The Lenkurt® Demodulator

NEWS FROM LENKURT ELECTRIC

VOL. 11, NO. 2 FEBRUARY, 1962

A new and important period of growth has begun for television. After fifteen years primarily as a medium of mass entertainment, television is achieving new status as a powerful technique for extending and improving education. Closed-circuit television networks, covering large areas, have been built in several states, and many others are in the planning stages. For such systems, microwave radio is the most likely method of transmitting the signals from their point of origin to outlying areas, except where the distance is very short. This article discusses monochrome and color television signals, and the characteristics required of microwave equipment used in their transmission.

Educational television is emerging from several years of experimentation as one of the best solutions to the severe shortage of good teachers in the United States. Educators believe that television will greatly improve the quality of teaching in almost all types of schools. In areas that are sparsely populated or where school budgets are low, television permits a broader curriculum and lessons of a better quality than otherwise available. Where teachers and finances are more abundant, television relieves teachers of the chore of presenting routine, generalized subjects and allows them more time to spend with small, specialized classes where their teaching skills may be used more effectively.

The present trend of commercial television is toward more and more use of

Figure 1. Principal value of educational TV is in improving quality rather than quantity of instruction. Television permits teaching-specialists a larger audience, and allows classroom teachers more time for personal contact with students, thus increasing effectiveness of both the specialists and local teachers.

color and this is believed to add even more to the effectiveness of television as an educational tool. Many national educational programs are now broadcast regularly in color.

Television has proved to be such an effective teaching medium that rather elaborate methods are sometimes employed to reach as many students as possible. In Indiana, for instance, two large four-engined aircraft loaded with television transmitters and video tape reproducers climb daily to about 23,000 feet where they broadcast on several channels to an estimated five million students in three states. Despite the high cost of the aircraft and their equipment (one plane is in reserve), the number of students served is very large, thus making the cost per student very low.

This approach, while effective in the particular region where it is used, is not economically suitable for most areas—for instance, where population is sparse, or concentrated in a few large cities. In addition, this transmission method is particularly vulnerable to such occurrences as bad flying weather, mechanical and electrical difficulties in the aircraft, and the like.

For these and other reasons, most television networks transmit their signals over coaxial cable or point-to-point microwave radio. Because of the high cost of coaxial cable, however, it is generally used only in special situations or where the transmission distance is quite short—three miles or less, typically. To date, most television networks, both commercial and educational, use microwave transmission.

The Television Signal

There are important differences between a television signal and most other types of signal commonly transmitted over microwave. Voice or other audio signals consist of only a single variable—a voltage or current which varies with time to represent the original sound vibrations. Reproduction of a picture or scene, however, requires that at least three independent variables be transmitted—information about the relative brightness of all points in the picture, and also their horizontal and vertical position.

These three variables are encoded into a single time-varying signal by systematically scanning the picture area very rapidly. Information about the scanning method is transmitted with the brightness information so that the picture can be "reassembled" at the receiver in the same manner in which it was "taken apart" at the transmitter. This scanning information takes the form of synchronizing pulses which tell the receiver when to begin each "frame" or picture image, and when to begin each of the line scans which make it up.

In the standard North American television system described in this article, the image is scanned 60 times a second. These image *fields* are paired and interlaced with each other to provide 30 *frames* or complete pictures a second. The 60-cycle field rate is rapid enough to be undetectable to the human eye, thanks to the eye's "persistence of vision" or poor high-frequency response.

As shown in Figure 2, picture brightness is transmitted by varying the amplitude of the video signal during each line scan. At the end of each line, it is "blanked" during its return by a pulse having an amplitude "blacker than black." During this blanking interval, the horizontal synchronizing pulse is transmitted which starts the next line scan on its way. Note that black or darkness results in *increased* modulation of the television signal, and white causes less modulation. The seemingly inverted presentation used in Figure 2 is based on the IRE (Institute of Radio

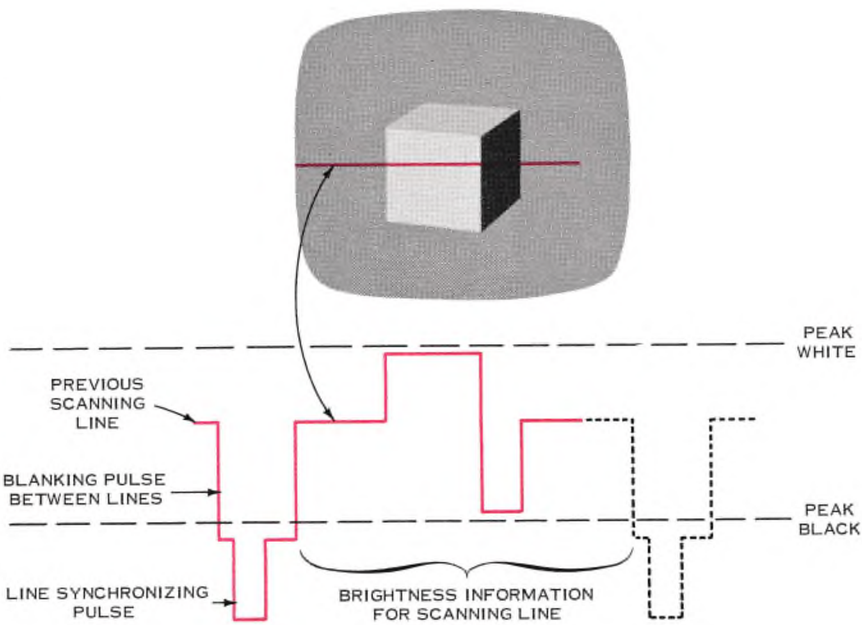


Figure 2. Basic television signal consists of a blanking pulse for darkening the tube between scanning lines, a synchronizing pulse for starting scan in step with the camera, and brightness or video information. The partial scan represented by the red line in the picture causes a waveform like that shown directly below it. The end of each frame is identified by a special combination of pulses, not shown.

Engineers) scale of amplitude relationships adopted as standard in the United States.

Image Detail

The fineness of detail that can be transmitted is called the resolving power or *resolution* of the system. It may seem surprising that resolution of the television system may be different in the horizontal direction than in the vertical. This is because of the way in which the complete television image is formed. Each complete frame consists of 525 horizontal scanning lines, about 40 of which are blanked out between frames and fields. The number of "active" or visible lines remaining determines how many discrete objects or picture elements can be distinguished in the vertical direction. The greater the number of scanning lines, the better the vertical resolution. Since the smallest object that can be resolved must be somewhat larger than the distance between lines (so that it can't fall between successive lines and be missed) the number of vertical picture elements that can be resolved is about 342.

Horizontal resolving power depends on the speed with which the scanning spot sweeps across the picture, and the ability of the electronic circuits to respond faithfully to very close transitions between dark and light. This ability is a direct function of the bandwidth of the system. The finer and closer the detail, the more rapidly the signal must vary, and the greater the bandwidth required. The sweep rate is determined by the need to scan all 525 lines in 1/30 second and the desirability of obtaining a horizontal resolution approximately equal to vertical resolution. These requirements are met in a television system having a bandwidth of about 4.3 megacycles.

This bandwidth is necessary only where 30 frames a second are required. If it is acceptable to transmit more slowly—say, five frames a second—the bandwidth can be reduced in proportion—to 700 kc in this example. This concept of "slow-scan" television is used in some industrial and commercial applications where the image does not change rapidly. It has been used by banks for examining signatures from a distance and by electric power companies for monitoring remote meters. Conversely, some technical processes may require *greater* bandwidth because of the need for more resolving power than is possible with the standard television system.

AMERICAN TELEPHONE AND TELEGRAPH CO

Figure 3. When bandwidth is reduced, horizontal definition is impaired without affecting vertical resolution. Compare the horizontal and vertical converging lines in this example in which bandwidth is limited to about one mc.

Color Television

Early, unsophisticated approaches to color television required three separate pictures to be transmitted, one for each of the primary additive colors. This required three times as much bandwidth as a monochrome signal, and was obviously undesirable, both from the standpoint of cost, and excessive use of bandwidth. In addition, such a system did not provide a signal suitable for viewing on conventional monochrome receivers.

In the color television method that finally evolved, a single signal is transmitted which strongly resembles the standard monochrome signal, and which can be received in a normal fashion on a conventional black-and-white receiver. Color information is added to the basic signal in the form of a special *chrominance* signal which is combined with the regular video transmission in such a way that it does not noticeably affect the picture as it appears on a monochrome receiver.

Actually, the chrominance signal adds two new independent variables to the basic television signal. One is the *hue* or color of the subject, and the other is its richness of color or *saturation*. A red object of highly saturated color would appear intensely red or crimson. If saturation is decreased without changing the hue, the subject would appear as some shade of pink. When the saturation of a color is low, it is the same as diluting the pure color with white.

The chrominance signal takes the form of a special sub-carrier, the sidebands of which modulate the regular video or luminance signal which supplies brightness information about the image. The color sub-carrier has a frequency of 3.579 mc, but is shifted in phase to indicate the exact hue of the scanned object at any instant. The amplitude of the color sub-carrier determines the saturation or richness of the resulting color.

The phase and amplitude values of the chrominance signal are extremely important, since they carry all color information. Even slight distortions affect the quality of color reproduction. In order to establish a suitable phase and frequency reference, a short "burst" of the unmodulated color sub-carrier is transmitted during the blanking pulse for each line. Although the color burst consists of only eight or nine cycles of the color sub-carrier, this is enough to correct the phase of an oscillator in the receiver, as required. In this way the color television receiver is effectively phase-locked to the transmitter.

In order to prevent the chrominance signal from affecting the black-and-white image on a monochrome receiver, its frequency (3.579 mc) is chosen to be an *odd* multiple of *half* the line scanning frequency. This has the effect

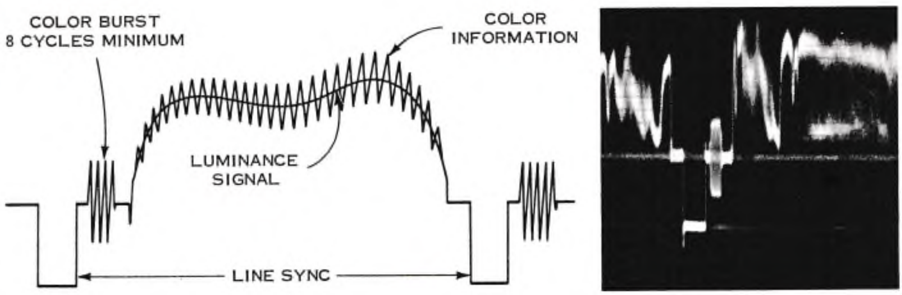


Figure 4. Basic color television signal is diagrammed at left, actual signal is pictured at right. So-called "color burst" is transmitted during blanking pulse to serve as a phase reference for the color information which modulates the basic video or luminance signal.

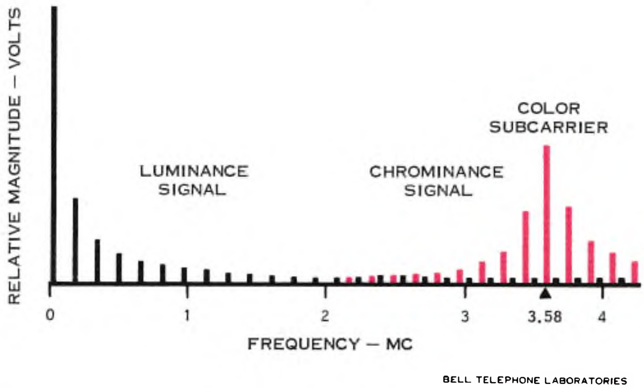


Figure 5. Energy distribution of the color television signal across the spectrum. Line scanning and color sub-carrier frequencies are so chosen that sidebands fall into portions of spectrum unused by each other, thus using bandwidth most efficiently.

of allowing the color modulation of the luminance signal to cancel itself out (as far as the eye can detect) in consecutive frames. For instance, in one frame, the color modulation on the luminance signal may tend to darken a certain spot. In the following frame, the same spot is lightened, thus neutralizing the darkening of that spot in the preceding frame. The *average* brightness remains the same.

This ingenious feature also conserves the bandwidth of the system. Since the television signal is interrupted by individual line scans and by 60-cycle fields, it consists of many harmonics of the line scan frequency, each of which is surrounded by 60-cycle sidebands. In monochrome television, the frequency spectrum between these sidebands is unused. By choosing a color sub-carrier frequency that is an odd multiple of half the line scanning frequency, all the chrominance signal components fall into these unused spaces between the luminance signal components. Accordingly, this system of color television requires no more bandwidth than the conventional monochrome system. Figure 5 shows the energy distribution of the color and monochrome signals across the video spectrum.

Microwave Design Considerations

The extreme complexity of the television signal—especially the color signal—imposes very stringent requirements on the transmission system. Distortion, poor frequency response, transmission irregularities all tend to degrade the quality of the final image. Since such distortions tend to be cumulative as the number of repeaters in the system increases, it is necessary to provide extremely good performance in each link of the system.

Ideally, the entire television system, including the microwave or other transmission equipment, should be free from amplitude distortion and non-linear phase shift from almost zero frequency to at least 4.5 mc. In practice this is very difficult to achieve, primarily because of the very great number of octaves which the signal must cover. By definition, an octave covers a range in which the highest frequency is just twice the lowest. Thus, the frequency range 10 to 80 cycles covers three octaves, and the television video spectrum covers nearly 18 octaves. Over such a broad range, the excessive use of negative feedback to maintain uniform frequency response may result in amplifier instability and serious phase distortion. When transistors are used, the problem is complicated even more by the varying phase shift introduced by the transistors themselves, as a function of signal level.

The technical demands on microwave are different for television and message service. In most message applications, non-linear phase shift and envelope delay distortion are relatively unimportant—but the random noise and intermodulation distortion contributed by the radio are of great importance. Monochrome and color television are greatly disturbed by single-frequency interference, particularly at low frequencies. For this reason, special emphasis must be placed on eliminating hum from any source. By contrast, this has hardly any effect on message service microwave.

One of the most important differences is the extreme sensitivity of the television signal to non-linear phase shift. This is almost always associated with variations in the amplitude frequency response of the system, particularly abrupt changes or transitions. The resulting non-linear phase shift delays some frequencies more than others, with the result that the signal waveform is distorted. Although delay distortion of a speech or music signal is not readily detected by the ear, similar distortion of the television signal is very noticeable and affects the quality of reproduction greatly. Minor waveform aberrations show up as noticeable changes in the image.

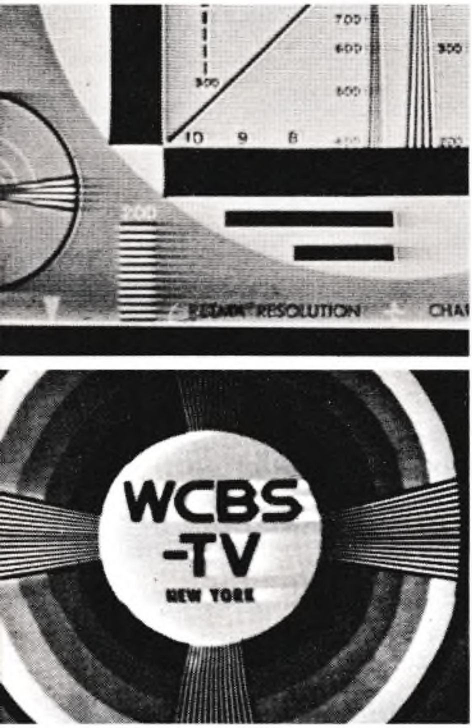
Color television is particularly vulnerable to *differential phase* and *differential gain*. Simply speaking, differential gain means a change in the gain of the system as a result of signal level variations. In a color television broadcast, the presence of differential gain may cause some colors to appear unsaturated or washed out, while others might appear excessively brilliant. These extremes may be produced merely by changes in the brightness of various scenes.

Similarly, differential phase refers to phase shift which occurs as a function of the video signal level. This is important in color television because the colors which appear on the screen are determined by the exact phase relationship between the color burst and the color sub-carrier. Differential phase causes color distortion which is not constant, but which varies according to the brightness of the scene. Thus, a crimson object might change to orange or some other color if the overall illumination level of the scene were to change.

Low Frequency Effects

Ideally, the television system should have uniform frequency response down to zero frequency—that is, dc—itself. This is generally impractical because of the complications it introduces into the design of amplifiers used in the system. Instead, the direct-current component required to provide a brightness reference or base is reinserted at various points in the transmission system by a so-called clamper or dc restoration circuit. Without the clamper, the brightness of the scene tends to vary according to the overall range of brightness in the picture. Thus, a scene of average brightness would be darkened all over by the addition of a single small area of much greater brightness.

Where the low-frequency "roll-off" (of the video amplitude response) lies in the region 30 to 60 cycles or lower, the picture may show some vertical shading because of the system's inability to achieve the correct amplitude level immediately following the field synchronizing pulses. When frequency re-



AMERICAN TELEPHONE AND TELEGRAPH CO.

Figure 6. Examples of streaking caused by poor response at the lower frequencies — positive streaking above, negative streaking below.

AMERICAN TELEPHONE AND TELEGRAPH CO.

Figure 7. Smearing results from frequency response deficiencies in the frequency range between 150 kc and one mc.

sponse is irregular in the range below about 150 kc, an image defect called *streaking* occurs. If the gain drops one or more db in this range, the waveform may show a long-duration "overshoot" at tonal transitions from dark to light and light to dark. This shows up on the picture tube as "negative" streaking in which a dark streak trails a bright object (or light streak following a dark object). If the gain increases in the lower frequency region, the following streak is of the same color as the preceding image area, and is called "positive" streaking. These are illustrated in Figure 6.

If the frequency aberration occurs in the middle frequency range, that is, from about 150 kc to nearly a megacycle, the picture may show *smearing;* vertical images are blurred along the horizontal axis to give an overall smeared effect to the picture. Like streaking, this effect is caused by the inability of the waveform to follow rapid transition from one brightness level to another, as required.

High Frequency Errors

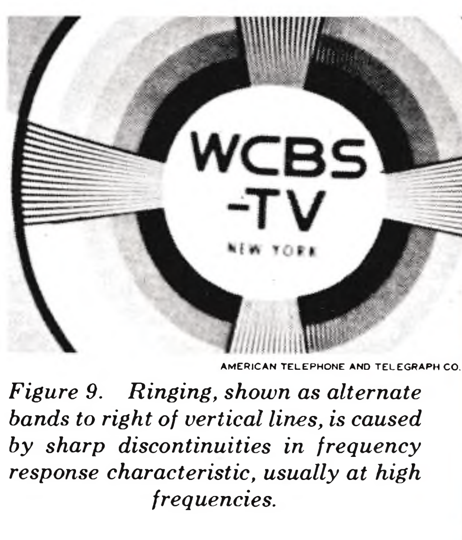
When the high-frequency gain of a television system is altered, the fine detail of the image is affected. If the high frequencies are depressed, there is some loss of horizontal detail and a general softening of vertical edges. If high-frequency gain is increased slightly, the picture assumes a much crisper quality due to the waveform's increased ability to follow very rapid changes and to make "squarer" pulses. If the high frequency gain is increased even more, the waveform may have a tendency to overshoot, thus producing a "spike" as it is often called. Figure 8 shows such a spike at the leading edge of a line synchronizing pulse. When this occurs in the picture, the overshoot may produce a very narrow contrasting outline at the right edge of contrasting objects. The higher the frequency of the increased response, the narrower the outline. This phenomenon is generally called a "following white" or "following black." If the overshoot occurs at lower frequencies, the outline is broadened, and smearing results.

A sharp "roll-off" of the high-frequency response of the system, or an irregularity of the frequency response within the pass-band of the system can result in "ringing" or damped oscillation immediately following an abrupt tonal transition. On the screen, this appears as a series of fine alternate light and dark lines just to the right of contrasting edges in the image. In long transmission systems, ringing may occur from the use of many tandem microwave links, even though the frequency cut-off of each is outside the video band. In effect, as the number of tandem microwave links increases, the ringing frequency becomes lower until it is noticeable in the picture. This can be minimized by avoiding a sharp frequency roll-off in the microwave frequency response, and keeping the over-all response free of irregularities which can be exaggerated by similar faults in succeeding links of the system.

Color television in particular is extremely sensitive to minor irregularities in the phase and frequency response in the upper part of the video spectrum. Even small frequency response deviations result in non-linear phase shift to some degree, and this has an important effect on the ability of the waveform to follow brightness variations faithfully. More important is the effect of such phase shift on the quality of color reproduction. Although the color subcarrier is at a frequency of approximately 3.6 mc, phase modulation of the carrier produces sidebands as low as

AMERICAN TELEPHONE AND TELEGRAPH CO.

Figure 8. Overshoot results from excessive gain at fairly high frequencies. Compare the "spike" at the leading edge of the synchronizing pulse and the "following white" to right of man's head.



AMERICAN TELEPHONE AND TELEGRAPH CO.

Figure 9. Ringing, shown as alternate bands to right of vertical lines, is caused by sharp discontinuities in frequency response characteristic, usually at high frequencies.

2 mc and as high as 4.2 mc. If some of these sidebands are delayed more than others by non-linear phase shift, the resulting colors produced at the receiver will be distorted in a noticeable and objectionable way. Figure 10 indicates some of the recommended tolerance limits for frequency response in an overall television system, including transmission facilities. Note that near the color sub-carrier frequency, requirements are as stringent as they are at the very low frequencies.

Both monochrome and color television have similar requirements at the low end of the video spectrum. Most of the transmission problems previously described affect both equally. Although it is extremely important to have excellent low-frequency response in the over-all system, the requirements imposed on the microwave system can be relieved greatly by the use of clamper circuits. Clampers, in effect, restore the lost direct-current component that establishes the brightness reference level, by measuring the voltage change or drift of the line-synchronizing pulse and applying a compensating bias voltage to restore the reference base. This frees the television image from changes in brightness of the over-all picture due to the brightness content of the picture.

Effective clampers, however, are generally complicated and expensive. Overly-simple clampers may substitute one trouble for another. If the microwave system is able to transmit direct-current information, clampers can be dispensed with altogether. Although this is generally impracticable, the need for clampers can be minimized by using a transmission system that can transmit extremely low frequencies that closely approach direct current.

The most stringent requirements at the upper end of the video spectrum are dictated by the need for as little differential phase and gain as possible in the transmission of color. This is best done by preserving a very wide bandwidth, free from irregularities well beyond the actual frequency limits of the television signal itself. The farther the cut-off frequency of the system is from the signal, the less distortion there

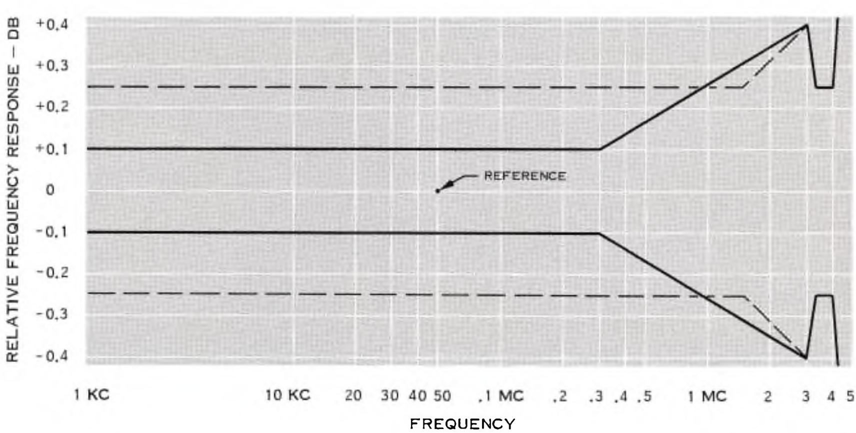


Figure 10. Typical frequency response limits specified for microwave systems used in transmitting color television. Variations within these limits are expected to be gradual, rather than abrupt.

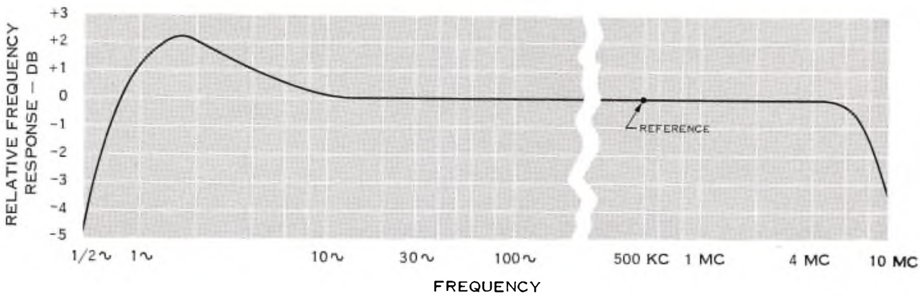


Figure 11. Typical frequency response characteristic for the Lenkurt 76A microwave system used for transmitting color television. Rising characteristic at very low frequencies compensates for non-linear phase shift effects, improves "square-wave tilt" and reduces need for clamping circuit.

will be in the final image. Figure 11 shows the frequency response characteristics of the Lenkurt 76A microwave system, especially developed to accommodate color television.

The Future of Color

Compatible color television is about seven years old in the United States and Canada, but is only now gaining wide public acceptance, primarily because of the high cost of color receivers. Now that costs are coming down and color broadcasting is increasing rapidly, it may be expected that even cheaper and better receivers will be developed. It seems reasonable to expect that color television will experience the same rapid growth that characterized the first television broadcasting fifteen years ago. Despite the extra complexity of the color receiver, large volume production will reduce prices considerably.

Although color enhances the attractiveness and entertainment value of commercial television, it should be particularly effective in educational television. The additional impact of color adds considerably to television's ability to convey information and impress the student viewer. Closed-circuit color television has already been used in medical and surgical teaching with excellent effectiveness.

Even if color television is not to be used in the immediate future, microwave transmission facilities should have the capability of transmitting color without distortion, since the lack of this capability will be one of the most important factors in retarding the future obsolescence of the system. •

Bibliography

1. *Teaching by Closed Circuit Television*, Report of a joint conference, Committee on Television, American Council on Education, Washington, D. C., and State University of Iowa, Iowa City, Iowa; 1956.
2. *Television Signal Analysis*, American Telephone and Telegraph Company; New York, 1955.
3. *Transmission Systems for Communications*, Bell Telephone Laboratories; New York, 1959.
4. John W. Wentworth, *Color Television Engineering*; McGraw-Hill, New York, 1955.

Lenkurt Electric Co., Inc.
San Carlos, California

Bulk Rate
U.S. Postage
Paid
San Carlos, Calif.
Permit No. 37

MR. W. F. CRUESS, SECTION MGR.
WESTINGHOUSE ELECTRIC CORP.
POWER CONTROL SALES
EAST PITTSBURG, PA. R-19516

RETURN REQUESTED

New Baseband Regulator Described

A new Baseband Regulator suitable for use with almost any microwave system is described in a new publication now available on request from Lenkurt or Lenkurt Sales Offices. The new regulator has its own pilot generator, thus freeing it from dependence on the microwave equipment with which it is used.

Ask for Bulletin 940A1-P4.

LENKURT ELECTRIC SAN CARLOS, CALIFORNIA, U.S.A. GENERAL SYSTEM

District Offices
New York • Minneapolis
Atlanta • Dallas
Chicago • San Carlos
Washington, D.C.

The Lenkurt Demodulator is a monthly publication circulated free to individuals interested in multi-channel carrier, microwave radio systems, and allied electronic products. Permission to reproduce material from the *Demodulator* will be granted upon request. Please address all correspondence to the Editor.

LITHO IN USA