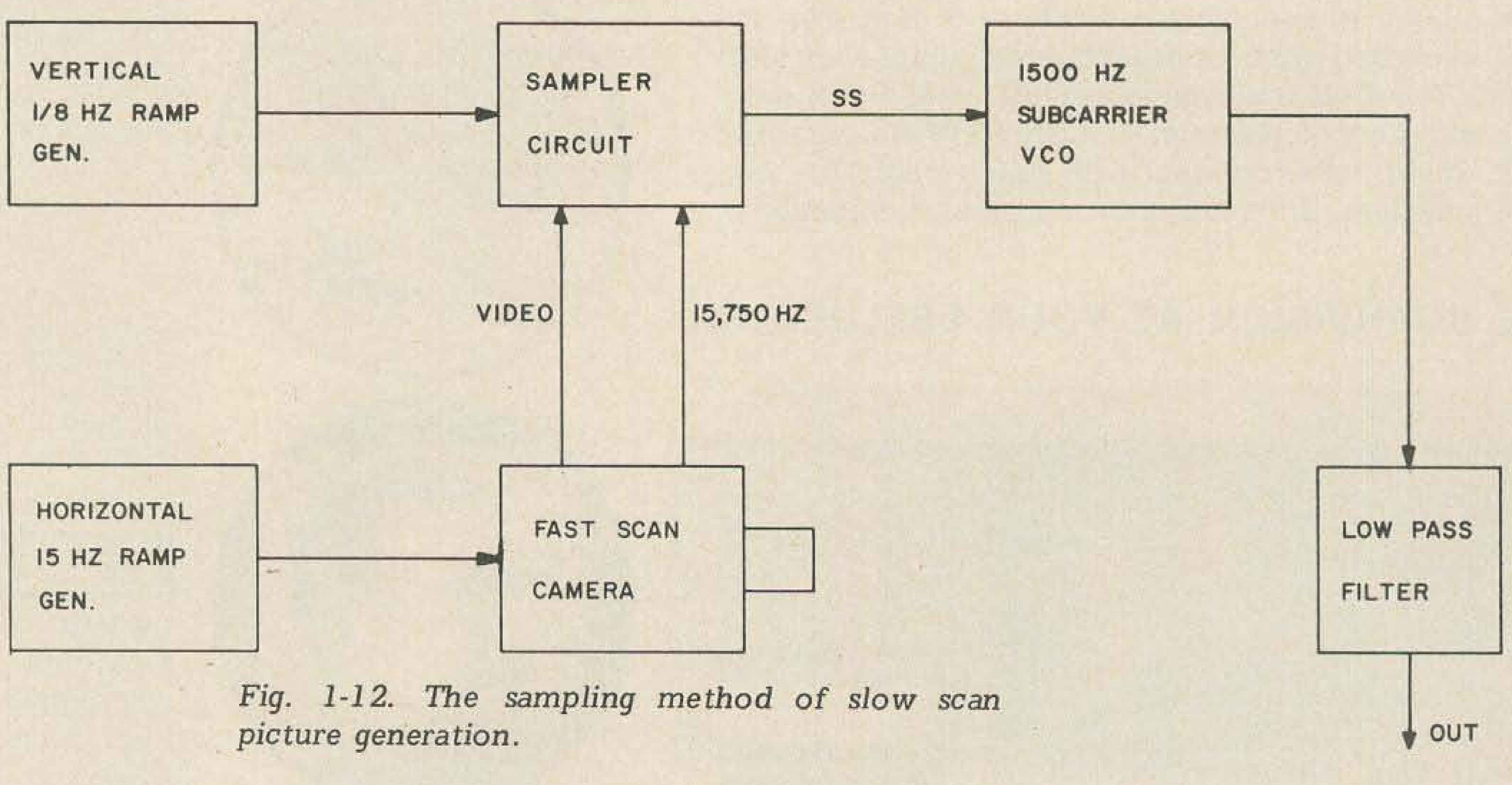

Fig. 1-12. The sampling method of slow scan picture generation.