SECTION 7: SPECIAL SYSTEMS

7.1

Color Television

Part I: The Basic NTSC System

FUNDAMENTALS

Color is a dimension that has been added skillfully to black-and-white television. To the engineering fraternity as a whole it signifies one of the most dramatic technological achievements of this age.

Nearly every branch of science including chemistry and psychology contributes in some way to the reality of color television. Through chemistry, improved phosphors are continually being found for use in color-picture tubes. Psychology enters into the selection of lighting arrangements and picture composition to obtain desirable interpretations by the viewer. But physics plays the leading role with intense application in optics and illumination as well as in the design of electronic circuitry and components for the complete television system.

Two specialized branches of physics, namely radio and television engineering, are responsible for the electronic techniques which make color television "compatible" with black-and-white, or monochrome, television, marking what is probably the greatest technical advance in television in the past decade.

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NOTE: Superscript numbers refer to footnotes at the end of this chapter.

Compatibility

The compatible color system offers tremendous economic advantages to the home viewer as well as to the television broadcaster. Because of compatibility, color telecasts can be seen (in monochrome) on black and white television receivers without any changes or added devices. Also, color receivers can receive monochrome as well as color telecasts. Since compatible color is transmitted over the same channels as monochrome and within the same framework of standards, the television broadcaster can utilize his monochrome system as the transmitting nucleus when installing equipment to broadcast color. Moreover, he can utilize his color equipment to produce monochrome telecasts.

Another important advantage of the compatible color system is the part it plays in the conservation of the radio-frequency spectrum. Compatible color requires no additional space in the spectrum. However, it employs techniques which make much more efficient use of the standards originally set up for monochrome television.

A brief review of the fundamentals of monochrome television, particularly the areas wherein specialized color methods are employed, is presented in the next few paragraphs as an aid in describing the basic color concepts.

Television: A System of Communications

Basically, television is a system of communications consisting of the television station at one

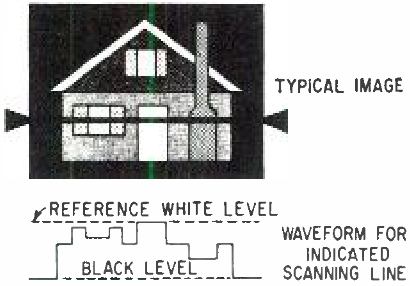


Fig. 1. Typical image and camera output waveform produced by light and dark areas during one scan along line indicated by arrows.

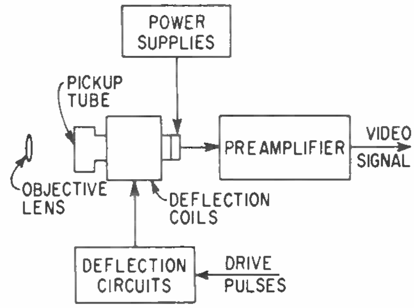


Fig. 2. Block diagram of monochrome-camera circuits.

end of the system and the television receiver at the other. As such, it is actually one of the highest capacity systems in use today, being able to transmit from station to receiver more than five million "bits" of picture information every second.

Very simply, the function of the television station is to divide and subdivide the optical image into over 200,000 picture elements, each of different light intensity; convert these light elements to electrical equivalents; and transmit them in orderly sequence over a radio-frequency carrier to the television receiver.

Reversing the process at the receiver, these electrical signals are each converted to light of corresponding brightness and reassembled to produce the transmitted image on the face of the picture tube.

Scanning

Picture elements to be transmitted in sequence are selected by a process of image scanning which takes place in the television camera focused on the studio scene at the station. Within the camera, an electron beam in a pickup tube scans a sensitive surface containing an "electrical image" of the scene of action. The electron beam successively scans the image at great velocity, beginning at the upper left corner and continuing left to right in a series of parallel lines to scan the image completely. Movement of the electron beam, which can be controlled magnetically by vertical-and horizontal-deflection coils surrounding the tube, is analogous to that of the eye in reading a printed page. The speed of movement is such, however, that 30 complete image frames of approximately 500 lines each are scanned every second. Of course, at the receiver, an electron beam in the kinescope, or picture tube, moves with the same speed and in synchronism with the camera-tube beam so that the corresponding picture elements appear in the proper relative position on the television screen.

Owing to "persistence of vision" and the speed of scanning, these elements appear to be seen all at once as a complete image rather than individually. Thus, the impression is one of continuous illumination of the screen and direct vision.

Scanning standards have been established in this country to assure that all television receivers are capable of receiving programs broadcast by any television station within range. The scanning pattern adhered to by manufacturers in the design of television receivers and broadcast equipment

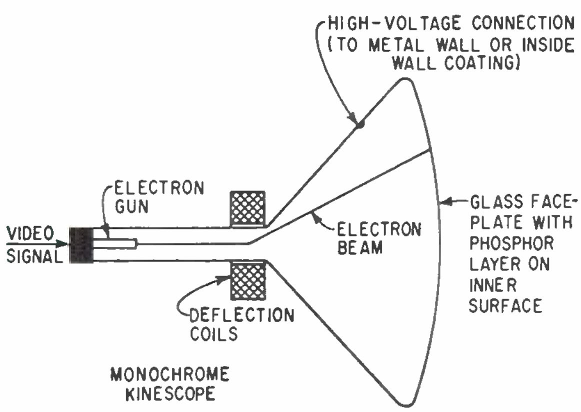


Fig. 3. Diagram showing principal elements of the monochrome kinescope picture tube.

consists of 525 lines with odd-line interlaced scanning. Interlaced scanning, effective in eliminating perceptible flicker, is a method whereby the electron beam scans alternate rather than successive lines. For example, the beam begins by scanning odd-numbered lines (1, 3, 5, 7, etc.) until it reaches the bottom of the image, whereupon it returns to the top of the image to scan the even-numbered lines (2, 4, 6, 8, etc.). Thus, each scan, or field, comprises only half of the total number of scanning lines, and two fields are required to produce the 525-line frame. Each field is completed in one-half the frame time. The vertical scanning frequency is 2 X 30 or 60 Hz, and horizontal scanning frequency is 30 X 525 or 15,750 Hz.

Resolution and Bandwidth

The degree of resolution, or fine detail, that can be seen in a televised image depends upon the number of scanning lines used and the bandwidth of the transmitting and receiving system.

The relationship between resolution and bandwidth can be seen by considering the number of picture elements that can be transmitted each second.

The standard 6 MHz broadcast channel provides a video bandwidth of approximately 4.1 MHz (the remaining bandwidth being required for a vestigial sideband plus the sound signal). Since each cycle of a sine wave is capable of conveying two picture elements (one black and one white), the maximum rate at which picture elements can be transmitted is 4,100,000 X 2, or 8,200,000 per second. Since 30 complete frames are transmitted per second, the number of picture elements per frame would be 8,200,000/30, or 273,333, if it were not for the retrace blanking problem, which requires interruption of the picture signal periodically by blanking pulses. Since the combination of horizontal and vertical blanking pulses requires nominally 25 percent of the total time, the maximum number of picture elements per frame is reduced in practice to 0.75 X 273,333, or approximately 205,000.

Synchronizing

In addition to the picture information, or video signals, blanking and synchronizing signals are transmitted by the television station to control the intensity and movement of the scanning beam in the kinescope of the television receiver. Both these signals are in the form of rectangular pulses. Moreover, their polarity and amplitude are such that they are received as "black" signals and therefore do not appear on the receiver screen.

Blanking pulses eliminate the "retrace" lines which would otherwise appear between scanning lines and at the end of each field from the bottom of the picture to the top. Horizontal blanking pulses, transmitted at the end of each line, or at intervals of 1/15,750 sec, blank the beam during retrace periods between lines. Vertical blanking pulses, transmitted at the end of each field, or at intervals of 1/60 sec, blank the beam during the time required for its return to the top of the picture. Because the vertical retrace is much slower than the horizontal, the vertical blanking periods are longer than the horizontal blanking periods. Vertical blanking pulses are about 20 lines duration, while horizontal blanking pulses have a duration of only a small fraction of a line.

Synchronizing signals keep the scanning beam of the kinescope in step with that of the camera tube. These signals consist of horizontal and vertical pulses which are transmitted within the respective blanking periods. Although the sync pulses are of the same polarity as the blanking pulses, they are of greater amplitude ("blacker than black") and thus easily separated in the receiver and fed to the deflection circuits of the kinescope.

Since the vertical sync pulses are quite long compared with the horizontal sync pulses and the two are of the same amplitude, separation at the receiver is accomplished through frequency discrimination. Serrations, or slots in the vertical pulses, prevent loss of horizontal sync during the vertical blanking period.

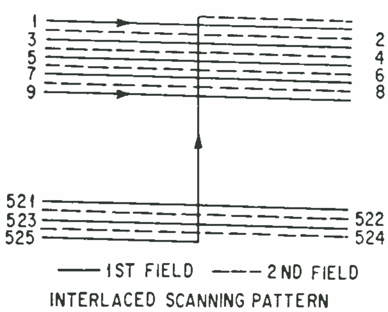


Fig. 4. Diagram showing paths of the electron beam in both the pickup tube and kinescope to produce the interlaced scanning pattern.

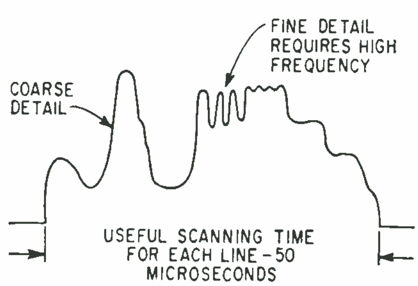


Fig. 5. Diagram illustrating the relationship between picture detail and signal bandwidth.

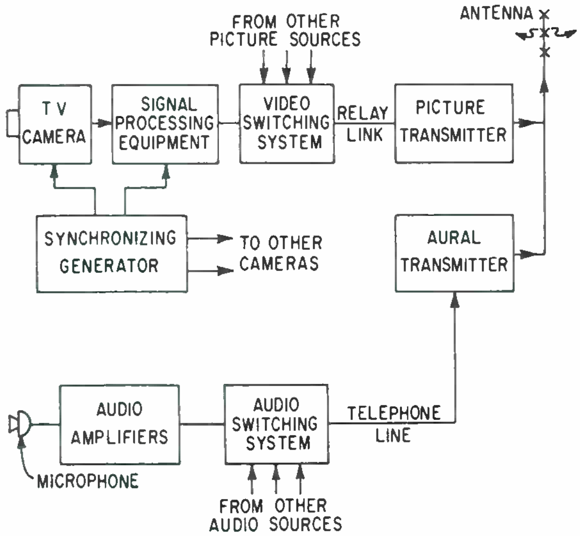


Fig. 6. Simplified block diagram of the monochrome-television station.

The Monochrome Television System

The major equipment in a typical television station consists of the aural and visual units illustrated in the block diagram of Fig. 6. In the visual channel, the video signal leaving the camera is passed through processing equipment which inserts the blanking and synchronizing signals and performs other functions such as aperture compensation and gamma correction. From the processing chain, the video signal is fed to a switching system which provides for selection from a number of video sources. The selected signal is then sent to the visual transmitter through coaxial cable or over a microwave relay link, depending upon the distance between the television studio and transmitter. In the transmitter, the composite video signal amplitude-modulates a carrier in the VHF or UHF range, which is radiated by the television antenna.

In the aural channel, the audio signal is fed from the microphone or other sound source through the switching system and to the aural transmitter. Frequency-modulated output from the aural transmitter is combined with the visual output and radiated from the same antenna.

The Radiated Picture Signal

Amplitude relationships between the synchronizing pulses and the tonal gradations from white to black in the picture are represented in the waveform of the radiated picture signal. From the illustration, it can be seen that modulation takes place in such a way that an increase in the brightness of the picture causes a decrease in carrier output power. Note that the reference-white line indicated on the sketch is relatively close to zero carrier level. Also, the synchronizing pulses are in the "blacker than black" region, representing maximum carrier power. Use of a widely different range of amplitude for the sync pulses makes it possible for home receivers to separate them by a simple clipping technique.

Receiver

The basic elements of the television receiving system are illustrated in the block diagram of the television receiver. The radiated television signal is picked up by an antenna and fed to a tuner which selects the desired channel for viewing. Output from the tuner is passed through an intermediate-frequency amplifier which provides the major selectivity and voltage gain for the receiver. A second detector then recovers a video signal which is essentially the same as that fed to the visual transmitter.

The sound signal is usually taken off at the picture second detector in the form of a frequency-modulated beat between the picture and sound carriers. The sound signal is further amplified in a special IF stage, detected by a discriminator or ratio detector, and applied to the speaker through an audio amplifier.

Picture output from the second detector is fed to two independent channels. One of these is the video amplifier which drives the electron beam in the kinescope, and the other is the sync separator, or clipper, which separates the sync pulses from the picture information. The separated pulses are then used to control the timing of the horizontal and vertical deflection circuits. The high-voltage supply, which is closely associated with the horizontal deflection circuit, provides accelerating potential for the electron beam.

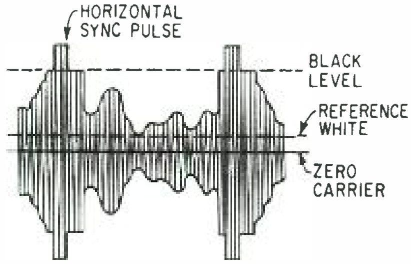


Fig. 7. Waveform and radiated picture signal.

The Three Variables of Color

Color is the combination of those properties of light which control the visual sensations known as brightness, hue, and saturation. Brightness is that characteristic of a color which enables it to be placed in a scale ranging from black to white or from dark to light. Hue, the second variable of a color, is the characteristic which enables a color to be described as red, yellow, blue, or green. Saturation refers to the extent to which a color departs from white, or the "neutral" condition. Pale colors, or pastels, are low in saturation, while strong or vivid colors are high in saturation.

The monochrome system is limited to the transmission of images that vary with respect to brightness alone. Thus, brightness is the only attribute of a color which is transmitted over a monochrome-television system. To produce a color image, therefore, provision must be made for the transmission of additional information pertaining to all three of the variables of color. However, since the primary-color process can be employed, it is not necessary to transmit information in exactly the form expressed by the three variables.

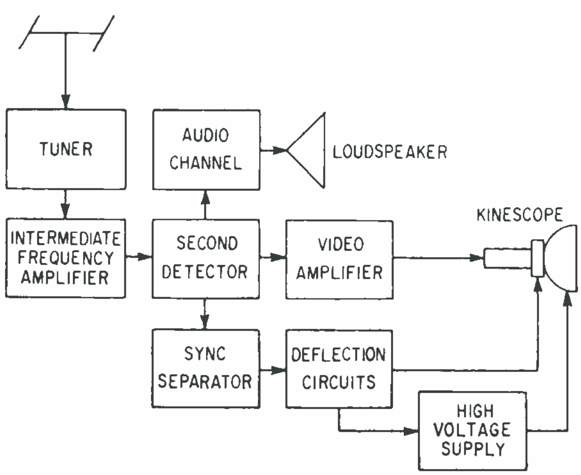


Fig. 8. Block diagram of monochrome-television receiver.

Primary Colors in Television

Experiments have proved conclusively that virtually any color can be matched by the proper combination of no more than three primary colors. While other colors could be used as primaries, red, green and blue have been selected as the most practical for color-television use. A few of the many colors that can be made by mixing lights of red, green, and blue are illustrated in Fig. 9 (see page 7.1-9). Red and green combined produce yellow, red plus blue give purple, and green plus blue give cyan or blue-green. The proper combination of all three of the primary colors produces white, or neutral, as shown at the center of the illustration. By relatively simple optical means, it is possible to separate any color image into red, green, and blue, or RGB components, as shown by Fig. 10.

Generating RGB Signals

Major components of a color-television camera may have the block-diagram form shown in Fig. 11. Whereas the monochrome camera contains only one pickup tube, or solid-state sensor, the color camera usually contains three separate pickup devices. An objective lens at the front of the camera forms a real image within a condensor lens which is located where the pickup device is usually mounted in a monochrome camera. A relay lens transfers this real image to a system of dichroic (color separating) mirrors or prisms which shunt the red and blue light to the red and blue pickup devices and permit the green to pass straight through to the green tube or sensor. In this manner, the three pickup devices produce three separate images corresponding to the RGB components of the original scene. These images are scanned in the conventional manner by common deflection circuits.

A single scanning line through the typical color image at the point shown (Fig. 18) produces three separate waveforms. It is important to note the correlation between these waveforms and the image at the top. The yellow shutters in the image, for example, must be produced by a mixture of red and green, and the blue signal is not required. Thus, at this interval of scanning the red and green signals are both at full value and the blue signal is at zero. The white door utilizes all three color signals. Of course, similar correlations can be seen for other parts of the image along the scanning line.

Displaying RGB Signals

RGB signals are displayed in color by the tricolor kinescope, the basic components of which are shown in the diagram of Fig. 12. Three electron guns produce three beams which are independently controlled in intensity by the red,

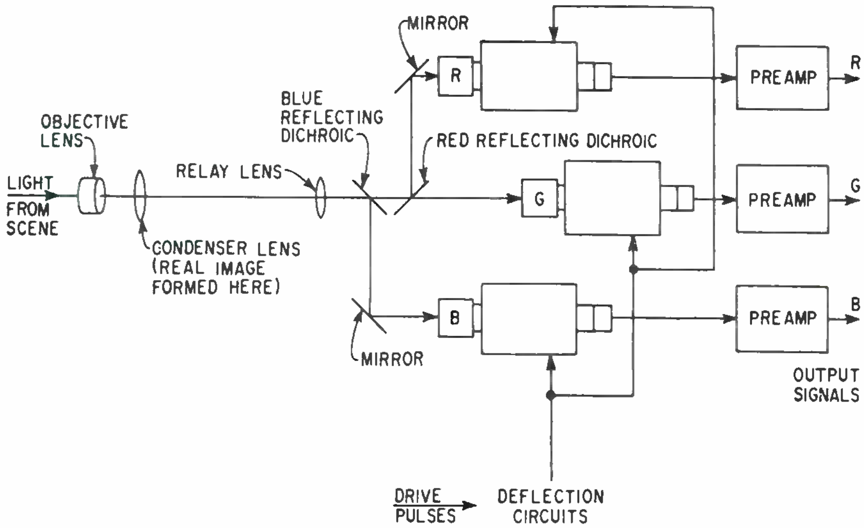


Fig. 11. Simplified block diagram of the optical and electrical components of the color camera.

green, and blue signals. These three beams are all made to scan in unison by deflection coils around the neck of the tube. The three beams converge at the screen owing to the magnetic field produced by a convergence yoke.

The phosphor screen of the color kinescope consists of an array of very small primary-color dots. Approximtely ½ in. behind the phosphor screen is an aperture mask which has one very small opening for each group of red, green, and blue phosphors. Alignment of this aperture mask and screen is such that each beam is permitted to strike phosphor dots of only one color. For example, all the electrons emitted by the red gun must strike red phosphor dots on the aperture mask; they cannot strike either the green or blue dots because of the "shadow" effect of the mask. Likewise, the beams emanating from the other two guns strike only green or blue dots.

In this way, three separate primary-color images are produced on the screen of the tricolor tube. But since these images are formed by closely intermingled dots too small to be resolved at the normal viewing distance, the observer sees a full-color image of the scene being televised.

ELECTRONIC ASPECTS OF COMPATIBLE COLOR TELEVISION

To achieve compatibility with monochrome television, color-television signals must be processed in such a way that they can be transmitted through the same channels used for monochrome signals, and they must also be capable of producing good monochrome pictures on monochrome receivers. Since color television involves three variables instead of the single variable (i.e., brightness) of monochrome television, an encoding process is required to permit all three to be transmitted over the one available channel. Likewise, a decoding process is required in the

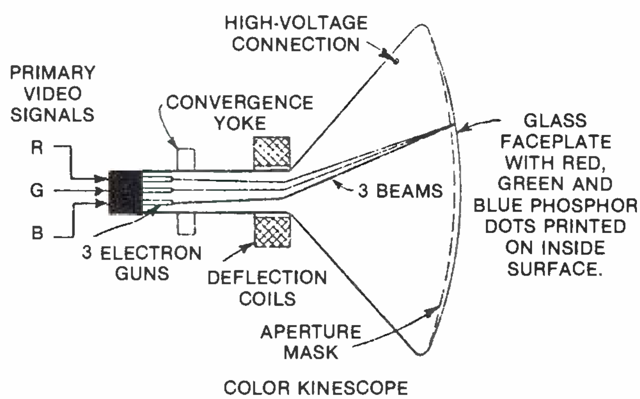


Fig. 12. Diagram showing components of the three-gun kinescope picture tube.

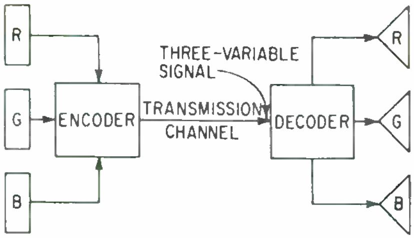


Fig. 13. Encoding of the RGB signals provides a three-variable signal which can be transmitted over existing monochrome channels.

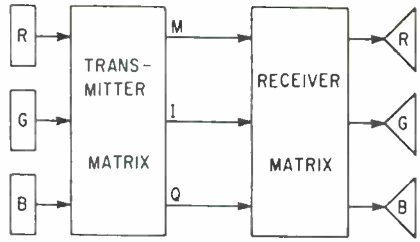


Fig. 14. A part of the encoding process is the matrixing of R, G, and B signals to provide M, I, Q signals.

color receiver to recover the independent RGB signals for control of the electron guns in the color kinescope. Moreover, the process used must enable existing monochrome receivers to produce a monochrome picture from the color information.

Encoding and decoding processes used in compatible color television are based on four electronic techniques known as matrixing, band shaping, two-phase modulation, and frequency interlace. It is these processes which make the color system compatible with monochrome and enable the color system to occupy the existing 6 MHz channel.

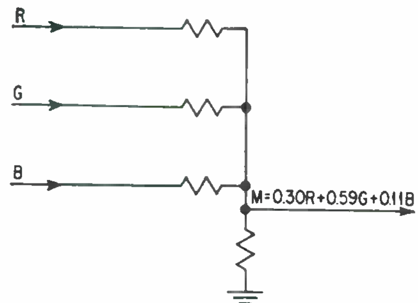


Fig. 15. Diagram of resistance matrix circuit used to produce the M luminance signal.

Matrixing

Matrixing is a process for "repackaging" the information contained in the red, green, and blue output signals from a color camera to permit more efficient use of the transmission channel. The matrix circuits which perform this function consist of simple linear cross-mixing circuits. They produce these signals, commonly designated M, I, and Q, each of which is a different linear combination of the original red, green, and blue signals. Specific values for these signals have been established by FCC standards.

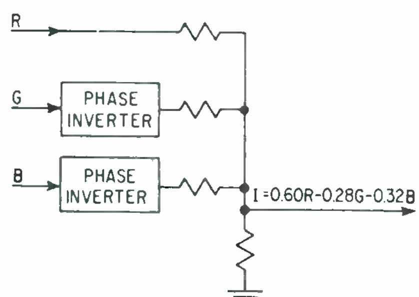


Fig. 16. Diagram of I matrix showing phase inverters to produce minus green and blue quantities.

The M-signal component, or *luminance* signal, corresponds very closely to the signal produced by a monochrome camera, and therefore is capable of rendering excellent service to monochrome receivers. The M component is obtained by combining red, green, and blue signals in a simple resistor network (Fig. 15) designed to produce a signal consisting of 30 percent red, 59 percent green, and 11 percent blue.

The I and Q signals are *chrominance* signals which convey information as to how the colors in the scene differ from the monochrome, or "neutral" condition. The component I is defined as a signal consisting of 60 percent red, -28 percent green, and -32 percent blue. Minus values are easily achieved in the matrix circuits by use of phase inverters to reverse the signal polarity (see Figs. 16 and 17). The Q signal is defined as

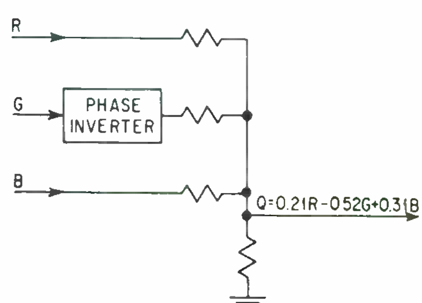


Fig. 17. Diagram of the Q matrix showing phase inverter to produce required minus green signal.

21 percent red, -52 percent green, and 31 percent blue.

It can be seen that the quantities are related so that when red, green, and blue are equal, corresponding to the neutral condition, both I and Q go to zero. Thus, when the color camera is focused on an object having no color information, such as a monochrome test chart, the I-signal and Q-signal components are absent, leaving only the M component, or monochrome signal.

The matrix circuits, therefore, produce a new set of waveforms corresponding to the M, I, and Q components of the image. A comparison of the MIQ and RGB waveforms (Figs. 18 and 19, see page of color illustrations on page 7.1-9) obtained from the image illustrates the correlation among the types of signals. It will be seen that the M signal remains in the region between black level and reference white. The I and Q signals, on the other hand, swing positive and negative around a zero axis.

Band Shaping

The eye has substantially less acuity in detecting variations in chrominance than it has for resolving differences in brightness. This important characteristic of human vision was considered in setting up the I and Q equations because it permitted a significant reduction in the bandwidth of these signals through use of low-pass filters. A bandwidth of approximately 1.5 MHz was found to be satisfactory for the I signal, which corresponds to color transitions in the range extending from orange to blue-green. For color transitions in the range from green to purple, as represented by the Q signal, the eye has even less acuity and the bandwidth was restricted to only 0.5 MHz. The M-signal component, which conveys the fine details, must be transmitted with the standard 4 MHz bandwidth.

Two-Phase Modulation: Generation of Color Subcarrier

Two-phase modulation is a technique by which the I and Q signals can be combined into a two-variable signal for transmission over a single channel. This is accomplished by adding the sidebands obtained through modulation of two 3.6 MHz carriers separated in phase by 90°. The resultant waveform is the vector sum of the components. Elements of the transmitting and receiving system are shown in Fig. 20. The two carriers, which are derived from the same oscillator, are suppressed by the balanced modulators. Thus, only the two amplitude-modulated sidebands, 90° out of phase, are transmitted. At the receiving end of the system, the I and Q signals are recovered by heterodyning the two-phase wave against two locally generated carriers of the same frequency but with a 90° phase separation and applying the resultant signals through low-pass filters to the matrix circuits. Typical signal waveforms are illustrated in Fig. 21.

The 3.6 MHz oscillator at the receiver must be accurately synchronized in frequency and in phase with the master oscillator at the transmitter. The synchronizing information consists of 3.6 MHz, "bursts" of at least 8 Hz duration transmitted during the "back-porch" interval following each horizontal sync pulse. The bursts are generated at the transmitter by a gating circuit which is

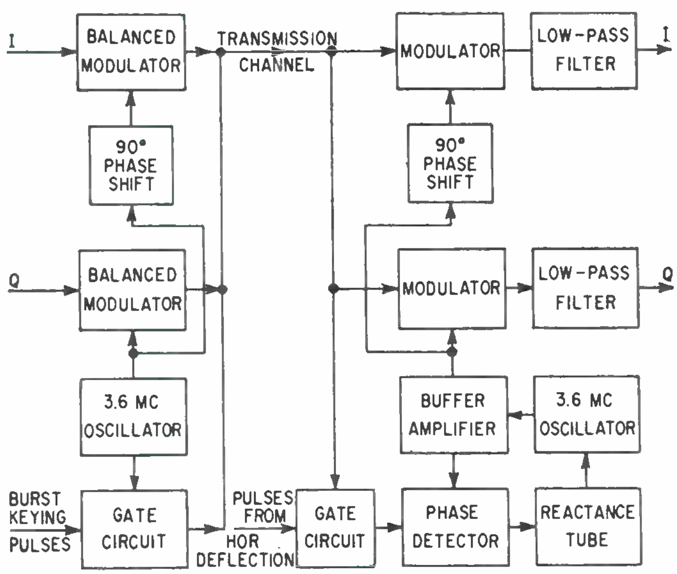


Fig. 20. Simplified block diagram showing elements for transmitting and receiving the I, Q, and burst signals.

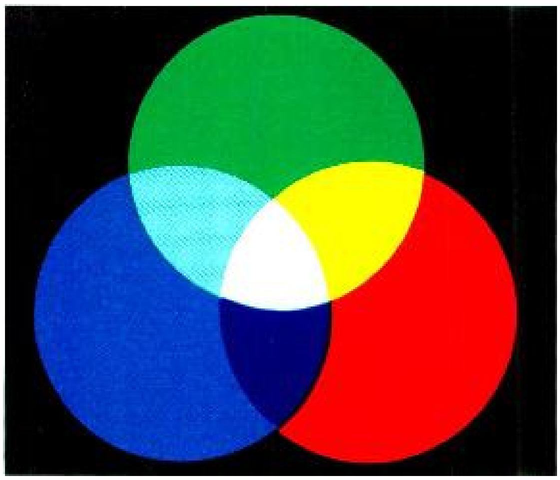


Fig. 9. The primary colors of television are red, green, and blue. Virtually any color can be matched by combining proper amounts of these primaries. White is produced by a combination of all three.

Fig. 10. Illustrating how a typical color image (upper left corner) can be separated by optical means into red, green, and blue counterparts.

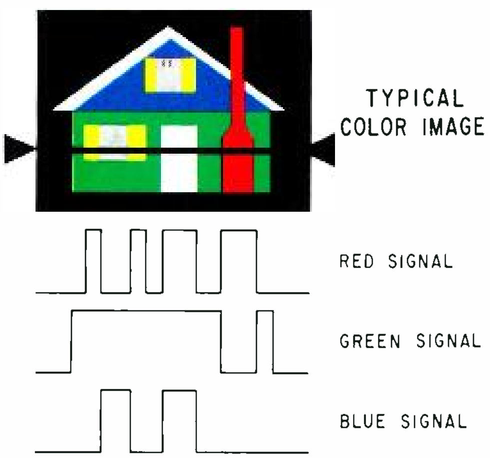


Fig. 18. Typical color image and RGB waveforms.

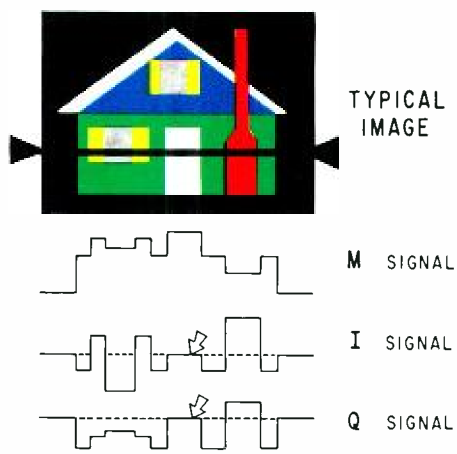


Fig. 19. Typical color image and MIQ waveforms.

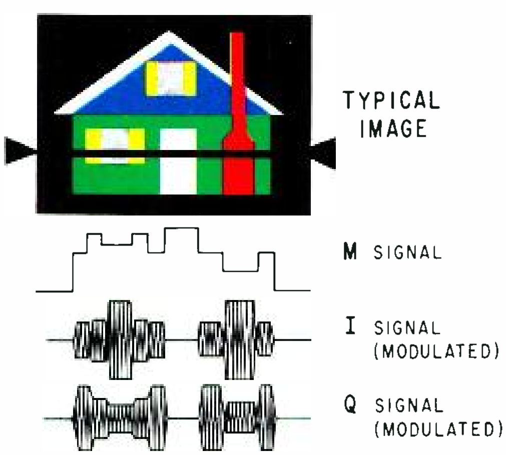


Fig. 27. Typical color image and waveforms of the M signal and modulated I and Q signals.

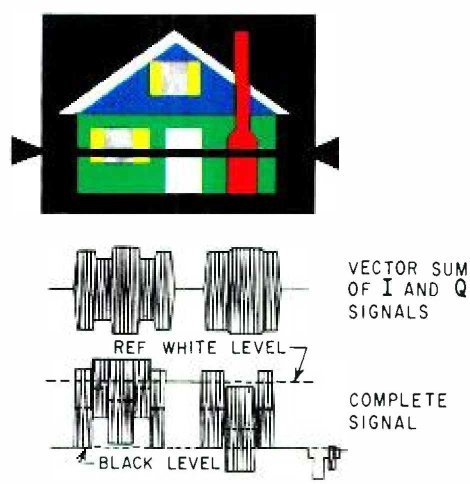


Fig. 28. Typical color image.

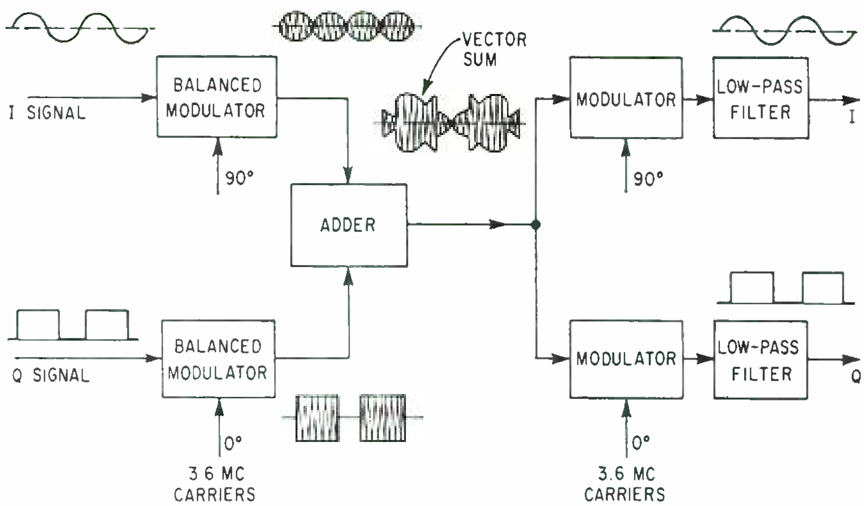


Fig. 21. Representative waveforms of the separate I, Q signals and the vector sum of the suppressed carrier sidebands at the modulator output. Original I and Q signals are recovered by heterodyning in balanced modulators at receiver.

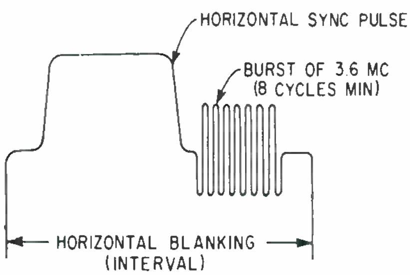


Fig. 22. Diagram showing position of subcarrier burst during horizontal blanking interval.

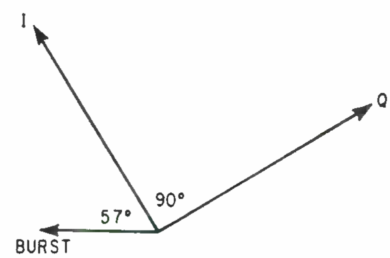


Fig. 23. Diagram showing phase relationship of I, Q, and burst signals.

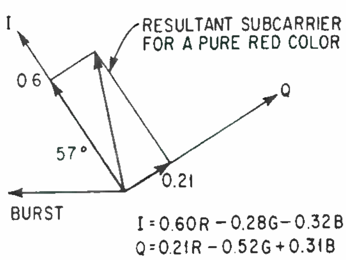


Fig. 24. Vector diagram showing phase and amplitude of subcarrier for a pure red signal.

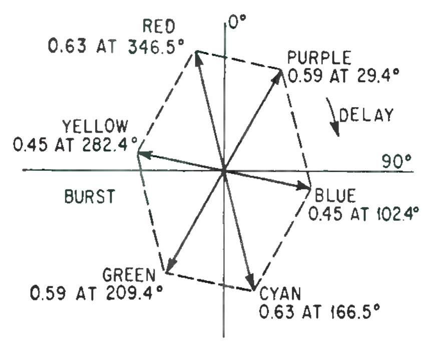


Fig. 25. Composite vector diagram showing subcarrier phase and amplitude for each of six colors.

turned "on" by burst keying pulses derived from the synchronizing generator. At the receiver, the two-phase modulated signal is applied to another gating circuit, known as a burst separator, which is keyed "on" by pulses derived from the horizontal deflection circuit. The separated bursts are compared in a phase detector with the output of the local 3.6 MHz oscillator. Any error voltage developed is applied through a smoothing filter to a conventional reactance tube or varactor which corrects the phase of the local oscillator.

FCC Standard phase relationships between the I and Q signals and the color synchronizing burst are shown in the vector diagram of Fig. 23. The

I and Q signals are transmitted in phase quadrature, and the color burst is transmitted with an arbitrary 57° phase lead over the I signal.

Several interesting properties of the two-phase modulated signal are illustrated by the vector diagrams which represent the resultant signal under known transmission conditions. For example, when a pure red color of maximum amplitude is being transmitted, the green and blue components are at zero and the I and Q signals have levels of 60 and 21 percent, respectively. When modulated upon their respective carrier, these signals produce the resultant shown in Fig. 24. The phase and amplitude shown are characteristic of pure red of maximum relative luminance. Fig. 25 is a composite vector diagram showing the phase and amplitude characteristics of the three primaries and their complementary colors. This composite diagram indicates that there is a direct relationship between the *phase* of the resultant two-phase modulated signal and the *hue* of the color being transmitted. There is also a relationship (although indirect) between the *amplitude* of the resultant signal and the saturation of the color being transmitted. If the phase of the resultant subcarrier and the level of the monochrome signal both remain constant, then a reduction in the amplitude of the subcarrier indicates a decrease in color saturation. The composite vector diagram also shows an interesting symmetry between complementary colors (colors are complementary if they produce a neutral when added together); the resultants for any two complementary colors are equal in amplitude but opposite in phase.

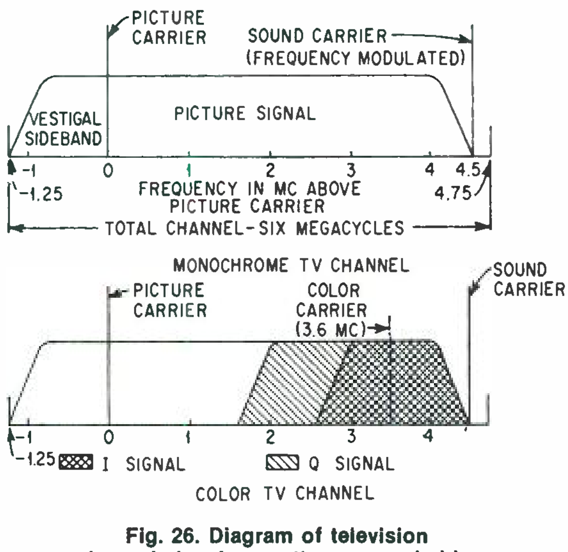


Fig. 26. Diagram of television channel showing portions occupied by color and monochrome signal components.

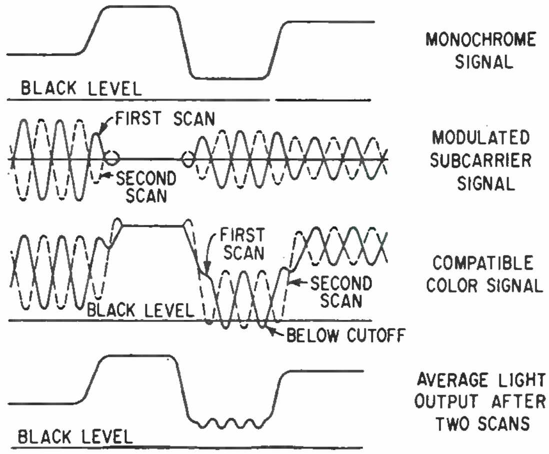


Fig. 29. Waveforms showing superposition of modulated subcarrier on scanning signals, compatible color signal, and effect of subcarrier on average light output.

Frequency Interlace

Since the 3.6 MHz carriers, consisting of the I and Q sidebands, fall within the video passband as shown in the diagram of the television channel (Fig. 26), they become subcarriers and can be handled in many respects like unmodulated video signals. By use of *frequency interlace* it is possible to add the several components of the chrominance and monochrome signals together without causing objectionable mutual interference.

The significance of the straightforward addition of signal components made possible by frequency interlace may be brought out by a study of waveforms derived from a simple color image. Fig. 27 shows M, I, and Q signals after the latter two have been modulated upon 3.6 MHz subcarriers. Note that both the I-and Q-signal components are at zero during the scanning of the white door, a neutral area. Fig. 28 (see page of color illustrations on (page 7.1-9) shows the vector sum of the I and Q signals and also the complete compatible color signal formed by adding together all the components, including synchronizing pulses and color-synchronizing bursts. The most significant fact about this signal is that it is still capable of providing good service to monochrome receivers, even though a modulated wave has been added to the monochrome-signal component. Although the modulated wave is clearly a spurious signal with respect to the operation of the kinescope in a monochrome receiver, its interference effects are not objectionable because of the application of the frequency-interlace principle.

The frequency-interlace technique is based on two factors: a precise choice of the color subcar-

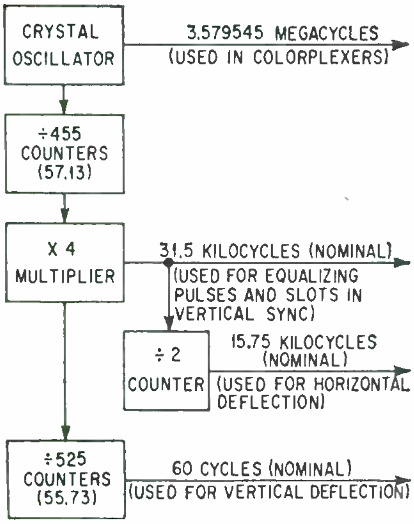


Fig. 30. Block diagram showing relationship between various frequencies used in color-television station.

rier frequency and the familiar "persistence-of-vision" effect. If the color subcarrier is made an *odd multiple of one-half the line frequency*, its apparent polarity can be made to reverse between successive scans of the same area in the picture. Since the eye responds to the average stimulation after two or more scans, the interference effect of the color subcarrier tends to be self-canceling, owing to the periodic polarity reversals. (see Fig. 29).

Color-Frequency Standards

The relationships among the various frequencies used in a compatible color system are illustrated in the block diagram of Fig. 29. The actual frequency of the color subcarrier, which has been referred to as 3.6 MHz is specified by FCC Standards as 3.579545 MHz or exactly 455 multiplied by ½ the line frequency.

In broadcast practice, the frequency of the color subcarrier provides a frequency standard for operation of the entire system. A crystal oscillator at the specified frequency provides the basic control information for all other frequencies. County stages and multipliers derive the basic frequencies needed in the color studio. A frequency of nominally 31.5 kHz required for the equalizing pulses which precede and follow each vertical sync pulse and for the serrations in the vertical sync pulse. A divide-by-2 counter controlled by the 31.5 kHz signal provides the line-frequency pulses at nominally 15.75 kHz needed to control the horizontal blanking and synchronizing waveforms. Another counter chain provides the 60 Hz pulses needed for control of the vertical blanking and synchronizing circuits.

The Overall Color System

The major functions performed in transmitting and receiving color are shown in the overall block diagrams of the transmitting and receiving systems (Figs. 31 and 32).

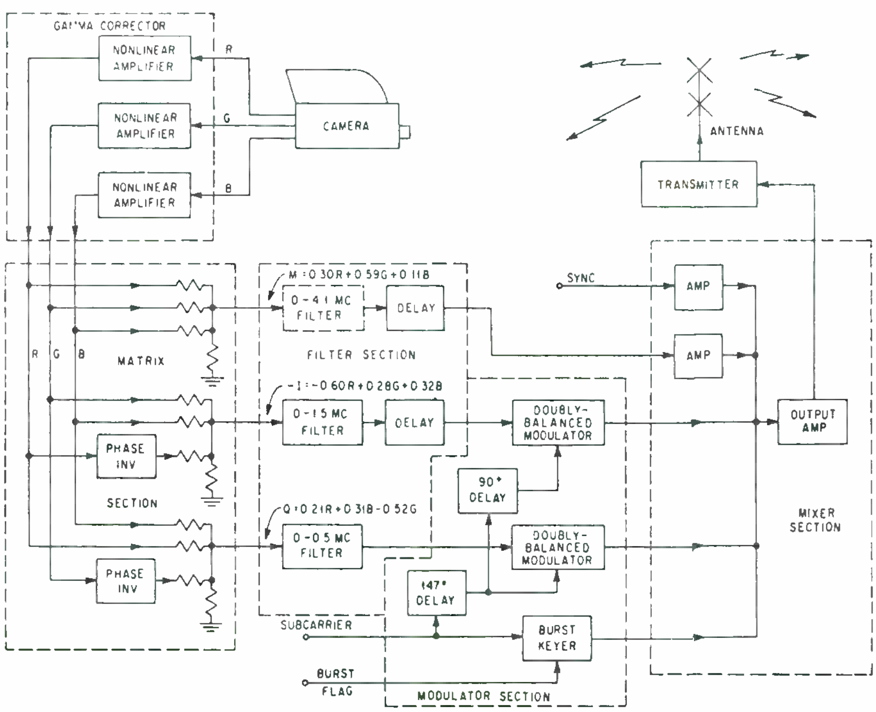


Fig. 31. Block diagram showing major functions of color-transmitting system.

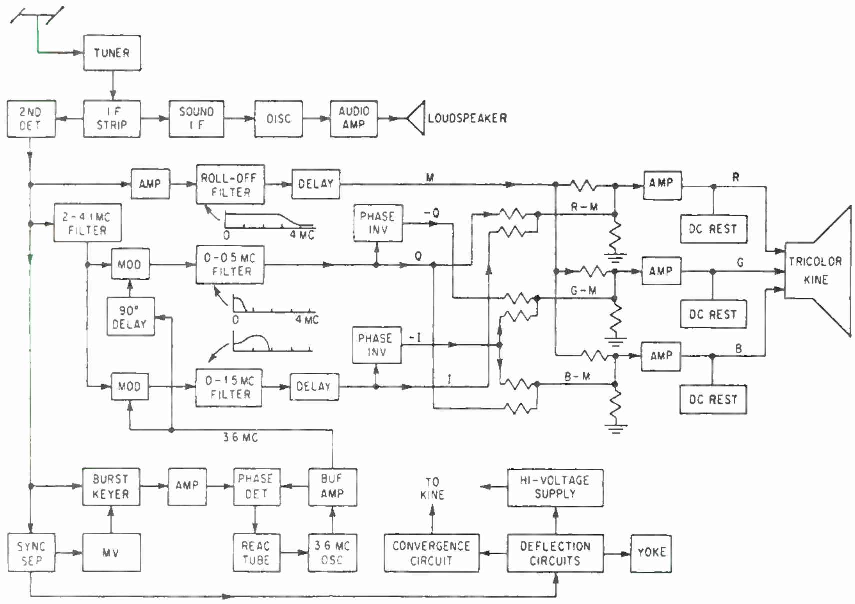


Fig. 32. Block diagram showing major functions of color-receiving systems.

At the transmitting end, camera output signals corresponding to the red, green, and blue components of the scene being televised are passed through nonlinear amplifiers (the gamma correctors) which compensate for the nonlinearity of the kinescope elements at the receiving end. Gamma-corrected signals are then matrixed to produce the luminance signal M and two chrominance signals I and Q. The filter section establishes the bandwidth of these signals. The 4.1 MHz filter for the luminance channel is shown in dotted lines because in practice this band shaping is usually achieved by the attenuation characteristics of the transmitter, and the filter is not required.

The bandwidths of 1.5 and 0.5 MHz known for the I and Q channels, respectively, are nominal only; the required frequency-response characteristics are described in more detail in the complete FCC signal specifications. Delay compensation is needed in the filter section in order to permit all signal components to be transmitted in time coincidence. In general, the delay time for relatively simple filter circuits varies inversely with the bandwidth. The narrower the bandwidth, the greater the delay. Consequently, a delay network or a length of delay cable must be inserted in the I channel to provide the same delay introduced by the narrower band filter in the Q channel, and still more delay must be inserted in the M channel.

In the modulator section, the I and Q signals are modulated upon two subcarriers of the same frequency but 90° apart in phase. The modulators employed should be of double balanced type, so that both the carriers and the original I and Q signals are suppressed, leaving only the sidebands. Some sort of keying circuit must be provided to produce the color-synchronizing bursts during the horizontal blanking intervals. To comply with the FCC signal specifications, the phase of the burst should be 57° ahead of the I component (which leads the Q component by 90). This phase position was chosen mainly because it permits certain simplifications in receiver designs. Timing information for "keying in" the burst can be obtained from a "burst flag generator," which is a simple arrangement of multivibrators controlled by horizontal and vertical drive pulses.

In the mixer section, the M signal, the two subcarriers modulated by I and Q chrominance signals, and the color synchronizing bursts are all added together. Provision is also made for the addition of standard synchronizing pulses, so that the output of mixer section is a complete color-television signal containing both picture and synchronizing information. This signal can then be put "on the air" by means of a standard television transmitter, which must be modified only to the extent necessary to assure performance within the reduced tolerance limits required by the color signal. (Since the color signal places more information in the channel than a black-and-white signal, the requirements for frequency response, amplitude linearity, and uniformity of delay time are more strict).

The Color-Receiving System

In a compatible color receiver, the antenna, RF tuner, IF strip, and second detector serve the same functions as the corresponding components of a black-and-white receiver except that the tolerance limits on performance are somewhat tighter.

The signal from the second detector is utilized in four circuit branches. One circuit branch directs the complete signal toward the color kinescope, where it is used to control luminance by being applied to all kinescope guns in equal proportions. In the second circuit branch, a band-pass filter separates the high-frequency components of the signal (roughly 2.0 to 4.1 MHz) consisting mainly of the two-phase modulated subcarrier signal. This signal is applied to a pair of modulators which operate as synchronous detectors to recover the original I and Q signals. It should be noted that those frequency components of the luminance signal falling between about 2 and 4.1 MHz are also applied to the modulators and are heterodyned down to lower frequencies. These frequency components do not cause objectionable interference, however, because they are frequency-interlaced and tend to cancel out through persistence of vision.

The remaining two circuit branches at the output of the second detector make use of the timing or synchronizing information in the signal. A conventional sync separator is used to produce the pulses needed to control the horizontal-and vertical-deflection circuits which are also conventional. The high-voltage supply for the kinescope can be obtained either from a "flyback" supply associated with the horizontal deflection circuit or from an independent RF power supply. Many color kinescopes require convergence signals to enable the scanning beams to coincide at the screen in all parts of the picture area; the waveforms required for this purpose are readily derived from the deflection circuits.

The final branch at the output of the second detector is the burst gate, which is turned "on" only for a brief interval following each horizontal sync pulse by means of a keying pulse. This pulse may be derived from a multivibrator controlled by sync pulses, as illustrated , or it may be derived from the "flyback" pulse produced by the horizontal output stage. The separated bursts are amplified and compared with the output of a local oscillator in a phase detector. If there is a phase difference between the local signal and the bursts, and error voltage is developed by the phase detector. This error voltage restores the oscillator to the correct phase by means of a reactance tube or varactor connected in parallel with the tuned circuit of the oscillator. This automatic-frequency-control circuit keeps the receiver oscillator in synchronism with the master subcarrier oscillator at the transmitter. The output of the oscillator provides the reference carriers for the two synchronous detectors; a 90° phase shifter is necessary to delay the phase of the Q modulator by 90° relative to the I modulator.

There is a "filter section" in a color receiver that is rather similar to the filter section of the transmitting equipment. The M, I, and Q signals must all be passed through filters in order to separate the desired signals from other frequency components which, if unimpeded, might cause spurious effects. The I and Q signals are passed through filters of nominally 1.5 and 0.5 MHz bandwidth, respectively, just as at the transmitting end. A step-type characteristic is theoretically required for the I filter, as indicated in Fig. 26, to compensate for the loss of one sideband for all frequency components above about 0.5 MHz. Actually, this requirement is ignored in many practical receiver designs, resulting in only a slight loss in sharpness in the I channel. A roll-off filter is desirable in the M channel to attenuate the subcarrier signal before it reaches the kinescope. The subcarrier would tend to dilute the colors on the screen if it were permitted to appear on the kinescope grids at full amplitude. Delay networks are needed to compensate for the different inherent delays of the three filters, as explained previously.

Following the filter section in the receiver there is a matrix section in which the M, I, and Q signals are cross-mixed to recreate the original R, G, and B signals. The R, G, and B signals at the receiver are not identical with those at the transmitter because the higher frequency components are mixed and are common to all three channels. This mixing is justifiable because the eye cannot perceive the fine detail (conveyed by the high-frequency components) in color. There are many possible types of matrixing circuits. The resistance mixers shown provide one simple and reliable approach. For ease of analysis, the matrix operations at the receiver can be considered in two stages. The I and Q signals are first cross-mixed to produce R-M, G-M, and B-M signals (note that *negative* I and Q signals are required in some cases), which are, in turn, added to M to produce R, G, and B.

In the output section of the receiver, the signals are amplified to the level necessary to drive the kinescope and the dc component is restored. The image which appears on the color kinescope screen is a high-quality full-color image of the scene before the color camera.

It should be made clear that the block diagram of Fig. 32 is intended only to illustrate the principles used in color receivers and does not represent any specific model now on the market. Design engineers of color receivers have shown great ingenuity in simplifying circuits, in combining functions, and in devising subtle variations in the basic process which have made possible significant cost reductions while maintaining excellent picture fidelity. The principles of compatible color television are firmly established, and it is to be expected that steady progress will be made in the practical application of those principles.

COLOR FIDELITY

"Color fidelity" as used herein, is the property of a color-television system to reproduce colors which are realistic and pleasing to the average viewer.

Although perhaps not apparent at first, color fidelity is analogous to "high fidelity" as applied to sound reproduction. Just as a high-fidelity audio system faithfully reproduces sounds reaching the microphone, the color-television system is capable of faithfully reproducing colors as seen by the television cameraman. In fact, the color television system is capable of reproducing colors more accurately than techniques presently used in color printing and color photography.

Tests have shown, however, that color-television pictures are generally more pleasing to the viewer when deliberate modifications are made in the reproduced colors to compensate for the surroundings in which they are reproduced. The situation is similar to that experienced in the art of sound reproduction in the case of a symphony orchestra recorded at high sound levels in a large hall and reproduced at lower sound levels in a small room. In this case, a more pleasing effect is obtained if the ear's new environment is taken into consideration and the reproduction is modified accordingly. Similarly, in color television, the changed environment of the eye must be con-

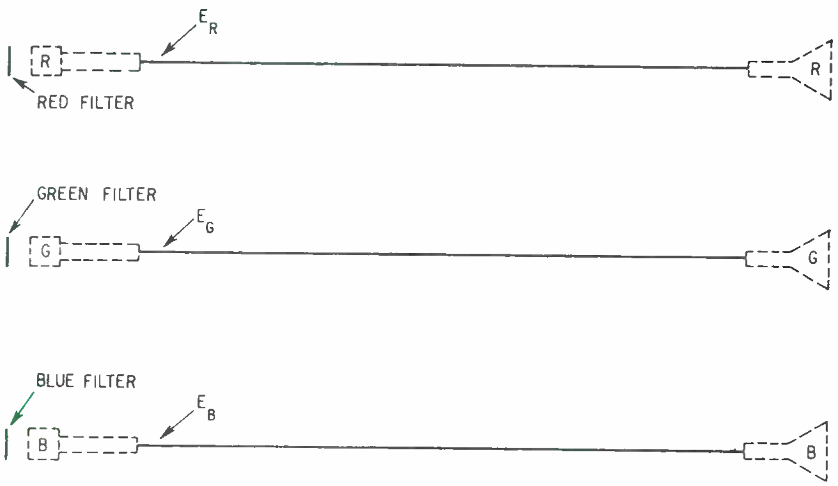


Fig. 33. Diagram of a theoretical color system showing linear RGB pickup tubes and kinescopes interconnected by wire.

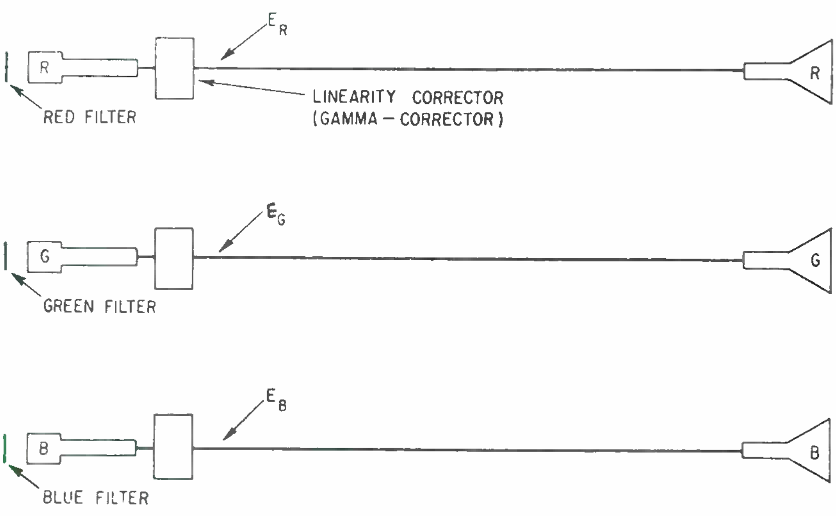


Fig. 34. The basic color system shown with necessary linearity correctors to compensate for color errors introduced by the nonlinear transducers.

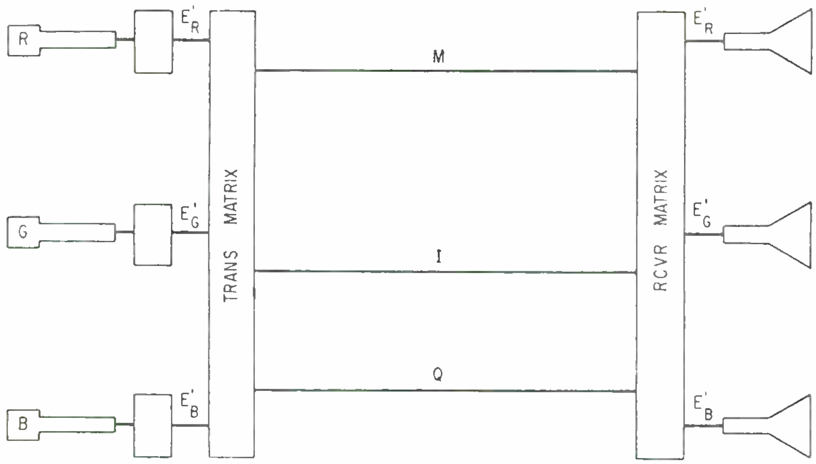


Fig. 35. Diagram showing transmitter and receiver matrix functions in the color system.

sidered and the reproduced colors modified accordingly.

Color fidelity, therefore, is a term used to indicate a color reproduction which pleases the viewer aesthetically and persuades him that he is viewing a faithful reproduction of the original colors in the scene being televised.[1]

The following describes possible distortions in the color system and their effect on the picture and prescribes amounts or degrees of distortion that can be tolerated without adverse effects on picture quality.

Color-System Analysis

Individual elements or areas of the complete color system are discussed in the following paragraphs with the aid of the diagrams shown in Fig. 33 through 37.

Fig. 33 is a theoretical color system in that it assumes linear camera tubes and a linear kinescope interconnected by a distortionless wire system. The only distortion that can result from this system is a flaw in colorimetry.

Fig. 34 introduces linearity correctors to compensate for color errors produced by nonlinearities in the transducers.

Figs. 35, 36, and 37 successively introduce the complexities of matrixing, band limiting, delay compensation, and the transmission system (shown dotted in Fig. 37). These diagrams, each representing a possible color system, introduce techniques used in compatible color television and permit the study of color distortions peculiar to each technique.

The systems diagrammed in Figs. 33 and 34 are described under Possible Distortions in Transducers, and those in Figs. 35, 36, and 37 under Possible Distortions in Encoding and Decoding Processes. The system shown in Fig. 37 is discussed under Distortions in the Transmission System.

Characteristics of the Eye

To appreciate fully the significance of color fidelity, it is helpful to consider some of the characteristics of the eye associated with color perception and to analyze such terms as color adaptation, reference white, and primary colors and determine their relationship to a color-television system.

Color Adaptation

One amazing characteristic of the eye is the phenomenon knows as color adaptation. It is this adaptation which enables one to describe accurately the color of an object under "white" light while viewing in nonwhite light. That is to say, recognition of color is surprisingly independent of the illumination under which an object is viewed. For example, if sunlight at high noon on a cloudless day is taken as "white" light, then, by comparison, the illumination from a typical 100-watt incandescent bulb is very yellow light. Yet it is known that an object viewed under sunlight looks very little if any different when viewed under incandescent light. Moreover, it is obvious to the observer, after a very few minutes in a room illuminated with incandescent lights, that the light is not yellow at all; it is really "white."

It is apparent, then, that the color seen by an observer is dependent upon the illumination to which that observer has been exposed for the past several minutes. This ambient illumination will have a marked effect on his choice of what color he is going to call "white."

This phenomenon can cause a loss of color fidelity under certain conditions. Consider, for example, a theoretically perfect color system with

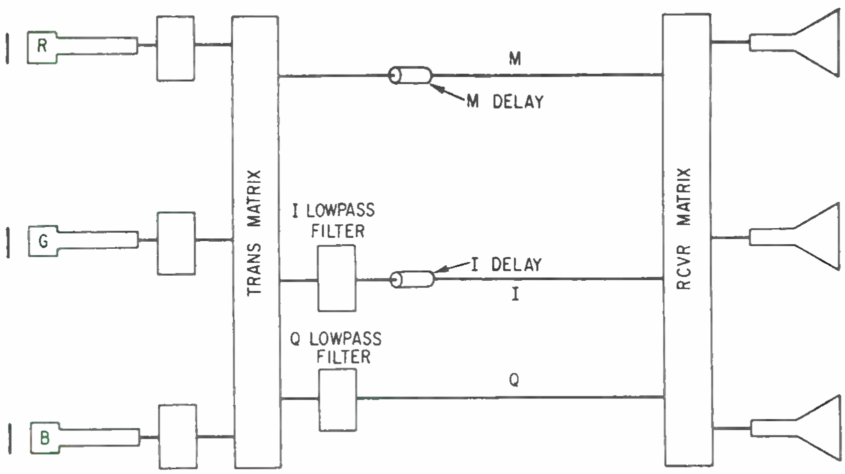


Fig. 36. Basic color system with band limiting and delay compensation.

camera viewing an outdoor scene under a midday sun while the reproduced picture is being viewed in a semidarkened room, with what little light is in the room also being derived from the midday sun. Under these conditions, the ambient illuminations at both camera and receiver are identical, so a man standing alongside the camera and a man viewing the receiver would both see the same colors. Now, if a change in the weather at the camera location should cause a cloud to cover the sun, the ambient illumination at the camera location would shift toward a bluer color. This shift would not disturb the viewer standing alongside the camera, because his eyes, bathed in the new ambient light, would rapidly adapt to the new viewing conditions and he would perceive the scene as being unchanged.

The man viewing the receiver would not be so fortunate. Assuming that he is far enough away that this same cloud would not affect his ambient, he would observe that everything on his screen had suddenly and inexplicably taken on a bluish cast, which he would certainly find most disturbing.

Such errors in color fidelity can be corrected by making the camera imitate the human eye in adaptation. The eye adapts to changes in ambient illumination by changing its sensitivity to a certain color. For example, if a light source changes from white to blue-white (as in the above example), the eye reduces its blue sensitivity until the light again appears to be white to the observer. Likewise, a camera operator can correct for the same situation by decreasing the gain of the blue

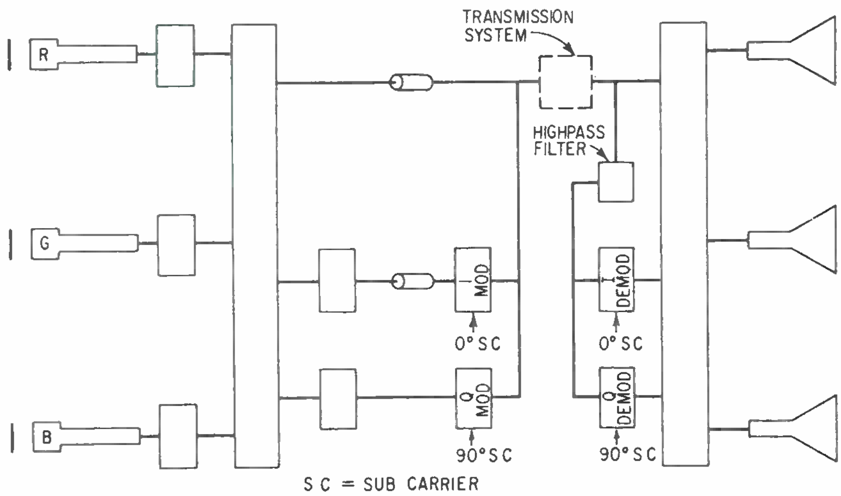


Fig. 37. Basic color system showing all major elements, including the transmission system.

channel of the camera or by attenuating the light reaching the blue camera tube. In this way, the camera is made to "color adapt," and the reproduced picture on a receiver loses its bluish cast.

Reference White

Although color adaptation can generate a problem such as the one just described, it also simplifies certain requirements. Specifically, it eases the requirement that white be transmitted as a definite, absolute color, for there clearly can be no absolute white when almost any color can be made to appear subjectively white by making it the color of the ambient illumination to which an observer's eye has adapted.

In color television, we take advantage of this characteristic in the following manner: A surface in the studio which is known by common experience to white, for example, the EIA Gray-Scale Chart of a piece of Neutracor white paper, is selected to be reproduced as white on a home receiver. The relative sensitivities of the three-color channels of the camera are then adjusted so that the camera "adapts" to this white regardless of the studio illumination. The home receiver can then be adjusted to reproduce the surface as any "white" which the home viewer prefers, depending upon his surroundings.

It has already been mentioned that the eye adapts readily to the illumination that surround conditions of an overcast day. This representative standard illumination has been adopted internationally as a base for the specification of the color of objects when they are viewed outdoors. This standard (Illuminant C) has been chosen to be the "standard-viewing-white" of the receiver. A slightly different illuminant has been proposed as (Illuminant D) more accurately representative of outdoor illumination and may replace Illuminant C in the near future.

The change in reference white between studio and home will inevitably produce errors in all reproduced colors, but the errors are small and, more important, then to be subjectively self-correcting, so that any given object will tend to produce the same color sensation whether viewed in relation to the studio reference white or the home reference white.

Consequently, a viewer may become familiar with an object such as a sponsor's packaged product and will recognize it on his television screen, under the fluorescent lighting of his supermarket, or under the incandescent lighting of his home and, furthermore, will note little difference in the colorimetric values of the package under the three conditions, even though the absolute colorimetric values would be appreciably different in the three situations.

Primary Colors

Of all the characteristics of the eye, there is perhaps none more fundamental to practical color television than that characteristic which allows us to choose certain colors called primary colors, and from these synthesize almost any other desired color by adding together the proper proportions of the primary colors. If it were note for this characteristic, each hue in a color system would have to be transmitted over a separate channel; such a system would be too awkward to be practical. Because of the eye's acceptance of synthesized colors, it is possible to provide excellent color rendition by transmitting only the three primary colors in their proper proportions.

Possible Errors in Transducers

The block diagram of Fig. 33 shows a fundamental color-television system using red, green, and blue primaries and three independent transmission channels. The camera tubes and kinescopes are shown dotted to indicate that any inherent nonlinearities in these devices are to be disregarded, for the moment, in order to simplify the discussion of the colorimetry of the system.

The general plan is a system such as that of Fig. 33 is to provide the three kinescopes with red, green, and blue phosphors, respectively, and to allow the corresponding camera tubes to view the scene through an appropriate set of red, green, and blue filters. If a phosphor and a filter have the same dominant wavelength, that is, if they appear to the eye to be the same color, it might be mistakenly supposed that they would be colorimetrically suited to be used as a filter and phosphor set for the channel handling that color. Actually, the basis for choosing filters and phosphors is much more complex and is based on the shape of the response curve of the filter, plotted against wavelength, and the shape of the light-output curve of the phosphor, also plotted against wavelength. The following paragraphs will discuss briefly a technique which might be used to determine the required relationship between the phosphor curves and the filter curves.

The color characteristics of the phosphor are generally less easily changed than are filter characteristics; for this reason characteristics of phosphors are taken as the starting point, and characteristics of the filters are determined from them. A laboratory setup which could be used to determine these characteristics is shown in Fig. 38. In this figure, an observer (who must have "normal" vision) is viewing simultaneously two adjacent areas, one of which is illuminated by a source of single-wavelength light which can select any wavelength in the visible spectrum, the other of which is illuminated by a red kinescope, a green kinescope, and a blue kinescope. The

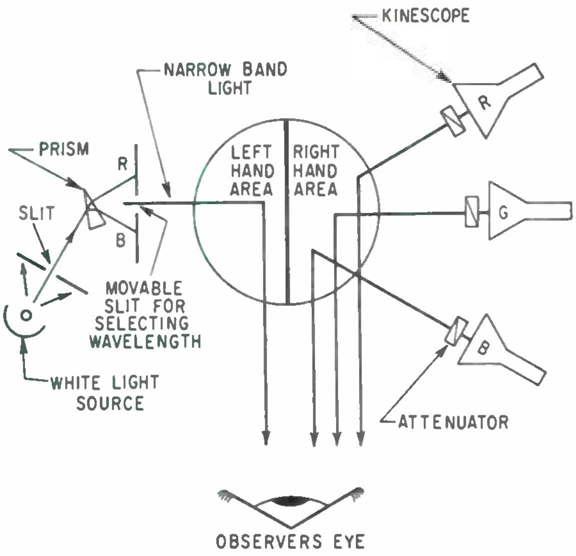


Fig. 38. Diagram showing laboratory setup arranged to compare narrow-band light source and R, G, and B light produced by kinescopes to determine proper camera-filter color characteristics.

phosphors of these kinescopes are the phosphors which are to be used in the color system. Starting at, say, the red end of the spectrum, a single-wavelength red is selected to illuminate the left-hand area, and the light from each of the three phosphors is varied until a color match is obtained between the left-hand and right-hand areas. The respective amounts of red, green, and blue lights needed to accomplish this match are recorded. Then another wavelength is chosen, the kinescope outputs varied to produce a match, and the new amounts of red, green and blue needed for a match are recorded. Similarly, points are obtained throughout the entire spectrum, and a graph is plotted showing the various required outputs versus wavelength. The shapes of these three curves—one for red, one for green, and one for blue—are the required shapes for the three camera-filter response curves. The resulting curves would in general resemble Fig. 38.

(To simplify the above discussion it was assumed that the camera tubes responded equally well to all wavelengths. In practice, camera tubes show higher output at certain wavelengths than at others. The filter-response curves derived by the above technique would have to be modified so that the combined response of filter and camera would be correct.)

Certain practical difficulties could result in errors in the above procedure. For example, if the observer had any deviations from normality in his color-vision characteristics (as most people do), these deviations would result in "nonstandard" matches and, hence, improper camera-filter characteristics. Also, if the phosphors were contaminated in any way during their manufacturing process (as most phosphors are, at least to some small degree), the resulting phosphor characteristics would not be the proper ones and hence would give rise to improper camera-filter characteristics. the observer errors can be normalized out by standard colorimetric procedures, but phosphor errors represent a basic error which may possibly be present not only in the above experiment but also in varying degrees in a large number of receivers. Quality control of phosphor manufacture is sufficiently good, however, to make the net effect unnoticeable in home receivers.

A striking practical difficulty would also arise regardless of observer or phosphor errors. For most wavelengths, no combination of red, green, and blue kinescope outputs could be found which would produce a match. In order to obtain a match at these wavelengths, it would be necessary to move one or two of the kinescopes over to the other side so that they could add their light to the single-wavelength light being matched. This procedure can be described mathematically, for graphing purposes, by saying that adding light to the left-hand area is the same as subtracting light from the right-hand area. Therefore, the amount of light added on the left would be considered as a negative quantity and would result in a point below the axis on the graph. Since this condition would be found to exist for several successive wavelengths, the resulting graph would show one or more minor lobes below the axis. These are called negative lobes.

These negative lobes represent a need for filters with negative light-transmission characteristics at certain wavelengths. Simple attenuating filters cannot yield such a characteristic, much more elaborate means would be required.

It is theoretically possible to achieve these negative lobes with added camera complexity but it has been shown that excellent color fidelity can be obtained by ignoring the negative lobes and

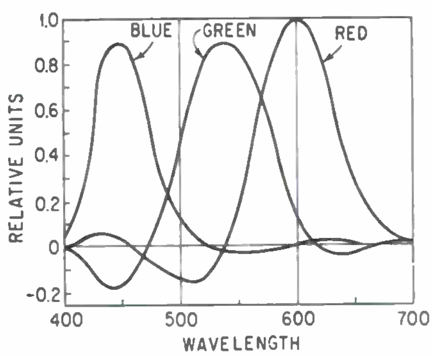


Fig. 39. Curves showing relative quantities in camera output required to produce correct kinescope colors over the visible spectrum.

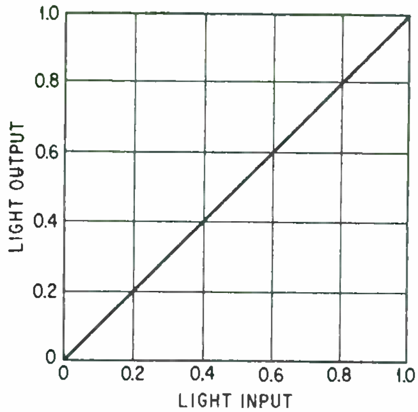


Fig. 40. Curve showing light-transfer characteristics of a perfectly transparent piece of window glass.

using filters which yield the positive lobes only. Positive-lobe processes such as color photography have gained wide acceptance for years. Masking techniques which employ electrical matrixing have been introduced which can modify the spectrum characteristics of a color camera. These techniques can be used to help compensate for deficiencies in the color fidelity such as the lack of negative lobes.

Transfer Characteristics

A piece of window glass is perhaps the nearest approach to a perfect video system. For a piece of glass, the light output (to the viewer) is essentially identical with the light output (from the scene). This fact is shown graphically in Fig. 40. This plot could be called the "transfer characteristic" of a piece of glass, since it describes the way that light is transferred through the system.

If the window glass is replaced by a neutral-density filter which attenuates light 3 to 1, the transfer characteristic will then be given by Fig. 40. The difference between Fig. 40 and 41 can be described by these simple relationships:

For the glass:

Light output = light input

For the neutral-density filter:

Light output = k X light input

Where:

k = ⅓ in this case.

Both systems are linear; that is, doubling the light input of either will double its light output; tripling input will triple output; etc. A nonlinear system does not exhibit this simple proportionality. For example, consider a system described by

Light output = k X (light input)^2

Doubling the input to this system will quadruple its output; a threefold increase in input will

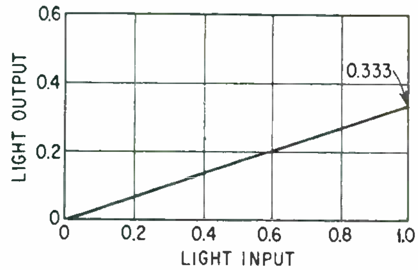


Fig. 41. Curve showing transfer characteristic of a neutral density filter with 3-to-1 light attenuation.

result in a ninefold increase in output; etc. The transfer characteristic for this type of system is shown in Fig. 42. Note that the characteristic is definitely nonlinear; that is, it is not a straight line as were Fig. 30 and 40.

In television and photography, nonlinearity is more common than linearity. For example, an ordinary kinescope is a nonlinear device, having a transfer characteristic which can be approximated by the expression

Light output = k (voltage input)$^{2.2}$

Camera tubes can be linear or nonlinear devices. For example, the characteristic of a vidicon is approximately

Current input = k (light input)$^{0.65}$

The general expression for nonlinear transfer characteristic can be given approximately as

Output = $k(input)^{\gamma}$

where the exponent is the Greek letter gamma.

Graphical Displays of Transfer Characteristics

Linear Plots

The first reaction of any person asked to display two variables (like light input and light output) on a set of XY coordinates is to divide

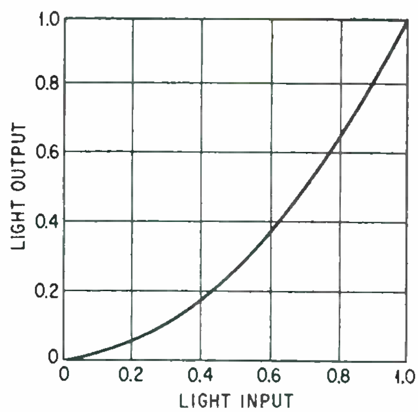


Fig. 42. Curve showing a nonlinear transfer characteristic.

X and Y coordinates into equal increments and plot the variables in this manner. A typical result of such a plot has already been described (Figs. 40 and 41). Such a plot has the advantage of showing at a glance the linearity of the device described by the variables. If the plot is a straight line, we say the device is linear; if curved, we say the device is nonlinear. Moreover, the slope of the line describes the attenuation (or gain) of the device. If the slope is unity (which occurs when the plot makes a 45° angle with the X axis), there is no attenuation; we are dealing with a very good piece of glass. For the neutral-density filter described above, which has the equation (light output) = ⅓ (light input), the line has a slope of one-third (see Fig. 41).

Such are the advantages of plotting transfer characteristics with equal-increment divisions of the X and Y axis. However, other advantages—very important ones—can be obtained by dividing up the X and Y coordinates logarithmically. Such a plot is called a log-log plot.

Log-Log Plots

Consider a system which has a transfer characteristic given by $L_0 = (L_{in})^{2.2}$ If this equation is plotted on axes which are divided logarithmically, the resulting plot is the same as though the logarithm of both sides of the equation were plotted on equal-increment axes. Taking the logarithm of both sides, we obtain

$$\log L_0 = \log (L_{in})^{2.2}$$

Since $\log (L_{in})^{2.2}$ is the same as $2.2 \log (L_{in})$, then

$$\log L_0 = 2.2 \log L_{in}$$

Comparing the form of this equation with an earlier equation, light output = ⅓ light input, we can see that just as the attenuation, 1/3, was the slope of the earlier equation, so 2.2, the exponent, is the slope of the latter equation. We see, then that the use of logarithmically divided coordinates yields a plot in which the exponent is given by the slope of the line. Therefore, this plot will show at a glance the magnitude of the exponent and will also show whether or not the exponent of the system is constant for all light levels. It also is advantageous in showing the effects of stray light.

Figs. 43a and 43b compare the two types of plotting for three types of transfer characteristics.

The Effect of a Nonlinear Transfer Characteristic on Color Signals

Effect of Identical Nonlinearities in Each Channel

In monochrome television, some degree of nonlinearity can be tolerated, but such is not the case for a color-television system. It can be shown that a system exponent different from unity must inevitably cause a loss of fidelity. For an example, consider a situation in which signals are being applied through linear amplifiers to the red and green guns of a perfectly linear (theoretical) kinescope. The green amplifier is receiving 1.0 volt; the red amplifier, 0.5 volt. If everything is perfectly linear, the proportions of the light output should be 1.0G + 0.5R = greenish yellow. However, if the kinescope has an exponent of 2.0, the light output will be $(1.0)^2G + (0.5)^2R = 1.0G + 0.25R$ = greenish yellow with an excess of green.

From the above specific case, it may be correctly inferred that in general, a system exponent greater than 1 will cause all hues made of the combination of two or more primaries to shift toward the larger or largest primary of the combination. Conversely, a system exponent less than 1 will shift all hues away from the largest primary of the combination.

In the above example, an exponent of 0.5 would yield $(1.0)^{0.5}G + (0.5)^{0.5}R = 1.0G + 0.707R$ = a greenish yellow which is a shade off a pure yellow.

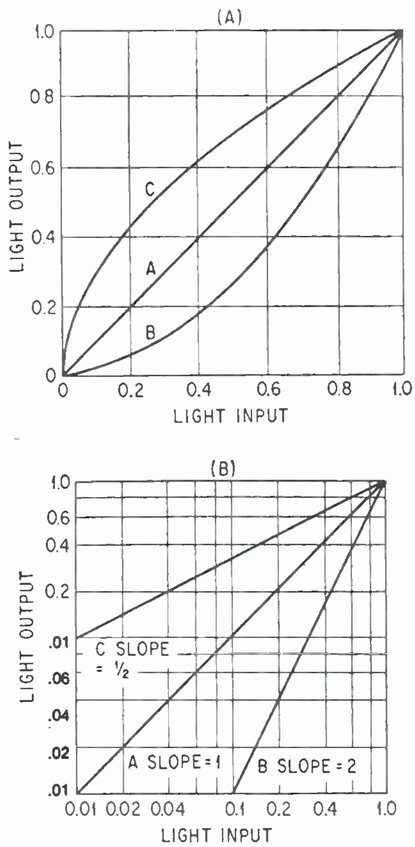


Fig. 43. Graphs showing the curves obtained by plotting A, B, and C types of transfer characteristics on linear coordinated (A) and on log-log coordinates (B).

In addition, the reader can correctly conclude that white or gray areas, in which all the primaries are equal, will not be shifted in hue by a nonunity exponent.

Effect of Differing Exponents in Each Channel

The preceding discussion assumed that all three channels (in Fig. 33) have the same exponent, whether unity or not. In practical systems, however, there is always the possibility that the exponents of the channels may differ from one another. This situation will produce intolerable color errors if the differences become even moderately large. In general, the requirements for "tracking" among the light-transfer characteristics of the individual channels are even more stringent than the requirement for unity exponent.

Figs. 44a, 44b, 44c, and 44d show graphically the effects of unequal exponents in the three channels. In all four figures, the red and blue exponents are taken as unity; in Figs. 44a and 44b the green exponent is taken as less than 1, and in Figs. 44c and 44d, as greater than 1. In Fig. 44a, the transfer characteristics are shown for the system adjusted to produce peak white properly. It can be seen that the bowed characteristic of the green channel will cause all whites of less than peak value to have too much green. A gray-scale step tablet before the camera would be reproduced properly only at peak white; the gray steps would all have a greenish tinge. Relative channel gains could be readjusted to reproduce one of the gray steps properly (Fig. 43b), but then all highlight steps would be purplish while lowlight steps would still be greenish.

A green-channel exponent greater than unity would reverse the above results (Figs. 44c and 44d). With gains adjusted to reproduce peak white properly (Fig. 44c), lowlights would be purplish; with gains readjusted to provide proper reproduction for one of the lower steps (Fig. 44d), highlights would be green and lowlights purple.

The Effect of Stray Light

If a kinescope is viewed in a lighted room, there will always be some illumination on the faceplate. Therefore, the eye will always receive some "light output" from the kinescope, regardless of the magnitude of the signal input voltage. Under this condition, a true black is impossible to obtain.

This condition is reflected in the transfer characteristic of the system. If, for example, the stray light were 5 percent of the peak highlight brightness of the picture, a linear plot of light output versus light input would have the entire transfer characteristic shifted upward by 5 percent. However, the most interesting change is found in the log-log plot, where, as seen in Fig. 45, the stray light causes a change in the slope in the lowlight regions. Since the slope is equal to the exponent, this change shows that stray light causes an effective exponent error in the lowlight regions of the picture and hence will cause color-fidelity errors which will be most marked in lowlight regions.

These errors will be noted by an observer as improper hues and saturations, with the saturation errors—a "washing out" of the more saturated lowlight areas—being the more objectionable to a viewer.

Stray light is not the only cause of errors of this type. Similar effects will be noted whenever the kinescope bias ("brightness") is set too high, if camera pedestal is set too high, or if stray light enters the camera (whether through lens flare or any other source). In general, any condition which prevents the light output of the system from becoming zero when the light input is zero will cause errors similar to those caused by stray light.

Linearizing a System

It can be shown that a system using a vidicon with an exponent of 0.675 to drive a kinescope with an exponent of 2.2 will have an overall exponent given by the product 0.65 x 2.2 = 1.43, assuming that all devices in the system are linear.

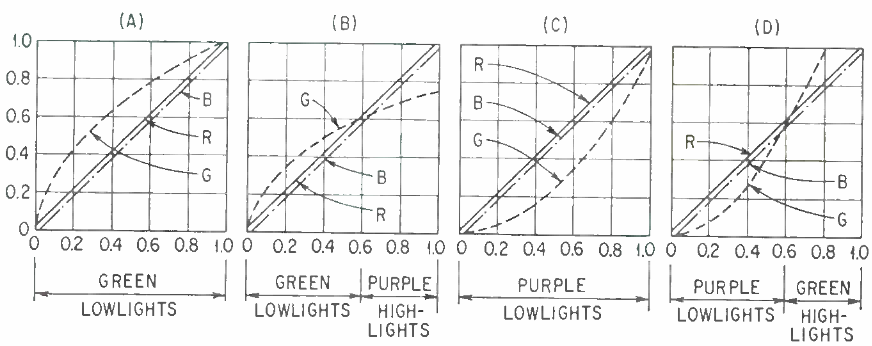


Fig. 44. Linear plots showing graphically the effect of unequal exponents in the R, G, and B channels. In all four graphs the R and B exponents are taken as unity. In (A) and (B) the green exponent is taken as less than 1, and in (C) and (D), as greater than 1.

In general, the overall exponent of a system is the product of the exponents of the cascaded elements.

This knowledge provides an excellent tool for linearizing a system. For example, a system with an overall exponent of 1.43 could be linearized by inserting somewhere (in a video path) an amplifier having an exponent of 1/1.43 (=0.7) so that the product becomes unity:

$$1.43 \text{ X } 1/1/43 = 1$$

In Fig. 34, a nonlinear amplifier, or gamma corrector, is shown inserted in each of the three paths.

Possible Encoding and Decoding Distortions

The second of the two systems discussed in the preceding section bordered on being a practical system but still required three independent 4 MHz channels. A fortunate characteristic of the human eye—the inability to see colored fine detail—allows us to modify this requirement to one 4 MHz channel for monochrome fine detail and two much narrower channels for color information. Before this modification can be made, the red, green, and blue signals must be combined to form three other signals, usually called M, I, and Q, such that the M signal alone requires a 4 MHz channel, and the I and Q channels, which contain the color information, are confined to narrower channels. This rearrangement of red, green, and blue to form M, I, and Q is called matrixing and was described in the previous part. A system which uses a matrix is block-diagramed in Fig. 35. The illustration also shows that to recover the original red, green, and blue signals at the receiving end, a "rearranging" device is needed. This device is usually called the receiver matrix.

Matrixing alone offers no advantage unless steps are taken actually to limit the I-signal and Q-signal channels to the narrow bandwidths allowed. Fig. 36 shows a system employing such band shaping. The band-shaping filters themselves always introduce delay, which must be compensated for by placing delay lines in the wider band channels, as shown in the diagram.

To put both color and monochrome information in the spectrum space normally occupied by monochrome only requires that the color information overlap the monochrome. This overlap can be allowed for both I and Q signals, without incurring visible cross talk, if two techniques, known as frequency interlace and two-phase modulation are employed. A system using these techniques, which were described in the section on Electronic Aspects of Compatible Color Television, is block-diagramed in Fig. 37.

Possible Errors in the Matrixing Process

The entire matrixing process can be summed up in two sets of equations, the first set describing how the transmitter matrix takes in red, green, and blue and turns out M, I, and Q:

$$\begin{aligned} M &= 0.30R + 0.59G + 0.11B \\ I &= 0.60R - 0.28G - 0.32B \\ Q &= 0.21R - 0.52G + 0.31B \end{aligned}$$

and the second set describing how the receiver matrix takes in M, I, and Q and recreates red, green, and blue:

$$\begin{aligned} R &= 0.94I + 0.62Q + M \\ G &= 0.27I + 0.65Q + M \\ B &= 1.11I + 1.7Q + M \end{aligned}$$

Both matrices can therefore be considered as analog computers which continuously compute the desired output from the given input. The coefficients in the above six equations are usually determined in the "computers" by precision resistors or, in the case of negative numbers, by precision resistors and signal-inverting amplifiers. The basic error that can occur, therefore, is a change in a resistor value or an amplifier gain, resulting in a change in one or more coefficient. In general, the resulting picture error resembles cross talk among the primary colors.

More specifically, the transmitter matrix can have two distinct types of errors. The first type involves the coefficients of the equation for M; the second type, the coefficients for I and Q. An error in an M coefficient will brighten or darken certain areas. In a monochrome reproduction of a color signal, such an error, if small, would not be noticed; if large, it would still probably be tolerated by the average viewer. In a color reproduction, however, even a small error would be objectionable. For example, a reduction of the red coefficient from 0.3 to 0.2 would cause a

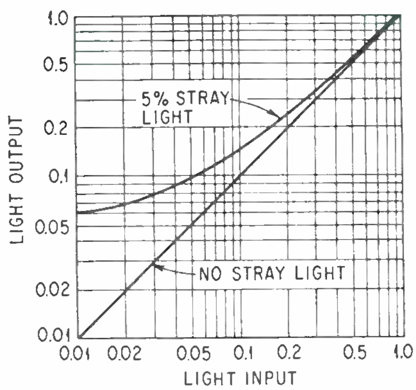


Fig. 45. Log-log plot of system with stray light, illustrating change of slope in the low-light regions.

human face to be reproduced with an unnatural ruddy complexion and dark red lips.

Note that the sum of the M coefficients is 1. An error in one coefficient would change this sum, so that peak white would no longer occur as 1 volt. An operator could mistake this condition for a gain error and adjust either M gain or overall gain in an effort to obtain the correct peak-white voltage. Changing M gain would cause errors to occur in all M coefficients; changing overall gain would put errors in all coefficients. Although such an error is rare in well-engineered equipment, it is a possible source of color error which can be compounded by misdirected attempts at correction.

Note that the sums of the Q and I coefficients are each zero, which means that when R = G = B (the condition for white or gray), Q and I both equal zero. An error in a Q or I coefficient would cause color to appear in white or gray areas and, in addition, would cause general errors in colored areas resembling cross talk among the primaries. Controls are usually provided in the Q and I matrices, called Q white balance and I white balance, respectively, which allow the operator to adjust the sum of the Q or I coefficients by changing the value of one of the coefficients. If the coefficient controlled is the one in error, then adjusting white balance restores the condition that the sum of the coefficients is zero, that is, it removes the color from white and gray objects, but it does so by giving the controlled coefficient an error which just counteracts the error of a nonadjustable coefficient, so that two coefficients are wrong instead of one. Again, such an error is rare in well-engineered equipment, for the adjustable coefficient is usually the one in error. However, the possibility of an error compounded by adjustment should be kept in mind.

A far more likely cause of white-balance error is an error in input level, that is, a discrepancy between the peak white levels of input red, green, or blue. In such a case, an operator can still achieve white balance (Q and I = 0 for white input) but the entire system will be in error. The starting point for all investigations of the cause of white balance errors should be the levels of the red, green, and blue colorplexer inputs.

In the receiver matrix, only one general type of error can occur instead of two as in the case of the transmitter matrix. This type of error, a general coefficient error, results in cross talk among the primary colors. For example, a change in the I coefficient for the red equation from 0.94 to 0.84 would yield about a 7 percent reduction in the peak red output available and would also result in unwanted red light output in green or blue areas at about 3½ percent of the green or blue level.

Gain Stability of M, I, and Q Transmission Path

In the system of Fig. 35, every gain device or attenuating device in the three transmission paths must maintain a constant ratio between its input and output in order to maintain the proper ratios among the levels of M, I, and Q at the input to the receiver matrix. A variation in the gain of one of these paths will result in a loss of color fidelity.

For example, a reduction in M gain must obviously cause a reduction in the viewer's sensation of brightness. Not quite so obvious are the effects of I and Q gain. Since these are color signals, their amplitude would be expected to influence the sensation of saturation, but the manner of this influence is not intuitively obvious until the factors which influenced the selection of I and Q compositions are recalled. It previously was pointed out that the eye has the greatest need for color detail in the color range from orange to blue-green (cyan) and the least in the range from green to purple. Hence I, the wider band signal, conveys mainly orange and cyan information, and Q, the narrower band signal, conveys principally the greens and purples. Therefore, a reduction in I gain could be expected to reduce the saturation sensation for colors in the orange and cyan gamut, leaving the greens and purples virtually unaffected. Conversely, Q gain will influence the greens and purples without causing much change in the appearance of orange and cyan objects.

Modulation and Demodulation

The system of Fig. 35, which introduced bandwidth limiting of the I and Q signals in accordance with the capabilities of the eye to see colored fine detail, is a fairly practical and economical system, except for the fact that three individual transmission channels are employed. If we are to have a compatible system, however, these three channels must be reduced to one through some multiplexing technique. The technique used has already been described, and a system employing this technique is block-diagrammed in Fig. 37.

Possible Errors in Modulation

Burst Phase Error

Perhaps the most fundamental error in the multiplexing process would be an error in the phase of the main timing reference, burst. Since the entire system is based on burst phase, an error in burst phase will appear as an opposite error in every phase except burst, because the circuits will insist that burst phase cannot be wrong. The general result will be an overall hue error in the reproduced picture. This effect can be better visualized by referring to Fig. 46.

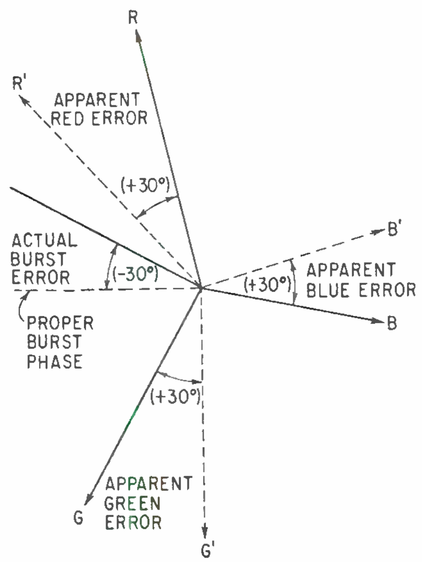


Fig. 46. Vector diagram showing how error in subcarrier phase becomes an opposite error in all other phases.

A phase error in burst produces the same result as holding burst phase stationary and allowing all other phases to slip around the circle an equal amount (but in a direction opposite to the burst-phase error). Each color "vector" then represents a hue other than the one intended.

Burst Amplitude Error

In theory, the receiver circuits which extract timing information from the burst are insensitive to variations in burst amplitude as long as the burst is large enough to maintain a respectable signal-to-noise ratio and not so large that some type of clipping or rectification upsets the burst circuitry. But practical receivers always exhibit some degree of sensitivity depending mainly upon the error in the subcarrier oscillator in the receiver. If the free-running frequency of the receiver oscillator is very different from burst frequency—particularly if the difference is so great that the burst is in danger of losing control of the oscillator—then a fairly appreciable amplitude sensitivity will be noted. This sensitivity will take the form of a phase error, and the net result will be indistinguishable from a burst phase error, as discussed above.

Some receivers have a circuit which automatically adjusts the gain of the color-information channels so that the viewer always sees the proper saturations, regardless of errors which might tend either to "wash out" or to oversaturate the picture. Such a circuit, called an automatic chroma control (ACC), derives its control information from the amplitude of burst, which is presumed to bear a constant ratio to the amplitude of chroma. Transmission distortions, for example, might decrease the amplitude of both burst and chroma, but since the ratios of their amplitudes would be preserved, an ACC receiver could automatically modify its chroma-channel gain to compensate for the decreased chroma amplitude. However, if a color encoder error should cause burst alone to decrease in amplitude, the ACC circuits would increase chroma gain just as in the above case, with the result that a viewer would receive an oversaturated picture.

Two-Phase Modulation Errors

The fidelity of color reproduction can be seriously affected if the phase separation of the Q and I subcarriers is not maintained at 90°. It can be shown that a "slip" in the angular position of the Q axis, for example, will result in cross talk of Q and I. The final result will be the same as cross talk among the primary colors.

Likewise, in a receiver, the phase relationship between the reference subcarriers must be maintained to avoid a similar error. Any deviation from the proper phase relationship will have a result similar to the above, that is, cross talk of I into Q or Q into I, with the net picture result resembling cross talk among all the primary colors.

Carrier Unbalance

In a properly operating doubly balanced modulator, the carrier component of the signal is suppressed in the modulator circuit. If some error in components or operation causes this suppression to be imperfect, the carrier will appear in the output. This condition is known as carrier unbalance.

The effect of carrier unbalance can be evaluated by considering the unwanted carrier as a vector of constant amplitude which adds itself vectorially to every vector present in the colorplexer output. In general, such a vector will shift all vectors and hence all hues seen in the picture toward one end of the other of the color axis represented by the unbalanced modulator. For example, a positive unbalance in the I modulator would shift all colors toward the color represented by the positive I axis, that is, toward orange. A negative I unbalance would shift all colors toward cyan.

To visualize this effect, refer to Fig. 47, in which has been added to each color vector a small positive vector which is parallel to the I axis. This small vector represents the amount of carrier unbalance. The resultant vectors will all be rotated toward the positive I axis and changed in amplitude as well. Such changes represent errors in both hue and saturation.

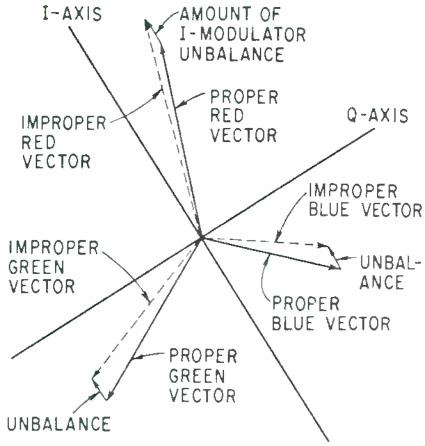


Fig. 47. Vector diagram of subcarrier phase and amplitude with positive vectors added to represent carrier unbalance in the I modulator.

Another error from carrier unbalance occurs in white and gray areas of the picture. In a normally operating colorplexer, a white (or gray) area in the scene causes the Q and I signals to become zero and thereby causes the modulator outputs to become zero. Hence, a white or gray area will normally appear in the signal as an interval of zero subcarrier amplitude. If one of the modulators begins to produce a carrier-unbalance vector, however, a white or gray area will become colored because of the subcarrier which will be added in this interval. Moreover, certain areas which are normally colored may have their subcarrier canceled by the carrier-unbalance vector and become white. Such white-to-color and color-to-white errors are very objectionable.

Video Unbalance

A doubly balanced modulator derives its name from the fact that it balances out or suppresses both the carrier (as described above) and the modulating video (Q or I). If, for any reason, the video suppression becomes less than perfect, the resulting condition is called video unbalance.

Video unbalance will cause unwanted Q or I video to appear in the modulator output, in addition to the desired sideband outputs. This unwanted video signal will be added to the luminance signal, thereby distorting the gray scale of the picture. For example, a slight positive unbalance in the Q modulator would slightly brighten reds and blues and slightly darken greens. A negative unbalance would have the opposite effect.

Subcarrier-Frequency Error

The color subcarrier frequency is specified by the Federal Communications Commission to be 3.579545 MHz ±10 Hz. Deviations within this specified limit are of no consequence (provided they are slow deviations). Large deviations, however, can affect color fidelity. The effect does not usually become serious within the possible frequency range of a good crystal-controlled subcarrier source driving a properly designed receiver.

In receivers, the subcarrier timing information is extracted from the burst on the back porch and used to control the frequency of a subcarrier-frequency oscillator in the receiver. As long as the unlocked frequencies of the burst and the receiver oscillator remain the same, the locked phase relationship between the two will remain the same. But if either the burst frequency or the receiver-oscillator frequency becomes different (and the difference between them is not so large that lockup is impossible), then the locked error, which obviously cannot be a frequency error, manifests itself as a phase error. This error can become as large as ±90° before the AFC circuit can no longer hold the receiver oscillator on frequency. The frequency range over which this phase shift occurs depends upon the receiver design.

Possible Distortions in the Transmission System

Preceding sections have described the processes involved in the generation and display of a color-television signal. Errors in these processes are not the only possible source of distortion; when the signal is transmitted over great distances, the transmission system itself may contribute errors. This section discusses parameters which specify the behavior of a transmission system and describes the effects that errors in these parameters can have on the reproduced picture.

This section is divided into two parts. The first relates to the parameters of a perfectly linear transmission system, while the second part discusses the additional parameters required to describe the nonlinearities that are inevitable in any practical system.

The Perfectly Linear Transmission System

A perfectly linear and noise-free transmission system can be described by its gain and phase characteristics plotted against frequency as the independent variable.[2] Typical plots are shown in Figs. 48 and 49, respectively. These two characteristics known, it is possible to predict accurately what effect the transmission system will have on a given signal.

Gain Characteristic

Fig. 48 is usually known as the frequency response or gain characteristic or the system.

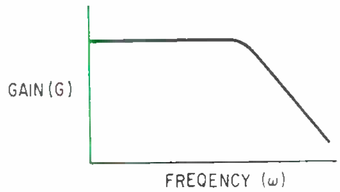


Fig. 48. Typical curve showing gain of a system plotted against frequency to determine its gain characteristic.

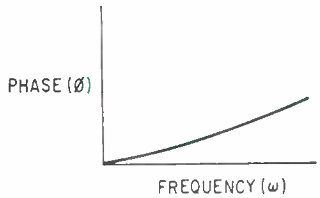


Fig. 49. Curve showing phase characteristic of a system plotted versus frequency.

Ideally, it should be perfectly flat from zero to infinite frequency, but this, of course, is impossible to attain. An amplifier has a definite gain-bandwidth product, depending upon the transconductance of its active elements (tubes or transistors), the distributed capacity shunting these elements, and the types of compensation (peaking) employed. The bandwidth of a given combination of tubes, transistors, stray capacitances, and peaking networks can be increased only by decreasing its gain, or conversely, its gain can be increased only by decreasing its bandwidth. There is a limitation, therefore, to the actual bandwidth that can be obtained. For a given scanning standard, the bandwidth required in a monochrome-television system is determined by the desired ratio between the horizontal resolution and the vertical resolution. Although nominally a 4.0 MHz bandwidth is required for the monochrome standards, the requirement can be relaxed to the detriment of only the horizontal resolution. The subjective result is a "softening" of the picture in proportion to the narrowing of the bandwidth (neglecting the influence of the phase characteristic in the vicinity of the cutoff frequency). As pointed out in preceding sections, the entire chrominance information of the color system is located in the upper 1.5 MHz of the prescribed 4.0 MHz channel; hence, any loss of response in this part of the spectrum can have a marked effect on the color fidelity of the reproduced picture.

One of the most serious forms of distortion inflicted on a color picture by bandwidth limiting is loss of *saturation*. Consider a case in which the bandwidth is so narrow as to result in no gain at the color subcarrier frequency. The output signal then contains no color subcarrier and hence reaches the color receiver as a monochrome signal, producing zero saturation. Nearly as poor results can be expected from an amplifier with response such that the gain at 3.58 MHz is one-half the low-frequency gain. Since the saturation depends chiefly on the amplitude of the subcarrier, the saturation will be correspondingly reduced. The resultant color picture will have a "washed out" look.

Loss of high-frequency response, which can be expected to contribute to loss of fidelity, is usually accompanied by phase disturbance, depending on the type of networks employed in the system. The intent in this section, however, is to treat each variable separately. Therefore, discussions are based on the effects of varying only one parameter of a system. It is suggested that the reader can determine the combined effect of two or more variables by comparing the results shown for the individual variables.

Phase Characteristic

An ideal system has a *linear* phase characteristic, as in Fig. 50a. Such a characteristic implies that all frequencies of a signal have exactly the same *time* delay in passing through this system, since the time delay is given by the phase angel divided by the (radian) frequency. It can be seen in Fig. 50 that if three frequencies are chosen arbitrarily, then the corresponding phase angles must have values proportional to their corresponding frequencies (because of the geometric properties of a right triangle). To state it another way, if $\phi_1/\omega_1 = 0.2$ μsec, then ϕ_2/ω_2 0.2 μsec and 2 also equals ϕ_3/ω_3, too, is 0.2 μsec. Plotting these three values and drawing a straight line through them as in Fig. 50a will show that the time delay for all frequencies is 0.2 μsec.

A signal is not distorted by delay as long as all parts of it are delayed by the same amount. However, when the phase characteristic is nonlinear (as in Fig. 51a), the time delays for all parts of the signal are no longer equal (see Fig. 51b). For example, if a complex waveform is made up of a 1 MHz sine wave and its third harmonic, these two components will suffer unequal delays in passing through a system having the characteristics of Fig. 50. The resultant distortion can be seen by comparing Fig. 52a, 52b, and 52c.

Such distortion is detrimental to both the luminance and chrominance of a composite signal. The luminance signal will have its edges and other important details *scattered*, or *dispersed*, in the final image. Such a transmission system is said to introduce *dispersion*. (Conversely, if a system does not scatter the edges and other

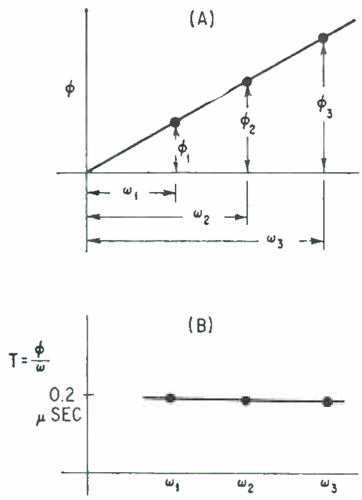


Fig. 50. Curves illustrating a system with linear phase characteristics, which will give the same time delay for signals of all frequencies.

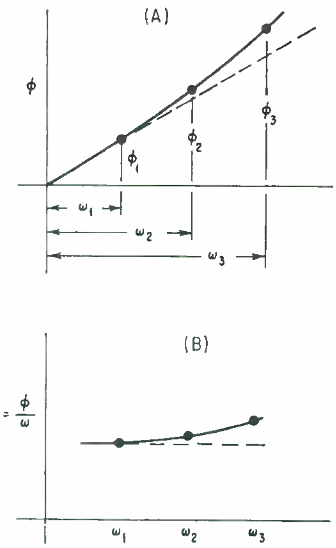


Fig. 51. Curves showing the effect of nonlinear phase characteristic on time-delay characteristic.

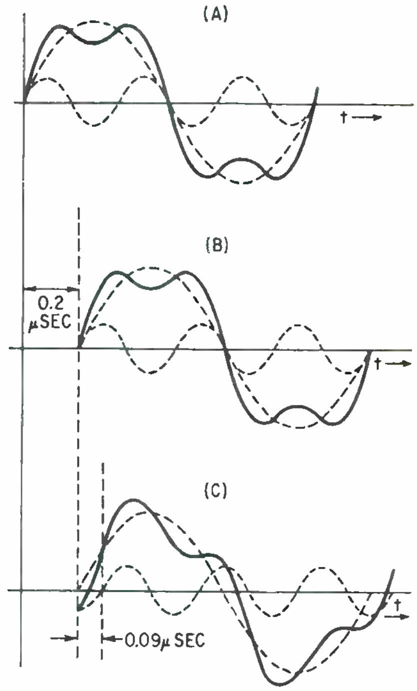


Fig. 52. Curves showing that a complex wave (A) is not distorted by time delay (B) when both components shown dotted) are delayed by the same amount. Unequal delays (C), however, cause distortion.

high-frequency information, it is said to be dispersionless.) The effect of phase distortion on the chrominance information is of a rather special nature and can best be explained by introducing the concept of *envelope delay*.

Envelope Delay

In the preceding discussion, the time delays ϕ_1/ω_1, ϕ_2/ω_2, and ϕ_3/ω_3 were always determined by measuring the frequencies and the phases from $\phi = 0$ and $\omega = 0$. It might be said that the delay at zero frequency is commonly taken as the reference point for all other delays. This method is usually adequate for determining the performance of systems that do not carry any signals which have been modulated onto a carrier. But a carrier, with its family of associated sidebands (Fig. 53b), can be thought of as a method of transmitting signals in which the zero-frequency reference is translated to a carrier-frequency reference. This translation can be understood by referring to Fig. 53a and 53b. To calculate the delay of the carrier-born signals *after* they have been demodulated, measurements of ϕ and ω must be referenced, not from zero frequency, but from *carrier* frequency.

In Fig. 54a, an impossible phase characteristic has been drawn to aid in further discussion of this subject. Such a characteristic, consisting of two perfectly straight lines, is never met in practice but makes a very simple system for developing the subject of envelope delay.

First, pass two frequencies ω_1 and ω_2 through this system. Let ω_1 be a carrier and ω_2 a sideband which might be, for example, 1,000 Hz higher. If ω_1 and ω_2 fall on the characteristic as shown in Fig. 54a, the delay which the 1,000 Hz will show after demodulation can be found putting new reference axes (shown dotted) with ω_1, the carrier, at zero on these new axes. Now, when ω_s and ϕ_s are measured as shown, the time delay after demodulation is ϕ_s/ω_s. In this case, the

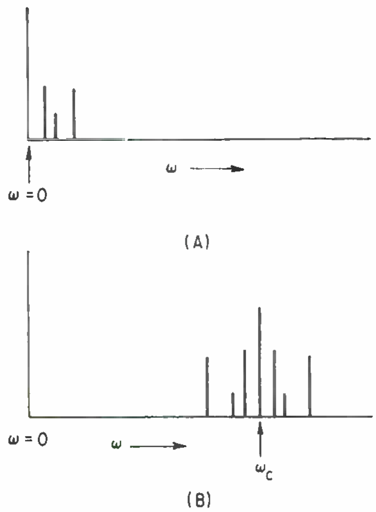


Fig. 53. Sketch showing how a group of frequencies near $\omega = 0$ [sec. (A)] can be translated by modulation onto a carrier to a group of sidebands near ω_c – α carrier frequency (B).

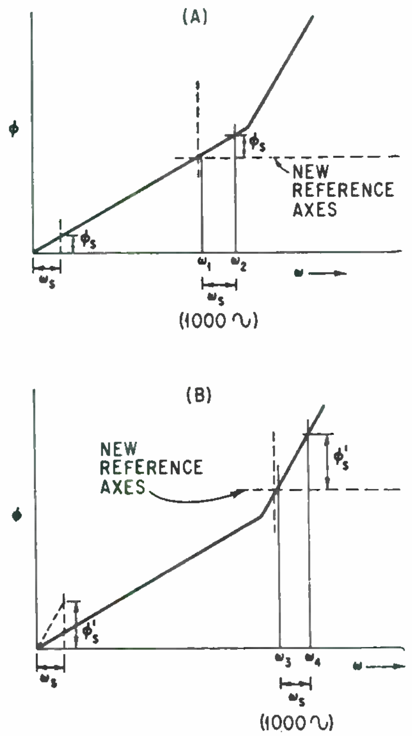


Fig. 54. Idealized straight-line phase characteristics showing how a carrierborne 1,000 Hz signal can be delayed excessively when the carrier and sideband fall on a steeper portion of the phase characteristic.

delay of the 1,000 Hz after demodulation is the same as it would have been had it been passed through the system directly.

Second, pass two other frequencies ω_3 and ω_4 through this system as redrawn in Fig. 54b. This time drawing in the new axes at ω_3, it can be seen that although ω_s is still 1,000 Hz, ϕ_s is larger than ϕ_s. Therefore, it can be concluded that the time delay ϕ_s/ω_s for this second case is greater than for the first case. The 1,000 Hz, when demodulated, will show a considerable error in timing.

Stressing the phrase "delay in a demodulated wave" should not be taken to mean that the demodulation process produces this delay or even make it apparent where it was previously not detectable. Any delay that a demodulated wave shows was also present when the wave existed as a carrier having an envelope. In short, the delay of the demodulated wave appears first as a delay of the envelope, hence the phrase "envelope delay."

Envelope delay does not constitute a distortion. If a system such as the one shown in Fig. 54a introduces a delay of 0.2 μsec to the 1,000 Hz wave (measured after demodulation), then the *envelope delay* of the system is 0.2 μsec. However, it was shown that a 1,000 Hz signal passed directly through the system (without first being modulated into a carrier) would also suffer a delay of 0.2 μsec. As long as the envelope delay ϕ_s/ω_s is the same as the time delay ϕ_1/ω_1, the envelope delay introduces no timing errors. But in the second system (Fig. 54b) the demodulated 1,000-Hz wave suffered a *larger* delay, say 0.29 μsec. A 1,000-Hz signal passed directly through this system, however, would still be delayed only 0.2 μsec. Therefore, the second system has an *envelope delay* of 0.29 μsec and an *envelope delay distortion* of 0.09 μsec.

It is probably wise to point out that the time delay ϕ_3/ω_3 in Fig. 54b is considerably less than the 0.29 μsec estimated for the value of envelope delay. Although ϕ_3/ω_3 would be greater than 0.2 μsec (say, for example, that ϕ_3/ω_3 is 0.22 μsec), the value would be optimistic about the amount of timing error that would be shown by the demodulated 1,000 Hz signal. The need for a knowledge of the envelope delay ϕ_s/ω_s of the system is therefore obvious.

Effect of Envelope-Delay Distortion on a Color Picture

A transmission system which exhibits envelope-delay distortion will destroy the time coincidence between the chrominance and luminance portions of the signal. This will result in misregistration between the color and luminance components of the reproduced picture. The following paragraph explains briefly how envelope-delay distortion causes this error.

Any colored area in a reproduced picture is derived from two signals, a chrominance signal and a luminance signal. Since these two signals describe the same area in the scene, they begin and end at the same time. The chrominance signal arrives at the receiver as a modulated subcarrier; the luminance signal does not. Therefore, as shown above, the delay of the chrominance signal is determined principally by the envelope delay of the system and the delay of the luminance signal is determined principally by the ordinary time delay ϕ/ω. If the two delays are not identical (that is, if there is envelope-delay *distortion*), then the chrominance signal does not coincide with the luminance signal and the resultant picture suffers *color-luminance misregistration* in a horizontal direction.

For example, in a system having the characteristic of Fig. 54b, the luminance signal is delayed by 0.2 μsec but the chrominance signal is delayed by 0.29 μsec. The error in registration then amounts to 0.09 μsec, or about 0.2 percent of the horizontal dimension of the picture, which is about 0.3 in. on a 21-in.(diagonal) picture.

Although the subject of compatibility is outside the scope of this part, it is worth noting in passing that envelope-delay distortion adversely affects compatibility, since it causes wideband monochrome receivers to display a misregistered dot-crawl image in addition to the proper luminance image.

General Method for Envelope Delay

The specific cases described above (Figs. 54a and 54b) made use of simple, idealized straight-line approximations to develop the concept of envelope delay. Practical circuits are not so simple. For example, a simple *RC* network has a ϕ versus ω plot as in Fig. 55. Finding the envelope delay of this curved-line plot will clarify what is meant by envelope delay.

Referring back to the plots of Figs. 53a and 53b, it can be seen that the characteristic of the plot that determines the value of envelope delay is its *slope*. The larger envelope delay, which was suffered by the ω_3-ω_4 pair (Fig. 54b), was a result of their lying on the steeper slope. The envelope delay of *any* system is equal to the slope of the phase versus frequency characteristic. If this characteristic is a curved line (as for the *RC* network, Fig. 55), then the slope is different at every frequency.

The slope of a curved line can be found by the methods of the differential calculus or to a good approximation by breaking up the line into a number of straight-line segments, as in Fig. 56. If the slope of each of these straight lines is plotted against its corresponding frequency (that corresponding to the center of the line), the resulting curve will be approximately the envelope-delay characteristic.

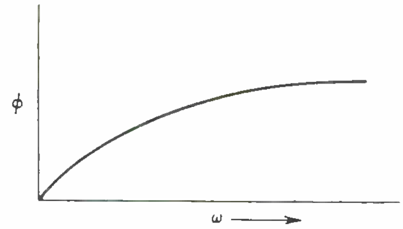


Fig. 55. Phase characteristic of an RC network.

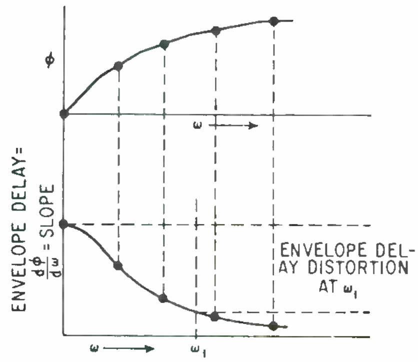


Fig. 56. Graphs showing how a series of straight-line segments can be used to approximate the smooth curve of Fig. 55 (top) and how the slopes of these segments may be plotted to approximate the envelope delay characteristics (bottom).

Nonlinearities of a Practical Transmission System

It is important to emphasize that the effect of nonlinearities in a color television system depends upon whether these nonlinearities precede or follow the matrixing and modulation sections of the system. Nonlinearities in transfer characteristics detract from color fidelity; the same degree of nonlinearity after matrixing and modulation also affects color fidelity although in a different way. The purpose of the following paragraphs is to discuss how a nonlinear transmission system affects a *composite* color signal. It is assumed that all other nonlinearities in the entire system either are negligible or have been canceled by use of nonlinear amplifiers such as gamma correctors.

The major sources of nonlinearity in a transmission system are its amplifying devices.[3] These devices—tubes and transistors—have a limited dynamic range. For example, if too much signal is supplied to them, an *overload* results.

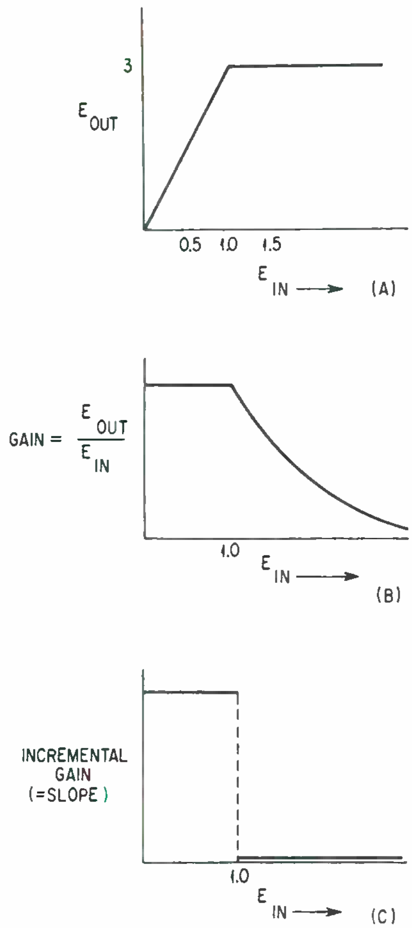


Fig. 57. Idealized straight-line plots showing (A) output voltage of an amplifier versus input voltage (B) gain of the amplifier versus input voltage and (C) incremental gain of the amplifier versus input voltage. Curve (C) is the slope of curve (A).

The transfer characteristic of such a system can be sketched as in Fig. 57a.

Such a nonlinearity is one of three types commonly encountered in video transmission systems. These three types are:

1. Incremental gain distortion
2. Differential gain
3. Differential phase

The paragraphs below will show that Type 2 is merely a special case of Type 1.

Incremental Gain

The concept of the slope of a plot, developed in the discussion of envelope delay, will be useful here as well. Consider a plot as in Fig. 57a which shows output voltage of an amplifier plotted against input voltage. Idealized straight-line plots are shown for simplicity. It can be seen that the amplifier has a maximum output of 3 volts for 1-volt input. Larger input voltages result in no more output; the amplifier *clips* or *compresses* when inputs larger than 1 volt are applied.

The gain of the amplifier is

$$\text{Gain} = \frac{E_0}{E_{in}} = \frac{3 \text{ volts}}{1 \text{ volt}} = 3$$

The gain is obviously constant below the clip point. For example, an input voltage of 0.5 volt gives

$$\text{Gain} = \frac{1.5 \text{ volts}}{0.5 \text{ volt}} = 3$$

But at an input of 1.5 volts, the output is still 3 volts, so the "gain" is only 2. (The word "gain" is of doubtful use here because of the clipping involved.) The gain, defined as E_0/E_{in}, is plotted against E_{in} in Fig. 57b. It can be seen in this figure that the gain is constant only as long as the *slope* of Fig. 57a is constant.

It is useful, then, to establish a new term, called *incremental gain*, which will be defined as the *slope* of a plot such as Fig. 57a. For the particular plot of Fig. 57a, the slope is constant up to $E_{in} = 1$ volt and then suddenly becomes zero. The corresponding plot of slope versus E_{in} is shown in Fig. 57c.

The importance of incremental gain in color television can be assessed by applying the input signal shown in Fig. 57 to the distorting system of Fig. 57a. Before being applied to the distorting system, such a signal could be reproduced on a monochrome receiver as a vertical white bar and on a color receiver as a pastel-colored bar, say, for example, a pale green. After passing through the distorting system, the signal would still be reproduced as a white bar on the monochrome receiver with the only apparent error being a luminance distortion, that is, a slight reduction in brightness, which, for the magnitudes shown here, would probably pass unnoticed. The color receiver, however, would receive a signal completely devoid of any color information and would reproduce a white bar in place of the former pale-green one.

The less extreme case is shown in Fig. 59. For the system represented by this characteristic, the slope (incremental gain) does not become zero for inputs above 1 volt but instead falls to one-half its below-1-volt value. The color signal of Fig. 59 would not lose all color in passing through this system, but the amplitude of the subcarrier would become only one-half of its proper value. Since saturation is a function of subcarrier amplitude, the pale green of the undistorted reproduction would, in this case, become a *paler* green. The luminance distortion would also be less than in the extreme (clipping) case.

It can be seen, then, that unless the incremental gain of a system is constant, that system will introduce compression which will distort the saturation and brightness of reproduced colors. Usually, the error is in the direction of *decreased* luminance and saturation. For certain systems, however, exceptions can be found. For example, the effect that the system represented by Fig. 59 will have on a signal depends on the polarity of the signal. For the signal as shown, the usual *decrease* in luminance and saturation is exhibited. For an inverted signal, however, the subcarrier amplitude would not be reduced, but the luminance signal would still be diminished. The subjective result of this distortion would be an *increase* in saturation. The unusual behavior of this particular system is attributable to its peculiar transfer characteristic, which was drawn with curvature at one end only to simplify the discussion. Most practical system-transfer characteristics exhibit curvature at both ends and therefore have an effect on the signal which is essentially independent of polarity.

Incremental gain can be measured in two ways, the first of which stems from its contribution to luminance distortion and the second, from its contribution to chrominance distortion.

In the first method, an equal-step staircase waveform such as shown in Fig. 60a is applied to the system to simulate a signal having equal luminance increments. If the system has constant incremental gain, the output will, of course, also have equal-step increments. But if the system does not have constant incremental gain, certain steps will be compressed, as in Fig. 60b. If the compression is as in the figure, the *incremental gain distortion* (IGD) is indicated by the distorted amplitude of the last step. Numerically, it can be stated as a percentage:

$$\text{IGD} = 1 - \frac{S_{\text{distorted}}}{S_{\text{undistorted}}} \text{ X } 100\%$$

where S is a step amplitude.

For example, if an undistorted step is 0.1 volt and the distorted one is 0.075 volt, then the incremental gain distortion would be 25 percent.

Using the other (chrominance distortion) technique, an input signal consisting of the step wave plus a small, high-frequency sine wave, as shown in Fig. 60c, is applied to the system. After the signal has passed through the system, it is fed through a high-pass filter which removes the low-frequency staircase. The incremental gain distortion then is indicated by the differences in the amplitude of the high-frequency sine waves (see Fig. 60d). In this case, the high-frequency sine wave associated with the top step is shown as having 75 percent of the amplitude of the sine waves associated with the lower steps, which are assumed to be undistorted. Again, the incremental gain distortion is 25 percent.

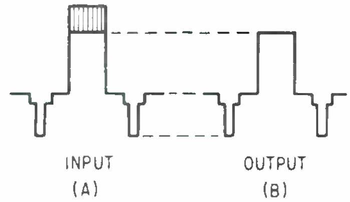


Fig. 58. Extreme case of distortion resulting from passing signal at left (A) through the amplifier represented by Fig. 57. The output (B) has no color information remaining.

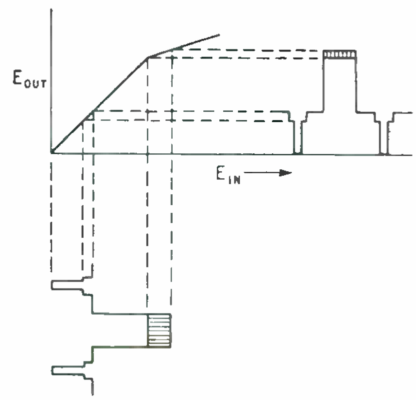


Fig. 59. Diagram showing effect of incremental gain distortion in reducing amplitude of color portion of signal.

A most important point must be made regarding the equivalence of these two techniques. Certain systems which show incremental gain distortion when tested by the luminance-step technique may or may not show the same distortion when tested by the high-frequency and high-pass-filter technique. Moreover, a system which shows distortion by the second technique may or may not show distortion by the first. In other words, the incremental gain distortion may be different for different frequencies. Such differences are frequently found in staggered amplifiers, feedback amplifiers, or amplifiers having separate parallel paths for high and low frequencies, such as might be found in stabilizing amplifiers.

A thorough test of a system, therefore, should include test of its incremental gain by both techniques. The staircase-plus-high-frequency waveform can be used to provide *both* tests by observing the system output (for this test waveform input) first through a low-pass filter and then through a high-pass filter. The first test will show

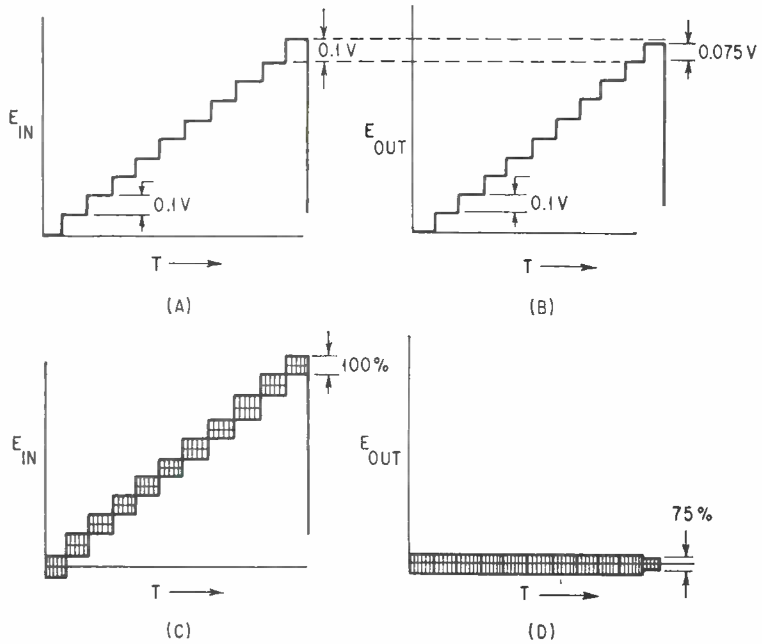


Fig. 60. Diagrams showing two methods of measuring incremental gain distortion, namely, in (A) and (B) by its contribution to luminance distortion and in (C) and (D) chrominance distortion.

low-frequency distortions; the second, high-frequency distortions.

Differential Gain

On the basis of the above discussion of incremental gain distortion, the extremely important concept of ***differential gain*** can be presented merely as a simple definition. Differential gain is identical with incremental gain distortion when the latter is measured by observing "...the difference in the gain of the system for a small high-frequency sine-wave signal at two stated levels of a low-frequency signal upon which it is superimposed."[4] In other words, differential gain is a special form of incremental gain distortion which describes the IGD of a system for the superimposed high-frequency case only.

One of the reasons for selecting the high-frequency aspect of incremental gain distortion for the IRE definition of differential gain was applied in Fig. 58, when the "...high-frequency sine wave..." of the definition was made equal to color subcarrier. This special case of differential gain explores the system gain linearity in the vicinity of this particularly important frequency. The definition of differential gain was purposely made in the broad terms of a "...high-frequency sine wave..." to allow the greatest possible versatility in devising methods of measurement. In present color-television practice, however, the "...high-frequency sine wave..." is always color subcarrier and the low-frequency signal mentioned in the definition is a 15,750 Hz staircase, sine-wave, or sawtooth. The complete specifications for the signal presently used in this measurement will be found elsewhere in this article.

Another reason for emphasizing high-frequency IGD was implied previously by the sentence "...the signal...would...be reproduced...with the only apparent error being a luminance distortion...which, for the magnitudes shown here, would probably pass unnoticed." The magnitude shown was a 25 percent IGD, which is passing unnoticed, indicating that large incremental gain distortions usually cause no detectable luminance errors. Incremental gain distortion is almost too sensitive a tool to measure luminance distortions. For this purpose, simple gain distortion (compression) is more useful. Therefore, the luminance-distortion aspect of IGD was deliberately omitted from the definition of differential gain.

Incremental Phase and Differential Phase

The phase characteristic sketched in Fig. 49 indicates that the system described by this plot will introduce a certain amount of phase shift for any given frequency. For example, it might be found that a certain system would introduce a phase shift of 60° at 2 MHz. If the system in question were perfectly linear, this 60° phase shift would be produced regardless of how the 2 MHz signal might be applied to the system.

It can be shown, however, that some systems, when presented with a signal of the type shown in Fig. 61, will introduce a delay *different* from 60°, depending on where the zero axis of the sine wave falls on the transfer characteristic of the system. For the case sketched in the figure, a phase shift of 70° is drawn for the largest zero-axis displacement.

By analogy with the incremental gain and differential gain arguments above, it is possible to define three quantities which pertain to this type of distortion. These quantities are *incremental phase, incremental phase distortion, and differential phase.* It can also be shown that of the three, differential phase is the most important quantity.

Incremental phase is the least exact analog, since it is not very similar in form to incremental gain. Incremental *gain* is a *slope*; incremental phase is simply the absolute value of phase shift. In the above system, the incremental phase was 60° or 70° (or somewhere in between), depending upon the location of the zero axis.

Incremental phase distortion, like its analog *incremental gain distortion*, depends upon the magnitude of the error. It should be zero for a perfect system. In the system of Fig. 61 the 2 MHz signal with 70° incremental phase would be said to have 10° incremental phase distortion, so it is clear that the difference between two phases (one of which is assumed to be "correct") gives the incremental phase distortion.

As previously stated, *differential gain* is identical with *incremental gain distortion* for the superimposed-high-frequency case only. Similarly, *differential phase* is identical with *incremental phase distortion*, but there is no need to limit the definition to the superimposed-high-frequency case, since there is no other case which is meaningful for phase distortion. Without the superimposed sine wave, no phase measurement is possible. Therefore, differential phase is identical with incremental phase distortion. In practical work, the first two terms are seldom used, for the last, differential phase, has been found completely adequate to describe this aspect of a system.

In summary, the differential phase of a system is "the difference in phase shift through the system for a small high-frequency sine-wave signal at two stated levels of a low-frequency signal on which it is superimposed.[5]

It is important that the phrases "differential phase *distortion*" and "differential gain *distortion*" be avoided because differential phase *is* distortion as is differential gain, since they are defined as being identical with incremental phase distortion and incremental gain distortion, respectively. To add the word *distortion* to either is redundant. A sample of proper usage is "this amplifier has a differential gain of 1.5 percent and a differential phase of 0.5°".

Effect of Differential Phase on a Color Picture

The phase of a subcarrier in a composite signal carries information about the *hue* of the signal

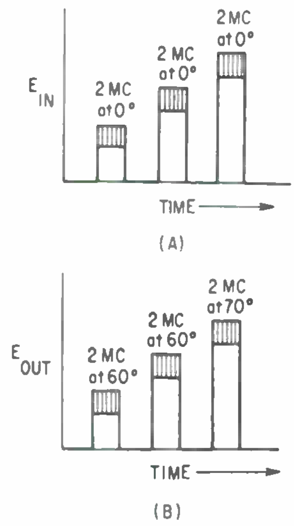


Fig. 61. Graphs illustrating how a signal (A) may undergo different phase shifts (B) depending upon where the zero axis at the sine wave falls on the system transfer characteristic. This distortion is called differential phase.

at that instant. If the signal passes through a system which introduces differential phase, the subcarrier phase (and hence, the hue) at the output will become dependent upon the amplitude of the luminance associated with the hue, since it is the luminance signal which determines the location of the zero axis of the subcarrier. For example, a system introducing 10° of differential phase might be adjusted to reproduce properly a low-luminance hue such as saturated blue or a high-luminance hue such as saturated yellow, but *not both.* One or the other would have to be in error.

State of the Art

The preceding portions of this part have discussed in general terms the possible sources of color errors in a color television system. In no practical system can any of these errors be reduced to zero; therefore, anyone working with practical systems should know how nearly perfect any given parameter should be to be considered acceptable according to the present state of the art.

System Colorimetry

Talking qualitatively about colorimetric accuracy is one thing; assigning numbers and magnitudes is quite another. For the practical purposes of this part, however, we are spared the need to digging deeply into the quantitative aspects of colorimetry by one simple fact: At the present time, color errors attributable to phosphor errors, filter errors, and other basic colorimetric errors are generally small in comparison with other sources of error.

System Exponent

At the present state of the art, adjusting a system to precompensate for a kinescope exponent of 2.2 is not enforced by the Federal Communications Commission, since this parameter is not yet well established. Adjusting the system to precompensate for this median value, however, can be done with precision. A gamma corrector which uses four or five diodes to make a series of straight-line approximations to a 0.7 exponent can be made so as to have a maximum error of less than 2 percent of the peak signal amplitude. The exponents of the three channels can be made to match within 1 percent of the peak signal amplitude.

Matrix Coefficients

A high-quality matrix, such as would be found in a well-engineered color encoder or studio monitor, uses 0.5 percent precision resistors for all resistances which will influence the values of the coefficients, while inverters and amplifiers are either stabilized by feedback or made adjustable. Errors of greater than 1 percent are rare in such circuits.

While balance in the transmitter matrix, which is a special case of the subject of matrix coefficients, can usually be adjusted and held to a tolerance of the order of 0.5 percent of peak white.

Phase Accuracies

Adjustment of Q subcarrier, I subcarrier, and burst to within 1° of their proper relative phases is easily accomplished using standard commercial equipment and techniques. This accuracy is ten times that required by the Federal Communications Commission.

Subcarrier-Frequency Accuracy

Subcarrier frequency can be easily adjusted to within ± 1 Hz the real limit on the accuracy of the adjustment being in the inherent accuracy of the standard used for frequency comparison. Long-term stability of well-engineered equipment should be easily within the required limits of ± 10 Hz.

Transmission Characteristics

A single amplifier should have a gain characteristic with less than ± ½ dB variation out to 8 MHz. Its envelope-delay error should be of the order of 0.001 μsec at 3.58 MHz, relative to 200 kHz. Differential gain of 0.5 percent and differential phase of 0.25° represent good performance.

Tolerable Color Errors

Sensitivity of the eye to color errors depends upon the manner in which two colors—the original and the reproduction—are compared. For example, if the two colors are placed side by side, the eye becomes a very sensitive indicator of color errors. However, if the comparison is made only by recollection or long term color memory, the eye is far more lenient in its requirements of perfect reproduction. Furthermore, if the reproduced color is one that the eye has not viewed before, the eye requires only that the color relayed to the brain be plausible, that is, that it be a reasonable color for the object.

Fortunately, side-by-side comparison of colors seldom, if ever, occurs in home viewing of color television. However, the system is frequently called upon to reproduce objects whose colors may be well known to the viewer, such as flesh tones or a sponsor's packaged product. Reproductions of these objects must be accurate enough to satisfy the viewer's recollection or color memory. If the system can satisfy the color memory of the viewer, the color-plausibility requirement will be easily met.

Investigations made to determine the sensitivity of the eye to color errors introduced by a deliberate shift of burst phase show that a shift of 10° or more produces perceptible change of hue. With color bar signals a burst phase shift of 3° can just be detected as a hue shift. With typical scenes a phase shift of 5° can be tolerated.

Tests have shown that the eye is much more tolerant of amplitude shifts in R, G, B components, which correspond to changes in color saturation, than it is of phase shifts or changes in hue.

One must distinguish between long-term adaptive errors in viewing of a color television picture and short-term differential color errors. In the first case the eye is quite tolerant of changes or shifts in color balance providing that no direct side-by-side comparisons are involved. Thus a viewer is reasonably well satisfied with color pictures in which white is reproduced within the range of 3200°K to 9500°K. As soon as he views two color TV pictures side-by-side at two different white balance conditions, there will be a much more critical reaction to color fidelity.

For this reason, it is important that color monitors in a broadcasting control room be adjusted to have the same effective white balance, the same color phasing, and the same peak brightness. Since such monitors are usually arranged in a row adjacent to each, great care must be taken so that when the same picture signal is applied to all monitors, there is negligible difference in the color picture displays. Only then can the color monitors be useful in matching and comparing color balance of the various camera signal sources.

It is unusual to have more than one color receiver at a home viewing location at a given time. There the absolute color balance problem has little direct impact.

Control of short-term differential color errors is vitally important to the broadcaster. In any broadcast sequence, a given scene is generally viewed from different angles with several color cameras, at various magnifications, and the available video signals are selected from camera to camera to obtain program continuity. The eye views these color scenes in quick succession and is very critical of even small color differences, particularly with regard to skin tone rendition. Variations of the R, G, B or primary color components of 2 percent can be detected. Although the eye can easily adapt to any of the pictures in a few seconds, the viewer will find the abrupt color shifts very disturbing with switching transitions. Thus great care is taken with colorimetric tolerances in color cameras and with color-balancing procedures to provide color matching among cameras which will be precise.

A similar situation exists in the reproduction of color motion pictures. A feature movie having adequate color quality is usually shown in a sequence lasting 15 minutes or more, with the eye having adequate time to adapt to any discrepancies in color balance and skin tones. Commercials spliced into this feature program produce an instantaneous switch to a new and different skin tone balance without time for eye-adaptation. This transition to commercials and back to the feature can exhibit color mismatch to varying degrees, depending on the colorimetric control which has been exercised.

In fact, if the feature film is somewhat misbalanced, and intentionally "corrected" by appropriate use of R, G, B gains or "paint-pot" controls, the transition to the commercial will be more objectionable since the "correction" can then increase the misbalance, even for a "perfectly-balanced" commercial. Effort is going on in the industry to tighten up tolerances on skin tone rendition so that adequate performance can be obtained by purely routine operating methods.

Conclusion

This discussion of color errors indicates *possible* degradations in color fidelity and their probable sources. However, in a properly adjusted color TV system the picture quality is excellent. The various techniques now in development to improve picture quality within the framework of the NTSC system have assured a bright future for color TV.

THE COLOR ENCODER

The color encoder in the color television system performs the required encoding of the R, G, B signals from three-tube cameras or the R, G, B and Y (luminance) signals from four-tube cameras into a single color video signal conforming to FCC specifications. It is the heart of the modern color television system and represents a most ingenious application of many elements of communication circuit theory.

Fig. 62 shows a block schematic of a basic color television system indicating the functions and major components of the color encoder.

A more detailed block diagram of the color encoder showing the matrixing, bandwidth-limiting and quadrature modulation functions is shown in Figs. 36 and 37.

Basic Functions

The principal operations and functions performed by the color encoder are:

1. Matrixing of R, G, B video signals to produced luminance and chrominance signals.
2. Filtering of the chrominance signals to obtain the required bandwidth.
3. Delay compensation to correct for band-limiting time-delay.
4. Modulation of 3.58 MHz carriers by chrominance signals.
5. Insertion of color sync burst.
6. Addition of luminance and chrominance signal to form a complete color signal.
7. Optional addition of sync.

Design and system philosophy determines whether a color encoder is a separate unit or an integral portion of a modular assembly. Present solid state equipment design tends toward the modular concept since it is generally easier to maintain, repair, up-date and revise specific modular units or board assemblies without affecting the overall installation.

The electrical color bar generator which is generally provided for systems test and color encoder alignment is available either as a separately contained unit or as a module in a complete operating assembly.

Color encoders of modern solid state design are inherently stable and require only routine verification or adjustment. Set-up of a color encoder involves the use of color-bars which are electrically generated waveforms of high precision. A color bar generator is capable of producing on a color monitor all of the signal bars illustrated in Fig. 63.

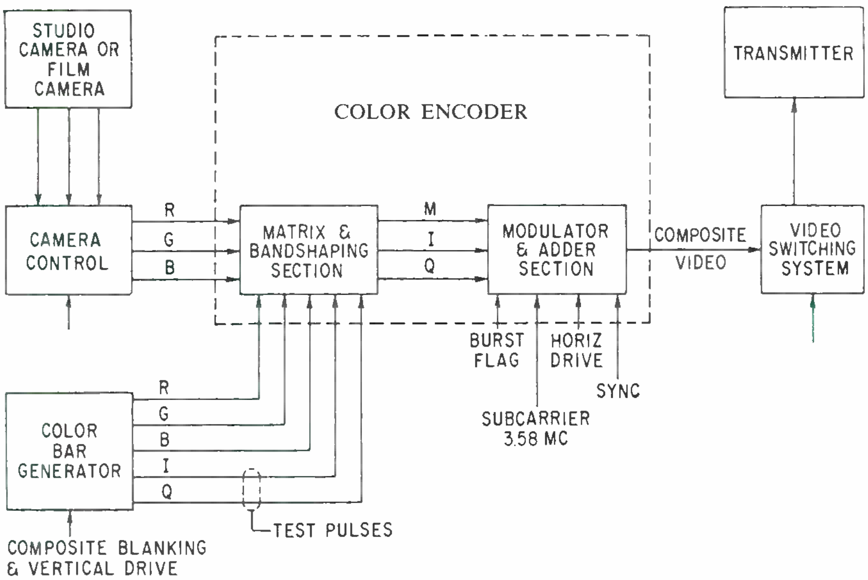


Fig. 62. Basic color-television system showing functions and major components of the color encoder.

Colors at the top of this display pattern are arranged from left to right as white, yellow, cyan, green, magenta, red and blue in their decreasing order of luminance. The lower portion of the pattern contains "I," "100% White," "Q," and black signal areas. The "I and Q" signals simplify subcarrier phase adjustments in the color encoder and the 100 percent white bar facilities white-balance adjustments. The specifications of the standard encoder color bar signal are given in EIA standard RS-189.

Waveforms

Fig. 64 shows the oscilloscope waveforms at a horizontal sweep rate of the color bar signals displayed on the television raster. Note that this is a composite representation of waveforms of the top and bottom areas of the raster. The color sync precedes the color bar pulse information.

Fig. 65 shows the various band-pass response characteristics of the luminance channel and of the "I" and "Q" channels of the color encoder.

A color encoder is set up and adjusted by using the calibrated color bars just described. The color encoder luminance gain is adjusted by using the 75 percent white bar as a reference. By switching off the luminance channel the appropriate "I" and "Q" waveforms are available to set the proper peak amplitudes and the 90° phase separation. Either a wide-band oscilliscope or a vectorscope can be used for display in a variety of specialized set-up procedures. The vector relationship of chrominance components is shown in Fig. 66.

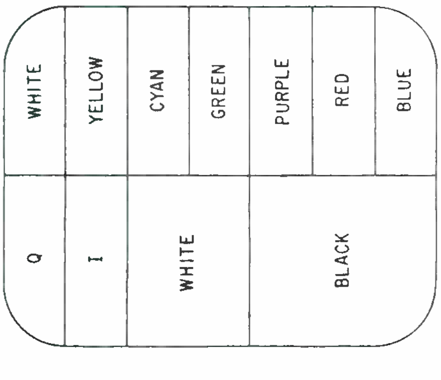


Fig. 63. Diagram showing color monitor display of color and test bars electronically produced by RCA color-bar generator.

Aperture Compensation

Aperture compensation is used in television systems to correct for the decrease in signal output at high frequencies caused by the finite-size limitations of the scanning spot or of equivalent optical lens aperture response. If one considers abrupt or black to white square-wave transitions at 400 TV lines, corresponding to 5 MHz video components, the video signal amplitudes from a Plumbicon or vidicon pick-up tube may be only 30 to 40 percent of the amplitude of low frequency transitions at 40 TV lines or 0.5 MHz. If the signal-to-noise ratio of the output video is good, aperture compensation to give practically 100 percent flat response at 5 MHz can be applied, producing subjectively sharper pictures.

Horizontal aperture correction is done by comparing the amplitude response of a given picture

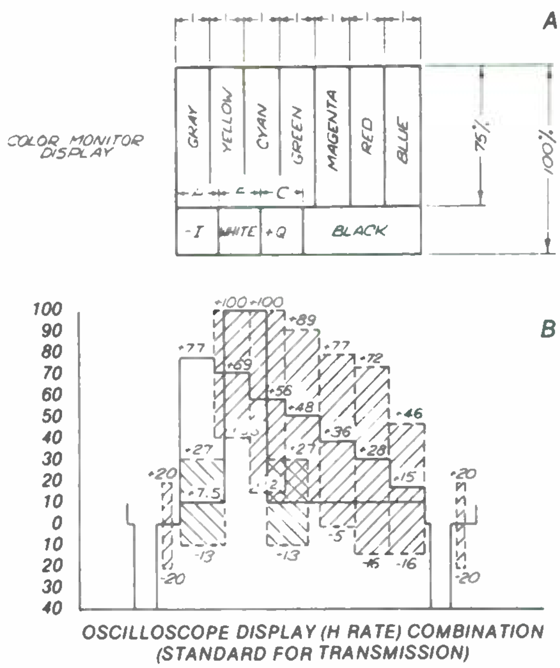
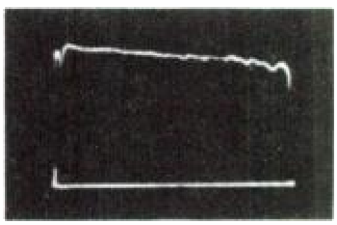


Fig. 64. (A) Color monitor display and (B) Oscilloscope display (H rate).

element with that from adjacent elements by the use of differential amplifiers and electrical delay lines. This difference, suitably amplified and of correct polarity is added to the signal being corrected which increases the sharpness of the transition.

Vertical aperture response can also decrease with increased line number and can similarly be improved by comparing the response of the picture elements on a given TV line with that of line elements preceding and following it. Differential amplifiers compare the video signals obtained from delay lines of a horizontal period (63.6 μsec) in duration with the picture elements of the TV line to be corrected.

Differences between these video responses are obtained from differential or comparison amplifiers amplified and suitably added to the



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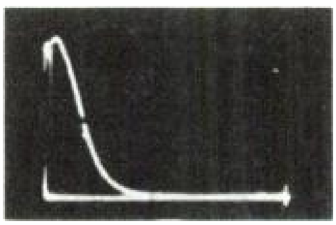

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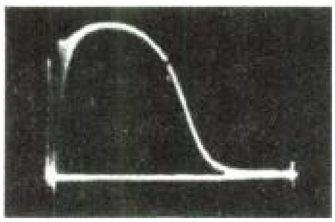

(*c*)

Fig. 65. Waveforms showing response characteristics of colorplexer monochrome, I and Q channels. (*a*) Response of monochrome channel without aperture correction, marker at 8.0 MHz, (*b*) output of I filter, marker at 2.0 MHz; (*c*) output of Q filter, marker at 500 kHz.

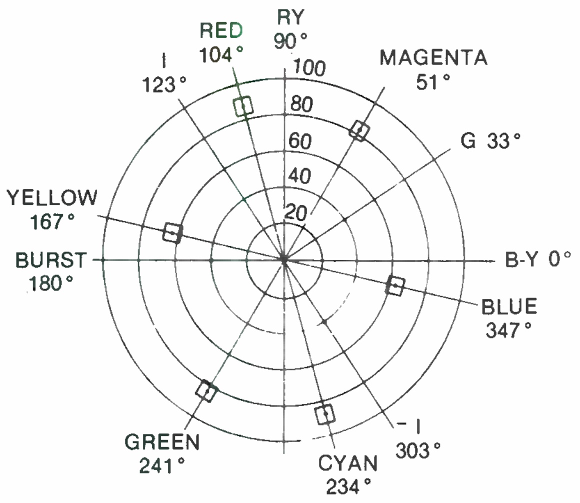

Fig. 66. Vector relationship among chrominance components.

main signal, to improve the vertical transition sharpness.

Judicious use of combined horizontal and vertical aperture correction or enhancement produces marked improvement in subjective picture sharpness. Since the luminance channel of a color system provides the sharpness information, it is generally used as the signal for aperture response improvement.

A block diagram of aperture compensation circuits is given in Fig. 67.

Factors Affecting Color Camera Performance

The following general principles, which outline procedures for the proper alignment and operation of color cameras, are directed toward three-tube color camera models and are presented to assist the station engineer in understanding the effect that each adjustment can have on the composite color picture. No attempt is made to present a step-by-step alignment procedure which, while basically the same for all cameras, will vary in detail depending on the manufacturer and the type of camera.

CAMERA ALIGNMENT

It is important to point out that color camera alignment should be made by viewing the proper test charts for a given adjustment or procedure. Such charts are useful for direct indication of the required camera adjustments. The practice of making an indiscriminate adjustment during a scene to "paint" a pleasing picture should be avoided in any operational procedure. Such an adjustment is usually successful for only isolated

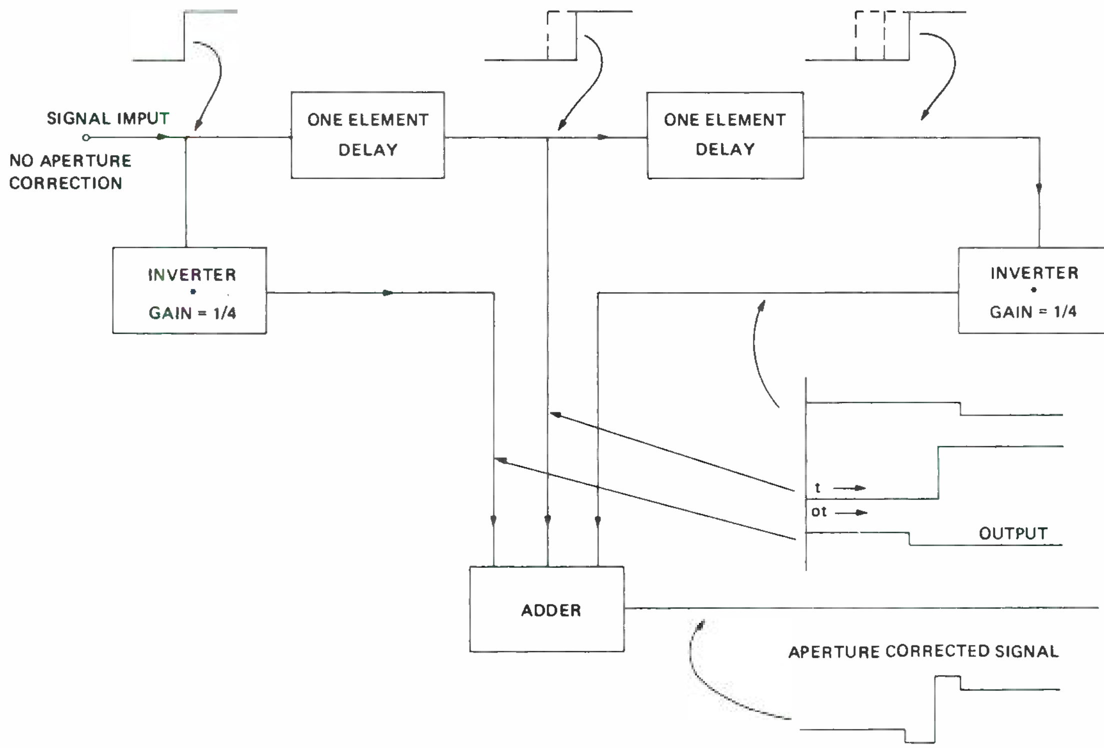

Fig. 67. Generalized aperture corrector.

conditions and may easily produce errors in subsequent scenes. It is also important to note that certain controls in the color cameras when improperly set may give a false indication that other controls are misaligned. Therefore, maximum effort should be given to logical rigorous routine alignment of the controls before program time.

During operation a properly aligned camera should require no more than exposure control using the lens iris as an opening control and an occasional adjustment of pedestal or black level setting.

The Three-Tube Concept

A three-tube camera consists basically of an optical system which "sees" the scene being televised through a dichroic mirror or prism assembly, suitably separated into its red, green, and blue image components. These three red, green, and blue images are focused on the photosensitive layer of the pickup tube in each color channel. By synchronous scanning of the three pickup tubes one obtains three independent video signals which differ only in their amplitude response to the three color images. Thus, we effectively obtain a red signal from the red tube, a green signal from the green tube and a blue signal from the blue tube. With the optical and electrical adjustments available, these three pictures are superimposed or registered on each other within an accuracy of a picture element. In order to carry out this registry process one has access to individual horizontal and vertical size and centering controls, as well as to mechanical rotation of the individual yokes and to "skew" which provides for orthogonal deflection by means of electrical cross-coupling between horizontal and vertical deflection. Thus, in principle one can obtain three independent R, G, and B channels which are effectively superimposed in space at the pickup device and in time by virtue of the synchronous deflection process. One could apply these three signals to the red, green, and blue gun of the color kinescope to produce a replica of the scene being televised. However, certain procedures are necessary to obtain normalized and predictable camera behavior.

Signal-to-Noise and Sensitivity

One must set the gains of the individual video amplifiers in the R, G, B channels to a specific value. Then a given signal current from the Plumbicon will produce the required output level at the required signal-to-noise ratio. The Plumbicon signal-to-noise ratio depends almost entirely on the figure of merit of the external video amplifier. Nominal values of signal current are of the order of 300 to 400 nanoamps. These are obtained at exposures of approximately f:4 with 150 to 200 fc on an average scene. In contrast to the Image Orthicon camera where the signal-to-noise ratio is determined primarily by the signal-to-noise ratio of the image orthicon tube itself, there is a trade-off possible between sensitivity with a 6 dB decrease in signal-to-noise ratio or four times this sensitivity with a 12 dB decrease in signal-to-noise ratio. As long as the signal-to-noise ratio under standard conditions is excellent, in practice about 50 dB before gamma correction, one can tolerate such a degradation to obtain increased sensitivity and still achieve pictures which have adequate signal-to-noise.

Specular Highlights

The signal current magnitude is chosen so as to achieve a compromise between signal-to-noise ratio and the ability of the tube to discharge highlights. A standard procedure is to adjust for a factor of two reserve in the signal current by proper beam bias adjustments. In set-up, the normal scene lens exposure opening is deliberately increased by one f stop, doubling the light to the Plumbicons and the beam currents in the R, G, and B tubes are then adjusted to just discharge the picture highlights. The exposure is then restored to its "normal" setting. With this camera adjustment procedure any increase in peak brightness due to speculars or highlights in a scene which does not exceed this factor of two will be discharged effectively in the Plumbicon by the "available" beam current reserve which has been provided. If one attempts to use larger signal currents than 400 nanoamperes there may be limitations in the gun which cause loss of normal resolution and an inability to supply the required beam current reserve for satisfactory discharge of highlights.

When a camera is operated under conditions of specular highlights and there is motion in the scene, the presence of undischarged areas in the raster will give rise to false color halo effects, generally red, which are usually described as comet tails. This comet-tail effect on motion is called "puddling" by British broadcasters. The two-to-one highlight beam reserve usually controls the comet-tail effect satisfactorily.

Gamma Correction

Since the gamma of the Plumbicon tube is essentially unit, gamma correcting amplifiers must be used to produce a pleasing picture display using modern color kinescopes. The effective gamma characteristic of the color kinescope has approximately a 2.2 exponent; thus gamma correction of 1/2.2 or 0.45 is needed to obtain an overall gamma or transfer function of unity.

In order to obtain color "tracking" with changes of lighting or exposure, it is important that the transfer characteristics or gamma of the R, G, B channels be indentical. This matching can be achieved by using techniques such as superimposing of the transfer characteristics waveforms on a display oscilloscope, using a standard input sawtooth, and adjusting the individual gamma circuits for the same power law and the individual black levels or capped lens references for zero. A direct check for transfer characteristic adjustment is to use the neutral EIA logarithmic gray scale chart[6] placed directly in the scene viewed by the camera. When the tube and gamma circuits are correctly adjusted to an overall gamma, which is the same for all three channels, and a 0.45 slope value is maintained, the color picture display of the EIA chart on the kinescope will be observed as neutral or shades of gray with no apparent color misbalance over the entire gray scale range.

Aperture Correction

The aperture response of Plumbicon tubes of the 30 mm variety generally used for color TV broadcast is approximately 35 to 45 percent at 400 TV lines or 5 MHz as compared to a 100 percent reference response for low line-number transitions. For this reason it has been almost universal practice to aperture-correct or crispen the picture both horizontally and vertically by the use of omnidirectional aperture correction circuits. The response can be made effectively 100 percent of the time within the 5 MHz TV channel without noticeably deteriorating the signal-to-noise ratio. Such aperture correction techniques are described in the section on color encoder and shown in Fig. 66. Clamping, blanking addition, and clipping of the processed signal, following accepted monochrome picture techniques, are performed on the three channels before they are ready to encode into the NTSC color encoded form adopted for transmission.

Color Matching Techniques

In a color television operation the color-matching of the individual color cameras against each other is of prime importance. Ideally there should be *no* discernible color differences in the color TV pictures from all cameras when viewing the same subject. Experience has shown that by excercising tight control on the production tolerances of dichroic colorimetric components in the optical system and on the electronic components, once can achieve accurate color rendition from any cameras used on a given scene.

In practice each camera is aligned under normalized video gain conditions so as to obtain the required signal-to-noise performance and the same effective sensitivity. Then routine adjustment procedures to obtain the same gamma correction or transfer characteristics in the R, G, B are carried out.

The cameras now view an EIA logarithmic neutral gray scale under standard conditions. If the inputs to the color encoder are standardized and cameras have been well aligned, the gray scales will be reproduced on a color monitor over the complete brightness range as a neutral picture, since the subcarrier amplitude everywhere in the scene should be zero. Such a chart is a very sensitive indicator of small misadjustments and is generally used as a tool for vernier balancing of a color camera.

Any minor discrepancies in color rendition of the cameras used in a studio are corrected by very small changs in either R, B, or G gain provided by "paint pots."

Operationally it has been found that one camera control operator, using a single color monitor, can match four cameras more rapidly and accurately than four operators working independently.

Electronic masking devices such as the RCA Chromacomp and the CBS Color Masking Processor permits color matching cameras to any degree of precision without upsetting white balance.

Flare in Pickup Tubes

Under certain conditions of scene content, an unwanted lift of black level or pedestal can occur in one or more of the color pickup tubes. The effect is due to light scattering in the photoconductive layer of the tube itself and is strongest in the red channel. Thus, for example, if a scene which is predominantly red is viewed by the camera, the red pedestal will rise by 3 or 4 percent producing a red cast in the picture. This can be corrected by manually resetting the red tube black-level control. Automatic circuits which are duty-cycle sensitive are often used to provide a good approximation to black level with changes in scene content without any operator attention. Flare in green is much less than in red and is quite negligible in the blue channel. Light scattering in optical components and lenses will also cause artificial lift of black level.

In a well-designed and well-aligned camera, color balance and color tracking are obtained automatically over a wide range of scene content and exposure.

A special opaque test pattern developed by BBC uses a "super-black" enclosure hole as a reference for black level setting in addition to the usual logarithmic gray scale for gamma checks. American broadcasters often use a square of clean black velvet as a "super-black" for flare-compensation circuit test and adjustment and as a solid black-level reference.

Lighting on the Scene

With Plumbicon cameras the incident lighting required for studio-quality signal-to-noise picture performance generally approaches 250 fc for a lens opening of f:4. The contrast of the scene which the color camera must handle is the product of the incident light and the reflectance of the subject matter. Technically, uniform or flat lighting is easiest to handle since this limits the range to the reflectance of the scene components, generally restricted to a highest white of 60 percent reflectance and a lowlight of 2 to 3 percent, giving a range of 20 or 30 to 1 at most. The rendition in monochrome TV is as important as the rendition in color since many of the TV viewers still look at the picture in monochrome. It is therefore important to select scene materials and surfaces so as to obtain good monochrome separation in the gray scale as well as to provide colorful rendition in the final color picture. Flat lighting, as mentioned previously, is easiest to carry out, but becomes monotonous and boring from the standpoint of the producer. Any departures from flat lighting must be executed with caution. It is necessary to "fill-in" holes and deep shadows in lighting the scene to obtain results which are pleasing from the standpoint of signal-to-noise, range, and lag.

Specular or mirror reflections can be controlled by positioning of lighting and cameras or by "dull-spraying" of the surfaces responsible. Dimming is not an acceptable method of controlled scene lighting, since skin tone balance, which is the key to good performance, is very susceptible to changes in illuminant color temperature. Changes in scene lighting are generally provided by changing the total number of fixtures illuminating the set. Where skin tones are not involved, some liberty can be taken in dimming or fading.

Outdoor Broadcast Pickup

When color cameras view outdoor scenes, such as football and baseball games and other outdoor events, the subject matter and the illumination on the scene are no longer under the direct control of the broadcaster. Thus, for example, in the sunlight and in the shadows the incident illumination can vary 10 to 1, thereby increasing the effective scene range from 200 to 1 or more for a reflectance gamut of 20 to 1. In this case the broadcaster has an option of exposing for proper rendition of detail in the lowlights and compressing the highlights or adjusting for proper highlight exposure and crushing the dark portions of the scene. Fortunately, with mutiple-camera pickups used in sporting events, one can attempt to provide correct exposure for a camera scene with minimal overlap into underexposed or overexposed areas.

Specular Reflections

An annoying problem frequently met in outdoor pickup is specular reflection from shiny surfaces which can effectively direct an image of a light source or the sun itself into the pickup tube. Under such conditions there will be "tailing," "puddling," or "comet-tail" effects during motion due to the fact that it is impractical in standard cameras to provide sufficient beam current to completely discharge such specular highlights. Usual practice is to provide a minimum of twice the normal peak signal reserve for beam current to take care of such specular highlights. The signals themselves, of course, are clipped electrically in the video circuits so as to avoid overload problems in transmission. New developments now underway show promise of providing relief from "comet-tail" effects by providing a very high current discharge beam during horizontal retrace time.

Low-Light Pickup

A frequent color camera problem is the case or providing satisfactory results with insufficient or minimal light on the scene. In this case one trades signal-to-noise ratio in the camera for increased sensitivity. For example, with a reduction of 6 dB in signal-to-noise ratio, an effective gain of 2 in sensitivity can be obtained. Even a factor of 4 gain in sensitivity is quite possible with acceptable signal-to-noise performance. However, at lower values of scene lighting, lag on motion becomes a factor in obtaining satisfactory performance. Under these conditions "bias lighting has been used experimentally in color cameras to provide increased sensitivity with reduced differential color lag on motion. A uniform "light level" applied to the red, green, and blue photocathodes of the Plumbicon tubes so as to increase the dark current to about 8 nanoamperes provides a noteworthy improvement in build-up and decay lag performance, under low-light operating conditions.

Color TV Film Chains

It is a universal American practice to use photoconductive pickup tubes in the reproduction of color film. A powerful reason for this choice is that conventional high reliability, intermittent pull-down motion picture film projectors for 16 and 35 mm film transport can be used. These are generally modified to convert the 24 frames per second motion picture standard to the 60 exposure fields per second required for nominal color TV standards, using the well-known 3-2 intermittent TV motion sequence. With a 3 to 2 intermittent film pull down, one motion picture frame is scanned by three television fields and the next picture frame is scanned by two television fields. Since each field lasts 1/60 second, the five fields take exactly 5/60 seconds or 1/12 second, which is exactly the same time as required to show two motion picture frames, 2/24 or 1/12 second. Thus, we have automatically the 24 frames to 60 field conversion needed for TV.

The use of photoconductive tubes with storage such as the vidicon or the Plumbicon permits nonsynchronous system operation. The projector can be driven from the nominal 60 Hz house power supply even though the color TV field frequency is slightly less than 60 Hz. There is an effective tolerance of ¼ to ½ Hz in the power supply frequency before any disturbing "application bar" effects can be noticed due to the nonsynchronous operation of the projector with respect to the vertical scan rate. Experience has shown that this tolerance is entirely adequate for well-stabilized electrical power systems used in America.

In addition to 16 mm and 35 mm color film, 2 X 2 in. slides are used for program announcements, commercials, and special tests. It is standard practice to provide as many as 3 or even 4 different optical inputs into the same color TV film chain by the use of moving-mirror or fixed-prism multiplexing techniques. Any one of these sources can be selected for color transmission thereby increasing the utilization of the equipment. Practically all modern color film chains use a field lens into which the image if projected. A typical film island is shown in Fig. 68 and a schematic of an optical multiplexer arrangement is shown in Fig. 69.

Network operations rely heavily on 35 mm color films for prime time programs. The local or regional stations use 16 mm color film and it is also used for news programs.

A publication titled, "Color Television" contains reprints or important color TV technical papers from the *Journal of SMPTE*, and is an important reference for the background of some of the fundamental developments in color TV theory, equipment design, and practice. It also provides a reference appendix listing current standards and recommended practices for TV and motion pictures, and a comprehensive bibliography of color television papers published in the SMPTE Journal.

COLOR TEST EQUIPMENT

The color television broadcast station relies heavily on specialized test and monitoring facilities in order to maintain adequate standards of performance and to ensure compliance with FCC regulations. In the early days of monochrome and color TV, the techniques and equipment were cumbersome and difficult to use on a routine basis. In recent years, test signals have become more sophisticated and yield much more information on the performance of monochrome and color TV systems.

A stable high-performance color monitor is an essential element of color test equipment. This, together with a vectorscope and a standard color bar generator for set-up and calibration serves as a means of evaluating performance.

The color monitor, vectorscope, and color bar generator find utilization in rapid routine day-to-day check of the television system adjustments.

Additional test equipment needed for color TV performance evaluation falls into two categories:

(1) equipment to evaluate studio performance and

(2) equipment to evaluate microwave relay and transmitter performance.

The important electrical characteristics to be measured in either category are:

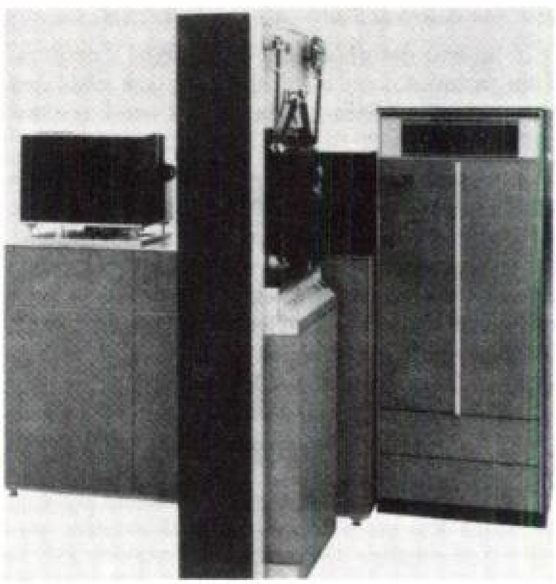

Fig. 68. A typical film island.

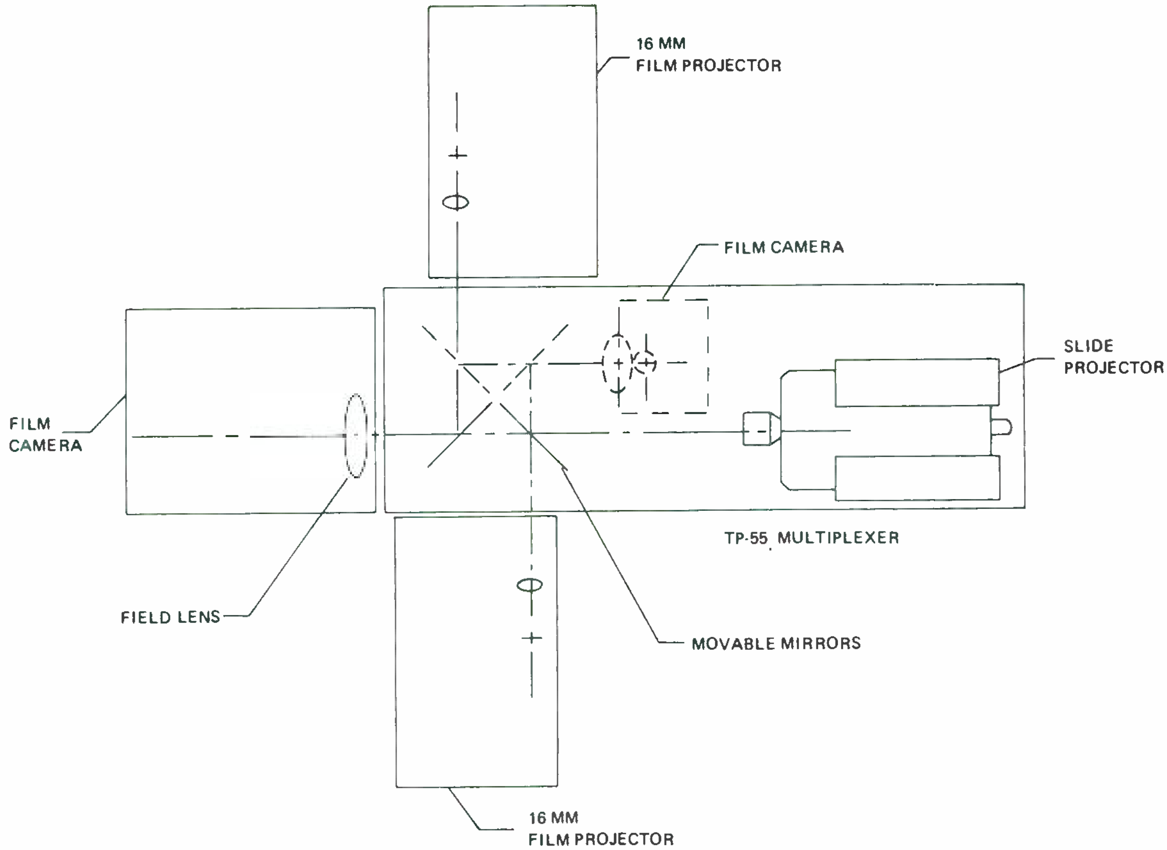

Fig. 69. Schematic of an optical multiplexer.

1. Linearity or differential gain;
2. Frequency response and differential phase performance;
3. Group delay characteristic;
4. Low frequency square-wave response.

Evolutionary developments have followed the requirement that specific test waveforms be made available which are compatible with normal television signal systems and can be introduced easily without disabling or upsetting normal operating conditions. Measurements of such test waveforms after passing through selected portions of the equipment or the complete system under evaluation, will give the required differential gain, phase and group delay information.

Stair-Step Generator

A modulated stair-step generator waveform is shown in Fig. 70. The signal conforms to IEEE standard IEEE 206. It consists of five 20-IRE-unit risers with subcarrier modulation on each transition. The amplitude-linearity or differential gain response of an amplifier can be determined directly from oscilliscope measurements of the output wave display. By the use of a high-pass filter, the differential gain characteristic can be displayed more graphically (Fig. 71, input), (Fig. 72, output) showing appreciable distortion. Differential phase measurements can be obtained by comparison of the subcarrier phase at each discrete level with phase of the color burst. Various oscillographic display techniques for precision phase measurements are available.

Sine-Squared Pulse and Bar

A second specialized waveform which is rapidly gaining popularity in color TV testing is the sine-squared pulse and bar with chrominance subcarrier modulation as shown in Fig. 73. It evolved from the monochrome sine-squared pulse and bar shown in Fig. 74. Use of this color test signal shows presence of differential gain distortions as in Fig 75 and delay distortions as shown in Fig. 76. Operationally the elegance of the method is in the direct-display presentation where distortion limits may be checked by reticle overlay techniques.

Another frequently used waveform is the multiburst signal, Fig. 77, which provides a series of selected frequency, constant-amplitude sine-wave electrical bursts of 0.5 MHz, 1, 2, 3, and 4 sweep

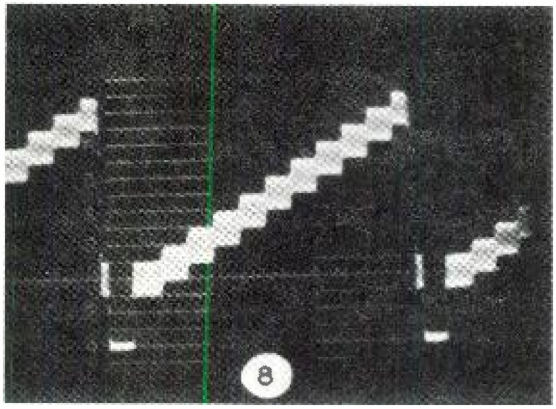

Fig. 70. Modulated stair-step generator waveform. (Picture courtesy of Marconi Instruments, Division of English Electric Corp.)

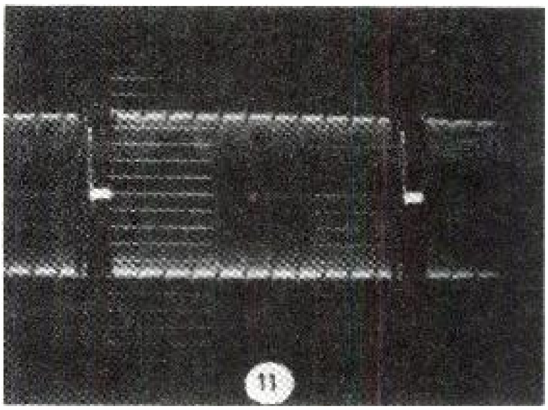

Fig. 71. High pass filter output with modulated stair-step waveform input. (Picture courtesy of Marconi Instruments, Division of English Electric Corp.)

signals which sequentially sample all frequencies in the video pass band. However, it is more convenient to use and to interpret in routine frequency response tests of broadcast equipment.

Vectorscope

The vectorscope[7] is a measurement instrument developed especially for color TV system tests and monitoring. Its essential feature is the polar or vectorial display of chrominance information in which the radial deflection is proportional to saturation of a color and the angular position is equal to the phase angle of that color subcarrier with respect to the color burst. The 360° polar coordinate display corresponds to a complete cycle of color subcarrier or 280 nanoseconds in a time display. By convention, the color burst is normalized at 180°. If the color bar signal described in Fig. 64 and Fig. 66 is applied to the input to the vectorscope and the burst is normalized at 180 , the display shown in Fig. 79 is obtained on the graticule.

It is noted that for standard signal levels each color vector in the color bar sequence falls within its approximately marked box on the graticule. The outer boxes define the FCC maximum permissible errors of ±10° in phase and ±20 percent in amplitude. The inner boxes correspond to ±2.5° phase error and 2.5 percent amplitude error.

A feature of the vectorscope color bar technique is that it gives immediate reassurance on system performance with a color bar test signal display.

By alternating two signal sources at the input, one can obtain direct readings on differential phase and amplitude behavior of any selected picture sources.

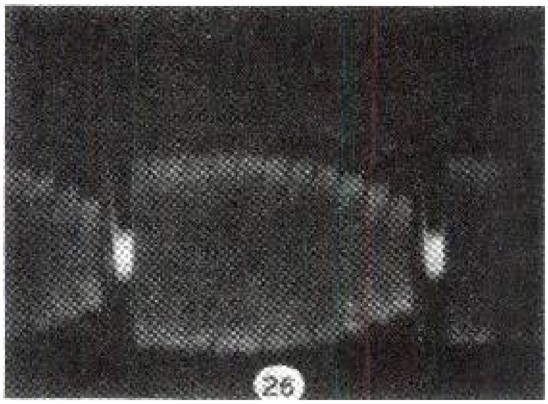

Fig. 72. High pass filter output of modulated stair-step waveform showing large amount of differential gain error in amplifier under test. (Picture courtesy of Marconi Instruments, Division of English Electric Corp.)

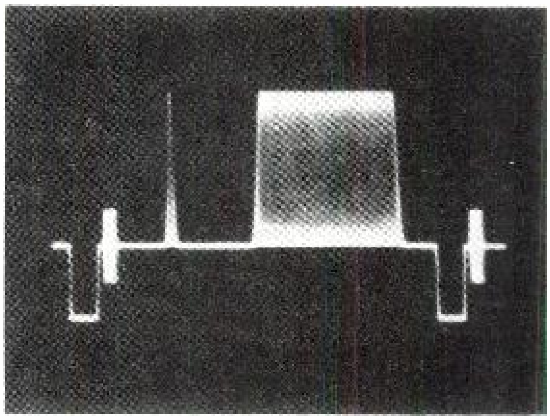

Fig. 73. Combined luminance and chrominance sine-squared pulse and bar. (Picture courtesy of Marconi Instruments, Division of English Electric Corp.)

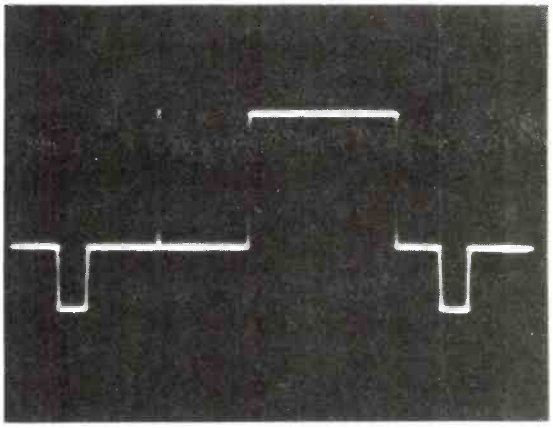

Fig. 74. Monochrome sine-squared pulse and bar. (Picture courtesy of Marconi Instruments, Division of English Electric Corp.)

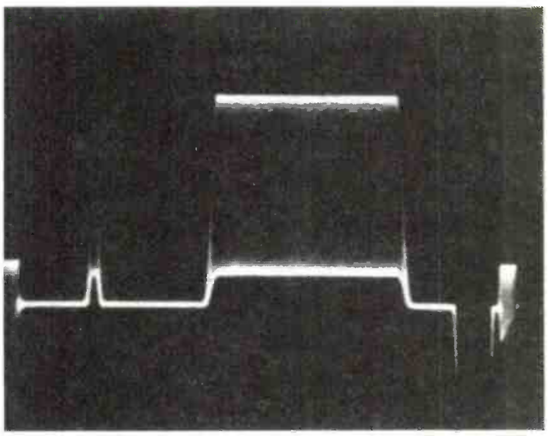

Fig. 75. Gain inequality indicated by combined luminance and chrominance sine-squared pulse and bar. Compare with waveforms of Fig. 73. (Picture courtesy of Marconi Instruments, Division of English Electric Corp.)

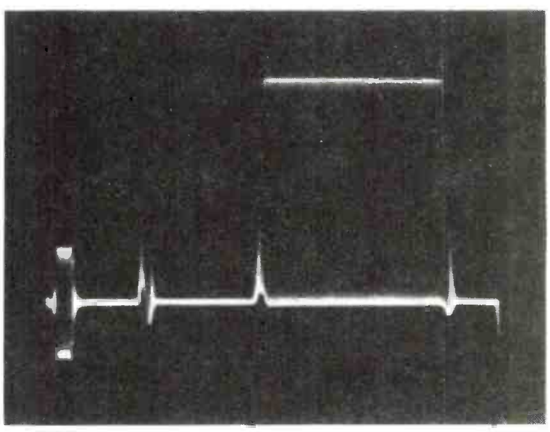

Fig. 76. Delay inequality indicated by the combined luminance and chrominance sine-squared pulse and bar. (Picture courtesy of Marconi Instruments, Division of English Electric Corp.)

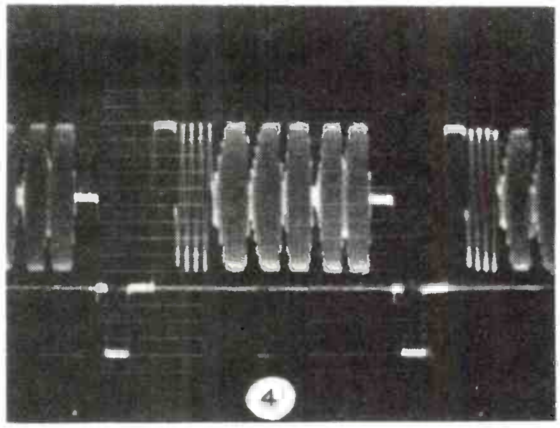

Fig. 77. Multiburst test signal with burst at 0.5 MHz, 1, 2, 3, and 4 MHz. (Picture courtesy of Marconi Instruments, Division of English Electric Corp.)

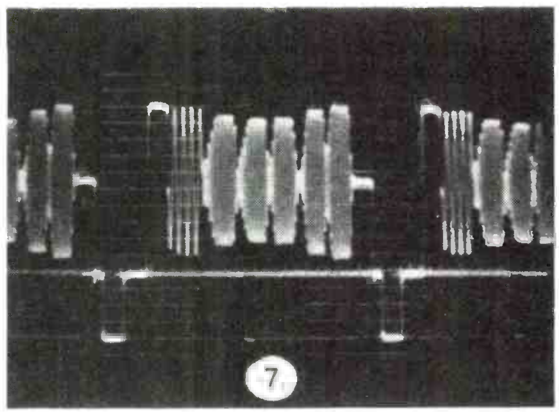

Fig. 78. Multiburst output signal from amplifier having distortion. Compare with Fig. 77. (Picture courtesy of Marconi Instruments, Division of English Electric Corp.)

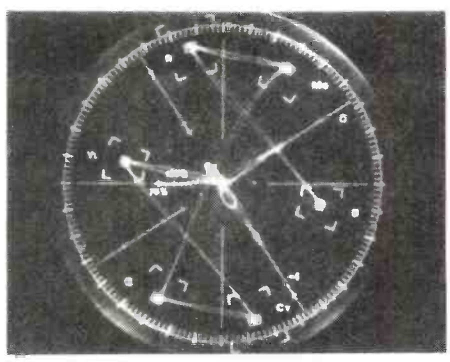

Fig. 79. Vector display. Split field color bars 75 per cent amplitude 100 percent white reference, 10 per cent set up. Conforms to EIA specification RS 189. (Picture courtesy of Tektronix, Inc.)

Vertical Interval Reference and Test Signals

A development which has important long-range possibilities is the use of a special signal transmitted in a specific line of the vertical blanking interval. The Vertical Interval Reference "VIR" signal, consists of a chrominance bar having the same phase as color burst, together with an appropriate luminance pulse and a black level interval. The Vertical Interval Reference signal is added to the main video signal and is in fact a certification that at the time it is added all conditions are normal. If various distortions occur to this Vertical Interval Reference, it can be corrected, with the expectation that the main signal will also be corrected. Thus more rigorous control and compensation of system errors is possible. A "VIT" or Vertical Interval Test signal is used to verify transmission conditions using multiburst, sine-squared or stair-step test signals. Such signals can be used for continuous monitoring of TV system performance, and in the future will probably find application in automatic control or correction of color system performance.

Test Charts

There are available several pictorial charts which serve to optically generate special test signals useful for color camera alignment and system adjustment. These were developed by industry technical committees and are available as opaques from EIA[8] or from equipment manufacturers for live cameras and as 2 X 2 in. slides from SMPTE for color TV film chains.

They are:

- EIA Resolution Chart,
- EIA Linear Gray Scale Chart,
- EIA Logarithmic Gray Scale,
- EIA Registration Chart,
- RCA Multiburst Chart,
- SMPTE Resolution Slide,
- Registration Slide,
- Linearity Slide.

The development of TV test signals and facilities is one which continually strives to increase the information to be obtained on systems performance, preferably on a continuous basis and without taking the system out of service. The "VITS" and "VIPS" concepts appear capable of providing a major step forward in test and measuring techniques.

FOOTNOTES

1. A detailed discussion of colorimetry and perception, and how these factors affect the viewer, is presented in "Color Television Engineering" by John W. Wentworth, McGraw-Hill Book Company, Inc., New York, 1955.
2. If the filters in the system are of the minimum-phase type, only one of the plots is needed, for either plot can be derived from the other for this type of filter. Almost all common interstage coupling networks are of the minimum-phase type.
3. FM systems can have nonlinearity as a result of *passive* networks, but this case is not considered here.
4. From the definition of differential gain by IRE Subcommittee 23.4.
5. From the definintion of differential phase by IRE Subcommittee 23.4.
6. Electronic Industries Association.
7. Tektronics Model 520 vectorscope is widely used for these measurements.
8. EIA—Electronic Industries Association.

REFERENCED TO FCC PART 73.699

	TIMING MEASUREMENTS	DEFINITION	RANGE			EIA RS-170A TENTATIVE STANDARDS SPECIFICATIONS APPLICABLE TO STUDIO FACILITIES	NOTES
			MINIMUM	NOMINAL	MAXIMUM		
1	H SYNC WIDTH	THE HORIZONTAL SYNC PULSE IS MEASURED BETWEEN THE -4 IRE POINTS ON THE LEADING AND TRAILING EDGES OF THE WAVEFORM.	4.45 μSEC, @-4 IRE	4.76 μSEC, @-4 IRE	5.08 μSEC, @-4 IRE	4.7 μSEC ±0.1 μSEC, @-20 IRE	FCC REQUIRES THAT THE HORIZONTAL SYNC PULSE MUST BE BETWEEN 4.45 AND 5.08 μSEC.
2	FRONT PORCH	THE FRONT PORCH IS MEASURED BETWEEN BLANKING AND THE LEADING EDGE OF H SYNC. THIS COMPONENT IS MEASURED FROM THE +4 IRE LEVEL AT BLANKING TO THE -4 IRE LEVEL ON THE LEADING EDGE OF THE H SYNC PULSE.	1.27 μSEC, SEE NOTE	1.54 μSEC, @-4 IRE	1.60 μSEC, @-4 IRE	1.5 μSEC ±0.1 μSEC, @+4 IRE -20 IRE	THE FCC SPECIFIES THAT THE FRONT PORCH, MUST BE NO LESS THAN 1.27 μSEC MEASURED FROM THE +4 IRE LEVEL AT BLANKING TO THE -4 IRE LEVEL ON THE LEADING EDGE OF H SYNC.
3	SYNC TO START OF VIDEO DURATION	THIS INTERVAL IS MEASURED FROM THE -4 IRE POINT ON THE LEADING EDGE OF H SYNC TO THE +4 IRE POINT ON THE TRAILING EDGE OF BLANKING.	9.22 μSEC, SEE NOTE	9.4 μSEC, SEE NOTE	9.61 μSEC, SEE NOTE	9.4 μSEC ±0.1 μSEC, @-20 IRE +4 IRE	THE FCC SPECIFIES 0.145 H MINIMUM DURATION, FOR THIS COMPONENT.
4	SYNC TO END OF BURST DURATION	THIS SECTION IS MEASURED FROM THE -4 IRE POINT ON THE LEADING EDGE OF H SYNC TO THE TRAILING ZERO CROSSING OF THE LAST BURST EXCURSION EXCEEDING 50% OF BURST AMPLITUDE.	7.07 μSEC, SEE NOTE	7.50 μSEC, SEE NOTE	7.94 μSEC, SEE NOTE	7.80 μSEC ±0.1 μSEC, @-20 IRE TO LAST CYCLE OF BURST EXCEEDING 50% AMPLITUDE	THE FCC SPECIFIES 0.125 H MAXIMUM DURATION, FOR THIS COMPONENT.
5	H BLANKING	THE FCC DEFINES HORIZONTAL BLANKING AS MEASURED BETWEEN POINTS ON THE WAVEFORM AT +4 IRE UNITS, WITH A DURATION OF 10.49 μSEC. THE MAXIMUM WIDTH SPECIFICATION FOR H BLANKING DEFINED BY THE FCC, IS 11.44 μSEC MEASURED AT 90 IRE UNITS.	10.49 μSEC, @4 IRE	10.8 μSEC, @20 IRE	11.44 μSEC, @90 IRE	10.9 μSEC ±0.2 μSEC @+20 IRE	THE MAXIMUM WIDTH SPECIFICATION FOR H BLANKING IS MEASURED AT 90 IRE UNITS ABOVE BLANKING. IT IS INTERESTING TO NOTE THAT MANY VIDEO SIGNALS DO NOT REACH 90 IRE IMMEDIATELY AFTER BLANKING.
6	COLOR BURST WIDTH	THE COLOR BURST IS MEASURED FROM THE LEADING ZERO CROSSING OF THE FIRST BURST EXCURSION EXCEEDING 50% OF THE BURST AMPLITUDE TO THE TRAILING ZERO CROSSING OF THE LAST BURST EXCURSION EXCEEDING 50% OF THE BURST AMPLITUDE.	8 CYCLES	9 CYCLES	10 CYCLES	9 CYCLES	FCC STANDARDS REQUIRE A MINIMUM OF 8 CYCLES OF COLOR BURST. THE NEW STANDARD WHICH IS NOW BEING USED IN THE INDUSTRY IS 9 CYCLES OF COLOR BURST.
7	BREEZEWAY WIDTH	THE BREEZEWAY IS DEFINED AS THE PERIOD BETWEEN THE TRAILING EDGE OF THE HORIZONTAL SYNC PULSE AND THE FIRST CYCLE OF COLOR BURST. THIS IS MEASURED FROM THE -4 IRE POINT ON THE TRAILING EDGE OF H SYNC TO THE LEADING ZERO CROSSING OF THE FIRST BURST EXCURSION EXCEEDING 50% AMPLITUDE	381 nSEC, SEE NOTE	600 nSEC, SEE NOTE	900 nSEC, SEE NOTE	600 nSEC ±100 nS, @-4 IRE TO FIRST CYCLE OF COLOR BURST EXCEEDING 50% AMPLITUDE	THE FCC SPECIFIES THAT THE BREEZEWAY MUST BE NO LESS THAN 381 μSEC, MEASURED FROM THE TRAILING EDGE OF HORIZONTAL SYNC PULSE A -4 IRE POINT, TO THE FIRST CYCLE OF COLOR BURST.
8	SUBCARRIER FREQUENCY	THE FREQUENCY OF THE COLOR SUBCARRIER, 3.579545 MHZ, IS AN ODD MULTIPLE OF HALF-LINE FREQUENCY, I.E., HORIZONTAL LINE FREQUENCY/2. $\frac{15734.264\ HZ}{2}$ = 7867.132 FOR NTSC COLOR TELEVISION. (7867.132) (455) = 3.579545 MHZ	3.579535 MHZ	3.579545 MHZ	3.579555 MHZ	3.579545 MHZ, ±10 HZ	THE FREQUENCY OF THE COLOR SUBCARRIER MUST BE HELD WITHIN 10 HZ OF 3.579545 MHZ. NOTE, SHORT TIME DURATION OF BURST SIGNAL MAKES DIRECT FREQUENCY COUNTING INACCURATE.
9	H SYNC RISE AND FALL TIMES	THE RISE AND FALL TIMES OF THE HORIZONTAL SYNC PULSE ARE MEASURED BETWEEN THE 10 AND 90% POINTS ON THE LEADING AND TRAILING EDGES OF THE WAVEFORM.	——	<250 nSEC, SEE NOTE	250 nSEC, SEE NOTE	0.14 μSEC ±0.02 μSEC MEASURED BETWEEN 10 AND 90% POINTS ON THE LEADING AND TRAILING EDGES OF THE PULSE	FCC REQUIRES THAT RISE TIME OF H SYNC BE LESS THAN 0.250 μSEC ASSUMING 40IRE UNITS OF H SYNC AMPLITUDE. 10% CORRESPONDS TO -4IRE AND 90% CORRESPONDS TO -36IRE.
10	SERRATION WIDTH	THE SERRATIONS ARE LOCATED IN THE VERTICAL SYNC PULSE AND MEASURED AT THE -4 IRE POINTS.	3.81 μSEC, -4 IRE SE@NOTE	4.45 μSEC, @-4 IRE SEE NOTE	5.08 μSEC, @-4 IRE SEE NOTE	4.7 μSEC ±0.1 μSEC, @-20 IRE	THE SERRATIONS IN THE V SYNC PULSE MUST BE BETWEEN 3.8 AND 5.08 μSEC, MEASURED AT -4 IRE LEVEL. THE RISE AND FALL TIMES OF THE SERRATIONS MUST BE LESS THAN 250 nSEC.
11	RISE AND FALL TIMES OF EQUALIZERS AND SERRATIONS	THE RISE AND FALL TIMES OF THE EQUALIZERS AND SERRATIONS ARE MEASURED BETWEEN THE 10 AND 90% POINTS ON THE LEADING AND TRAILING EDGES OF THE WAVEFORMS.	——	250 nSEC, SEE NOTE	250 nSEC, SEE NOTE	0.14 μSEC ±0.02 μSEC MEASURED BETWEEN 10 AND 90% POINTS ON THE LEADING AND TRAILING EDGES OF THE PULSE	FCC SPECIFIES RISE AND FALL TIMES OF EQUALIZERS AND SERRATIONS MUST BE LESS THAN 250 nSEC. THE 10% AND 90% POINTS CORRESPOND TO -4 IRE AND -36 IRE UNITS, RESPECTIVELY.
12	EQUALIZING PULSE WIDTH	THE EQUALIZING PULSES PRECEDE AND FOLLOW THE VERTICAL SYNC PULSE INTERVAL. THEY ARE MEASURED AT THE -4 IRE LEVEL.	2.00 μSEC, @-4 IRE	2.26 μSEC, @-4 IRE	2.54 μSEC, @-4 IRE	2.3 nS ± 0.1 μSEC, @-20 IRE	THE TOLERANCE ON EQUALIZING PULSES, IS THAT THE AREA OF THESE PULSES MUST BE BETWEEN 45 AND 50% OF THE AREA OF THE HORIZONTAL SYNCHRONIZING PULSE.
13	V BLANKING WIDTH	VERTICAL BLANKING INTERVAL IS THE TIME BETWEEN THE LAST PICTURE INFORMATION AT THE BOTTOM OF ONE FIELD TO THE FIRST PICTURE INFORMATION AT THE TOP OF THE NEXT FIELD.	19 LINES	20 LINES	21 LINES	FIELD I = 20 LINES FIELD II = 19.5 LINES	IN TERMS OF TIME, VERTICAL BLANKING MUST BE GREATER THAN 1.17 mSEC, BUT LESS THAN 1.33 mSEC. NOTE, THE BROADCAST INDUSTRY NOW FAVORS A MAXIMUM OF 20 LINES OF VERTICAL BLANKING.
14	V SYNC PULSE INTERVAL	THE VERTICAL SYNC PULSE SHOULD HAVE A DURATION EQUAL TO THREE HORIZONTAL LINES. THE SERRATIONS IN THE VERTICAL SYNC PULSE SHOULD BE BETWEEN 3.8 TO 5.1 μSEC, MEASURED AT -4 IRE LEVEL.	——	3H	——	3H H = 1 HORIZONTAL LINE H = 63.55 μSEC	FCC REQUIRES THE VERTICAL SYNC PULSE TO HAVE A DURATION OF THREE HORIZONTAL LINES. IN TERM OF TIME, 3 H = 190.67 μSEC. THE VERTICAL SYNC PULSE IS TO BE EXACTLY 3 HORIZONTAL LINES.

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FCC time-base specifications for NTSC-M color television.

Color Television

Part II: Worldwide Color Television Standards—Similarities and Differences*

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WORLDWIDE COLOR TELEVISION STANDARDS

Introduction

A simple, concise summary of the similarities and differences in the ever-changing color television system techniques and standards employed throughout the world is difficult to achieve, as evidenced by the efforts of the CCIR (International Radio Consultative Committee) in attempting to establish the elusive "universal" system. Nevertheless, it is hoped that this tutorial review and up-date may be useful for those who desire a conceptual overview of the technical situation.

The picture performance of a motion picture system in one location in the world is generally the same as in any other location. Thus, international exchange of film programming is comparatively straightforward.

Not so in the case of broadcast color television systems. The lack of compatibility has its origins in many factors such as constraints in communications channel allocations and techniques, differences in local power source characteristics, network requirements, pickup and display technology, and political considerations relating to international telecommunications agreements. The intent of this paper is to provide a tutorial review of the technical standardization characteristics pertinent to the problem of international exchange of images—not a system's performance comparison.

Background

The most outstanding as well as the most controversial effort of the Eleventh Plenary Assembly of the CCIR, held in Oslo in 1966, was an attempt at standardization of color television systems by the contributing countries of the world. The discussions pertaining to the possibility of a universal system proved inconclusive. Therefore, the CCIR, instead of issuing a unanimous recommendation for a single system, was forced to issue only a report describing the characteristics and recommendations for a variety of proposed systems. It was, therefore, left to the controlling organizations of the individual countries to make their own choice as to which standard to adopt.

This outcome was not totally surprising since one of the primary requirements for any color television system is compatibility with a coexisting monochrome system. In many cases, the monochrome standards, already existed and were dictated by such factors as local power line frequen-

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NOTE: Superscript numbers refer to references at the end of this chapter.

cies—relevant to field and frame rates—as well as radio frequency channel allocations and pertinent telecommunications agreements.

Thus, such technical factors as line number, field rate, video bandwidth, modulation technique, and sound carrier frequencies were predetermined and varied in many regions of the world. The ease with which international exchange program material may be accomplished is thereby hampered and is accomplished at present by means of standards conversion techniques, or "transcoders," with varying degrees of loss in quality.

On the other hand, these techniques have provided surprisingly good service in more recent years with the growing use of "satellite relays" coupled with the advances in digital signal processing technology in both the video and audio domains. In view of this rapidly changing situation and considering that more and more countries, particularly in Latin America (Region II), arrive at the point of deciding on a color system, it becomes apparent that a clear understanding of the implications of system variations has a high order of priority for those involved in international live television broadcast and film/videotape programming exchange.

The data quoted herein is referenced to the recent recommendations of the Fourteenth Plenary Assembly of the CCIR held in Kyoto, Japan in 1978. It should be recognized that the situation is of a continually shifting nature and future decisions can and no doubt will alter some of the details.

"Monochrome-Compatible" Color TV Systems

In order to achieve success in the introduction of a color television system, it is essential that the color system be fully compatible with the existing black-and-white system. That is, monochrome receivers must be able to produce high-quality black-and-white images from a color broadcast, and color receivers must produce high-quality black-and-white images from monochrome broadcasts. The first such color television system to be placed into commercial broadcast service was developed in the United States. On 17 December 1953, the Federal Communications Commission (FCC) approved transmission standards and authorized broadcasters, as of 23 January 1954, to provide regular service to the public under these standards. This decision was the culmination of the work of the NTSC (National Television System Committee) upon whose recommendation the FCC action was based.[1] Subsequently, this system, now referred to as the NTSC system, was adopted by Canada, Japan, Mexico, and others.

That 26 years later, in 1980, these standards are still providing color television service of good quality testifies to the validity and applicability of the fundamental principles underlying the choice of specific techniques and numerical standards.

The previous existence of monochrome television standards was two-edged in that it provided a foundation upon which to build the necessary innovative techniques while simultaneously imposing the requirement of compatibility. Within this framework, an underlying theme—that which the eye does not see does not need to be transmitted nor reproduced—set the stage for a variety of fascinating developments in what has been characterized as an "economy of representation."[1]

The countries of Europe delayed the adoption of a color television system, and in the years between 1953 and 1967, a number of alternative systems that were compatible with the 625-line, 50-field existing monochrome systems were devised. The development of these systems was to some extent influenced by the fact that the technology necessary to implement some of the NTSC requirements was still in its infancy. Thus, many of the differences between the NTSC and other systems are due to technological rather than fundamental theoretical considerations.

Most of the basic techniques of NTSC are incorporated into the other system approaches. For example, the use of wideband luminance and relatively narrowband chrominance, following the teachings of the principle of "mixed highs," is involved in all systems. Similarly, the concept of providing horizontal interlace for reducing the visibility of the color subcarrier(s) is followed in all approaches. This feature is required to reduce the visibility of signals carrying color information that are contained within the same frequency range as the coexisting monochrome signal, thus maintaining a high order of compatibility.

An early system that received approval was one proposed by Henri de France of the Compagnie de Television of Paris. It was argued that if color could be relatively band-limited in the horizontal direction, it could also be band-limited in the vertical direction. Thus, the two pieces of coloring information (hue and saturation) that need to be added to the one piece of monochrome information (brightness) could be transmitted as subcarrier modulation that is sequentially transmitted on alternate lines—thereby avoiding the possibility of unwanted crosstalk between color signal components. Thus, at the receiver, a one-line memory, commonly referred to as a 1-H delay element, must be employed to store one line to then be concurrent with the following line. Then a linear matrix of the "red" and "blue" signal components (R and B) is used to produce the third "green" component (*G*). Of course, this necessitates the addition of a line-switching identification technique. Such an approach, designated as SECAM (*S*equential *C*ouleur *A*vec *M*emoire, for sequential color with memory) was developed and officially adopted by France and the USSR, and broadcast service began in France in 1967.

The implementation technique of a 1-*H* delay element led to the development, largely through the efforts of Walter Bruch of Telefunken Company, of the *P*hase *A*lternation *L*ine or PAL system. This approach was aimed at overcoming an implementation problem of NTSC that requires a high order of phase and amplitude integrity (skew-symmetry) of the transmission path characteristics around the color subcarrier to prevent color quadrature distortion. The line-by-line alternation of the phase of one of the color signal components averages any colorimetric distortions to the observer's eye to that of the correct value. The system in its simplest form (simple PAL), however, results in line flicker (Hanover bars). The use of a 1-*H* delay device in the receiver greatly alleviates this problem (standard PAL). PAL systems also require a line identification technique.

The standard PAL system has been adopted by numerous countries in continental Europe as well as in the United Kingdom. Public broadcasting began in 1967 in Germany and the United Kingdom using two slightly different variants of the PAL system (to be described shortly).

NTSC, PAL, and SECAM Systems Overview

In order to properly understand the similarities and differences in systems used today, a familiarization with the basic principles of NTSC, PAL, and SECAM is required. As previously stated, because many basic techniques of NTSC are involved in PAL and SECAM, a thorough knowledge of NTSC is necessary in order to understand PAL and SECAM.

The same *R*, *G*, and *B* pickup devices and the same three primary color display devices are used in all systems. The basic camera function is to analyze the spectral distribution of the light from the scene in terms of its red, green, and blue components on a point-by-point basis as determined by the scanning rates. The three resulting electrical signals must then be transmitted over a band-limited communications channel to control the three-color display device to make the *perceived* color at the receiver appear essentially the same as the *perceived* color at the scene.

It is useful to define color as a psycho-physical property of light—specifically, as the combination of those characteristics of light that produces the sensations of brightness, hue, and saturation as shown in Fig. 1. Brightness refers to the relative intensity; hue refers to that attribute of color that allows separation into spectral groups perceived as red, green, yellow, etc. (in scientific terms, the dominant wavelength); and saturation is the degree to which a color deviates from a neutral gray of the same brightness—the degree to which it is "pure," or "pastel," or "vivid," etc. These three characteristics represent the total information necessary to define and/or recreate a specific color stimulus.

This concept is useful to communication engineers in developing encoding and decoding techniques to efficiently compress the required information within a given channel bandwidth and to subsequently recombine the specific color signal values in the proper proportions at the reproducer. The NTSC color standards define the first commercially broadcast process for achieving this result.

A preferred signal arrangement was developed that resulted in reciprocal compatibility with monochrome pictures and is transmitted within the existing monochrome channel as shown in

BRIGHTNESS (Luminance):

RELATIVE INTENSITY OF THE COLOR

HUE

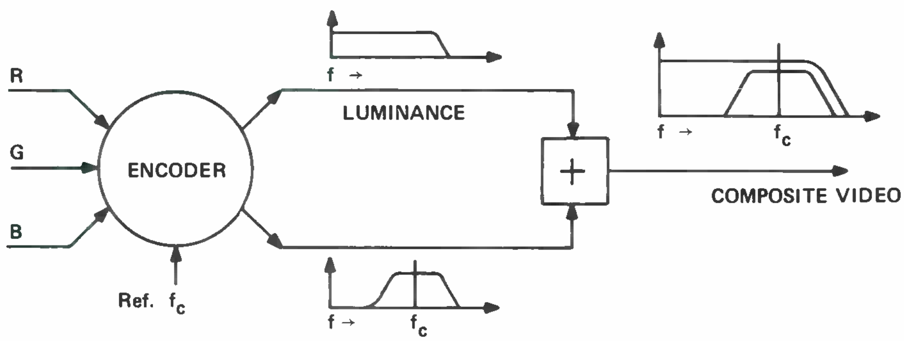
THE ATTRIBUTE THAT ALLOWS DESIGNATION IN TERMS OF RED, YELLOW, BLUE, etc. (Dominant wavelength).

SATURATION

DEGREE TO WHICH A COLOR DEVIATES FROM A NEUTRAL GRAY OF THE SAME BRIGHTNESS – PURITY, PASTEL, VIVIDNESS, etc.

Fig. 1. Basic definition of "color."

- COMPATIBILITY WITH CO-EXISTING MONOCHROME SYSTEM.
- ENCODE WIDEBAND R, G, B COLOR PRIMARY SIGNALS.
  - WIDEBAND LUMINANCE (BRIGHTNESS)
  - NARROW-BAND MODULATION OF A COLOR SUBCARRIER (Hue and Saturation)



- SUBCARRIER FREQUENCY INTERLACE
  - ODD MULTIPLE OF ½ H TO REDUCE VISIBILITY OF CHROMINANCE INFORMATION SUBCARRIER.

Fig. 2. Basic communications channel principles applied to color television.

Fig. 2. Thus, one signal (luminance) is chosen in all approaches to occupy the wide-band portion of the channel and to convey the *brightness* as well as the detail information content. A second signal, termed the chrominance signal, representative of the chromatic attributes of *hue* and *saturation*, is assigned less channel width in accordance with the principle that in human vision full three-color reproduction is not required over the entire range of resolution—commonly referred to as the "mixed-highs principle."

Another fundamental principle employed in all systems involves arranging the chrominance and luminance signals within the same frequency band without excessive mutual interference. Recognition that the scanning process, being equivalent to sampled-data techniques, produces signal components largely concentrated in uniformly spaced groups across the channel width, led to introduction of the concept of horizontal frequency interlace (dot interlace). The color subcarrier frequency is so chosen as to be an odd multiple of one-half the line rate (in the case of NTSC) such that the phase of the subcarrier is exactly opposite on successive scanning lines. This substantially reduces the subjective visibility of the color signal "dot" pattern components.

Thus the major differences among the three main systems of NTSC, PAL, and SECAM are in the specific modulating processes used for encoding and transmitting the chrominance information. The similarities and differences are briefly summarized in Fig. 3.

The following four sections discuss the basic color television systems in some technical detail, including some never actually implemented. For a summary and comparison of system standards and specifications, the reader is referred to a later section.

The NTSC Color System

The importance of the colorimetric concepts of brightness, hue, and saturation comprising the three pieces of information necessary to analyze or recreate a specific color value becomes evident in the formation of the composite color television NTSC format.

The luminance, or monochrome, signal is formed by addition of specific proportions of the red, green, and blue signals and occupies the total available video bandwidth of 0-4.2 MHz. The NTSC, PAL, and SECAM systems all use the same luminance (*Y*) signal formation, differing only in available bandwidths.

The "*Y*" signal components have relative voltage values representative of the brightness sensation in the human eye. Therefore, the red (E'_R), green (E'_G), and blue (E'_B) voltage components are tailored in proportion to the standard luminosity curve at the particular values of the dominant wavelengths of the three color primaries chosen for color television. Thus, the luminance signal makeup for all systems, as normalized to white, is described by

- ALL SYSTEMS:
  - THREE-PRIMARY ADDITIVE COLORIMETRIC PRINCIPLES
  - SIMILAR CAMERA PICK-UP AND RECEIVER DISPLAY TECHNOLOGY
  - WIDEBAND LUMINANCE AND NARROW-BAND COLOR
- COMPATIBILITY WITH CO-EXISTING MONOCHROME SYSTEM:
  INTRODUCES FIRST ORDER DIFFERENCES
  - LINE NUMBER
  - FIELD/FRAME RATES
  - BANDWIDTH
  - FREQUENCY ALLOCATION
- MAJOR DIFFERENCES IN COLOR TECHNIQUES
  - NTSC – PHASE AND AMPLITUDE QUADRATURE MODULATION OF INTERLACED SUBCARRIER
  - PAL – SIMILAR TO NTSC BUT WITH LINE ALTERNATION OF "V" COMPONENT
  - SECAM – FREQUENCY MODULATION OF LINE SEQUENTIAL COLOR SUBCARRIERS

Fig. 3. General comparison of worldwide television systems.

$$E'_Y = 0.299\ E'_R + 0.587\ E'_G + 0.114\ E'_B \quad [1]^*$$

Fig. 4 also indicates the equations for the chrominance signal components. Signals representative of the chromaticity information (hue and saturation) that relate to the differences between the luminance signal and the basic red, green, and blue signals are generated in a linear matrix. This new set of signals is termed *color-difference* signals and is designated as $R-Y$, $G-Y$, and $B-Y$. These signals modulate a subcarrier that is combined with the luminance component and passed through a common communications channel. At the receiver, the color difference signals are determined, separated, and individually added to the luminance signal in three separate paths to recreate the original R, G, and B signals according to the equations

$$\begin{aligned} E'_Y + E'_{(R-Y)} &= E'_Y + E'_R - E'_Y = E'_R \\ E'_Y + E'_{(G-Y)} &= E'_Y + E'_G - E'_Y = E'_G \qquad [2] \\ E'_Y + E'_{(B-Y)} &= E'_Y + E'_B - E'_Y = E'_B \end{aligned}$$

In the specific case of NTSC, two other color-difference signals, designated as "I" and "Q", are formed at the encoder and used to modulate the color subcarrier, indicated in Fig. 4. The reason for the choice of I and Q signals is discussed later.

It may be noted that the $B-Y$, $R-Y$, and $G-Y$ color signal modulation components are the same in NTSC, PAL, and SECAM.

Another reason for the choice of signal values in the NTSC system is that the eye is more responsive to spatial and temporal variations in luminance than it is to variations in chrominance. Therefore, the visibility of luminosity changes due to random noise and interference effects may be reduced by properly proportioning the relative chrominance gain and encoding angle values with respect to the luminance values. Thus, the "principle of constant luminance"** is incorporated into the system standards.[1, 2]

The voltage outputs from the three camera tubes are adjusted to be equal when a scene reference white or neutral gray object is being scanned for the color temperature of the scene ambient. Under this condition, the color subcarrier also automatically becomes zero. The colormetric values have been formulated by assuming that the reproducer will be adjusted for "Illuminant C," representing the color of average daylight.

*The signal of Equation [1] would be exactly equal to the output of a linear monochrome camera tube with ideal spectral sensitivity if the red, green, and blue camera tubes were also linear devices with theoretically correct spectral-sensitivity curves. In actual practice, the red, green, and primary signals are deliberately made nonlinear to accomplish gamma correction (adjust the slope of the input/output transfer characteristic). The prime mark (′) is used to denote a gamma-corrected signal.

**The IEEE Standard Dictionary of Electrical and Electronics Terms notes that in constant-luminance signal and no control of luminance is provided by the chrominance signal. Noise signals falling within the bandwidth of the chrominance channel produce only chromaticity variations, which if they are coarse-structured are subjectively less objectionable than correspondingly coarse-structured luminance variations.

LUMINANCE:

$$E'_Y = 0.299\ E'_R + 0.587\ E'_G + 0.114\ E'_B$$

(Common for all systems)

CHROMINANCE:

NTSC

$$E'_I = -0.274\ E'_G + 0.596\ E'_R - 0.322\ E'_B$$

$$E'_Q = -0.522\ E'_G + 0.211\ E'_R + 0.311\ E'_B$$

$$B\text{-}Y = 0.493\ (E'_B - E'_Y)$$

$$R\text{-}Y = 0.877\ (E'_R - E'_Y)$$

$$G\text{-}Y = 1.413\ (E'_G - E'_Y)$$

PAL

$$E'_U = 0.493\ (E'_B - E'_Y)$$

$$\pm E'_V = \pm 0.877\ (E'_R - E'_Y)$$

SECAM

$$D'_R = -1.9\ (E'_R - E'_Y)$$

$$D'_B = 1.5\ (E'_B - E'_Y)$$

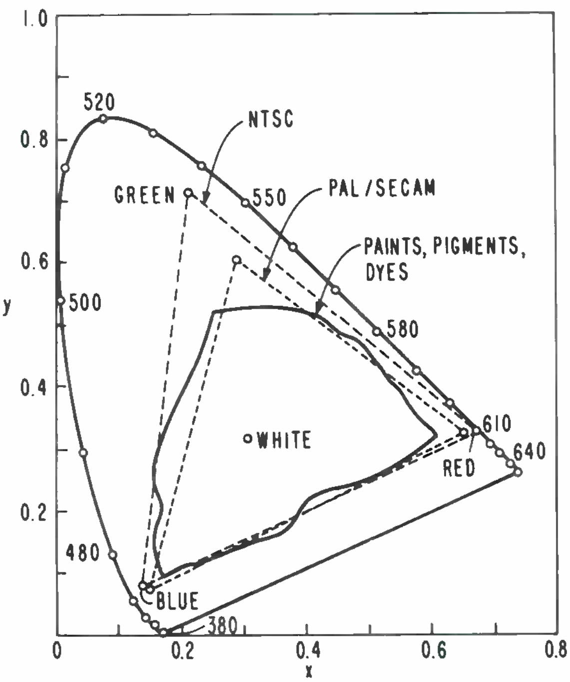
Fig. 4. Electronic color signal values for NTSC, PAL, and SECAM.

Fig. 5 is a CIE chromaticity diagram (CIE = Commission Internationale de l'Eclairage) indicating the primary color coordinates for NTSC, PAL, and SECAM. It is interesting to compare the television available color gamut relative to that of all color paint, pigment, film, and dye processes.

In NTSC color standards, the chrominance information is carried as simultaneous amplitude and phase modulation of a subcarrier chosen to be in the high frequency portion of the 0-4.2 MHz video band and specifically related to the scanning rates as an odd multiple of one-half the horizontal line rate as shown by the vector diagram in Fig. 6. The hue information is assigned to the instantaneous phase of the subcarrier. Saturation is determined by the *ratio* of the instantaneous amplitude of the subcarrier to that of the corresponding luminance signal amplitude value. For details of the derivation, the reader is directed to References 2, 3, and 4.

The choice of the *I* and *Q* color modulation components relates to the variation of color acuity characteristics of human color vision as a function of the field of view and spatial dimensions of objects in the scene. The color acuity of the eye decreases as the size of the viewed object is decreased and thereby occupies a small part of the field of view. Small objects, represented by frequencies above about 1.5 to 2.0 MHz, produce no color sensation ("mixed-highs"). Intermediate spatial dimensions (approximately 0.5–to 1.5 MHz range) are viewed satisfactorily if reproduced along a preferred orange-cyan axis. Large objects (0–0.5 MHz) require full three-color reproduction for subjectively pleasing results. Thus, the *I* and *Q* bandwidths are chosen accordingly and the preferred colorimetric reproduction axis is obtained when only the "*I*" signal exists by rotating the subcarrier modulation vectors by 33°. In this way, the principles of "mixed-highs" and "*I, Q* color-acuity axis" operation are exploited.

At the encoder, the "*Q*" signal component is band-limited to about 0.6 MHz and is representative of the green-purple color-axis information. The "*I*" signal component has a bandwidth of about 1.5 MHz and contains the orange-cyan color axis information. These two signals are then



		x	y
NTSC	R =	0.67	0.33
	G =	0.21	0.71
	B =	0.14	0.08
PAL/SECAM	R =	0.64	0.33
	G =	0.29	0.60
	B =	0.15	0.06
WHITE:	NTSC(ILL. C) =	0.310	0.316
	PAL/SECAM(D6500) =	0.313	0.329

Fig. 5. CIE chromacity diagram-system comparison.

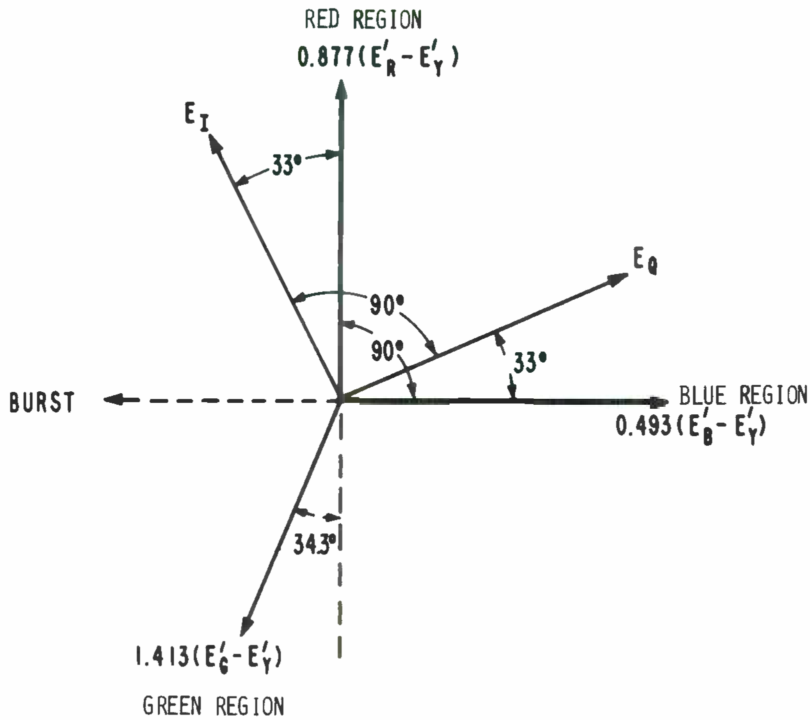


Fig. 6. NTSC color modulation phase diagram.

used to individually modulate the color subcarrier in two balanced modulators operated in phase quadrature. The "sum products" are selected and added to form the composite chromaticity subcarrier. This signal in turn is added to the luminance signal along with the appropriate horizontal and vertical synchronizing and blanking signals to include the color-synchronization burst. The result is the total composite color video signal.

Quadrature synchronous detection is used at the receiver to identify the individual color signal components. When individually recombined with the luminance signal, the desired R, G, and B signals are recreated. The receiver designer is free to demodulate either at I and Q and matrix to form $B-Y$, $R-Y$, and $G-Y$, or as in nearly all present-day receivers, at $B-Y$ and $R-Y$ and maintain 500-kHz equiband color signals.

The chrominance information can be carried without loss of identity provided that the proper phase relationship is maintained between the encoding and decoding processes. This is accomplished by transmitting a reference "burst" signal consisting of eight or nine cycles of the subcarrier frequency at a specific phase $[-(B-Y)]$ following each horizontal synchronizing pulse as shown in Fig. 7.

The specific choice of color subcarrier frequency in NTSC was dictated by at least two major factors. First, the necessity for providing horizontal interlace in order to reduce the visibility of the subcarrier requires that the frequency of the subcarrier be precisely an odd multiple of one-half the horizontal line rate. Fig. 8 shows the energy spectrum of the composite NTSC signal for a typical stationary scene. This interlace provides line-to-line phase reversal of the color subcarrier, thereby reducing its visibility (and thus

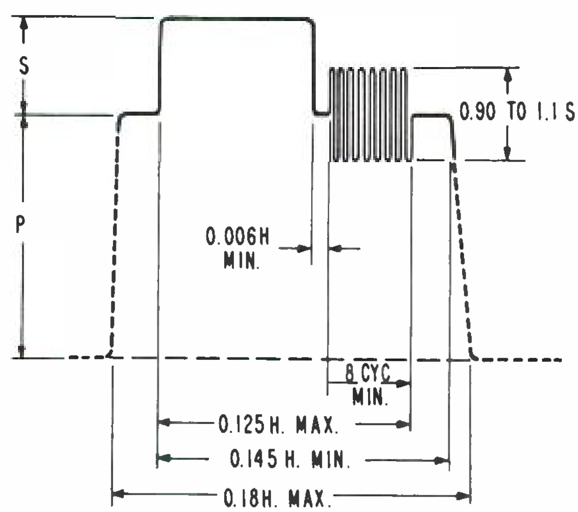


Fig. 7. NTSC color burst synchronizing signal.

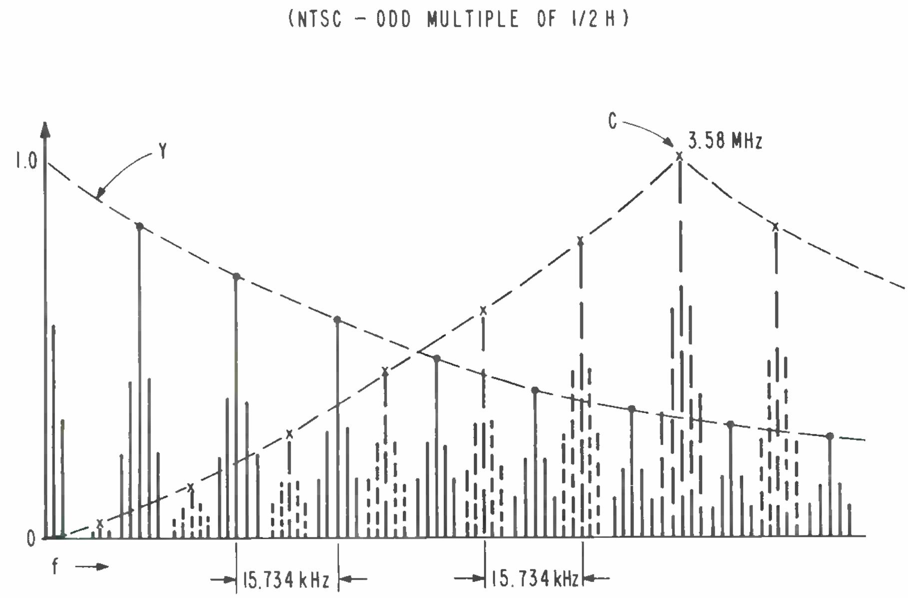


Fig. 8. Luminance/chrominance horizontal frequency interlace principle.

improving compatibility with monochrome reception). Second, it is advantageous to also provide interlace of the beat-frequency (about 920 kHz) occurring between the color subcarrier and the average value of the sound carrier. For total compatibility reasons, the sound carrier was left unchanged at 4.5 MHz and the line number remained at 525. Thus, the resulting line scanning rate and field rate varied slightly from that of the monochrome values, but stayed within the previously existing tolerances. A good rule of thumb is that the difference is exactly one part in a thousand. The exact specifications and method of calculating the frequencies are shown in Fig. 9.

CHOICE OF EXACT FREQUENCIES

$$f_{LINE} = \frac{4.5 \times 10^6}{286} \text{ cps} = 15{,}734.26 \text{ cps}$$

$$f_{FIELD} = \frac{f_{LINE}}{525/2} \text{ cps} = 59.94 \text{ cps}$$

$$f_{SC} = \frac{13 \times 7 \times 5}{2} \times f_{LINE}$$

$$f_{SC} = \frac{455}{2} \times f_{LINE}$$

$$f_{SC} = \frac{455}{2} \times \frac{4.5 \times 10^6}{286} \text{ cps}$$

$$= 3.579545 \text{ MHz}$$

Fig. 9. Calculation of NTSC specific line, field, and color subcarrier frequencies.

It is seen that the line rate is 15.734 kHz, the field rate is 59.94 Hz and the color subcarrier is 3.579545 MHz.

The NTSC system fundamentals have been reviewed in some detail since it was the first truly compatible system placed in commercial use and because the other systems subsequently proposed make use of most of the basic principles, differing mainly in the techniques of color encoding primarily to overcome early implementation difficulties.

PAL Color System

Except for some minor details, the color encoding principles for PAL are the same as those for NTSC. However, the phase of the color signal, $E_v = R - Y$, is reversed by 180° from line-to-line. This is done for the purpose of averaging, or cancelling certain color errors resulting from amplitude and phase distortion of the color modulation sidebands. Such distortions might occur as a result of equipment or transmission path problems.

The NTSC chroma signal expression within the frequency band common to both I and Q is given by

$$C_{NTSC} = \frac{B - Y}{2.03} \sin \omega_{sc} t + \frac{R - Y}{1.14} \cos \omega_{sc} t \quad [3]$$

The PAL chroma signal expression is given by

$$C_{PAL} = \frac{U}{2.03} \sin \omega_{sc} t \pm \frac{C}{1.14} \cos \omega_{sc} t \quad [4]$$

where U and $\pm V$ have been substituted for $B - Y$ and $R - Y$ signal values, respectively.

The PAL employs equal bandwidths for the U and V color-difference signal components which are about the same as the NTSC I signal bandwidth (1.3 MHz at 3 dB). There are slight differences in the U and V bandwidth in different PAL systems due to the differences in luminance bandwidth and sound carrier frequencies as discussed later under the heading of Summary and Comparisons. Reference is made to the CCIR documents[5] for specific details.

The "V" component was chosen for the line-by-line reversal process because it has a lower gain factor than "U" and therefore is less susceptible to switching rate ($\frac{1}{2} f_H$) imbalance. Figure 10 indicates the vector diagram for the PAL quadrature modulated and line-alternating color modulation approach.

The result of the switching of the V signal phase at the line rate is that any phase errors produce complementary errors from V into the U channel. In addition, a corresponding switch of the decoder V channel results in a constant V component with complementary errors from the U channel. Thus, any line-to-line averaging process at the decoder, such as the retentivity of the eye (simple PAL) or an electronic averaging technique such as the use of a 1-H delay element (standard PAL), produces cancellation of the phase (hue) error and provides the correct hue but with somewhat reduced saturation—this error being subjectively much less visible.

Obviously, the PAL receiver must be provided with some means by which the V signal switching sequence may be identified. The technique employed is known as A B sync, PAL sync, or "swinging burst" and consists of alternating the

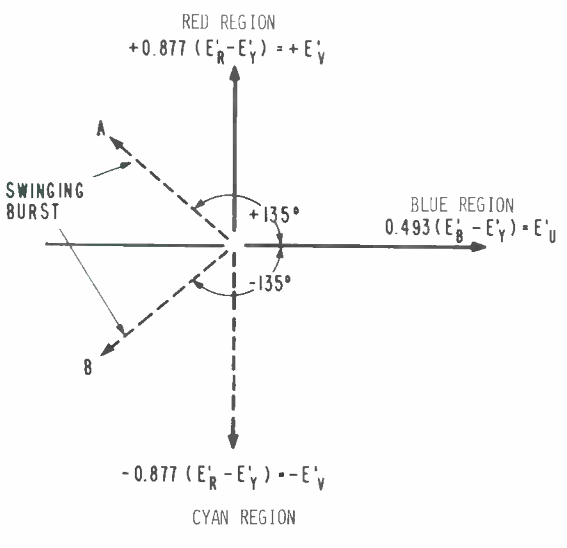


Fig. 10. PAL color modulation phase diagram.

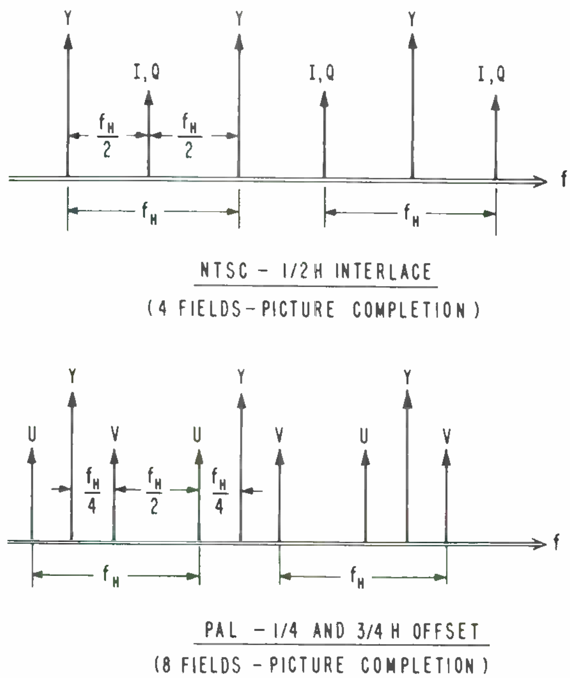


Fig. 11. NTSC and PAL frequency interlace relationship.

phase of the reference burst by $\pm 45°$ at a line rate as shown in Fig. 10. The burst is constituted from a fixed value of U phase and a switched value of V phase. Because the sign of the V burst component is the same sign as the V picture content, the necessary switching "sense" or identification information is available. At the same time, the fixed-U component is used for reference carrier synchronization.

Figure 11 explains the degree to which horizontal frequency (dot) interlace of the color subcarrier components with the luminance components is achieved in PAL and may be summarized as follows: In NTSC, the Y components are spaced at f_H intervals due to the horizontal sampling (blanking) process. Thus the choice of a color subcarrier whose harmonics are also separated from each other by f_H (as they are odd multiples of $\frac{1}{2} f_H$) provides a half-line offset and results in a perfect "dot" interlace pattern that moves upward. Four complete field scans are required to repeat a specific picture element "dot" position.

In PAL, the luminance components are also spaced at f_H intervals. Because the V components are switched symmetrically at half the line rate, only odd harmonics exist, with the result that the V components are spaced at intervals of f_H. They are spaced at half-line intervals from the U components which, in turn, have f_H spacing intervals due to blanking. If half-line offset were used, the U components would be perfectly interlaced but the V components would coincide with Y and thus not be interlaced, creating vertical, stationary dot patterns.

For this reason, in PAL, a ¼-line offset for the subcarrier frequency is used as shown in Fig. 11. The expression for determining the PAL subcarrier specific frequency for 625-line/50-field systems is given by

$$f_{SC} = \frac{1135}{4} f_H + \frac{1}{2} f_V \qquad [5]$$

The additional factor $\frac{1}{2}f_V$ = 25 Hz is introduced to provide motion to the color dot pattern thereby reducing its visibility. The degree to which interlace is achieved is therefore not perfect, but is acceptable, and eight complete field scans must occur before a specific picture element "dot" position is repeated.

One additional function must be accomplished in relation to PAL color synchronization. In all systems, the burst signal is eliminated during the vertical synchronization pulse period. Because, in the case of PAL, the swinging burst phase is alternating line-by-line, some means must be provided for ensuring that the phase is the same for the first burst following vertical sync on a field-by-field basis. Therefore, the burst reinsertion time is shifted by one line at the vertical field rate by a pulse referred to as the "meander" gate. The timing of this pulse relative to the A vs. B burst phase is shown in Fig. 12.

The transmitted signal specifications for PAL systems include the basic features discussed above. Although description of a great variety of receiver decoding techniques is outside the scope and intent of this paper, we should here review at least briefly the following major features: "Simple" PAL relies upon the eye to average the line-by-line color switching process and can be plagued with line beats call Hanover bars caused by the system nonlinearities introducing visible luminance changes at line rate. "Standard" PAL employs a 1-H delay line element to separate U color signal componenets from V color signal components in an averaging technique coupled with summation and subtraction functions. Hanover bars can also occur in this approach if imbalance of amplitude or phase occurs between the delayed and direct paths.

For an excellent discussion of the variety of other decoder approaches such as Chroma Lock, Super PAL, New PAL or PAL (not to be confused with N(PAL)), readers are referred to Vol. 2 of *Colour Television* by Carnt and Townsend.[3]

In a PAL system, vertical resolution in chrominance is reduced as a result of the line averaging processes. The visibility of the reduced vertical color resolution as well as the vertical time coincidence of luminance and chrominance transitions differs depending upon whether the total system, transmitter through receiver, includes one or more averaging (comb filter) processes.

Thus PAL provides a similar system to NTSC and has gained favor in many areas of the world, particularly for 625-line/50-field systems.

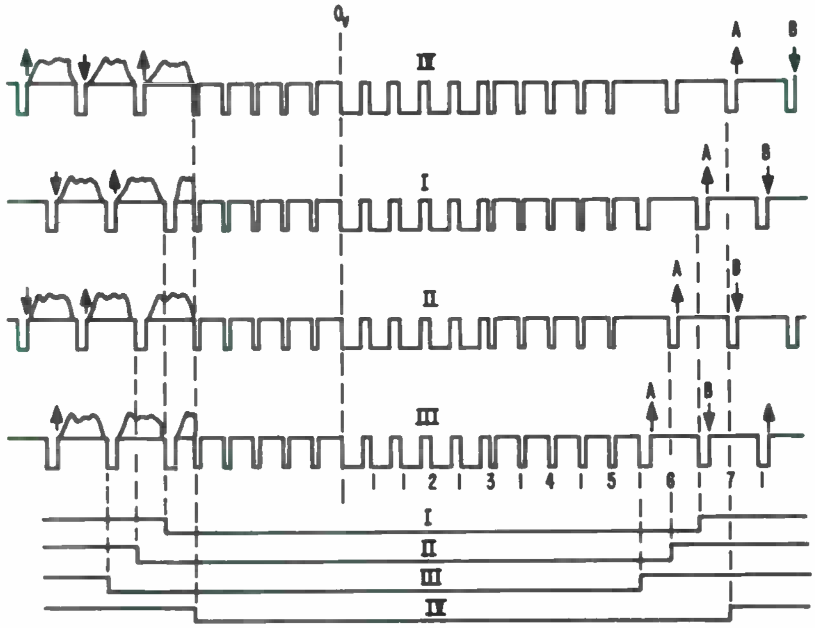


Fig. 12. PAL "meander" burst blanking gate timing diagram for *B*, *G*, *H*, and *I* PAL.

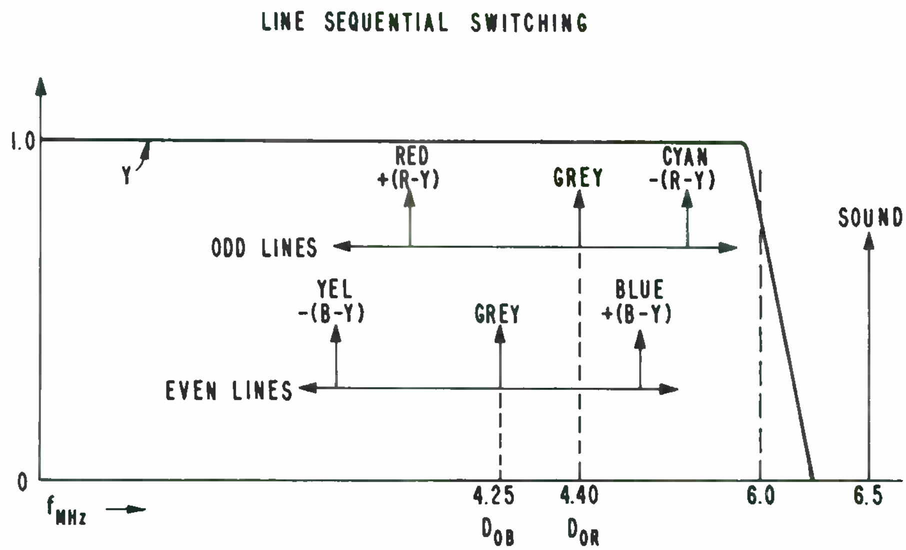


Fig. 13. SECAM FM color modulation system.

SECAM Color System

The "optimized" SECAM system, called SECAM III, is the system adopted by France and the USSR in 1967. The SECAM method has several features in common with NTSC such as the same E'_Y signal and the same $E'_B - E'_Y$ and $E'_R - E'_Y$ color-difference signals. However, this approach differs considerably from NTSC and PAL in the manner in which the color information is modulated onto the subcarrier(s).

First, the $R-Y$ and $B-Y$ color difference signals are transmitted alternately in time sequence from one successive line to the next—the luminance signal being common to every line. Since there is an odd number of lines, any given line carries $R-Y$ information on one field and $B-Y$ information on the next field. Second, the $R-Y$ and $B-Y$ color information is conveyed by frequency-modulation of different subcarriers. Thus, at the decoder, a 1-H delay element, switched in time synchronization with the line switching process at the encoder, is required in order to have simultaneous existence of the $B-Y$ and $R-Y$ signals in a linear matrix to form the $G-Y$ component.

The $R-Y$ signal is designated as D'_R and the $B-Y$ signal as D'_B. The undeviated frequency for the two subcarriers, respectively, is determined by

$$f_{0B} = 272 f_H = 4.250000 \text{ MHz}$$
$$f_{0R} = 282 f_H = 4.406250 \text{ MHz} \quad [6]$$

These frequencies represent zero color difference information (zero output from the FM discriminator), or a neutral gray object in the televised scene.

As shown in Fig. 13, the accepted convention for direction of frequency change with respect to the polarity of the color difference signal is opposite for the D_{0B} and D_{0R} signals. A positive value of D_{0R} means a decrease in frequency whereas a positive value of D_{0B} indicates an increase in frequency. This choice relates to the idea of keeping the frequencies representative of the most critical color away from the upper edge of the available bandwidth to minimize the instrumentation distortions.

The deviation for D'_R is ± 280 kHz and D'_B is ± 230 kHz. The maximum allowable deviation, including preemphasis, for $D'_R = -506$ kHz and $+350$ kHz while the values for $D'_B = -350$ kHz and $+506$ kHz.

Two types of preemphasis are employed simultaneously in SECAM. First, as shown in Fig. 14, a conventional type of preemphasis of the low-frequency color difference signals is introduced. The characterisitic is specified to have a reference level break-point at 85 kHz (f_1) and a maximum emphasis of 2.56 dB. The expression for the characteristic is given as

$$A = \frac{1 + j(f/f_1)}{1 + j(f/3f_1)} \quad [7]$$

A second for of preemphasis (Fig. 14) is introduced at the subcarrier level where the amplituded of the subcarrier is changed as a function of the frequency deviation. The expression for this inverted "bell" shaped characteristic is given as

$$G = M_o \frac{1 + j16\left(\dfrac{f}{f_c} - \dfrac{f_c}{f}\right)}{1 + j1.26\left(\dfrac{f}{f_c} - \dfrac{f_c}{f}\right)} \quad [8]$$

Where:
f_0 = 4.286 MHz and $2M_0$ = 23% of the luminance amplitude (100 IRE).

This type of preemphasis is intended to further reduce the visibility of the frequency modulated subcarriers in low luminance level color values and to improve the signal-to-noise ratio in high luminance and highly saturated colors. Thus, monochrome compatibility is better for pastel average picture level objects but sacrificed somewhat in favor of S/N in saturated color areas.

Of course, precise interlace of frequency modulated subcarriers for all values of color modulation cannot occur. Nevertheless, the visibility of the interference represented by the existence of the subcarriers may be reduced somewhat by the use of two separate carriers, as is done in SECAM. Fig. 15 indicates the line-switching sequence in that at the undeviated "resting" frequency situation, the two-to-one vertical interlace in relation to the continuous color difference line-switching sequence produces adjacent line pairs of f_{OB} and f_{OR} signals. In order to further reduce the subcarrier "dot" visibility, the phase of the subcarriers (phase carries no picture information in this case) is reversed 180° on every third line and between each field. This, coupled with the "bell" preemphasis, produces

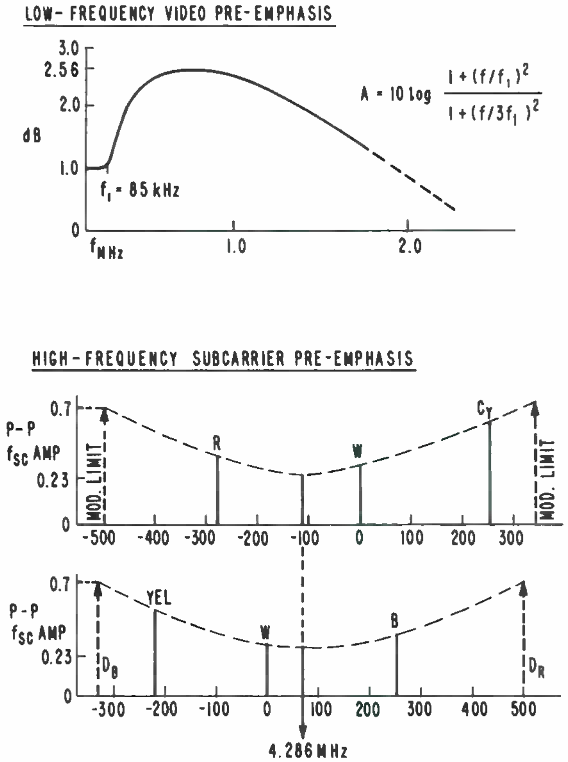


Fig. 14. SECAM color signal pre-emphasis.

a degree of monochrome compatibility considered subjectively adequate.

As in PAL, the SECAM system must provide some means for identifying the line-switching sequence between the encoding and decoding processes. This is accomplished, as shown in Fig. 16, by introducing alternate D_R and D_B color iden-

FIELD	LINE #	COLOR	SUBCARRIER Ø
ODD (1)	n	f_{OR}	0°
EVEN (2)	n + 313	f_{OB}	180°
ODD (3)	n + 1	f_{OB}	0°
EVEN (4)	n + 314	f_{OR}	0°
ODD (5)	n + 2	f_{OR}	180°
EVEN (6)	n + 315	f_{OB}	180°
ODD (7)	n + 3	f_{OB}	0°
EVEN (8)	n + 316	f_{OR}	180°
ODD (9)	n + 4	f_{OR}	0°
EVEN (10)	n + 317	f_{OB}	0°
ODD (11)	n + 5	f_{OB}	180°
EVEN (12)	n + 318	f_{OR}	180°

Note:
- 2 frames (4 fields) for picture completion.
- Subcarrier interlace is field-to-field and line-to-line of same color.

Fig. 15. Color vs. line and field timing relationship for SECAM.

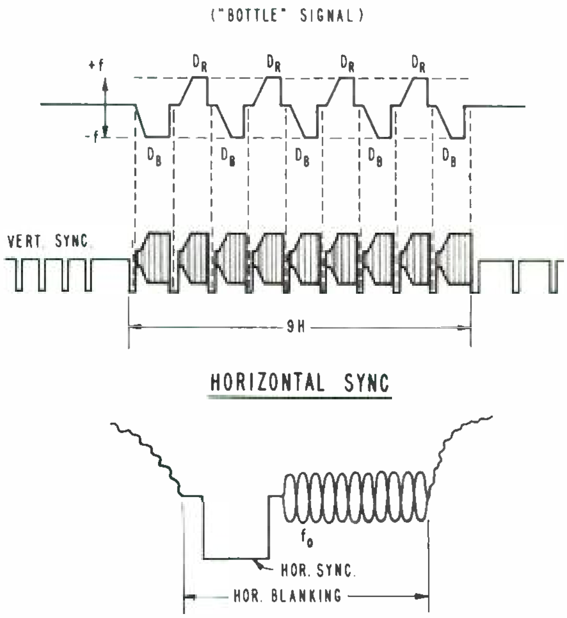


Fig. 16. SECAM line identification signal.

tifying signals for nine lines during the vertical blanking interval following the equalizing pulses after vertical sync. These "bottle" shaped signals occupy a full line each and represent the frequency deviation in each time sequence of D_B and D_R at zero luminance value. These signals can be thought of as fictitious green color that is used at the decoder to determine the line-switching sequence.

During horizontal blanking, the subcarriers are blanked and a burst of f_{0B}/f_{0R} is inserted and used as a gray level reference for the FM discriminators, to establish their proper operation at the beginning of each line.

Thus the SECAM system is a line sequential color approach using frequency modulated subcarriers. A special identification signal is provided to identify the line-switch sequence and is especially adapted to the 625-line/50-field wideband systems available in France and the USSR.

It should be noted that SECAM, as practiced, employs amplitude modulation of the sound carrier as opposed to the FM sound modulation in other systems.

Additional Systems of Historical Interest

Of the numerous system variations proposed over the intervening years since the potential development of the NTSC system, at least two others, in addition to PAL and SECAM, should be mentioned briefly. The first of the these was ART (Additional Reference Transmission) which involved the transmission of a continuous reference pilot carrier in conjunction with a conventional NTSC color subcarrier quadrature modulation signal. A modification of this scheme involved a "multiburst" approach that utilized three color bursts, one at black level, one at intermediate gray level, and one at white level, to be used for correcting differential phase distortion.

Another system, perhaps better known, was referred to as *NIR* or SECAM IV. Developed in the USSR (*NIR* = *N*auchni *I*ssledovatelskaia *R*abota or Scientific Discriminating Work), this system consists of alternating lines of (1) an NTSC-like signal using an amplitude and phase modulated subcarrier and (2) a reference signal having *"U"* phase to demodulate the NTSC-like signal. In the linear version the reference is unmodulated, and in the nonlinear version, the amplitude of the reference signal is modulated with chrominance information.

To the author's knowledge, neither ART nor NIR were ever implemented or used for commercial broadcast. Still, they are of theoretical and historical interest; details may be found in Ref. 3.

Summary and Comparisons of Systems Standards and Specifications

History has shown that it is apparently impossible to obtain total international agreement on "universal" television broadcasting standards. Even with the first scheduled broadcasting of monchrome television in 1936 in England, the actual telecasting started using two different systems on alternate days from the same transmitter. The Baird system was 250 lines (noninterlaced) with a 50 Hz frame rate while the EMI (Electric and Musical Industries) system was 405 lines (interlaced) with a 25 Hz frame rate.

These efforts were followed in 1939 in the United States by broadcasting a 441 line interlaced system at 60 fields per second (the Radio Manufacturers Association—RMA—system). In 1941, the NTSC initiated the present basic monochrome standards in the U.S. of 225 lines (interlaced) at 60 fields per second, designated as system M by the CCIR. In those early days, the differences in power line frequency were considered as important factors and were largely responsible for the proliferation of different line rates versus field rates as well as the wide variety of video bandwidths. However, the existence and extensive use of monochrome standards over a period of years soon made it a top-priority matter to assume reciprocal compatibility of any developing color system.

The CCIR documents[5] define recommended standards for worldwide color television systems in terms of the three basic color approaches—NTSC, PAL, and SECAM—as shown in Fig. 17. The variations —at least 13 of them—are given alphabetical letter designations; some represent

THREE BASIC SYSTEMS
- NTSC
- PAL
- SECAM

THIRTEEN VARIATIONS OR SUBSYSTEMS:
A*, M, N, C*, B, G, H, I, D, K, KI, L, E*

SYSTEMS A (405 LINES), C (625 LINES) AND E (819 LINES) NOT RECOMMENDED FOR NEW SERVICE*

98 COUNTRIES LISTED BY CCIR AS EMPLOYING ONE OR MORE SYSTEMS

Fig. 17. CCIR worldwide color television designations.

major differences while others signify only very minor frequency allocation differences in channel spacings or the differences betweeen the VHF and UHF bands. In 1978, at least 98 countries were listed as either employing or considering one or more of the proposed systems in monochrome and/or color format.

The key to understanding the CCIR designations lies in recognizing that the letters refer primarily to *local monochrome standards* for line and field rateds, video channel bandwidth, and audio carrier relative frequency. Further classification in terms of the particular color system then adds to NTSC, PAL, or SECAM as appropriate. For example, the letter "M" designates a 525-line/60-field, 4.2-MHz bandwidth, 4.5-MHz sound carrier monochrome system. Thus, M(NTSC) describes a color system employing the NTSC technique for introducing the chrominance information within the constraints of the above basic monchrome signal values. Likewise, M(PAL) would indicate the same line/field rates and bandwidths but employ the PAL color subcarrier modulation approach.

In another example, the letters "I" and "G" relate to specific 625-line/50-field, 5.0 or 5.5 MHz bandwidth, 5.5 or 6.0 Mhz sound carrier monochrome standards. Thus, G(PAL) would describe a 625-line/50-field,5.5 Mhz bandwidth, color system utilizing the PAL color subcarrier modulation approach. The letter "L" refers to a 625-line/50-field, 6.0 Mhz bandwidth system to which the SECAM color modulation method has been added (often referred to as SECAM III).

System E is an 819-line/50-field, 10 MHz bandwidth, monochrome system. This channel was used in France for early SECAM tests and for system E transmissions.

Some general comparison statements can be made about the underlying monochrome systems and existing color standards:

1. There are four different scanning standards: 405-lines/50-fields, 525-lines/60-fields, 625-lines/50-fields, and 819-lines/50-fields.
2. There are six different spacings of video-to-sound carriers, namely 3.5, 4.5, 5.5, 6.0, 6.5, and 11.15 MHz.
3. Some systems use FM and others use AM for the sound modulation.
4. Some systems use positive polarity (luminance proportional to voltage) modulation of the video carrier while others, such as the U.S. (M)NTSC system, use negative modulation.
5. As previously discussed, there are also differences in the techniques of color subcarrier encoding represented by NTSC, PAL, and SECAM, and of course, in each case there are many differences in the details of various pulse widths, timing, and tolerance standards. It is evident that one must refer to the CCIR documents for accurate information on the combined monochrome/color standards. Fig. 18 presents a comparison of the relative bandwidths, color subcarrier frequencies, and sound carrier spacing for the major color systems used in the world today.

The signal in the M(NTSC) system occupies the least total channel width, which when the vestigial sideband plus guard bands are included, requires a minimum radio frequency channel spacing of 6 Mhz. The L(III) SECAM system signal occupies greater channel space with a full 6 MHz luminance bandwidth. Signals from the tow ver-

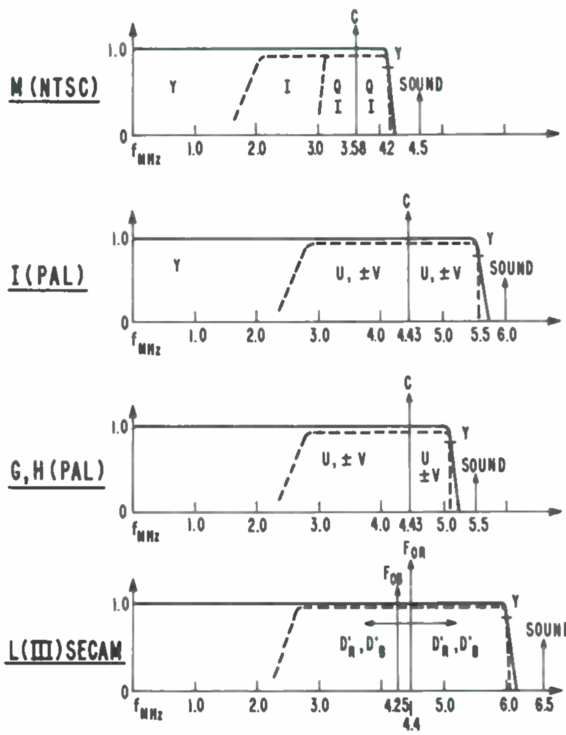


Fig. 18. Bandwidth comparison between NTSC, PAL, and SECAM.

- BASEBAND → LUMINANCE
- QUADRATURE MODULATED SUBCARRIER
  - PHASE → HUE
  - AMPL. → SATURATION

"M"
- LINE/FIELD = 525/60
  - f_H = 15.734 kHz
  - f_V = 59.94 Hz
  - f_{SC} = 3.579545 MHz
- BANDWIDTH = 4.2 MHz
- SOUND = 4.5 MHz (FM)
- UNITED STATES
- CANADA
- JAPAN

"N"
- LINE/FIELD = 625/50
  - f_H = 15.625 kHz
  - f_V = 50 Hz
  - f_{SC} = (?)
- BANDWIDTH = 4.2 MHz
- SOUND = 4.5 MHz (FM)
- MAY TAKE FORM OF N(NTSC) OR N(PAL)
- COLOR UNDECIDED IN REGION II

Fig. 19. CCIR designation for NTSC system—summary.

- BASEBAND → LUMINANCE
- QUADRATURE MODULATED SUBCARRIER
  - PHASE → HUE
  - AMPL. → SATURATION
  - LINE ALTERNATION OF "V" COMPONENT

"I"
- LINE/FIELD = 625/50
  - f_H = 15.625 kHz
  - f_V = 50 Hz
  - f_{SC} = 4.433618 MHz
- BANDWIDTH = 5.5 MHz
- SOUND = 6.0 MHz (FM)
- UNITED KINGDOM

"B", "G", "H"
- LINE/FIELD = 625/50
  - f_H = 15.625 kHz
  - f_V = 50 Hz
  - f_{SC} = 4.433618 MHz
- BANDWIDTH = 5.0 MHz
- SOUND = 5.5 MHz (FM)
- CONTINENTAL EUROPE

"M"
- LINE/FIELD = 525/60
  - f_H = 15.750 kHz
  - f_V = 60 Hz
  - f_{SC} = 3.575611 MHz
- BANDWIDTH = 4.2 MHz
- SOUND = 4.5 MHz (FM)
- BRAZIL

Fig. 20. CCIR designation for PAL system—summary.

- BASEBAND → LUMINANCE
- FREQUENCY MODULATED SUBCARRIERS
  - LINE SEQUENTIAL D_R AND D_B SIGNALS
  - D_R → ODD LINES
  - D_B → EVEN LINES

"E"
- LINE/FIELD = 819/50
  - f_H = 20.475 kHz
  - f_V = 50 Hz
- BANDWIDTH = 10 MHz
- FRANCE
- MONOCHROME ONLY
- USED TO TEST EARLY SECAM
- BECOMING EXTINCT

"L", (III)
- LINE/FIELD 625/50
  - f_H = 15.625 kHz
  - f_V = 50 Hz
  - f_{OR} = 4.40625 MHz = 282 f_H
  - f_{OB} = 4.25000 MHz = 272 f_H
- BANDWIDTH = 6.0 MHz
- SOUND = 6.5 MHz (AM)
- FRANCE
- USSR

"K", (IV), (NIR)
- LINE/FIELD = 625/50
  - f_H = 15.625 kHz
  - f_V = 50 Hz
  - f_O = $(284\text{–}1/4)\, f_H + \frac{V}{2}$
- LINEAR OR NON-LINEAR
- NTSC ALTERNATE LINES
- Y + "U" REFERENCE PHASE
- USSR

(Not broadcast at present)

Fig. 21. CCIR designation for SECAM system—summary.

	NTSC	PAL	SECAM
TV SYSTEM	M	G, I	L
FIELD RATE (f_V Hz)	59.94	50	50
TV LINES	525	625	625
LINE RATE (f_H kHz)	15.734	15.625	15.625
LUMA BANDWIDTH (MHz)	4.2	(5.0) (5.5)	6.0
SOUND (MHz)	4.5 (F 3)	(5.5) (6.0) (F 3)	6.5 (A 3)
VERTICAL INTERLACE	2:1	2:1	2:1
GAMMA	2.2	2.8	2.8
WHITE	ILL. "C" (D6500)	D6500	D6500

Fig. 22. General system technical summary—Part I.

sions of PAL also occupy greater channel widths (though less than SECAM signal) and vary in vestigial sideband width as well as color and luminance bandwidths. NTSC is the only system to incorporate the *I, Q* color acuity bandwidth variation. PAL minimizes the color quadrature phase distortion effects by line-to-line averaging, and SECAM avoids this problem by only transmitting the color components sequentially at a line-by-line rate.

Figs. 19 through 24 summarize, in "organization chart" form, the CCIR designations for NTSC, PAL, and SECAM basic system identifications and characteristics. In Fig. 19, M(NTSC) identified the system used in the United States, Canada, Japan, Mexico, the Philippines and several other Central American and Caribbean area countries. The N system may be implemented in color either in the NTSC or the PAL format. At present, many Latin American countries are in the process of adopting one or the other version of this approach.[6] Fig. 20 provides a summary of the PAL systems. PAL systems in one or another of the 625-line formats are predominately used in Continental Europe, the United Kingdom, some African countries, and China. An "M" (525-line) version of PAL has been in use in Brazil.

Fig. 21 summarizes the SECAM III system, which is in use primarily in France and the USSR. The SECAM IV system, as a proposal,[1] almost gained favor in 1966 as a universal European approach but to the authors' knowledge has never been used for normal broadcasting. The E system, mentioned in connection with early SECAM tests in France, is limited to monochrome broadcasts and is slowly becoming extinct even in this application.

	NTSC	PAL	SECAM
COLOR SUBCARRIER (MHz)	3.579545	4.433618	4.250000 = f_{OB} 4.406500 = f_{OR}
f_{SC} MULTIPLE OF f_H	$\frac{455}{2} f_H$	$\frac{1135}{4} f_H + \frac{f_v}{2}$	272 f_H = f_{OB} 282 f_H = f_{OR}
CHROMA ENCODING	PHASE & AMP. QUAD. MOD.	PHASE & AMP. QUAD. MOD. (LINE ALTERNATION)	FREQUENCY MODULATION (LINE SEQUENTIAL)
COLOR DIFFERENCE SIGNALS	I, Q, (1.3 MHz) (0.6 MHz)	U, ± V (1.3 MHz) (1.3 Mhz)	D_R (f_{OR}) (> 1.0 MHz) D_B (f_{OB}) (> 1.0 MHz)
COLOR BURST PHASE	–(B-Y)	U and ± V	f_{OR} AND f_{OB} 180° PHASE SWITCH EVERY 3rd LINE AND EVERY FIELD
COLOR SWITCH IDENT.	NOT REQUIRED	SWINGING BURST ± 45°	9 LINES OF D_R AND D_B DURING VERTICAL INTERVAL
ADDITIONAL SIGNALS	NONE	"MEANDER" GATE $f_{H/2}$	$f_{H/2}$, $f_{H/4}$, f'_v, $f_{v/2}$

Fig. 23. Chrominance encoding systems comparison—Part II.

Fig. 22 (Systems Comparison Summary—Part I) provides a "summary-at-a-glance" of the major color television system general characteristics as presently practiced, whether it be monochrome only or including the addition of chrominance information. Fig. 23 (Part II) characterizes the fundamental features relating to the differences between NTSC, PAL, and SECAM in the critical areas of color encoding techniques. Similarily, Fig. 24 (Part II) indicates the color encoding line-by-line color sequence operation for the three systems.

The information conveyed in these last seven charts (Fig. 18-24) highlights the technical equalities and differences among the systems and attempts to show some kind of order as an aid to understanding the existing worldwide situation. It serves as well to point out the difficulties of entertaining the notion of a "universal" system.[7]

Comments on International Exchange of Images

The international exchange of images in broadcast television in the face of the variety of standards is difficult. It should be remembered that all TV systems, both monochrome and color, can be operated from movie film. Special television camera chains have been developed and manufactured that are capable of operating at 655-lines and 48-field rate—the field rate purposely being made to be compatible with the 24-frame rate motion picture standards.

It is comparatively straightforward to exchange television program material by tape, microwave, or satellite between areas employing the same scanning rates: the video bandwidths are, of course, not equivalent but the differences do not result in major image degradation. Electronic standards converters have been developed and used for converting between 50-fields/s and 60 fields/s systems.

The direct exchange of color television programs between the three major systems is obviously more complex. Special transcoding systems have been developed to translate color subcarrier frequencies between similar color systems having different scanning rates. More complex transcoders are possible which translate from one color technique to another, although always at the cost of some degradation of resolution or reduction of performance. Even simultaneous translation between different scanning rates and different color systems, such as between 525-line NTSC and 625-line PAL, has been accomplished.

As previously stated, the advent of satellite worldwide television relay, coupled with recent advances in digital processing of television signals, has given new importance to standards conversion relative to the exchange of program material on an international basis. Thus, the intent of this worldwide color systems standards review is to highlight the similarities as well as the major differences for those who desire an overview of the related television concepts and standards. A thorough understanding of those concepts and standards by many people is essential if effective international exchange of programming is to grow.

Acknowledgements

The authors would like to acknowledge the aid and suggestions provided by A. Lind of the RCA Broadcast Products Division, and are especially

	LINE (N)	LINE (N + 1)	LINE (N + 2)	LINE (N + 3)
NTSC:				
CHROMA:	I, Q	I, Q	I, Q	I, Q
BURST PHASE:	−(B-Y)	−(B-Y)	−(B-Y)	−(B-Y)
PAL				
CHROMA:	U,+ V	U,− V	U,+ V	U,− V
BURST PHASE:	−U + V = +135°	−U − V = +225°	−U + V = +135°	−U − V = +225°
SECAM: (FM)				
CHROMA:	D_R ± 280 kHz	D_B ± 230 kHz	D_R ± 280 kHz	D_B ± 230 kHz
BURSTS:	(D_R DEVIATION = + 350 kHz / − 500 kHz)		(D_B DEVIATION = + 500 kHz / − 350 kHz)	

CHROMA SWITCH IDENT. LINES DURING VERTICAL INTERVAL

LINE #:	7	8	9	10	11	12	13	14	15
	320	321	322	323	324	325	326	327	328
INDENT SIGNALS:	D_R	D_B	D_R	D_B	D_R	D_B	D_R	D_B	D_R

(NOTE: Phase reversed 180° every 3rd line and every field).

Fig. 24. Line-to-line chroma signal sequence comparison—Part III.

grateful for the assistance and information provided by R. Mills and E. Rutishauser of the Laboratories RCA Ltd., Zurich.

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7.2

Using Operational Amplifiers in Broadcasting

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This chapter is a brief, practical guide for the broadcast engineer in the use of operational amplifiers, or "opamps". Understanding the opamp, which has been the fundamental building block of broadcast audio equipment since the mid-1970s, provides a basic understanding of how most analog audio equipment in a modern broadcast facility operates.

The operational amplifier concept is essentially one of a truly universal amplifier, shown schematically as a triangle with a differential input and single-ended output, whose operational characteristics are determined soley by feedback provided by external components. The original opamps were developed as universal computational blocks for use in analog computers and performed many functions including addition, subtraction, inversion, differentiation, and integration. These first opamps were built with vacuum tubes so that reliability and stability were not very good. Integrated circuit opamps first appeared commercially in the 1960's at which time the concept of a universally insertable, standardized amplifier for computational blocks had already evolved. The ideal characteristics of these standardized amplifiers were and are:

Infinite gain;

Infinite bandwidth (dc to daylight);

Perfectly balanced differential input with infinite common mode rejection;

Infinite input impedance (zero input current);

Zero output impedance, a true voltage source with infinite output current capability;

Zero dc offset;

Low cost.

The ideal characteristics described above are not available in the real world; but technology continues to improve and sometimes the deviation from the ideal becomes almost inconsequential. This is true for certain low noise and low offset input stages and certain high current output stages. Unfortunately the average piece of broadcast equipment is not constructed with these enhanced opamps.

Lack of adequate open loop gain bandwidth and excessive loading of output stages are common problems in broadcast equipment made with opamps. The earliest broadcast equipment built with opamps has to be upgraded to keep the facility competitive. By carefully following the recommendations in this chapter, older broadcast equipment can be made to sound competitive with, if not better than, some new broadcast equipment.

The opamps commonly encountered in broadcast equipment are monolithic integrated circuits (ICs), although some are hybrids. There are also some made with discreet components, such as the JE 990, and various potted opamps from companies such as Datatronics (API), Modular Audio

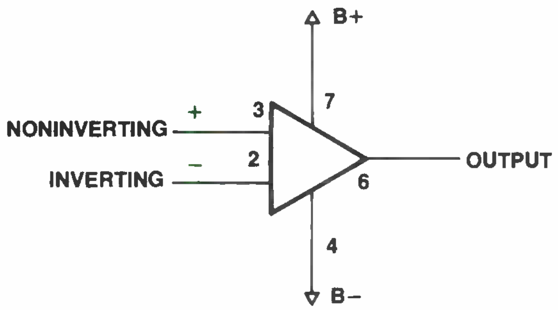


Fig. 1. Standard "741" pin connections.

Products, and Melcor (no longer produced). These discreet component modules, for the most part, have better input noise figures and lower output impedances than monolithic ICs. Many times broadcast products are built with monolithic opamps supporting a discreet output stage, which is considered to be part of the opamp triangle even though it is not shown that way on the schematic. It is also common to have a discreet low noise input stage (also considered to be part of the triangle), either FET or bipolar, to improve the noise performance of a monolithic (IC) opamp.

These low noise differential input stages should also be considered as part of the triangle unless they are very special open-loop differential input stages used for esoteric applications. Unless the input stage is this kind of open loop front end or, the circuit is designed as an oscillator, the feedback will appear only on the inverting input.

Monolithic opamps have become somewhat standardized in terms of their pin connections. The most common arrangement for single opamp devices is known as the "741 pinout" shown in Fig. 1.

Our illustrations will use this pinout for convenience. The unity gain noninverting voltage follower shown in Fig. 2 is the simplest opamp configuration in terms of component count. R_{bias} provides the reference operating voltage for the stage, bias current to the input transistor of the opamp, and sets the input impedance of the stage, since it is in parallel with the noninverting input which, in this configuration, has a theoretically infinite input impedance. There is a direct connection without attenuation from the output to the inverting input which provides 100% negative feedback, forcing the output voltage to follow the input voltage exactly. This configuration is useful as an impedance buffer since the input impedance is infinite (actually, the normally high value of R_{bias}) and output impedance is theoretically zero and is in actual practice a very low value.

A non-inverting amplifier with gain is shown in Fig. 3. The stage voltage gain is set by the ratio of R_{fb} plus R_{in} divided by R_{in}. This formula assumes that the open loop voltage gain of the opamp is more than the voltage gain called for by the divider, as do all of the formulas for gain. The input and output impedance characteristics and value of R_{bias} are essentially the same as the noninverting voltage follower configuration.

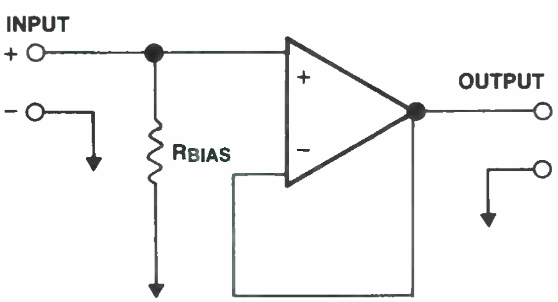


Fig. 2. The simplest opamp configuration is the noninverting voltage follower.

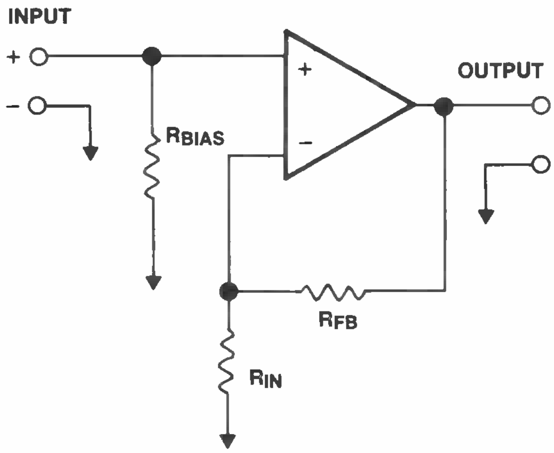


Fig. 3. This noninverting amplifier has voltage gain which is determined by the input and feedback resistor values.

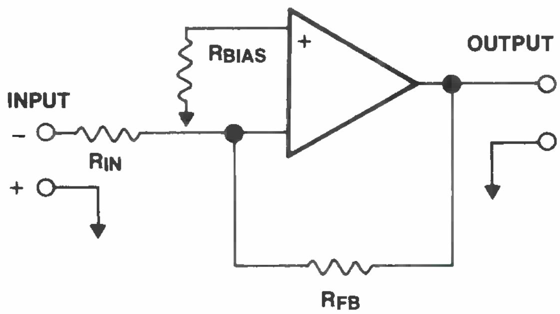


Fig. 4. The output of this amplifier is inverted. Source impedance affects gain as a component of R_{IN}.

The inverting amplifier is shown in Fig. 4. The gain of this stage is the feedback resistor divided by the input resistor. This gain formula assumes a zero source impedance signal driving the circuit. Any output series resistance of the driving stage must be added to the value of R_{in} when calculating amplifier gain. Feeding this circuit directly with a reactive source such as a transformer, dynamic microphone, tape head, or phono cartridge will cause frequency response errors because the source output resistance changes with frequency. The stage's input impedance is approximately equal to the input resistor, since the inverting input with feedback applied is a "virtual ground." It is called a "virtual ground" because all the signal currents in the circuit meet here to produce zero (or very close to zero) signal voltage. This is also referred to as the "summing point." The actual impedance of this virtual ground is the feedback resistor divided by the product of the open-loop gain (which varies with frequency) and the closed loop gain.

Notice that, once again, the noninverting input is connected to ground through R_{bias}, which in this configuration, has no effect on the voltage gain of the stage. The value of R_{bias} should be the parallel resistance of R_{in} and R_{fb} in order to minimize undesirable dc shifts on the output caused by input offset. Many times in broadcast audio equipment applications where dc parameters are not critical, R_{bias} is omitted and the noninverting input is brought directly to ground. Sometimes R_{bias} will have a capacitor in parallel with it. This is to shunt the small amount of ac noise generated in the resistor to ground. Without the capacitor, this resistor's ac noise would be amplified along with the desired signal. This problem is particularly troublesome in high impedance circuits.

The most basic differential input opamp configuration is shown in Fig. 5. This circuit appears in a wide variety of broadcast equipment misnamed "active balanced input". It is a differential input, but it is not balanced to ground. The input impedance of the MINUS input is the value of R1 (plus the actual summing point impedance, see the description of the inverting amplifier, above). The input impedance of the PLUS input is R1 plus R2. This circuit therefore creates a longitudinal imbalance to any line across which it is placed. The voltage gain of the circuit is equal to the ratio of R2 divided by R1. R1 must match R1' as closely as possible and, similarly, R2 must match R2'. The degree of matching of these resistors is the primary determinant of common mode rejection ratio (CMRR). Allowing one percent deviation in the value of these resistors could result in a common mode rejection ratio of only 40 dB. One tenth of 1% deviation in resistor value matching provides a common mode rejection

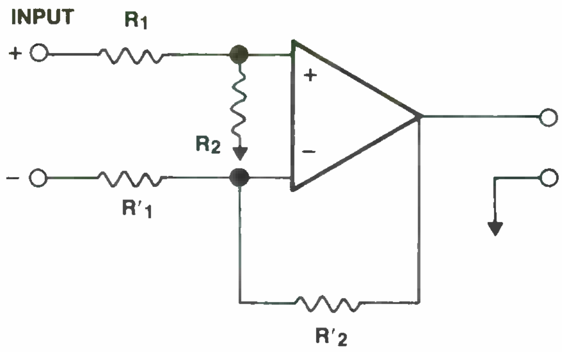


Fig. 5. This basic differential input amplifier is often mislabeled as "balanced."

ratio of 60 dB. As in the above circuit, these figures are based on the assumption that the circuit is fed by a perfectly balanced source exhibiting a very low output impedance. For this reason this circuit should not be used to bridge outside circuits coming into the broadcast facility such as telephone lines. It is, however, an ideal alternative to unbalanced wiring within a control room where there are relatively short interconnections and known driving sources.

The circuit in Fig. 6 is known as an instrumentation amplifier with a cross-coupled differential preamplifier which has a true electronically balanced input. It is a logical progression of the basic differential input amplifier in Fig. 5. The input impedance is fully symmetrical to ground and is set by the values of R_{bias} and R_{bias}' which is matched to R_{bias}'. Their matching determines the symmetry of the input. The circuit common mode rejection is not affected by minor longitudinal imbalances of the line feeding it because of the impedance buffering action of U1

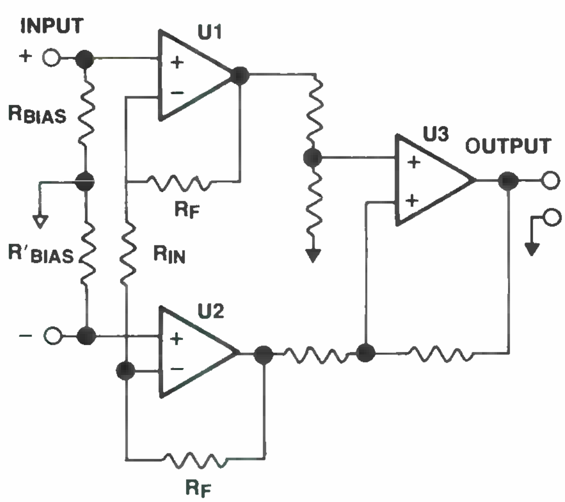


Fig. 6. In this configuration, the differential inputs are balanced and cross-coupled.

and U2. The circuit around U3 is identical in operation to Fig. 5 but since it is fed directly from the outputs of U1 and U2, common mode rejection characteristics are controlled, making the use of a laser trimmed resistor network a practical means of optimizing common mode rejection. The differential gain of the first stage is R_{in} plus $2R_f$ divided by R_{in}, but the common mode gain of this stage remains unity for all values of differential gain. This characteristic of cross coupling the summing points with a single input resistor using opposite summing points as returns, combines synergistically with the impedance buffering characteristics of the two opamps in front of the differential amplifier to provide levels of common mode rejection ratio beyond what can be offered with transformers (until input overload occurs). Another advantage of this configuration for broadcast audio applications is that the input impedance of the stage is set by the value of R bias because both inputs are noninverting opamps with a theoretical input impedance of infinity. A very high impedance, absolutely balanced bridging circuit can be achieved using this technique, allowing many inputs to be simultaneously connected to the same low impedance balanced program line without loading or disturbing the balance of the line. The line noise will remain low assuming a near zero source impedance of an active differential drive. Please note that the traditional 600 ohm line impedance power transmission system can be interfaced with these circuits if required. The system that we are describing here is known as a Voltage Transmission System and has better noise immunity that the traditional 600 ohm power transmission system. The Voltage Transmission System with its low source impedances and high input impedances is capable of extremely large fanouts, i.e. a considerable number of equipment inputs can be driven with one program source without loading considerations. Maintaining ground symmetry (balance) is the most important consideration in a Voltage Transmission System and the cross-coupled input preamplifier differential configuration (the three opamp instrumentation amplifier described above) is an essential element in building large systems. The simple differential input consisting of a single opamp and four resistors is adequate for smaller systems with just a few inputs connected to each output and short, predictable cable runs.

The circuit shown in Fig. 7 is an optimal driver for the balanced line system described above. U1 provides an unbalanced input with high impedance (set by R_{bias}) and provides impedance buffering for U3 and input bias for U2. U1 can also be configured as a gain stage by adding the appropriate feedback divider network. Opamp U2 is a noninverting unity gain buffer with an output source impedance of R_{output}. U3 is configured as a unity gain inverting amplifier, R_{in} equals R_f. The output source impedance of U3 is determined by R_{output}. The differential output impedance is twice the value of R_{output}. R_{output} should be closely matched to R_{output}' for best line balance. The value of R_{output} is chosen to be the minimum amount necessary to isolate the output stage of the opamp from the reactive effects of the line. A good practical value for R_{output} in a typical broadcast plant when using opamps such as 5534s into 22 AWG twisted shielded pairs is approximately 60 ohms, producing a differential source impedance of 120 ohms. This value assumes terminations with cross-coupled differential amplifiers such as Fig. 6 with R bias values 10k ohms or higher and no 600 ohm terminations across the line. When the output impedance of the driving stage is known to be low, a more practical and commonly found implementation of Fig. 7 is shown in Fig. 8. U1 is a unity gain noninverting amplifier and U2 is a unity gain inverting amplifier.

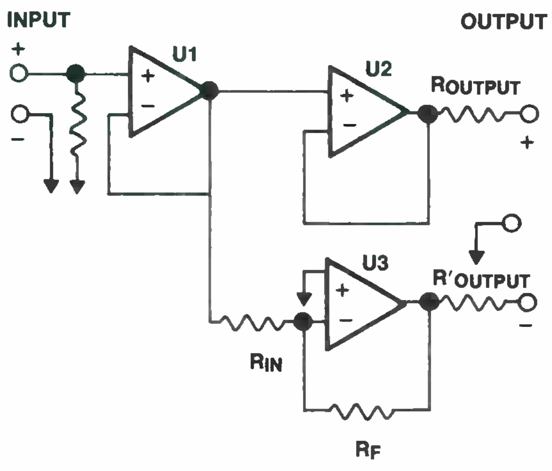


Fig. 7. Ideal differential output stage.

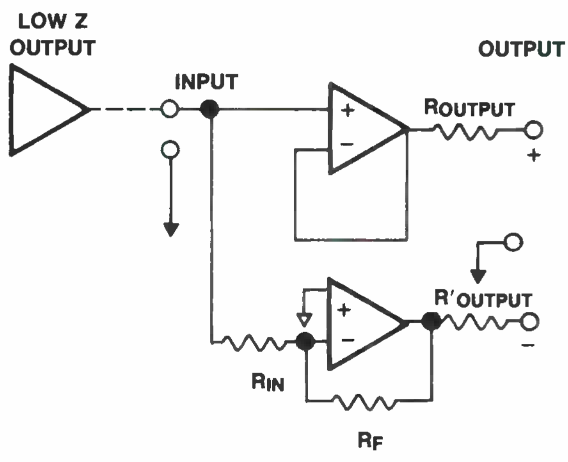


Fig. 8. Practical differential output stage.

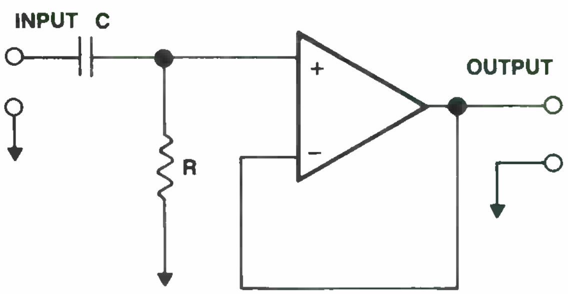
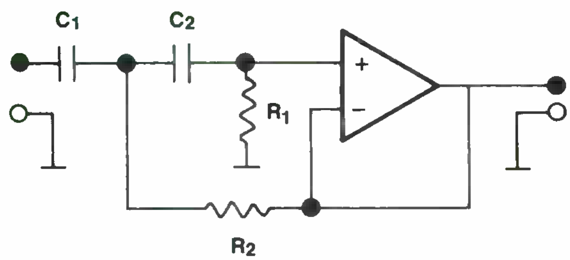


Fig. 9. High pass filter, single pole.



$$F_C = \frac{1}{2\pi C_1 (R_1 \cdot R_2)^{1/2}}$$

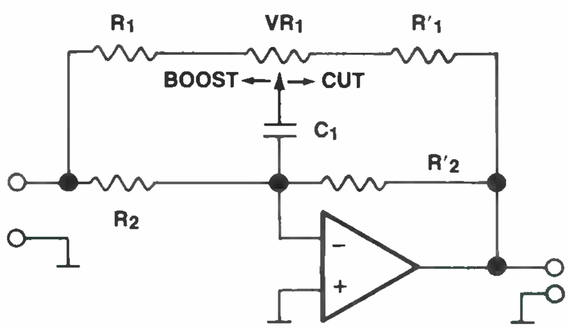
$C_1 = C_2$, $R_2 = .5 \cdot R_1$

Fig. 10. High pass filter, two pole.

ACTIVE FILTERS AND EQUALIZERS

Another common use of opamps in broadcast equipment is shaping program frequency response, phase delay or both. The IC opamp, with its small package, low price, good availability, and simple operating rules, has made the realization of very complex active networks a practical reality. The high input impedance and low output impedance of the opamp make it ideal for assisting in virtually every filter application, from being an impedance buffer stage to simulating the energy storage characteristics of bulky inductors. Fig. 9 illustrates the most basic opamp filter application as an impedance buffer. The high pass filter configuration consisting of C and R will exhibit the ideal charateristics of the formula shown without loading interaction caused by the next stage's input impedance.

Fig. 10 illustrates a second order high pass filter which is realized without the use of inductors. The opamp serves not only as a buffer but simulates the energy storage of the inductive element. Its resonant frequency calculation is shown with the illustration. Transposing the R and C elements produces a low pass filter. Basic shelf-type tone controls with a 20 dB boost or cut are shown in Fig. 11. The circuits in Fig. 12 illustrate the manipulation of phase without affecting frequency response. This configuration is also known as a first order (or single pole) all-pass filter. Multiple pole all-pass filters are sometimes referred to in the broadcast plant as phase scramblers and are used to process an audio signal



MAX BOOST OR CUT

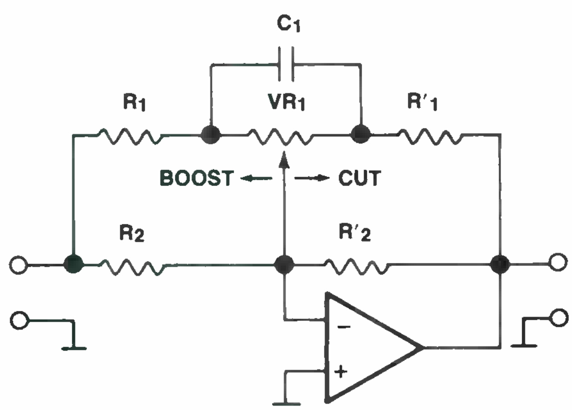
$$\frac{R_2 || VR_1}{R_1 || R_2}$$

$$F = \frac{1}{2\pi R_2 C_1}$$

BASS $R_2 = R'_2$ $R_1 = R'_1$

$R_2 = 10 \cdot R_1$ $VR_1 = 5 \cdot R_2$
FOR 20 dB BOOST OR CUT

Fig. 11A. Shelf-type tone control: bass.



$$F = \frac{1}{2\pi R_1 C_1}$$

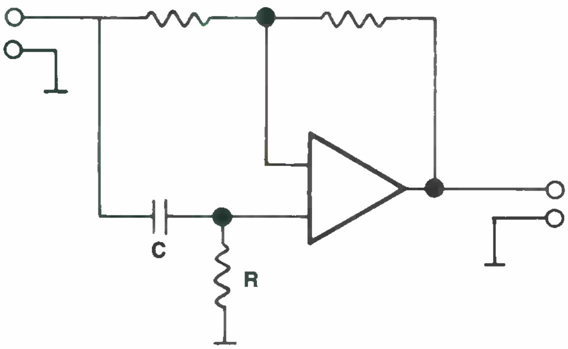
$R_1 = R'_1$

$R_2 = R'_2$

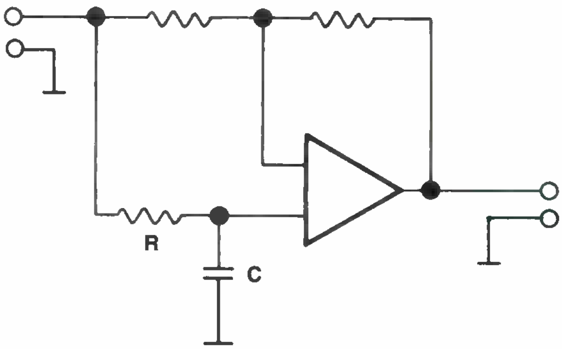
FOR 20 dB BOOST OR CUT: $VR_1 = 5 \cdot R_2$, $R_2 = 10 \cdot R_1$

$$\text{MAX BOOST OR CUT} = \frac{R_2 || VR_1}{R_1 || R_2}$$

Fig. 11B. Shelf-type tone control: treble control.



(a) Leading Phase



(b) Lagging Phase

Fig. 12. All pass filters, single pole.

so that the peaks are symmetrical about the base line of the signal. The first phase-scrambler packaged for use in broadcast plants was the Kahn Symmetra Peak introduced in the 1960s. The Symmetra Peak is a multi-pole passive all pass filter.

A full discussion of active filter techniques is beyond the scope of this chapter. Please see suggested readings below.

IMPROVING OLDER EQUIPMENT

Broadcast equipment produced with the first generation of monolithic opamps sounds inferior to the last commercial generation of vacuum tube broadcast equipment. As of this writing some manufacturers are still using first generation monolithic opamps, but this equipment can be upgraded by the broadcast engineer in the field for relatively low cost. Monolithic opamps have, for the most part, maintained the basic pinouts of earlier generations. The most common single-circuit-per-package 8 pin mini-DIP pinout is known in the industry as the 741 pinout. Some of the more common first generation device numbers in this single package genre which exhibit poor performance and should be replaced are 741, 301, 310, MC1456, CA3140, and OP-01. An exception to this replacement rule is the 318/518 opamp which is still considered an excellent device by today's standards.

The 741 pinout is usually followed for round can packages, sometimes referred to with a "T" suffix in the part number. All of these devices employ Pin 3 for the noninverting input, Pin 2 for the inverting input, and Pin 6 for the output. The power supply connections are positive to Pin 7 and negative to Pin 4. There is some variation in dc offset adjustment and frequency compensation techniques. Many broadcast audio circuits will use opamps without external frequency compensation or dc offset nulling, so that the devices listed below can generally be inserted without any circuit changes (other than the occassional requirement of additional high frequency bypass capacitors at the appropriate IC pins should the original circuit be deficient in this area). Caution should be taken and manufacturer's specification sheets should be consulted before replacing any operational amplifier IC in a circuit which has frequency compensation or an offset nulling potentiometer.

Two general types of plug-in replacements are available for the 741 pinout devices. Circuits which require low bias current, i.e. operate with a high impedance input circuit, and are driving a load which is greater than 2,000 ohms benefit from the use of commonly available BiFET (Field Effect Transistor input stage with a Bi-polar output stage) devices such as the TLO71, TLO81, or LF351. These BiFET devices are inexpensive, have high slew rates, and are audibly superior to the opamps they are replacing, but have poor dc performance and are relatively noisy (high 1/F noise figures). The LF411 and AD611 types are more costly but offer much improved dc performance when this parameter is important. When optimum noise performance and the ability to drive low impedance loads are requirements, the NE5534 bipolar input devices are the best choice. For best stability, the 5534 must be compensated with a 22 pF capacitor between Pins 8 and 5 when the circuit has an ac voltage gain of less than 3 (10 dB). Ceramic capacitors are not recommended for audio applications. Some other high performance bipolar input devices include the OP27, OP37, and the AD518.

Replacing single package dual opamp devices listed below on a pin for pin basis is much easier than the single opamp per package devices because compensation and offset pins are not available in these packages. The original dual 8 pin minidip packaged devices are the MC1458, MC4558, and CA3240. The pinout for this family is: first amplifier—noninverting input Pin 3, inverting input Pin 2, first amplifier output Pin 1. Second amplifier - noninverting input Pin 5, inverting input Pin 6, second amplifier output pin 7. Power supply connections are positive on Pin 8, negative to Pin 4. Some of the dual BiFET replacements are TLO72, TLO82, and LF353.

There are two standard pinouts for quad opamps in a 14 pin package. All 14 pin quads are internally compensated. Some early quad devices with the same pinout are the HA4741, HA4605, and the OP11. The positive supply is Pin 4, the negative supply (sometimes ground) is Pin 11. The first opamp uses Pin 2 for its inverting input, Pin 3 for the noninverting input, and Pin 1 as its output. The second opamp uses Pin 6 for its inverting input, Pin 5 for its noninverting input, and Pin 7 for its output. The third opamp uses Pin 9 for its inverting input, Pin 10 for its noninverting input and pin 8 for its output. The fourth opamp in this package has its inverting input appearing on Pin 13, its noninverting input on Pin 12, and its output on Pin 14. To improve the performance of earlier equipment, these quads can be pin for pin replaced with the TL074 and LF347 BiFET opamps. The other popular quad pinout is known as the 4136 pinout which can be directly replaced by the TLO75 quad BiFET. The 4136 pinout is as follows: the first opamp's inverting input is Pin 1, its noninverting input is Pin 2, and its output is Pin 3. The second opamp uses Pin 6 for its inverting input, Pin 5 for its noninverting input and Pin 4 for its output. The third opamp employs Pin 8 for its inverting input, Pin 9 as its noninverting input, and Pin 10 for the output. The inverting input of the fourth opamp is connected to Pin 14, Pin 13 is the noninverting input and the output of the fourth opamp appears on Pin 12. The positive supply is applied to Pin 11 and the negative supply (sometimes ground) is connected to Pin 7.

It is also a good idea to install sockets when changing opamps, if no socket was in the original equipment. This brief treatment of opamps should give you a base to work from. Some additional reading material is referenced below for those interested in further pursuing the subject.

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AC Power Systems

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Broadcast Engineering Magazine
Overland Park, Kansas

We all take the utility company power system for granted. If you want ac service, you just call the local office and order a power drop. You expect the utility company lines to be operating all day, every day. But how is this intricate ac power system designed? How is it interfaced to user equipment? What problems can it present to broadcasters?

An understanding of the answers to these questions is important to proper planning of a broadcast facility. Like any other area of engineering, the first requirement in system planning is an understanding of the basic principles involved.

THE UTILITY POWER SYSTEM

The details of power distribution in the United States vary from one utility company to another, but the basics are the same. See Fig. 1.

Power from a generating station or distribution grid comes into an area substation at 115 kV or higher. The substation will deliver output voltages around 60 kV to subtransmission circuits which feed distribution substations. These substations convert the energy to approximately 12 kV and provide voltage regulation and switching arrangements that permit "patching around" a problem. The 12 kV lines power the pole- and surface-mounted transformers, which supply various voltages (generally 208-240 V 3 phase) to the individual loads.

Fuses and circuit breakers are included at a number of points in the 12 kV distribution system to minimize fault-caused interruptions of service. Ground-fault interrupters are also included at various points in the 12 kV system to open the circuit if excessive ground currents begin to flow on the monitored line. In addition, reclosers may be included as part of overcurrent protection of the 12 kV lines. They will open the circuit if excessive currents are detected, and re-close after a preset length of time. The recloser will perform this trip off-reset action several times before being locked out.

In some areas, the actions of circuit breakers, pole-mounted switched and reclosers are controlled by two-way radio systems that allow status interrogation and switching of the remotely-located devices from a control center. Some utilities use this method sparingly, others make extensive use of it.

Depending on the geographic location, varying levels of lightning protection are included as part of the ac power system design. Most service drop transformers (12 kV to 208 V) have integral lightning arresters. In areas of severe lightning activity, a ground wire will be strung between the top insulators of each pole, thus attracting lightning to the grounding wire, and away from the hot leads.

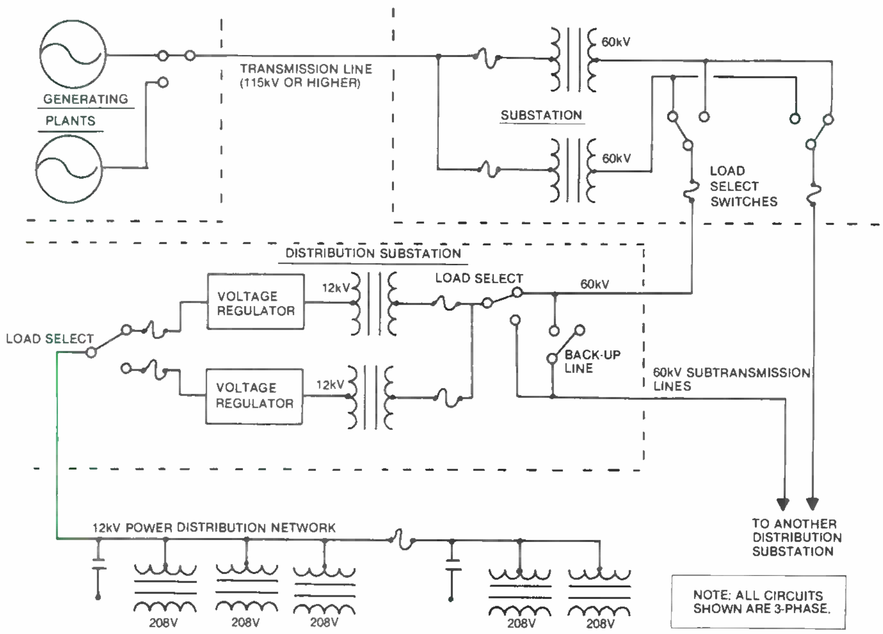


Fig. 1. A simplified block diagram of a basic utility company power distribution system. The devices shown as fuses could be circuit breakers or reclosers, which function as automatic-resetting circuit breakers. All circuits shown are three phase. The capacitors perform power factor correction duty.

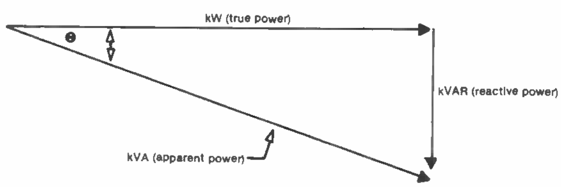
Power Factor

Capacitor banks are placed at various locations in the 12 kV distribution system. The number of banks and where they are located in the system is determined by the load distribution and *power factor* of the circuit. The capacitors will improve the short-term line voltage regulation (in the millisecond range) and reduce transient activity on the line. Spikes are reduced because the capacitors will present a high impedance to the 60 Hz line voltage frequency, but a low impedance to a high frequency transient. The capacitors are placed on the line in order to keep the power factor as close to unity (100%) as possible. Transient suppression is simply a by-product.

Power Factor (PF) is defined as the ratio of *true power* to *apparent power*. It is generally expressed in percent. Reactive loads (inductive or capacitive) act on power systems to shift the current out of phase with the voltage, and the cosine of the resulting angle between the current and voltage is the power factor. A utility line that is looking into an inductive load (which is most often the case) is said to have a *lagging power factor*, while a line feeding a capacitive load has a *leading power factor*. Fig. 2 illustrates the concept.

A poor power factor will result in excessive losses along utility company feeder lines because more current is required to supply a particular load with a low power factor than would be demanded if the load had a power factor close to 100%.

For example, a motor requiring 5 kW from the line is connected to the utility service entrance. If the motor has a power factor of 86%, the actual amount of power demanded by the load will be 5 kW divided by 86%, or better than 5,800 watts. 5 kW is the true power, 5.8 kW is the apparent power. The same amount of work is being done by the motor, but the closer the power factor is to unity, the more efficient the system will be.



$$\text{COS } \theta = \frac{\text{kW}}{\text{kVA}} = \text{PF}$$

$$\text{SIN } \theta = \frac{\text{kVAR}}{\text{kVA}}$$

θ = the phase angle, a measure of the net amount of inductive reactance in the circuit.
kW = the true power that performs the "real work" done by the electrical circuit (measured in kilowatts).
kVA = the apparent power drawn by a reactive load (measured in kilowatts).
kVAR = the kilovolt-ampers-reactive component of an inductive circuit. The kVAR component (also known as the *phantom power*) provides the magnetizing force necessary for operation of inductive loads.

Fig. 2. The mathematical relationships of an inductive circuit as they apply to power factor (PF) measurements. Reducing the KVAR component of the circuit causes θ to diminish, improving the PF. When KW is equal to KVA the phase angle is zero and the power factor is unity (100%).

In an effort to keep the power factor as close to 100% as possible, utility companies place capacitor banks at various locations in the 12 kV distribution system, thereby offsetting the inductive loading (lagging power factor) of most user equipment. The idea is to create an equal amount of leading PF in the system to match the load's lagging PF. When a balance is made, the power factor is unity.

In practice this is seldom attainable, since loads are switched on and off at random times, but utilities routinely (through much effort) maintain a power factor of approximately 99%. To accomplish this, capacitor banks are switched in and out of the system automatically to compensate for changing load conditions. The actual power factor of a particular system is determined by a complicated series of steps that involves measuring line parameters and correlating them with various charts and look-up tables.

Utility Company Interfacing

Most utility company connections in this country are the standard Delta-Wye type, as illustrated in Fig. 3. The transformer is usually connected with the Delta side facing the high voltage and the Wye side facing the load. This type of configuration provides good isolation of the load from the utility and retards somewhat the transmission of transients from the primary to the secondary. The individual three phase loads are denoted by Z-1, Z-2, and Z-3. They carry load currents as shown.

Some utility connections, on the other hand, use the Open-Delta arrangement shown in Fig. 4. Problems are often encountered when operating a sensitive three phase load from such a connection because of the system's poor voltage regulation characteristics under varying load conditions. The Open-Delta configuration is also subject to high third harmonic content and transient propagation. The three loads and their respective load currents are shown in the diagram.

Several other primary power connection arrangements are possible, such as Wye-to-Wye or Delta-to-Delta, and like the Delta-to-Wye configuration, they are not susceptible to the problems that can be experienced with the Open-Delta (or V-V) service.

The Open-Delta system can develop a considerable imbalance between the individual phases in either voltage or phase or both. Such an occurrence can introduce a strong 120 Hz ripple frequency in three phase power supplies, which are designed to filter out a 360 Hz ripple. The effects of this imbalance can be increased output noise from the supply, overheating of transformers, and possible damage to protection devices across power supply chokes.

Depending on the loading of an Open-Delta transformer arrangement, high third harmonic energy can be transferred to the load, producing transients (of up to 300% of the normal voltage)

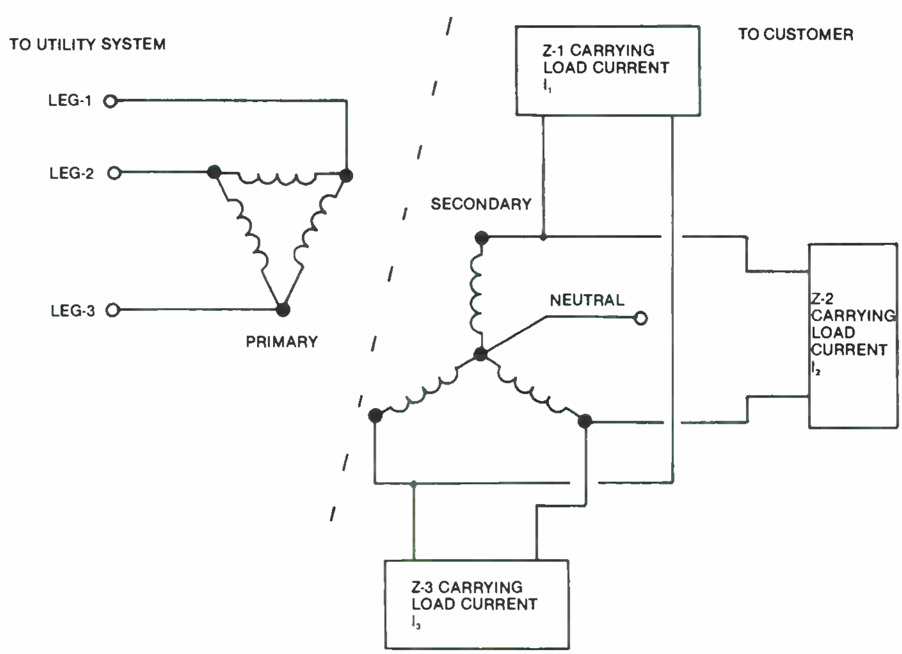


Fig. 3. The Delta-Wye transformer configuration for utility company power distribution. This common type of service connection transformer provides good isolation of the load from the 12KV distribution system line.

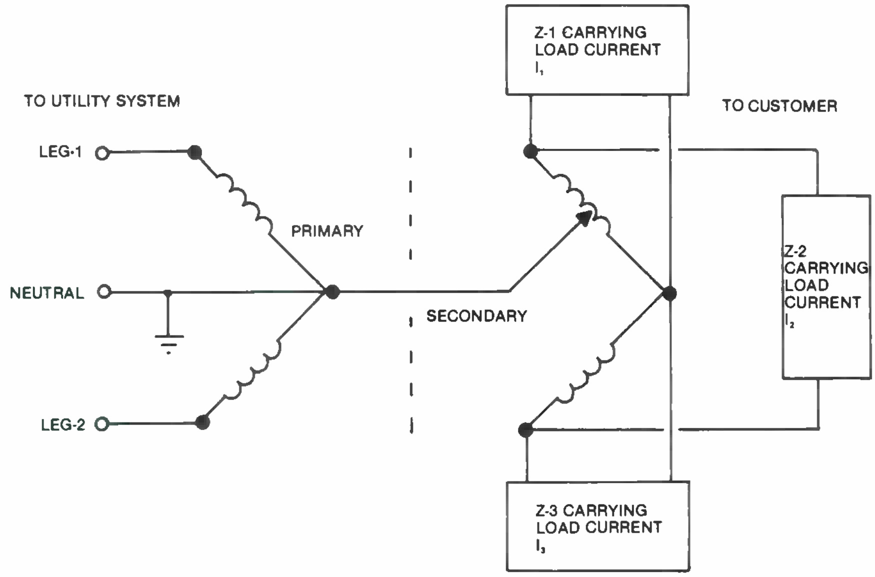


Fig. 4. The Open-Delta (or V-V) utility company service connection transformer. Use of this configuration is not recommended due to the tendency of the design to provide poor voltage regulation, high third harmonic content and transient disturbance propagation.

which severely strain rectifiers, capacitors and inductors in the power supply, as well as adding to the supply's output noise.

The phase-to-phase voltage balance of a utility company line is important to a broadcast facility not only because of the increased power supply ripple it may cause, but also because of the heating effects that may result. Even simple 3-phase devices such as motors should be operated from a power line that is well balanced (preferably within 1%). Studies have shown that a line imbalance of just 3.5% can produce a 25% increase in the heat generated by a 3-phase motor. A 5% imbalance can cause a potentially destructive temperature increase of 50% above normal. Similar heating can also be observed in the windings of a 3-phase power transformers used in broadcast equipment.

Phase-to-phase voltage balance can be accurately measured over a period of several days with a slow-speed chart recorder. The causes of imbalanced operation are generally large single-phase power users on the 12 kV distribution line. Uneven currents through the utility company power distribution system will result in uneven line-to-line voltages at the customer's service drop entrance.

It is important when using a Wye-connected system that the building neutral lead be tied to the mid-point of the transformer windings, as shown in Fig. 3. The neutral line provides a path for the removal of any harmonic currents that may be generated in the system due to rectification of the secondary voltages.

AC Line Disturbances

The ac power line into a broadcast plant is the lifeblood of any operation. It is also, however, a frequent source of equipment malfunctions and component failures. The utility company ac feed contains not only the 60 Hz power needed to run the facility, but also a variety of voltage sags, surges and transients. These abnormalities cause different problems for different types of equipment.

An ac voltage *sag* is generally defined as a decrease of 10-35% below the normal line voltage for a period of 16 milliseconds to 30 seconds. A *surge*, on the other hand, is a voltage increase of 10-35% above normal lasting 16 millisecond to 30 seconds. See Fig. 5. Sags and surges may occasionally result in operational problems for the equipment on-line, but generally automatic protection (or correction) circuits will take appropriate actions to ensure there is no equipment damage. *Transients*, however, are not so easily identified or eliminated. Many devices commonly used to correct for sag and surge conditions, such as ferroresonant transformers or motor-driven auto transformers, are of limited value in protecting a load from high energy, fast rise-time spikes on the ac line.

The Scope of the Problem

Transient suppression is important to broadcasters because the sensitive, high-speed solid state equipment in use today can be disrupted, or even destroyed by random short-duration spikes riding on the ac waveform. If not attenuated, these brief pulses (sometimes only a few microseconds in duration) can destroy semiconductors, disturb logic operations or latch-up microcomputer routines.

Experience in the computer industry has shown that the vast majority of unexplained problems resulting in disallowed states of operation are actually caused by transient overvoltages on the utility feed. With the increased use of microcomputers in broadcasting, this warning cannot be ignored. The threat to broadcast facilities is compounded by the fact that microcomputers are being used at critical stages in the transmission chain, including program automation equipment and transmitter control systems.

The subject of transient overvoltages has been extensively studied in the computer industry. A pioneering effort by the IBM Systems Development division in 1974 (conducted by George Allen and Donald Segall), showed that voltage spikes lasting between 10 and 100 μs in a frequency range of 10-100 kHz occur on an average of better than 50 times per month in a typical commercial environment.

Other more recent studies have shown that power line transients caused by utility company switching, distribution system faults, large loads going on- and off-line and lightning, can occur as often as 900 times per month. These spikes can reach 2 kV (or more) and last up to 30 milliseconds.

Assessing the Threat

Someone once jokingly said that the best transient eliminator is a transient monitor. Anyone who has monitored primary power service lines with an oscilloscope for any length of time would surely agree with that statement. Recent developments in digital technology, however, have moved the business of assessing the threat posed by unprocessed ac from an educated guess to a fine science.

Sophisticated monitoring equipment can give the user a complete, detailed look at what is coming in from the power company. Such monitoring devices can provide a wealth of information on the problems that can be expected when operating data processing, transmitting or other sensitive electronic equipment from an unprotected ac line. Typically the power at a facility to be protected is monitored for a week or more, after which an assessment is made as to whether ac processing equipment is needed at the installation.

As a case in point, a recently-completed study for a San Francisco Bay area company planning to install a new data processing center graphically demonstrates the scope of the transient problem.

The firm wanted to determine the extent of transient activity that could be expected at the new site so that an informed decision could be made on the type of power conditioning needed. A Dranetz Engineering Laboratories model 606-3 ac line monitor was connected to the 480 V dedicated drop at the new facility for a period of 6 days. During this time the monitor recorded *thousands* of spikes, many exceeding 2 kV, on one or more of the three phase inputs. The transient recording threshold was 460 V *above* the nominal ac voltage level of 480 V, phase-to-phase.

An expert from the report summary states that, on one particular day, the facility was plagued by many high-level transient periods, stretching from 8:30 a.m. until 3:00 p.m. In fact, the transient counters overflowed on the monitor's daily summary printout. The highest voltage recorded

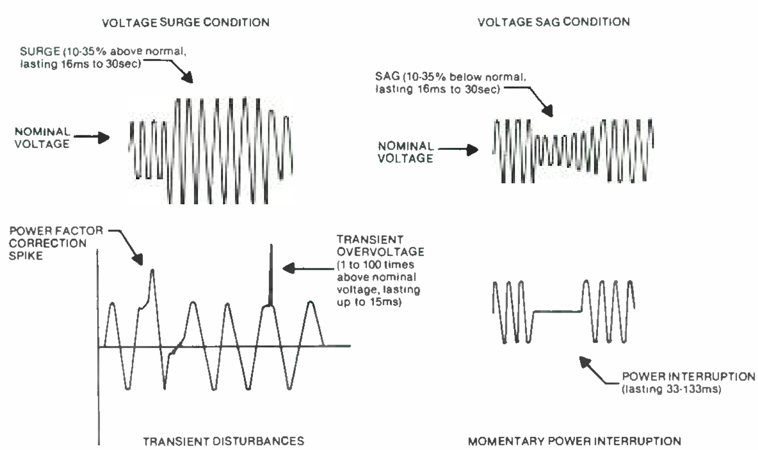


Fig. 5. Various classifications of power-line disturbances. Voltage sags and surges can garble data and stress hardware components. Momentary power interruptions can cause a complete loss of volatile memory and severely stress hardware components, especially if the ac supply is allowed to surge-back automatically. Transient disturbances can cause a wide variety of operational problems, from logic errors to complete system failure.

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C  1792V  IMPULSE
A  0544V  IMPULSE
C  1984V  IMPULSE
A  0592V  IMPULSE
C  1856V  IMPULSE
A  0544V  IMPULSE
C  1824V  IMPULSE
A  0560V  IMPULSE
C  1488V  IMPULSE
A  0496V  IMPULSE
C  1664V  IMPULSE
A  0528V  IMPULSE
C  1600V  IMPULSE
A  0544V  IMPULSE
B  2480V  IMPULSE
11:19:11
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Fig. 6. A portion of the ac monitor readout from the San Francisco area power quality study. The first column indicates on which phase (A, B or C) the spike occurred. The second column is an actual readout of the transient (impulse) magnitude in volts.

during this period was 4.08 kV. (This transient activity occurred, by the way, during periods of good weather.)

Fig. 6 is part of the printout from this study. The data covers transients exceeding more than twice the normal line voltage that occurred within a period of just *30 seconds*. Even though these transients were very brief in duration, any sensitive equipment connected to the power line would suffer damage in a very short period of time.

While this is certainly a worst-case example of dirty ac, it points up the need for a minimal amount of spike protection on all incoming power lines. Studies such as the one detailed here should not be construed to be an indictment of utility company engineering standards. Very few power drops are as bad as the one analyzed in this study. Further, most transient activity on ac lines is generated by power customers, not utility companies.

Standards of Measurement

It is difficult to assess the threat posed by transient disturbances without a guideline on the nature of spikes in ac power systems. To this end, a Working Group of the Institute of Electrical and Electronic Engineers (IEEE) has suggested two waveforms, one unidirectional and the other oscillatory, for measurement and testing of transient suppression components and systems in ac power circuits with rated voltages of up to 277 V line-to-ground. The guidelines also recommend specific source impedance or short-circuit current values for transient analysis.

The voltage and current amplitudes, waveshapes and source impedance values suggested in the IEEE Guide (now ANSI/IEEE Standard C62.41-1980) are designed to approximate the vast majority of high-level transient disturbances, but are not intended to be worst case conditions—a difficult parameter to predict. The timing of a transient overvoltage with respect to the power line wave is also an important parameter in the examination of ac disturbances. Certain types of semiconductors exhibit failure modes that are dependent on the position of a transient on the 60 Hz ac system sine wave.

Fig. 7 shows the ANSI/IEEE representative waveform for an *indoor-type spike* (for 120-240 V ac systems). Field measurements, laboratory observations and theoretical calculations have shown that the majority of transient disturbances in low-voltage indoor ac power systems have oscillatory waveshapes, instead of the unidirectional wave most often thought to represent a transient overvoltage. The oscillatory nature of the indoor transient waveform is caused by the natural resonant frequencies of the ac distribution system. Studies by the IEEE show that the oscillatory frequency range of such disturbances extend from 30 Hz to 100 kHz, and that the waveform changes depending upon where in the power distribution system it is monitored.

The waveform shown in Fig. 7 is the result of extensive study by the IEEE and other independent organizations of various ac power circuits. The representative waveshape for 120 and 240V systems is described as "a 0.5 μs-100 kHz ring wave." This standard indoor spike has a rise time of 0.5 μs and then decays while oscillating at 100 kHz. The amplitude of each peak is approximately 60% of the preceding peak.

Fig. 8 shows the ANSI/IEEE representative waveform for an *outdoor-type spike*. The classic

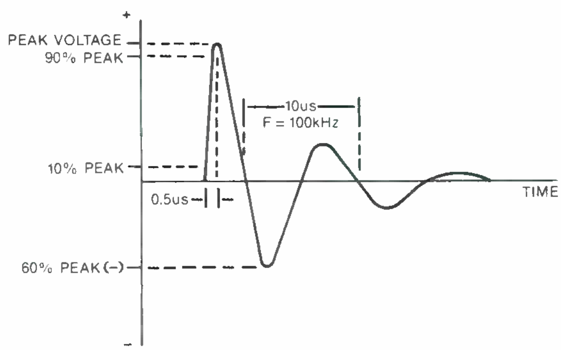

Fig. 7. The suggested IEEE indoor-type transient overvoltage test waveform (0.5 μs-100 kHz ring wave, open-circuit voltage).

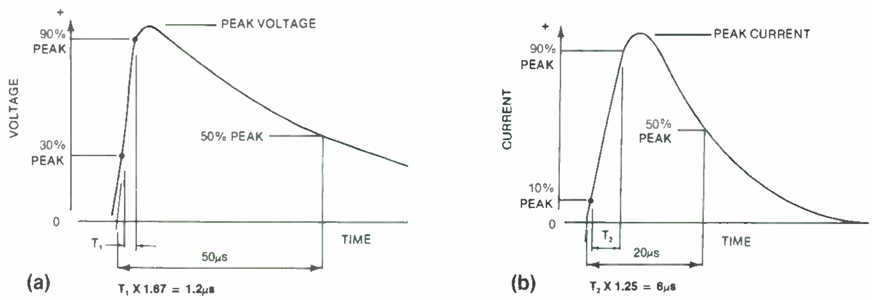

Fig. 8. The unidirectional waveshape for outdoor-type transient overvoltage test analysis based on ANSI Standard C62.1. Figure (a) shows the open-circuit waveform and Figure (b) shows the discharge current waveform.

lightning overvoltage pulse has been established as 1.2/5 50 μs waveshape for a voltage wave and a 8/20 μs waveshape for a current wave. Accordingly, the ANSI/IEEE standard waveshape is defined as "1.2/50 μs for the open-circuit voltage (voltage applied to a high-impedance device), and 8/20 μs for the discharge current (current in a low-impedance device)."

The outdoor waveshapes, while useful in analysis of components and systems, are not meant to represent all transient patterns seen in low voltage ac circuits. Lightning discharges can cause oscillations, reflections and other disturbances in the utility company power systems that can appear at the service drop entrance as decaying oscillations.

Equipment Performance Recommendations

The susceptibility of computer equipment to failure because of disturbances on the ac power line was analyzed in a far reaching study conducted between 1968 and 1978 by Lieutenant Thomas Key of the Naval Facilities Engineering Command, Washington, D. C. The work identified three distinct categories of recurring disturbances on the utility company power system. See Table 1. Note that the duration of the disturbance, not the magnitude of the voltage, determines the classification.

The study found that most computer failures caused by ac line disturbances occurred during periods of bad weather. In fact, according to a report on the findings of the study*, the incidence of thunderstorms in a given area may be used in predicting future equipment failures.(**The Effects of Power Disturbances on Computer Operation*, IEEE Industrial and Commercial Power Systems Conference Paper, delivered in Cincinnati, Ohio, June 7, 1978.)

The type of power transmission system used by the utility company was also found to have an effect on the number of disturbances observed on power company lines. For example, an analysis of utility system problems in Washington,

TABLE 1. The three types of power line disturbances identified in the research by Key, and the characteristics of each classification.

DEFINITION	TYPE 1 Transient and oscillatory overvoltage	TYPE 2 Momentary undervoltage or overvoltage	TYPE 3 Power outage
CAUSES	Lightning, power network switching, operation of other loads	Power system faults, large load changes, utility company equipment malfunctions	Power system faults, unacceptable load changes, utility equipment malfunctions
THRESHOLD*	200 to 400% of rated RMS voltage or higher (peak instantaneous above or below rated RMS)	Below 80-85% and above 110% of rated RMS voltage	Below 80-85% of rated RMS voltage
DURATION	Spikes 0.5 to 200 μs wide and oscillatory up to 16.7ms at frequencies of 200Hz-5kHz and higher	From 4 to 60 cycles depending on type of power system distribution equipment	From 2 to 60 seconds if correction is automatic; from 15 minutes to 4 hours if manual

*The approximate limits beyond which the disturbance is considered to be harmful to the load equipment.

D.C., Norfolk, Virginia, and Charleston, South Carolina showed that underground power distribution systems experienced only ⅓ as many failures as overhead lines in the same area.

Based on his research, Key developed a voltage tolerance envelope for computer equipment, shown in Fig. 9. It is designed as a guide for computer manufacturers in system tolerance design and in diagnosing power-related equipment failures.

Other Considerations

Another fault condition associated with the utility company ac power supply is single-phasing. This is caused when one or more lines of a multi-phase system is (are) open. Multi-phase equipment, particularly motors, not protected against such occurrences will generally overheat, and sometimes fail.

Unfortunately, the power quality problems affecting many areas of the nation are becoming worse, not better. Broadcasters cannot depend upon power suppliers to solve the transient problems that exist. Utility companies are rarely interested in discussing ac disturbances that are measured in the microseconds or nanoseconds. The problem must be solved instead, at the input point of sensitive loads.

Utilities have traditionally checked the quality of a customer's service drop by connecting a chart recorder to the line for a period of several days. The response time of such recorders, however, is far too slow to document any transient spike. Slow-speed analog recorders will only show long-term surge and sag conditions (as earlier defined), which can generally be dealt with by the regulated power supplies or high voltage protection systems normally used in broadcast equipment.

The degree of protection afforded a radio or television facility is generally a compromise between the line abnormalities that will account for better than 90% of the expected problems, and the amount of money available to spend on that protection. Each installation is unique and requires an assessment of the importance of keeping the system up and running at all times, the threat posed by the utility company feed and the budget available for protection devices and systems.

Suppression Devices

The decision on how to proceed with a transient protection program is not an easy one, but it is made somewhat less complicated by the economics involved. Most commonly-available discrete protection devices can be purchased for $5.00 to $20.00 each and installed by station personnel at critical points in the transmission plant. The alternative method is to purchase a transient suppressor system designed for connection to the utility company primary input lines at the protected facility. The *systems* approach is certainly

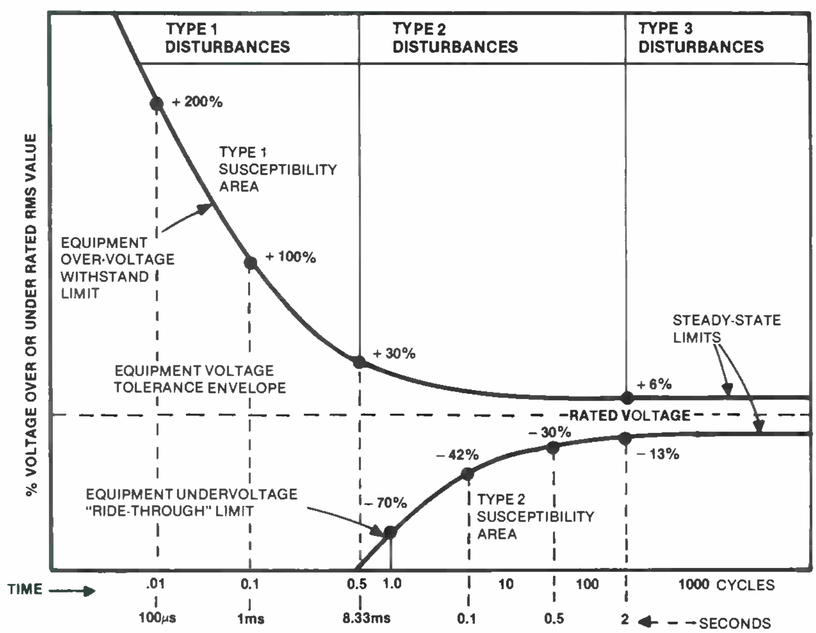

Fig. 9. The recommended voltage tolerance envelope for computer equipment. This chart is based on pioneering work done by the Naval Facilities Engineering Command. The study identified how the magnitude *and* duration of a transient pulse must be considered in determining the damaging potential of a spike. The design goals illustrated in the chart are recommendations to computer manufacturers for implementation in new equipment.

TABLE 2. The use of ac interface equipment in controlling disturbances on ac power line inputs. (Based on the research by Key.)

TYPE OF DISTURBANCE	UPS SYSTEM AND STANDBY GENERATOR	UPS SYSTEM	SECONDARY SPOT NETWORK[1]	SECONDARY SELECTIVE NETWORK[2]	MOTOR-GENERATOR	SHIELDED ISOLATION XFMR	SUPPRESSORS, FILTERS, LIGHTNING ARRESTERS	SOLID-STATE LINE-VOLTAGE REGULATOR
#1	ALL SOURCE TRANSIENTS	ALL SOURCE TRANSIENTS	NONE	NONE	ALL SOURCE TRANSIENTS	MOST SOURCE TRANSIENTS	MOST TRANSIENTS	MOST SOURCE TRANSIENTS
	NO LOAD TRANSIENTS	NO LOAD TRANSIENTS			NO LOAD TRANSIENTS	NO LOAD TRANSIENTS		NO LOAD TRANSIENTS
#2	ALL	ALL	NONE	MOST	MOST	NONE	NONE	SOME. DEPENDING ON RESPONSE TIME OF SYSTEM
#3	ALL	ALL OUTAGES SHORTER THAN BATTERY SUPPLY DISCHARGE TIME	MOST	MOST	ONLY "BROWN-OUTS"	NONE	NONE	ONLY "BROWN-OUTS"

NOTES:
1. Dual power feeder network.
2. A dual power feeder network using a solid-state switch to select which line is fed to the load.

TABLE 3. Approximate costs for various methods of ac power processing. It should be emphasized that these values are only approximate, and may vary substantially depending on the installation requirements and vendor chosen.

BASIS OF COMPARISON[1]	UPS SYSTEM AND STANDBY GENERATOR	UPS SYSTEM	DUAL POWER FEEDERS	MOTOR-GENERATOR	SHIELDED ISOLATION XFMR	SUPPRESSORS, FILTERS, LIGHTNING ARRESTORS	SOLID-STATE LINE-VOLTAGE REGULATOR
INSTALLATION AND EQUIPMENT COSTS	\$1,500 to \$2,000 per kVA	\$1,100 to \$1,500 per kVA	Installation cost will vary greatly depending on site	\$250 to \$400 per kVA	\$50 to \$150 per kVA	\$1 to \$10 per kVA	\$250 to \$280 per kVA
MAINTENANCE COSTS	\$2,000 to \$4,000 per year	\$1,100 to \$3,000 per year	NONE	Less than \$1,000 per year	NONE	NONE	Less than \$1,000 per year
OPERATING EFFICIENCY[2]	80-85%	80-85%	100%	80-90%	Up to 98%	100%	90-98%

NOTES:
1. A power conditioning system rated for approximately 25kVA is assumed.
2. Efficiency applies to the ac power conditioning equipment only. Losses in environment support systems are not taken into account.

the more effective way to prevent damaging transient overvoltages from entering a broadcast plant. It is also however, the more expensive way.

The amount of money a broadcaster is willing to spend on transient protection is generally a function of how much money is available in the engineering budget and how much the station has to lose. An expenditure of \$10,000 for transient protection for a major-market station, where spot rates can run into the hundreds or thousands of dollars, is easily justifiable. At small or medium market stations, however, justification is not so easy to come by.

Tables 2 and 3 show the various options available to station engineers to protect sensitive broadcast equipment from disturbances on the ac line, and the approximate costs of that protection. Because each installation is unique, a detailed investigation of the station's exact needs should be made before any ac line protection equipment is purchased.

The high-performance end of transient suppression equipment available to broadcasters is occupied by motor-generated units, uninterruptable power systems and various types of power line filters.

Motor-Generator Units (MGU)

As the name implies, a motor-generator unit consists of a motor powered by the ac utility supply that is mechanically tied to a generator, which feeds the load. Transients on the utility line will have no effect on the load when an arrangement such as this is used. Further, the addition of a flywheel to the motor-to-generator shaft will provide protection against brief power dips (up

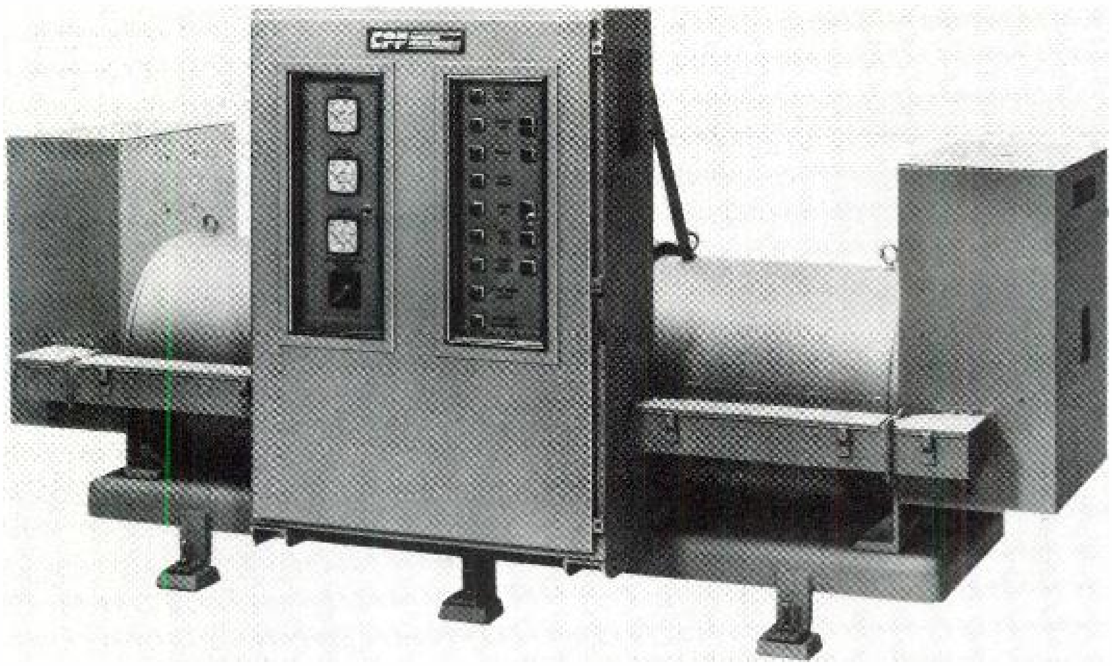

Fig. 10. The design layout of a typical motor-generator unit. The MGU shown is manufactured by Computer Power Products, Inc., of Los Angeles. Systems performing similar functions are also manufactured by several other companies.

to ½ second on many models). Fig. 10 shows the construction of a typical MGU.

Other features available from a motor-generator unit include output voltage and frequency regulation, ideal sine wave output, elimination of common-mode and transverse mode noise, elimination of utility company power factor correction problems and true 120 degree phase shift for 3 phase models. The efficiency of a typical MGU ranges from 65% to 89%, depending on the size of the unit and the load.

Uninterruptable Power Systems (UPS)

Another method guaranteed to eliminate spikes on utility company power lines is the rectifier-inverter combination, used in many Uninterruptable Power Systems. As shown in Fig. 11, ac from the utility is rectified to a given voltage, such as 120 volts dc, across which floats a bank of a batteries connected in series to yield slightly less than 120 volts. This dc power drives a closed-loop inverter, which provides voltage and frequency regulation. The output of the inverter is generally a sine wave, or pseudo sine wave (really a stepped square wave). If the utility voltage should drop or disappear, current is drawn from the batteries. When the ac power is restored, the batteries are re-charged.

Many UPS systems incorporated a standby diesel generator that is started as soon as the utility company feed is interrupted. With this arrangement, the batteries are called upon to supply the operating current for only 10 seconds or so, until the generator gets up the speed.

Processing Line Filters

Processing systems for ac power are available from a number of manufacturers in a variety of configurations and designs. Some use shunt elements to clip transient overvoltages, and others use a series element—in addition to the shunt—to absorb the transient energy. Another type of filter commonly found is the high-performance isolation transformer.

Transients, as well as noise (RF and low level spikes) can pass through transformers not only by way of the magnetic lines of flux between the primary and the secondary, but through resistive and capacitive paths between the windings as well. Increasing the physical separation of the pirmary and secondary windings will reduce the resistive and capacitive couplings, however, it will also reduce the inductive coupling, and thus decrease the power transfer. A better solution is to shield the primary and secondary windings from each other and thereby divert much of the primary noise current to ground, while leaving the inductive coupling basically unchanged. This idea can be carried a step further by placing the primary winding in a shielding box that shunts noise current to ground and reduces the capacitive coupling between the windings.

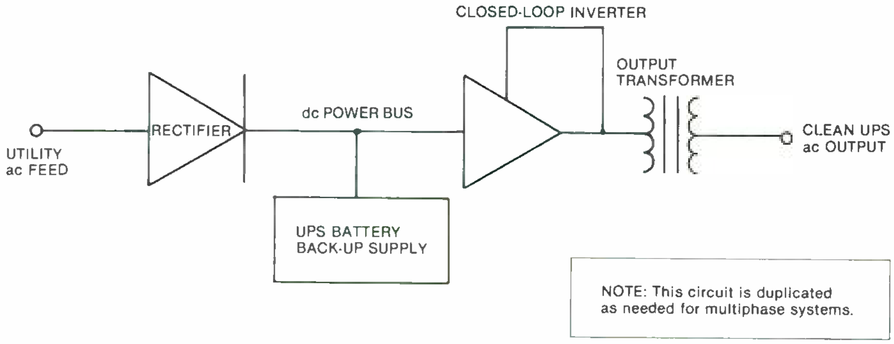

Fig. 11. A block diagram of a typical Uninterruptable Power System using ac rectification to float the battery supply. A closed-loop inverter draws on this supply and delivers clean ac power to the protected load.

Fig. 12. A typical Uninterruptable Power System using externally-located batteries. The control panel on the front of the chassis is used to check the performance of the equipment and to monitor the quality of the incoming ac power. This particular unit is manufactured by the Topaz Electronics Company of San Diego, CA. Units performing similar functions are also made by several other firms.

One application of this technology is shown in Fig. 13, in which transformer noise de-coupling is taken still further by placing the primary *and* secondary windings in their own wrapped foil box shields. The windings are separated physically as much as possible for the particular power rating, and placed between special Faraday shield separator plates. This gives the transformer high noise attenuation from the primary to the secondary, as well as from the secondary to the primary. The interwinding capacitance of a typical transformer using this technology is 0.005 picofarads. Common mode noise attenuation is typically greater than 120dB and transverse mode noise attentuation is typically in excess of 60dB.

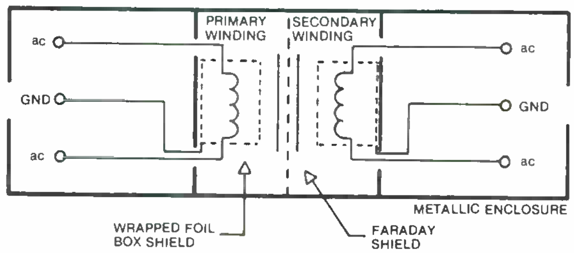

Fig. 13. The shielding arrangement used in a popular high performance isolation transformer. The design goal of this type of unit is high common-mode and transverse-mode noise attentuation.

STANDBY POWER SYSTEMS

When utility company power problems are discussed, most people immediately think of blackouts. The lights go out and everything stops. Blackouts, however, occur only rarely in most areas of the country and are generally of short duration. Studies have shown that 50% of all blackouts last 6 seconds or less, and another 35% are less than 11 minutes long. These failure rates are not usually cause for concern to commercial users, except where broadcasting is concerned.

A station that is off the air for 11 minutes—or even 5 minutes—will suffer a drastic audience loss that can take hours (or perhaps days) to rebuild. Coupled with this threat is the possibility of extended power service loss due to storm conditions. Many broadcast transmitting sites are located in remote, rural areas, or on mountaintops. Such locations are not well known for their power reliability. It is not uncommon in mountainous areas for utility company service to be out for days after a major storm. Few broadcasters are willing to take such risks with their air signal, and choose to install standby power systems at appropriate points in the transmission chain.

The cost of standby power for a broadcast facility (particularly high power radio or TV) can be substantial, and an examination of the possible alternatives should be conducted before any decision on equipment is made. Management should clearly define the direct and indirect costs and weigh them appropriately. This cost-versus-risk analysis should include the standby power system equipment purchase and installation price, the exposure of the transmission system to utility company power failure, the alternative transmission methods available to the station and the direct and indirect costs of lost air time due to blackout conditions.

Standby System Options

The classic standby power system using an engine-generator is shown in Fig. 14. An automatic transfer switch monitors the ac voltage coming from the utility company line for any power failure conditions. Upon detection of an outage for a predetermined period of time (generally 1 to 10 seconds), the standby generator is started and once up to speed, the load is transferred from the utility to the local generator. Upon return of the utility feed, the load is switched back and the generator is stopped. This basic type of system is widely used in the broadcast industry and provides economical protection against prolonged power outages (5 minutes or more).

In some areas, usually metropolitan centers, the utility company can bring two power drops into a facility as a means of providing a source of standby power. As shown in Fig. 15, two separate utility company service drops—from separate power distribution systems—are brought into the plant and an automatic transfer switch changes the load to the backup line in the event of a main

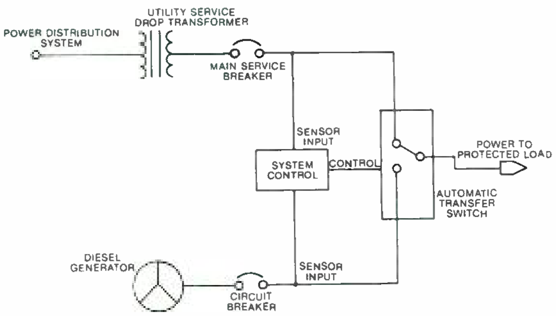

Fig. 14. The classic standby power system using an engine-generator unit. This system protects a facility from prolonged utility company power failures.

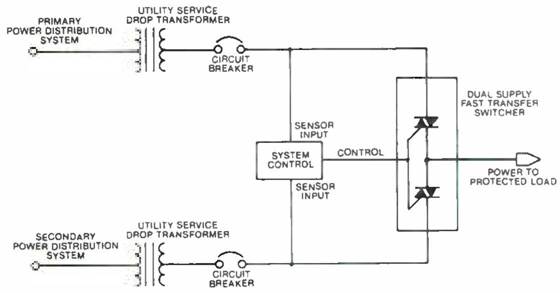

Fig. 15. The dual feeder system of ac power loss protection. An automatic monitoring system switches the load from the main utility line to the standby line in the event of a power disruption.

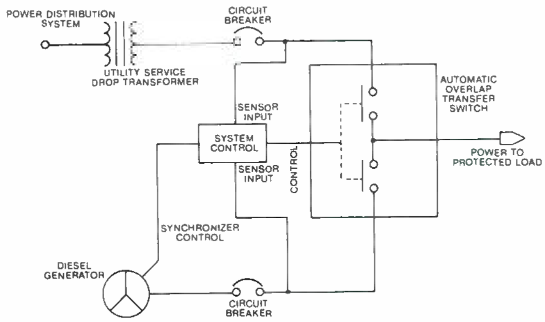

Fig. 16. The use of a diesel generator for emergency power and peak power shaving applications. The automatic overlap transfer switch changes the load from the utility feed to the generator instantly so that no disruption of normal operation is encountered.

line failure. This dual feeder system has an advantage over the auxiliary diesel arrangement shown in Fig. 14 in that the power transfer from main to standby can be made in less than a second. Time delays are involved in the diesel generator system which limit its usefulness to power failures lasting more than several minutes.

The dual feeder system of protection is based on the assumption that each of the service drops brought into the facility is routed via different paths. This being the case, the likelihood of a failure on both power lines simultaneously is very remote. The dual feed system will not, however, protect against area-wide power failures, which can occur from time to time.

The dual feeder system is primarily limited to urban areas. Rural or mountainous regions are not generally equipped for dual redundant utility company operation. Even in urban areas, the cost of bringing a second power line into a broadcast facility can be high, particularly if special lines must be installed for the feed.

Fig. 16 illustrates the use of a backup diesel generator for both emergency power and *peak* *power shaving* applications. (See "Peak Demand" discussion on page 7.3-92.) Commercial power customers can often realize substantial savings on utility company bills by reducing their energy demand during certain hours of the day. Fig. 16 shows the use of an automatic overlap transfer switch to change the load from the utility company system to the local diesel generator. This change-over is accomplished by a special transfer system that does not disturb the operation of load equipment. This application of a standby generator can provide financial return to the station regardless of whether the generator is ever needed to carry the load through a commercial power failure.

Advanced System Protection

A more sophisticated power control system is shown in Fig. 17, where a dual feeder supply is used to feed a motor-generator unit (MGU) to provide clean, undisturbed ac power to the load. The MGU will smooth-over the transition from the main utility feed to the standby, often making a commercial power failure unnoticed by station personnel. An MGU will typically give up to 1/2 second of power-fail ride-through, more than enough to accomplish a transfer from one utility feed to the other.

The principle is further refined in the application shown in Fig. 18, where a diesel generator has been added to the ac power supply system. With the automatic overlap transfer switch shown at the generator output, this system can also be used for peak demand power shaving.

The generator rating for a standby power system should be chosen carefully, keeping in mind any anticipated future growth of the broadcast plant. It is good practice to install a standby power system rated for at least 25% greater output than the peak facility load. This headroom gives a margin of safety for the standby equipment and allows future expansion of the facility without worry about overloading of the system.

The type of generator chosen should also be given careful consideration. Generators rated for more than 100 kW power output are almost always diesel-powered. Smaller generators are available that use diesel, gasoline, natural gas or propane as a fuel source. The type of power plant chosen is usually determined primarily by the environment in which the system will be operated.

For example, a standby generator that is located in an urban area office complex may be best suited to the use of an engine powered by natural gas, because of the problems inherent in storing large amounts of fuel. State or local building codes may place expensive restrictions on fuel storage tanks and make the use of a gasoline-or diesel-powered engine impractical. The use of propane is usually restricted to rural areas, and the availability of propane in periods of bad weather (which is when most power failures occur) must also be considered.

Critical System Buss Protection

A station seeking standby power capabilities should consider the possibility of protecting key pieces of equipment at a facility from power

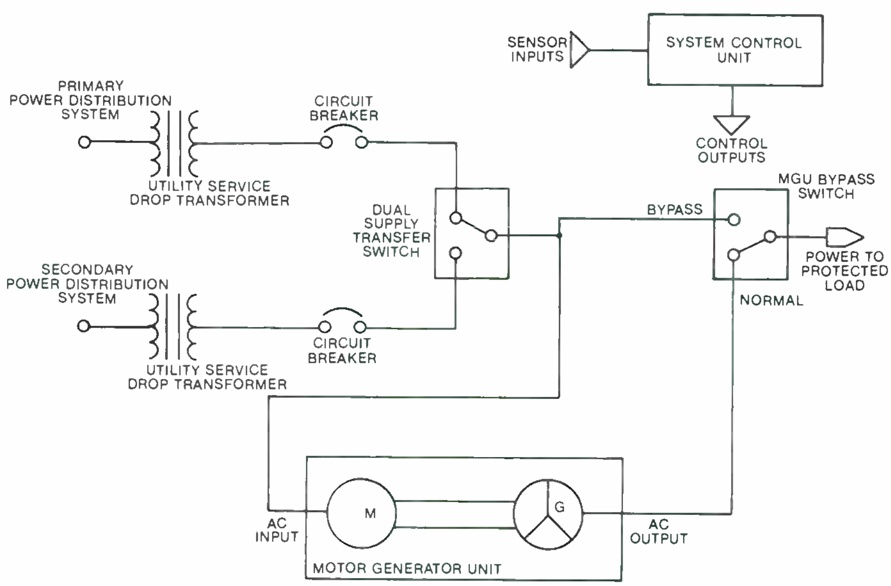

Fig. 17. The dual feeder standby power system using a motor-generator unit to provide power-fail ride-through and transient disturbance protection. Switching circuits allow the MGU to be bypassed, if desired.

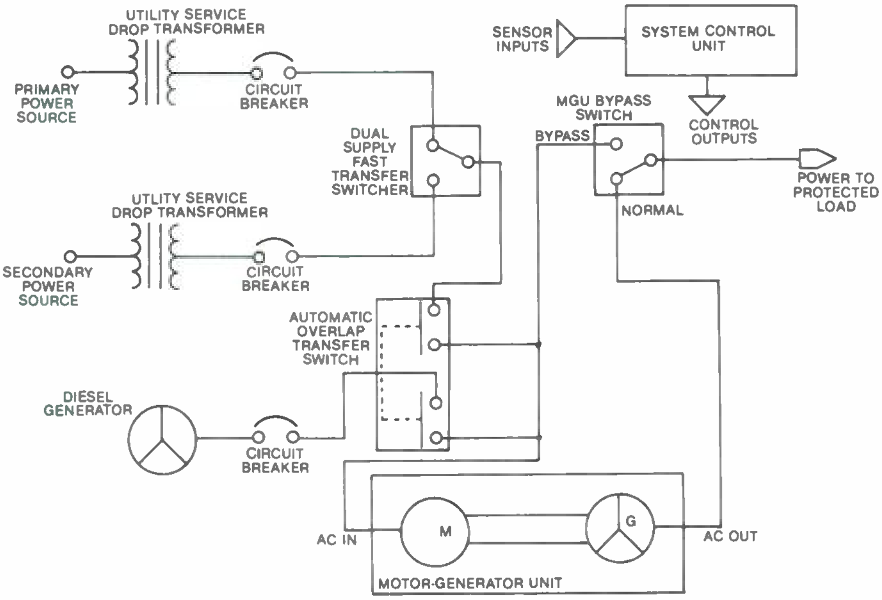

Fig. 18. A premium power supply backup and conditioning system using dual utility company feeds, a diesel generator and a motor-generator unit. An arrangement such as this would be used for critical loads that require a steady supply of clean ac.

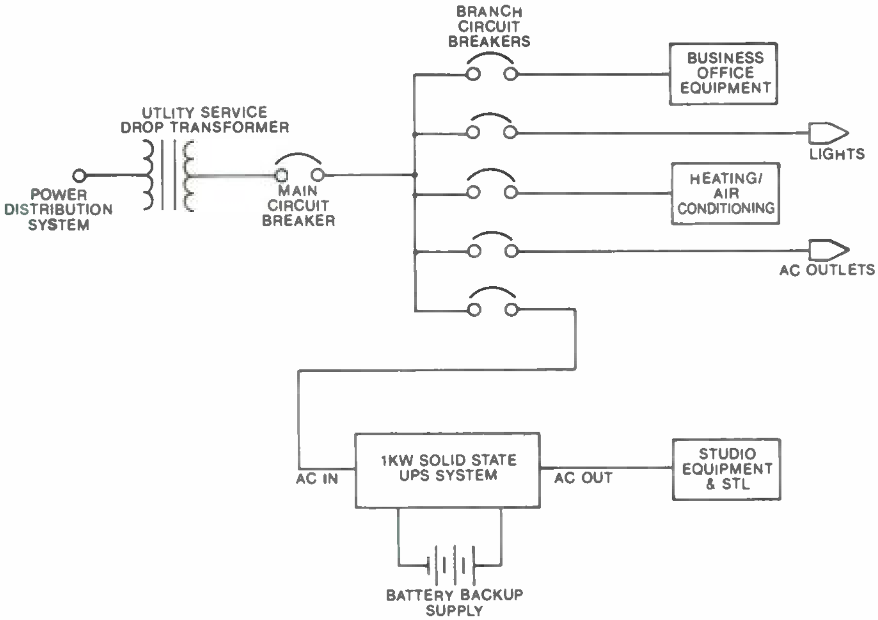

Fig. 19. An application of the critical load power buss concept. In the event of a power failure, all equipment necessary for continued operation is powered by the UPS equipment. Non-critical loads would be dropped until commercial ac returned.

failures with small, dedicated, uninterruptable power systems. Small UPS units are available with built-in battery supplies for microcomputer systems and other hardware used by broadcasters. If cost prohibits the installation of a system-wide standby power supply (using generator or solid-state UPS technology), the engineer should consider establishing a *critical load buss* that is connected to a UPS system or automatic transfer generator unit.

This separate power supply would be used to provide ac to critical loads, thus keeping the protected systems up and running, as illustrated in Fig. 19. Unnecessary loads would be dropped in the event of a power failure. A standby system built on the critical load principal can be a cost-effective answer to the power failure threat.

THE EFFICIENT USE OF ENERGY

Utility company power bills are becoming an increasingly large part of a station's operating budget. In order to reduce the amount of money spent each month on electricity, the broadcaster must understand the billing methods used by the utility. Saving energy is more complicated than simply turning-off unnecessary lights.

The amount of money that can be saved through a well-planned energy conservation effort is often substantial. Reductions of 20% are not uncommon, depending upon the facility layout and extent of energy conservation methods already in use. Regardless of any monetary savings that might be realized from a power-use reduction program, the items discussed here should be considered for any well-run broadcast facility.

Billing Procedures

The rate structures of utility companies vary widely from one area of the country to another. Some generalizations can be made, however, with respect to the basic rate-determining factors.

The four primary parameters used to determine a customer's bill are (1) energy usage, (2) peak demand, (3) load factor and (4) power factor. These items can often be controlled, to one extent or another, by the customer.

Energy Use

The KWH usage can be reduced by turning-off loads such as heating and air conditioning systems, lights and office equipment when they are not needed. The installation of timers, photocells or sophisticated computer-controlled energy management systems can make substantial reductions in a facility's KWH demand each month.

Common sense will dictate the conservation measures applicable to a particular situation. Obvious items include reducing the length of time high power TV studio lights are in operation, setting heating and cooling thermostats for reasonable levels, keeping office equipment turned-off during the night and avoiding excessive amounts of indoor or outdoor lighting.

While energy conservation measures should be taken in every area of broadcast station's operation, the greatest savings can generally be found where the largest energy users are located. Transmitter plants consume a large portion of the monthly power bill, and so particular attention should be given to the equipment, physical layout and system efficiency at the RF facility.

Transmitter room heating should be accomplished with a logic controlled PA exhaust recycling system, and air conditioning equipment should be planned for efficient operation by a knowledgeable consultant in the field. Tower light photocells should be inspected regularly for proper operation, as should antenna element heating control systems. A failure in either of these two circuits can result in a substantial increase in power consumption (if failure latches the system on), or a potentially dangerous condition (if failure latches the system off).

The efficiency of the transmitter itself is an item of critical importance to energy conservation efforts. Most transmitters available today are significantly more efficient than their counterparts of just 10 years ago. In UHF, in particular, major efforts have been made in improving efficiency. Station management can often find economic justification for updating or even replacing an older transmitter on the power company savings alone. Most new transmitters specify a typical ac power consumption figure for the rated RF output, and this point should be seriously considered when the purchase of a unit is planned.

Comparing the efficiency figures of FM transmitters is a straightforward task, since the power consumption does not change with modulation. AM and TV transmitters, however, require further investigation. The overall efficiency figure of an AM or TV transmitter at a carrier-only condition is of little comparison use, since the system is never operated that way. Many manufacturers, though, are now specifying overall ac power consumption at *typical* or 100% modulation for AM transmitters, and *average* or *black picture* in the case of TV equipment. These figures make the comparison process easier and more accurate. Engineers should be somewhat cautious, however, about the typical or average modulation value because of the wide variation that could be expected with respect to what defines *typical* and *average*.

After selecting a transmitter, the final amplifier stage efficiency should be monitored and any necessary tuning adjustments should be made to keep the unit operating at peak efficiency. A final amplifier even slightly out of tune can raise power consumption not only due to inefficient stage operation, but also due to increased air conditioning requirements caused by additional PA stage heat generation.

Significant advancements have been made in recent years that have improved the efficiency of new UHF-TV transmitters. Some manufacturers also offer conversion packages for updating older equipment to the current state-of-the-art.

In virtually any broadcast facility, energy conservation can best be accomplished through careful selection of equipment, thoughtful system design and good maintenance practices.

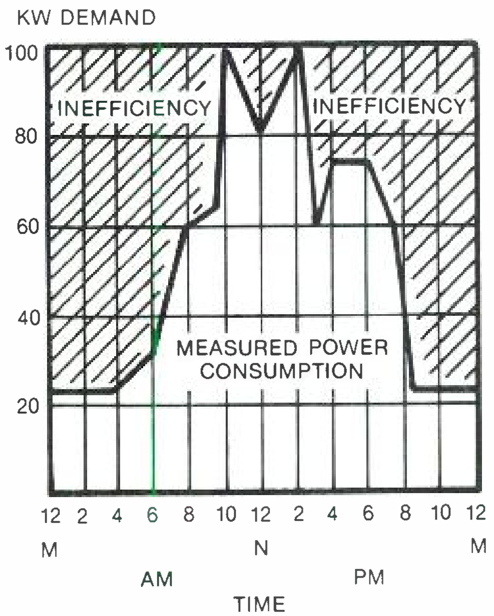

Fig. 20. The charted power consumption of a facility not practicing energy management techniques. Note the inefficiency that the utility company must absorb when faced with a load such as this.

Peak Demand

Conserving energy is a big part of the power bill reduction equation, however it is not the whole story. The *peak demand* of the customer's load is an important criteria in the utility company's calculation of rate structures.

The peak demand figure is a measure of the maximum load placed on the utility company system by a customer during a predetermined billing cycle. The measured quantities may be kilowatts, kilovolt-amperes, or both. Time intervals used for this measurement range from 15 minutes to 60 minutes. Billing cyles may be annual or semi-annual. Fig. 20 shows an example of varying peak demand.

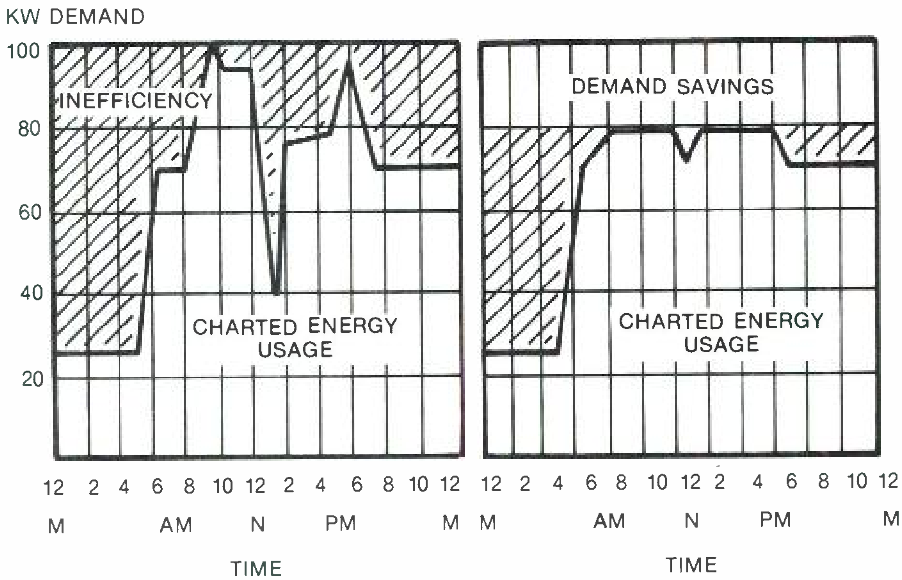

Fig. 21. An example of the successful application of a load shedding program. Energy usage has been spread more evenly throughout the day in the diagram on right resulting in reduced peak demand, and consequently, a better rate from the utility company.

If a facility operated at basically the same power consumption level from one hour to the next and one day to the next, the utility company could accurately predict the demand of the load, and size its equipment (including the allocation of energy reserves) for only the amount of power actually needed.

For the example shown in Fig. 20, however, the utility company must size its equipment (including allocated energy reserves) for the peak demand. The area between the peak demand and the actual usage is the margin of inefficiency that the customer forces upon the utility. The peak demand factor is a method used by utility companies to assess penalties for such operation, thereby encouraging the customer to approach a more efficient (from the utility's viewpoint) state of operation.

Load Shedding is a term used to describe the practice of trimming peak power demand in order to reduce high-demand penalties. The goal of load shedding is to schedule the operation of non-essential equipment so as to provide a uniform power demand from the utility company, and thereby a better KWH rate.

Nearly any operation has certain electrical loads that can be rescheduled on a permanent basis or deferred as power demand increases during the day. Fig. 21 illustrates the results of a load shedding program. This more efficient operation has a lower overall peak demand and a higher average demand.

Peak demand reduction efforts can cover a wide range of possibilities. It would be unwise from an energy standpoint, for example, to test a standby transmitter during the afternoon hours, when air conditioning units may be in full operation. Morning or evening hours would be a better choice, when the air conditioning is off and the demand of office equipment is reduced. For an AM plant, standby transmitter testing should be done during periods of low power operation, further reducing the peak-to-average ratio. Each broadcast operation is unique and requires an individual assessment of the load shedding options.

A very effective method of controlling peak demand is through the use of a computerized power demand controller. A controller can analyze the options available and switch loads as needed to maintain a relatively constant power demand from the utility company. Such systems are programmed to recognize which loads have priority and which loads are non-essential. Power demand is then automatically adjusted by the computer, based upon the rate schedule of the particular utility company.

Many computerized demand control systems will also give the customer a printout of the demand profile of the plant, further helping management analyze and reduce power costs.

Load Factor

The load factor on an electric utility company bill is a product of the peak demand and energy usage. It is usally calculated and applied to the customer's bill each month. Reducing either or both the peak demand or energy usage levels will decrease this added cost factor. Reducing power factor penalties will also help to reduce the load factor charges.

Power Factor

Power Factor (PF) charges are the result of heavy inductive loading of the utility company system. A poor power factor will result in excessive losses along utility company feeder lines because more current is required to supply a particular load with a low power factor than would be demanded if the load had a power factor close to 100%.

The power factor charge is a penalty that customers pay for the extra current needed to magnetize motors and other inductive loads. This magnetizing current does not show up on the service drop wattmeter. It is, instead, measured separately or pro-rated as an additional charge to the customer. The PF penalty charge can sometimes be reduced through the addition of on-site power factor correction capacitors. The capacitors provide a leading power factor to offset the lagging power factor of inductive loads. When a balance is made, the PF is 100%.

Power factor meters are available for measurement of a load's PF performance. It is usually less expensive in the long run, however, to hire a local electrical contractor to conduct the PF survey and recommend possible correction methods.

The use of power factor correction capacitors is usually the simplest and most versatile method of PF improvement. The point of diminishing returns for PF correction is approximately 95%. Loads which exhibit a power factor below 95% can usually benefit economically by the installation of power factor correction components. An experienced electical contractor and the local utility company should be consulted before any attempt is made to change a broadcast facility's power factor situation.

Possible sources of PF problems include transmitters, blowers, air conditioners, heating equipment and fluorescent and high-intensity discharge lighting fixtures ballasts. Most transmitting equipment exhibits fairly good PF performance, with 90-95% being typical. When purchasing a new transmitter, this point should be taken into consideration, due to the increased operating costs that may be incurred from the power company due to PF penalties.

Plant Maintenance

Any serious energy management effort should include an examination of the present circuit layout and maintenance procedures. Power system cables should be heavy enough to carry the full load demanded without heating losses. The system should also be examined for any loose connections, dirty contacts or cable insulation problems. Phase-to-phase load balance likewise should be checked on a regular basis at various points in the ac power distribution system.

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Translators and Low Power Television Systems

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REGULATORY FRAMEWORK AND DEFINITIONS

Low Power Television and TV translators are governed by Part 74, Subpart G of the FCC Rules, which define a translator as a device which retransmits a television signal while altering none of its characteristics except frequency and amplitude. An LPTV station is defined as one that may operate as a translator or originate programming and operate as a subscription service. Under Subpart L of Part 74, an FM translator station is defined identically to a TV translator, except that its operating frequency is within the FM broadcast band. Block diagrams and typical installations of these stations appear in Figs. 1 through 6.

MULTIPLE OUTPUTS

The use of more than one output at a translator station may be authorized, if connected to different antennas whose patterns do not overlap and whose different outputs provide signal to different communities or areas. Manufacturers have responded to this provision by designing translators having multiple outputs and translator amplifiers which will accept a single translator output and provide up to four outputs identical to it, thus allowing the translator operator to expand his coverage area in each four different directions. Such a multiple output amplifier is diagrammed in Fig. 4 on page 7.4-98. Although the regulations place no specific upper limit on the number of outputs, more than four of one polarization is usually impractical because of the problem of transmitting antenna pattern overlap.

SITE SELECTION

The selection of a site for a station must satisfy regulatory, engineering and practical requirements. All types of translator and Low Power TV stations are defined by the FCC Rules as providing a secondary service which must not cause interference to any primary broadcast service or to existing land mobile communications services. Additionally, earlier services are protected from later installations of the same type. From a technical viewpoint, the requisite input signal must be available at the site or deliverable to the site by economically feasible means and a clear propagation path from the transmitting antenna to the planned service area is of crucial importance if useful service is to be provided with the relatively low power transmitters ordinarily permitted under Part 74. Practically speaking, the translator site must be accessible under varying weather conditions and not subject to erosion or other damage from wind, snow, heat or water.

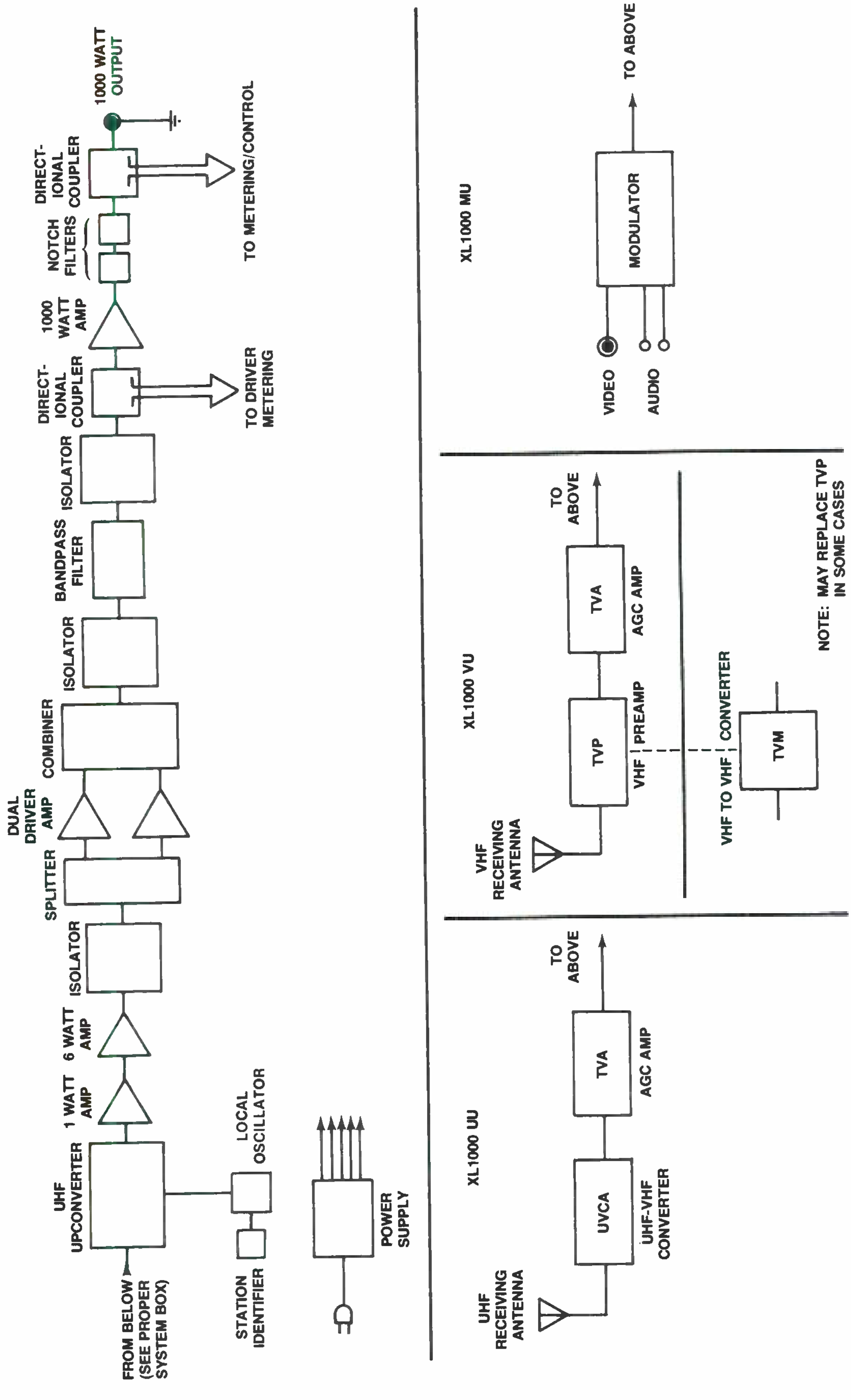

Fig. 1. Block diagram, television technology XL1000U LPTV Transmitter.

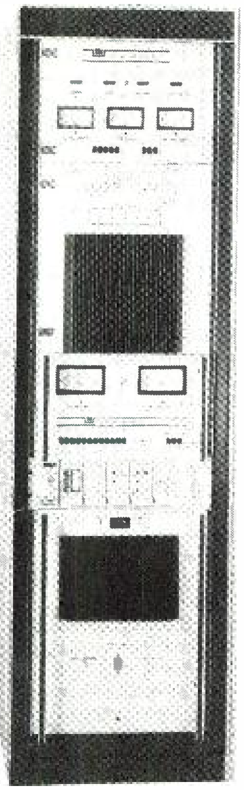

Fig. 2. Television technology XL1000MU LPTV transmitter.

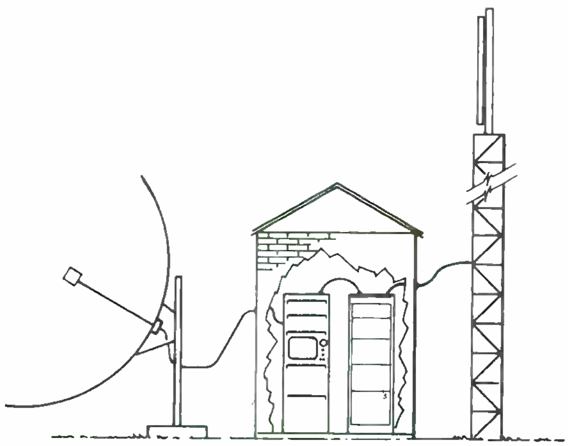

Fig. 3. Satellite fed only LPTV station.

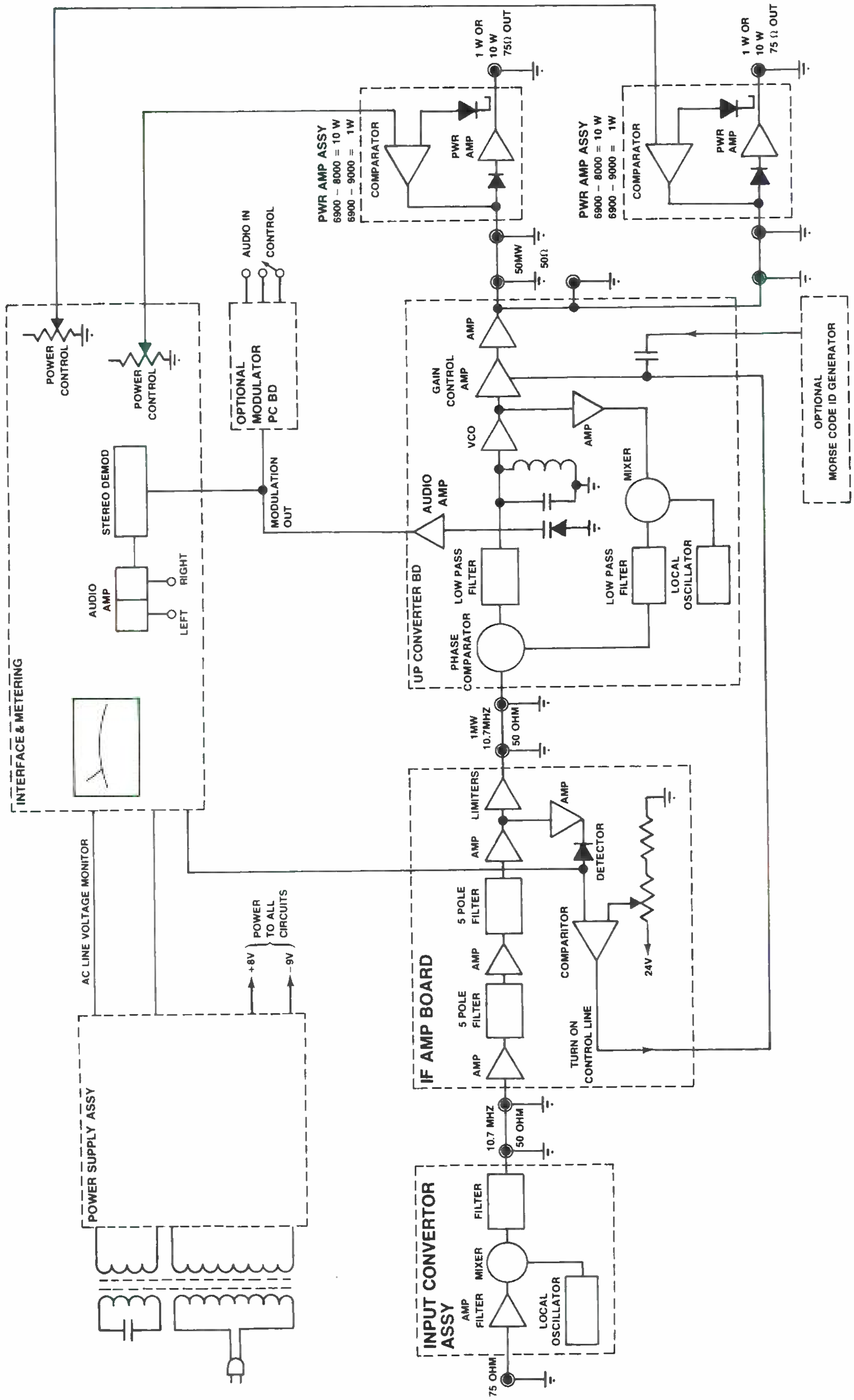

Fig. 4. Block diagram, TTC FM translator.

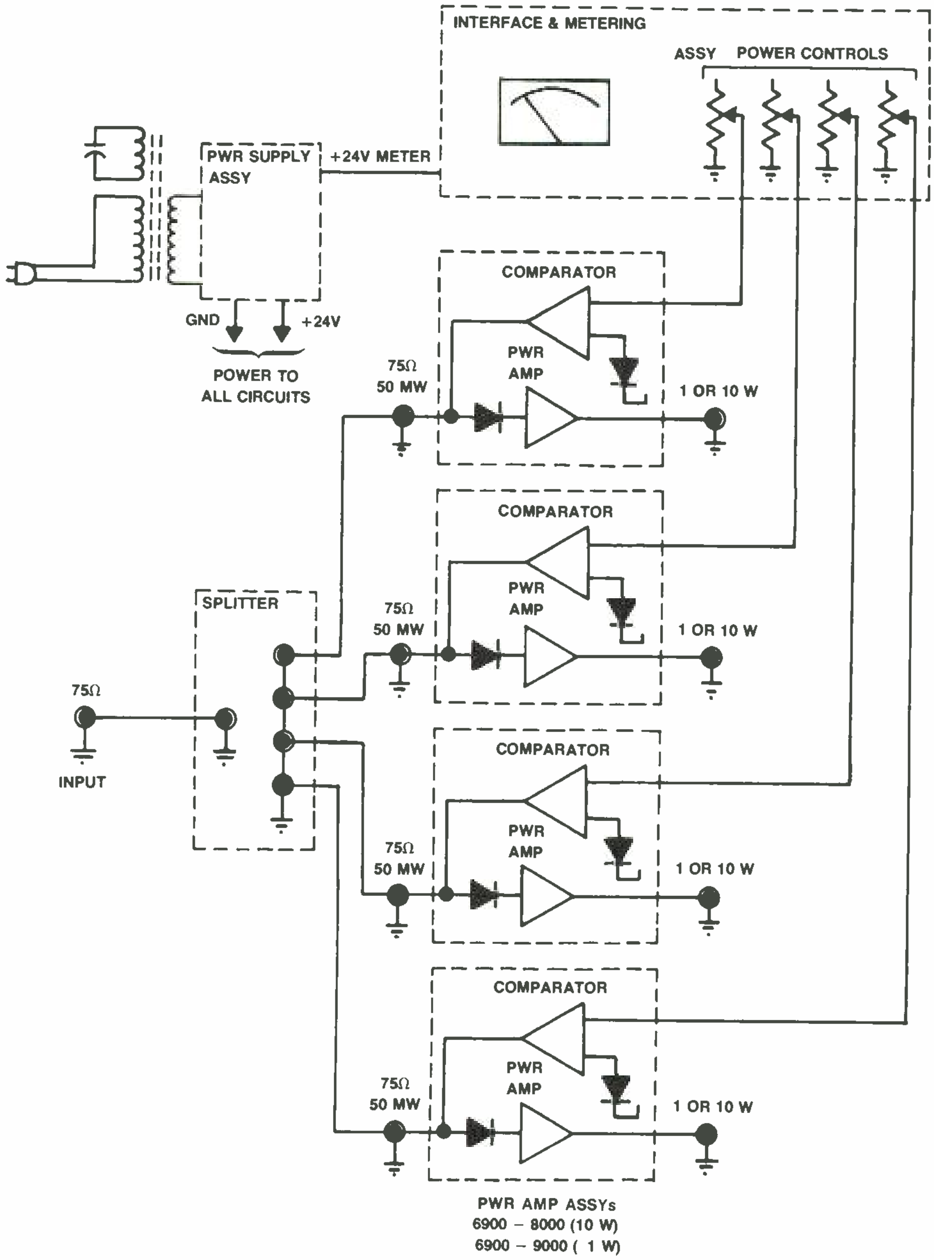

Fig. 5. Block diagram, TTC multiple output FM amplifier.

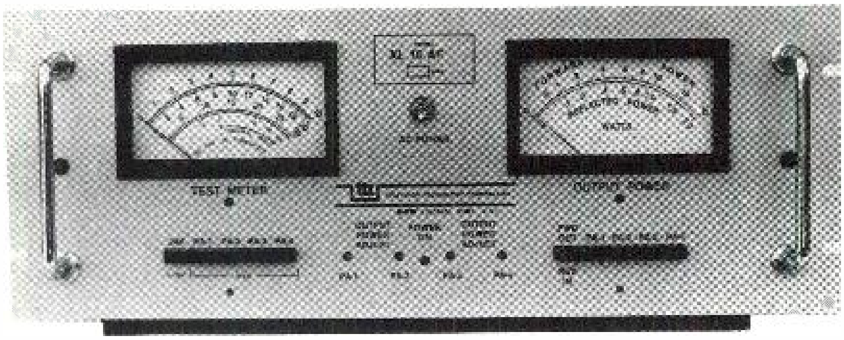

Fig. 6. TTC multiple output FM amplifier.

TABLE 1
Eligibility Requirements and Permissible Program Sources

	Translator	LPTV (Originate)	FM Translator
Who May Operate	Any Financially and Legally Qualified Individual, Group, Broadcast Station or Governmental Body		
What Station May Carry	Rebroadcast of TV Station, LPTV, or Microwave, Satellite, Translator Relay	Same as Translator Plus Local origination, Subscription TV	Full Power FM Except Any Owned by Licensee
Where	See Tables 2 and 3		

TV Regulatory Requirements

Parts 74.705 and 74.707, which outline detailed interference protection standards for LPTV and translator installations, are summarized in Table 2. After establishing a permissible site location, the predicted field strength based upon height above average terrain (HAAT) and effective radiated power (ERP) must not conflict with co-channel and certain other full service stations or existing LPTV stations. Unlike full power TV stations licensed under Part 73, HAAT for Part 74 installations is determined along a radial whose heading is in the direction of concern, rather than averaged over a full 360° circle of radials. Table 3 shows the required field strength ratios.

The restrictions reflected in Tables 2 and 3 apply to operating full-service stations but it is important to take into account the TV Table of Assignments in 73.606 to allow for future TV stations in making channel and site selections.

FM Regulatory Requirements

FM translators rebroadcasting a commercial FM station are authorized to operate on Class A channels, but a channel must be selected which will cause no interference to primary stations or other FM translators. If it is not possible to select a Class A channel and a class B or C channel seems suitable, it is necessary to include with the application a request for waiver of 74.1202 (b) (1) of the Rules. The request must include a detailed engineering showing that no Class A is available in the service area.

Noncommercial FM translators are authorized to operate on FM channels 201 through 220 from the Table of Assignments used by noncommercial FM stations.

FM on-channel boosters have also been used, but may only be licensed to the primary station whose signal the booster will retransmit *within* the station's 1 mV/m field strength contour. There are some severe engineering limitations which confine their use to very special situations. Multipath problems can occur in two ways with on-channel boosters. (1) Any location which will receive signals from both the originating station and the booster will exhibit multipath reception problems, and (2) if the output from the booster contaminates the input with the booster station's own signal, multipath deriving from multiple trips though the booster will degrade the signal.

The transmitted signal from a booster is typically 90 to 110 dB stronger than the desired input signal and if the feedback contamination is to be held to -30 dB as a limiting value, the isolation between receiving and transmitting antennas must be in the 120 to 140 dB range and the circuitry of the booster must be designed to preserve this isolation. Very substantial shielding

TABLE 2
Prohibited LPTV Transmitter Site Locations

PROPOSED LPTV IS:	REGULAR TV		EXISTING LPTV[c]	
	VHF	UHF	VHF	UHF
Co-channel or adjacent channel[a]	within Grade B[b]		within protected contour	
14 or 15 channels above	n/a	within Grade B	n/a	within protected contour
7 channels below	n/a	spaced less than 100 kilometers (62 miles)		
2, 3, 4 or 5 above or below	n/a	spaced less than 32 kilometers (20 miles)	n/a	no restriction

TABLE 3
Interference Protection — Field Strength Ratios

PROPOSED LPTV IS:	REGULAR TV		EXISTING LPTV	
	VHF (protected within Grade B contour)	UHF	VHF (within protected contour as defined)[c]	UHF
Co-channel	−45dB or −28dB with off-set (interference based on F (50,10) chart)			
	Note — all values below based on F (50, 50) chart			
lower adjacent	+ 6dB	+15dB	+ 6dB	+15dB
upper adjacent	+12dB	+15dB	+12dB	+15dB
7 channels below	n/a	n/a	n/a	0dB
14 channels above	n/a	+23dB	n/a	+23dB
15 channels above	n/a	+ 6dB	n/a	+ 6dB

[a]Channels 4 and 5, 6 and 7, and 13 and 14 are not adjacent.
[b]Protected contour is Grade B, defined by the following field strengths; CH 2-6, 47dBu; Ch 7-13, 56dBu; Ch 14-83, 64dBu.
[c]The protected contour for a LPTV station is defined as the following field strengths: Ch 2-6, 62dBu; Ch 7-13, 68dBu; Ch 14-83, 74dBu.
n/a: not applicable

of the receiving antenna by the terrain or a building is necessary and the booster must have detached input circuitry located near the receiving antenna. Additional techniques for achieving sufficient isolation include spacing the input and transmitting antennas at least 300 feet apart, antenna cross-polarization and locating the antennas in one another's null areas.

Generally, the interconnection between the receiving and transmitting halves of the booster will be at an intermediate frequency such as 10.7 MHz and a reference conversion frequency must also be carried between the sections so there is no frequency shift whatever between the input and the output in the process of making two conversions. Finally, the FCC is quite aware of all these problems, so any application for an FM on-channel booster must include a statement concerning the steps which have been taken to prevent signal degradation due to booster operation.

TRANSLATOR AND LPTV COVERAGE

Coverage of full service high power stations is usually determined statistically by the use of the FCC F(50, 50) curves for the appropriate TV channel or for the FM band. These curves are detailed in FCC Regulations section 73.699 for TV and 73.333 for FM. They may be used as a guide for LPTV or translator coverage but it is more desirable to make an estimate of the area to be covered using topographic maps to determine the areas which can be reached with a propagation path having at least 0.6 first Fresnel Zone clearance.

For a signal path whose origin is within about five miles of the translator site, ordinary rectangular graph paper may be used. At greater distances 4/3 earth radius paper should be used which takes into account the earth's curvature and the slight normal bending of radio waves in the earth's atmosphere. 4/3 graph paper is readily available from most translator or microwave equipment manufacturers as a promotional give-away item. Fig. 7 is an example of this paper.

An assumption must be made about the height of the listener's or viewer's receiving antenna. The FCC assumes 30 feet above ground to be a nominal receiving antenna height for purposes of the 50/50 tables; when dealing with the substantially lower power of LPTV and translator installations, however, a more conservative approach would be to assume the average receiving antenna to be located at 10 feet above ground.

The following formula is provided to locate 0.6 first Fresnel Zone clearance:

$$R = 2280\sqrt{\frac{d_1 d_2}{Fd}}$$

Where:

R = first Fresnel Zone in feet;

d is the distance from transmitter to receiver;

d_1 is the distance from transmitter to the significant obstacle in miles;

d_2 is the distance from the significant obstacle to the receiver in miles; and

F is the frequency in megahertz of the subject signal.

Clearance is then 0.6 R.

Once the clearance has been determined, add a little headroom to allow for trees, buildings, and other additions to the terrain. Depending on local circumstances, this amount may range from 25 to 60 feet.

The signal strength available to the most distant area of interest must be determined using the above approach and, taking into account the inverse square law which states that a signal will decrease in intensity by a factor of four for every doubling of distance. For example, a coverage rate increase of 3.16 is achieved with an effective radiated power increase of 10 (3.16 is the square root of 10). Such an increase in ERP can be achieved by increasing transmitter power or trans-

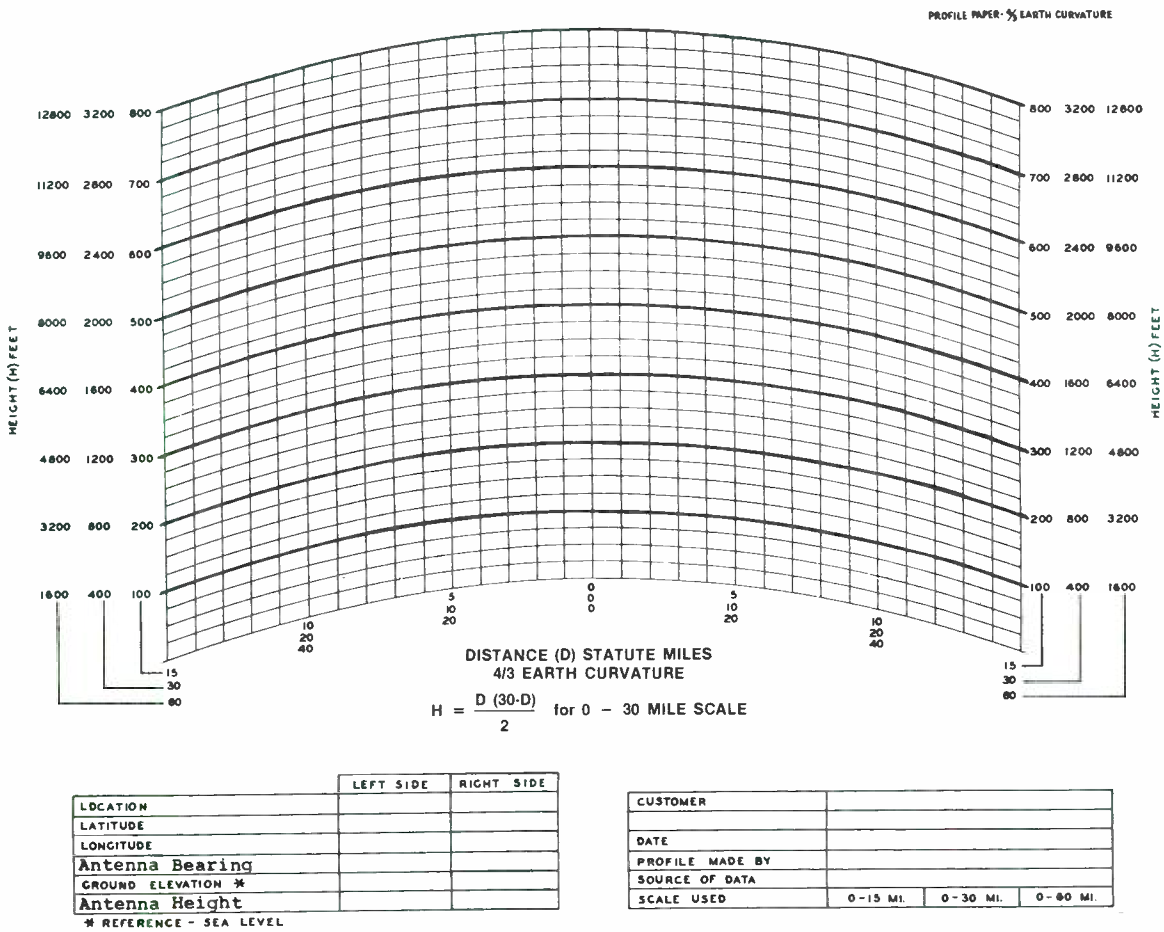

Fig. 7. 4/3 Earth profile chart.

TABLE 4
Free Space Path, Signal Reception Distance in Miles.

	VHF				UHF					
	10W Lowband Ch 2-6		10W Highband Ch 7-13		100W			1000W		
Horizontal Angle	**Omni 20W ERP**	**90° 80W ERP**	**Omni 40W ERP**	**90° 160W ERP**	**Omni 710W ERP**	**220° 1000W ERP**	**80° 2450W ERP**	**Omni 7100W ERP**	**220° 10000W ERP**	**80° 24500W ERP**
Rabbit ears or loop indoors	3	6	3.5	7	3	4	5.5	9.5	12.5	17
Small outdoor	12	24	10	21	9	11	16.5	28	35	52
Large outdoor	17	34	15	30	15	18	28	47	56	88
Large outdoor w/preamp	20	40	21	42	30	36	56	95	114	177

Low band in particular and to a lesser extent high band reception may be inhibited by man made noise and long distance co-channel interference.

Heavy foliage will reduce usable distance of UHF signal to about ¼ of above distance. Reception at distances in excess of 40 miles will frequently be limited by earth's curvature.

ERP (Effective Radiated Power) is typical practical value for transmitter power shown. Distances in this chart are based upon *distances* only and assume a "free space" propagation path exists to receiving antenna.

mitting antenna gain. Higher antenna gain is obtained at the expense of narrower beamwidth and increased tower and antenna costs. Thus, antenna gain usually becomes a compromise between the horizontal angle of coverage and the maximum distance required of the signal. High antenna gain through restricted vertical beamwidth requires an antenna array that is large in its vertical aspect. If it is many wavelengths high, it will be difficult to install and costly. Vertical beamwidths of two or three degrees are achievable—particularly at UHF—but such high gain antennas must be installed exactly perpendicular to the horizon within a tolerance of a small fraction of a degree, requiring very precise installation and a tower of sufficient rigidity to maintain the tolerance even in strong winds. Additionally, such high gain antennas often require beam tilt compromises or null fill for satisfactory reception close to the translator. The discussions in Section Two of this book on the subject of full power antennas are applicable to LPTV and translator installations except that the latter more commonly used directional antennas.

A frequent oversight in LPTV and translator planning has been the existence of feedline losses. The chapter on that subject will provide substantial understanding of the phenomenon and how it applies to various types of feedline. LPTV and translator installations, because they are often designed under severe budgetary restraints and operate at relatively low power, frequently use low cost and small diameter coaxial cables. The hardware savings in these cables are achieved at the cost of signal level. Transmitting antenna feedlines are generally low loss and are provided with detailed engineering data which allow the user to accurately calculate and allow for losses.

Not so complete or accurate, however, is the information which accompanies much of the small diameter 50 or 75 ohm receiving antenna cable used at the input of a translator. Two hundred feet of commonly used RG-59/U cable can cost up to 12 dB of signal at 200 MHz and become virtually useless at UHF. It is therefore important to carefully select the best cable possible for the application.

INPUT SIGNAL CONSIDERATIONS

The delivery of the input signal to the transmitter is an extremely important part of the overall system design, as the quality of that signal may be the limiting factor in the system's overall performance. Previously, the cable degradation of the input signal strength has been discussed but there are other factors which also become important. Virtually every conceivable method of input signal delivery can be found in use and each one has its unique problems and solutions.

All translators were originally confined by regulation to rebroadcasting signals received off the air from primary stations or other translators. Although 1983 saw these restrictions lifted for TV, FM translators are still so confined. Now TV translators may use any technically feasible arrangement. In addition to off the air reception, both AM and FM microwave and satellite fed signals are in common use. A few LPTV stations are fed directly from video tape recorders or by direct connection to an adjacent studio. Microwave, VCR and direct video/audio signal delivery require that a modulator be part of the transmitter; off the air signal delivery requires the use of reception circuitry with a heterodyne mixing system which converts the already modulated input signal to a new channel without demodulation.

Recently, there has been some demand for unattended switching systems that do not merely shut off the translator carrier in the absence of input signal, but rather select another available input signal, usually from a local modulator. This allows local origination in the event of failure of the normal supply signal.

VHF, FM and UHF off the air signals are commonly used in translators and sometimes require extraordinary measures to receive and retransmit cleanly. With respect to management of the input signal, the translator operator is faced with similar technical problems as the cable TV operator, for indeed, if satisfactory reception of the desired signal were easy to achieve, there would be no need for either service. The major problem faced by both is usually a weak signal with poor signal-to-noise ratio. This signal must be pried loose from the noise before it enters the transmitting system as the transmitter will send to the transmitting antenna whatever signal it is provided, noise and all. Thus, a well designed receiving antenna, preamplifier and signal conditioning system must be built into the receiving half of a translator.

Of these, the most important is the receiving antenna and its location. Location, height and cable length have already been discussed so this discussion is limited to the antenna array itself. Numerous techniques have been employed to maximize the performance of receiving antennas. If reliable and noise-free reception can be achieved with a single cut-to-channel yagi on a tower conveniently close to the translator, the operator is fortunate. More often, it will be necessary to increase the antenna gain or narrow the pattern beyond that achievable with such an arrangement.

Sometimes the approximate 30 degree horizontal pattern width of a single receiving antenna allows reception of an interfering signal from a different city. Techniques for solving translator reception problems include antenna-mounted preamplification, signal filtering, and several antenna stacking techniques, both horizontal and vertical.

Briefly, preamplification increases signal level, filtering minimizes out-of band products, stacking increases antenna gain and directivity, and can make positive use of the phase differences at varying angles from the supplying station's or an interfering station's transmitter or those found in certain reflected signals.

Preamplification

Tower-mounted preamplifiers are available from many manufacturers and commonly have gains varying from 10 dB to over 60 dB. Most are powered from a dc voltage impressed on the transmission line between the preamplifier and the translator, thus making use of the translator's available power. Translators not equipped with dc power diplexers for this purpose may ordinarily be so equipped upon inquiry to the manufacturer of the translator or the preamplifier. Preamplifiers are mounted as close to the antenna as possible because the received signal is subject to further losses and increased noise as it travels down the cable to the translator. This occurs due to cable capacitance, impedance variations arising from kinks, bends, and connectors, and losses resulting from line resistance.

Ideally, a well-selected preamplifier will have no effect on the received signal except to augment its amplitude sufficient to overcome all system and cable losses and render the signal useful. A preamplifier having 45 dB gain does not necessarily perform better than a unit whose gain is 20 dB. High-gain preamps are more prone to overload with increased signal input. Each preamplifier must be carefully selected to match the installation and its input signal requirements must not be exceeded. An overloaded input stage will produce a severely distorted signal that can never be "cleaned up" by any subsequent stage. Further, if a preamplifier sees at its input a poor signal-to-noise ratio, the same—or slightly worse—signal-to-noise ratio will show up at its output.

Filtering

This technique may be used in any of several ways. A translator's input amplifier is typically tuned to the frequency of use, providing substantial attenuation of out-of-band products. Particularly in early gain stages of translator equipment, tuning is not particularly sharp as increasing sharpness of input tuning tends to make this system noise figure rise. Individual cimcumstances may dictate that this phenomenon be accepted, thanks to a strong first or second adjacent signal which might either take a "free ride" into the translator or, more commonly, overload the input.

Bandpass filters or traps may be used at the input to the equipment or on the tower to solve special reception problems. A bandpass filter normally attenuates all but the desired signal and a trap is selected to attenuate a specific interfering signal. Use of either equipment is subject to the attendant increase in system noise figure because of their insertion losses, which may range from 0.5 to 6 dB.

Antenna Stacking

Properly used, this technique will deliver the cleanest signal to the translator. Antenna stacking can become critical and expensive for the same reasons that numerous transmitting antenna elements become so. See the section on translator and LPTV coverage earlier in this chapter for the discussion of that subject. The one major difference is that the supply signal comes from one point and thus reception from any but the exact desired direction is unwanted. Antennas may be stacked in the horizontal plane and in the vertical plane. Additionally, they may be offset to solve a particular reception problem.

Horizontal stacking: This technique is used to narrow the beamwidth from side to side of the array and to add 3 dB to the antenna gain for each doubling of the antenna stack if the antennas are connected together in phase. A single yagi antenna has a horizontal angle of acceptance that is about 30 degrees wide between the 3 dB down points off its front. Utilizing horizontal stacking, the horizontal beam width can be substantially reduced and specific off-axis signals can be greatly attenuated. This technique does not alter the vertical beam width of the array.

Vertical Stacking: This method affects the vertical beam width and is useful to enhance the gain of the array.

Stacking Variations: Normally used to solve particular reception and interference problems, antenna stacking may be varied in several ways. One of them is offset antenna arrangements, allowing phase reinforcement off the front of the array and phase cancellation off the rear of the array. Here is how it is done: Vertically stack the antennas, with one antenna forward of the other by exactly 1/4 wavelength at the center frequency of the channel to be rejected. That distance in inches is provided by the formula:

$$d(inches) = \frac{2951}{\text{Frequency of undesired signal (MHz)}}$$

Connect the rearmost antenna to the common junction with a short length of feedline, and connect the forward antenna to the common junction with a feedline whose length is the result of the above formula multiplied by the velocity of propagation of the cable used, plus the amount of cable used for the rear antenna. This is required because signals travel faster in free space than in cable. The velocity of propagation of a cable will normally be expressed in percent. Therefore, if 1/4 wavelength is 15.1 inches and the cable has a velocity of propagation of 68% and the rear antenna requires 8 inches of cable to arrive at the common connection, the forward antenna will require 68% of 15.1 plus 8, or 18.268 inches of cable running to the common connection. At the subject frequency this will cause the antennas to add when reception is off the front and cancel the signal received off the rear.

In another arrangement, the spacing from one antenna boom to the other can be set so that cancellation of an unwanted signal arriving from a particular forward direction can be achieved. The antennas are installed with the center of each spaced such that the undesired signal is out of phase at the connection between the two antennas, so that the interfering signals cancel one another at the combined output, while the desired station received along the aiming axis appear in phase.

TRANSMITTING SYSTEMS

The FCC technical standards for TV translator and LPTV transmitting systems are in Part 74.750 and those for FM translators are contained in 74.1250 of the FCC Rules. Although transmitting equipment and linear amplifiers such as

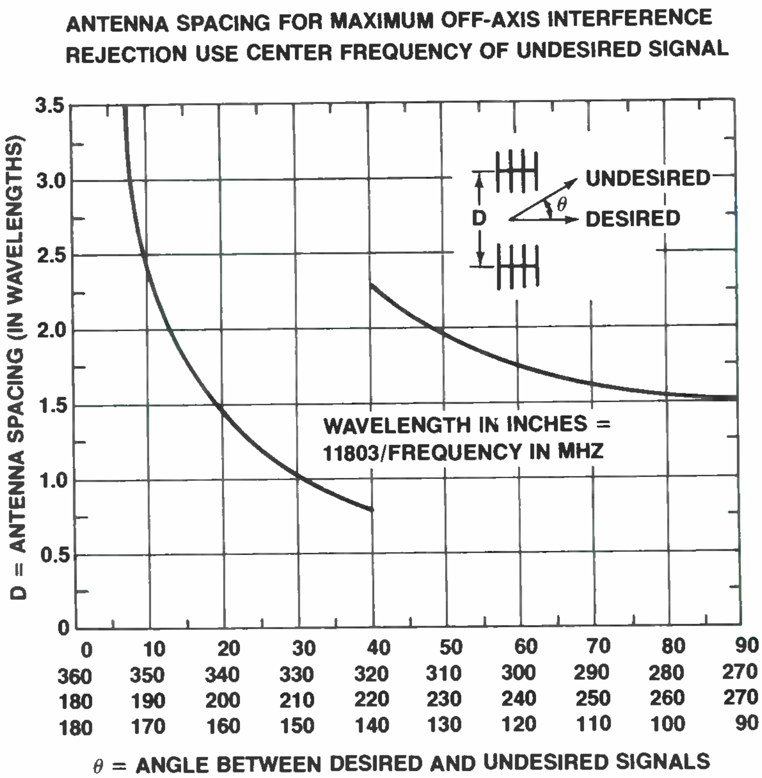

Fig. 8. Antenna spacing chart.

multiple output amplifiers must be type-accepted by the FCC, no such requirements exist for antennas or auxiliary equipment.

Antennas

With respect to transmitting antennas, there are several types available. For omnidirectional use at UHF, slot antennas have found wide use. The radiating elements of these antennas are "windows" in a metal tube, whose size is a function of the channel or channels used. Some of these antennas are broadband allowing the use of a single antenna for several diplexed transmitters. For omnidirectional FM use, low-power versions of the standard FM transmitting antennas are used and can be provided in horizontally and elliptically polarized models. Additionally, FM turnstile antennas are available. Directional antennas for all transmitting purposes within the translator and LPTV industry often resemble heavy-duty versions of their receiving counterparts. FM and VHF-TV antennas, commonly rated in power to 100 watts are often Yagi, log-periodic or folded dipoles with a single reflector and may be stacked to provide higher antenna gain. UHF directional antennas may take the form of dipole/reflector arrays resembling receiving antennas or may take the form of panel antennas. A panel antenna consists of a group of driven dipoles and matching electronics all mounted on a panel and covered by a radome. Virtually all transmitting and receiving antennas are available in 50 or 75 ohm models.

For a particular installation, the terrain studies covered earlier in this chapter will have already determined that the antenna selection will be a general type. By this time, the operator will know the necessary gain, height, and directivity pattern required of the installation. However, several other considerations peculiar to antennas will still be open to discussion. One of the most important is the relationship between the tower and the radiating elements.

Not only must the tower be capable of withstanding the wind loading presented by the antenna, it must not substantially alter the antenna's directivity pattern after installation. Mounting must be made to minimize the tower's electrical effect on antenna performance. In any antenna selection, the antenna and tower manufacturers selected must be consulted about all phases of these possible problem areas.

Transmission Lines

Cautions about the low-cost small diameter coaxial cable used in some receiving antenna installations or between components within equipment have been outlined earlier in this chapter and installation considerations are located toward the end of the chapter. Losses in this or any transmission cable must be taken into account when planning the installation. For LPTV and translator use, transmitting feedlines normally are available in two configurations.

Foam Dielectric:

This cable is flexible and does not require pressurization. It also exhibits comparatively high losses in use. Prolonged exposure to high temperatures have sometimes caused center conductors to migrate and exhibit subsequent variations of impedance along the cable. If its losses are acceptable within the limits set by the transmitting antenna gain and transmitter output power capabilities and it is installed carefully with no kinks or sharp bends, it may prove to be an economical alternative to air-dielectric transmission line.

Air Dielectric:

This transmission line is manufactured with a spiral-wound spacer along its length which holds the center conductor in position. It is much stiffer in use than foam cable and is thus more difficult to handle and install properly. Its diameter ranges in size from 1/2″ to 5″ but the most commonly used sizes in translator and LPTV applications are 7/8″ and 1-5/8″. By comparison to foam cable, losses are lower but it requires pressurization, usually supplied by a nitrogen bottle and regulator situated near the transmitter and connected to a pneumatic joint on a cable connector.

Towers

The tower supporting any broadcasting antenna is an extremely important item in the overall installation. Towers are costly, have great impact on the surrounding environment, and are potentially dangerous. The loss of a tower in an LPTV installation can cost more time off the air than the loss of virtually any other major component and can cause severe damage. Therefore, the initial cost of the best grade tower for the purpose will not equal the cost of two towers plus whatever other damage might be done in the event of failure.

The FCC may require with the application an environmental impact statement if erection of the tower is in certain areas or is 300 feet or more in height. Section 1.1305 of the FCC Rules is the source of the correct and current information. If an installation meets the test of a "major action" under this rule, the application may be subject to delays or rejection and a second choice tower location may be indicated. Additionally, the FAA has a great interest in radio and television towers. Part 17 of the FCC Rules deals with the subject of marking, lighting, and maintenance of antenna structures.

Standing Wave Ratio, Combiners, Isolators and Systems Considerations

The combination of installed feedline and antenna represent the load into which the transmitter will be expected to operate. In the ideal case, the system would represent a lossless system having a standing wave ratio of 1:1. In practicality, a completed antenna system installation will show a higher VSWR . . . typically, up to 1.4:1 upon initial measurement. If it runs higher than that, there may be some problem with the installation. Adverse moisture conditions and aging of the transmission line will usually make the VSWR rise over time; thus, it is most important to get it as low as possible during initial system installation. Particularly at UHF, isolators are frequently used to absorb reflections in the transmission system as well as to protect the transmitter.

The Television Technology XL1000U transmitter, diagrammed in Fig. 1, incorporates a circuit which turns the output power level of the unit down as VSWR rises, thus protecting the equipment and allowing the signal to remain on the air.

Translator installations, thanks to their normally unattended operation, are likely candidates for such protection as the VSWR is not monitored on a frequent basis. It is important that some form of protection, whether an isolator or a power reduction circuit, be used in unattended applications.

There are several other factors to be considered in the overall transmitting system. The combination of a transmitter and receiving elements on the same site implies some possible problems of signal feedback and noise. With most translator frequency selections, signal feedback does not cause the same "multiple trips through the equipment" problems inherent in FM boosters, but does cause an increase in system noise. Selection of an output channel widely spaced from the frequency of the input channel and physical separation of the receiving and transmitting antenna elements will improve this situation. If the assigned channels are close-spaced, the input tuning of the translator can, if necessary, be tuned more sharply and signal filters, as discussed previously, may be used.

Careful antenna placement is normally the best overall engineering approach to feedback reduction. Each antenna is normally provided with horizontal and vertical polar patterns which show the antenna's null areas. If the antennas are located within one another's null areas, the distance requirement between them may not be so great. Although the horizontal null areas are the most frequently considered, high gain antennas in particular also allow beneficial use of the vertical pattern of each antenna. If the antennas can be practically mounted at different heights so that they are in one another's horizontal and vertical null areas, a substantial amount of possible signal feedback will be reduced. Other techniques include shielding by means of natural topographical features or buildings.

System Noise—TV

The noise figure in the specifications of a translator can become an important factor in the overall system performance. In a properly installed system whose input signal is of sufficient level (usually 750–1,500 microvolts) and having a good S/N ratio, the translator will provide a clean and relatively noise-free signal to its viewers. There are, however many cases in which the signal is very weak or the noise level is high and noise becomes one of the most critical issues in an installation. In a multihop translator system, the signal to noise ratio deteriorates with each hop. If, in addition to that noise increase, the signal is weak, evaluations must be made of each component in the system.

To evaluate an overall planned translator system, some data and requirements must be known. Measurement of the available input signal, study of the manufacturer's translator equipment specifications, and knowledge of the FCC Rules together provide the fundamental information for system planning. The noise factor of a typical installed translator system is determined by the following equation:

$$F_{abc} = F_a + \frac{F_b\text{-}1}{G_a} + \frac{F_c\text{-}1}{G_aG_b} \qquad [1]$$

Where:

F_a = Antenna-mounted preamp noise factor
F_b = line noise factor
F_c = Translator (input amplifier) noise factor
G_a = Preamp gain
G_b = Line loss

To convert noise factor to noise figure (stated in dB), use:

Noise Figure (dB) = 10 $\log_{10}$ Noise Factor
To determine the noise power at the input, use:

$$\text{Noise} = kTB \qquad [2]$$

Where:

k = Boltzmann's constant ($= 1.38 \times 10^{-23}$ joules/Kelvin)
T = Temperature Kelvin (nominally 289.9 degrees in temperate zones)
B = Bandwidth in Hertz

Using the above formulas and information and knowing (1) the available signal level, (2) the noise figure/factor of the translator, and, (3) the required 55 dB S/N ratio at the translator's output, it should not be difficult to plan a properly designed translator installation.

FM Noise Considerations

The TV system noise information is partially applicable to FM translators. Noise not transmitted by the FM translator will normally be removed by the limiter in the listener's FM radio, assuming his received signal level is high enough to achieve full limiting action. FM receivers are typically about 10 dB more sensitive than TV receivers and the bandwidth of an FM channel is 200 kHz rather than the TV channel bandwidth of 6 MHz, so there is less opportunity for the intrusion of atmospheric noise.

A TYPICAL UHF TRANSLATOR

UHF Input

Fig. 9 is a block diagram of a basic UHF translator. A UHF signal at the input enters the UHF-VHF input converter module where it is amplified, and mixed down to a VHF channel. The converter has a UHF stripline filter at the input followed by a broadband UHF preamplifier. A double balanced mixer is employed to maximize dynamic range. The local oscillator is a crystal oscillator followed by two to three stages of multiplication, depending upon the frequency of use. The input converter has a gain of about 20 dB.

VHF Input

If the translator is a VHF input model, the signal enters a VHF preamplifier, which typically contains a two-pole bandpass filter followed by a two-stage broadband preamp. The gain of the VHF preamp is variable and is normally factory set for the specific application. With some VHF input frequencies, the VHF input channel is converted to another VHF channel by a converter module. This additional conversion is necessary as direct conversion of some input channels to the UHF output channel will result

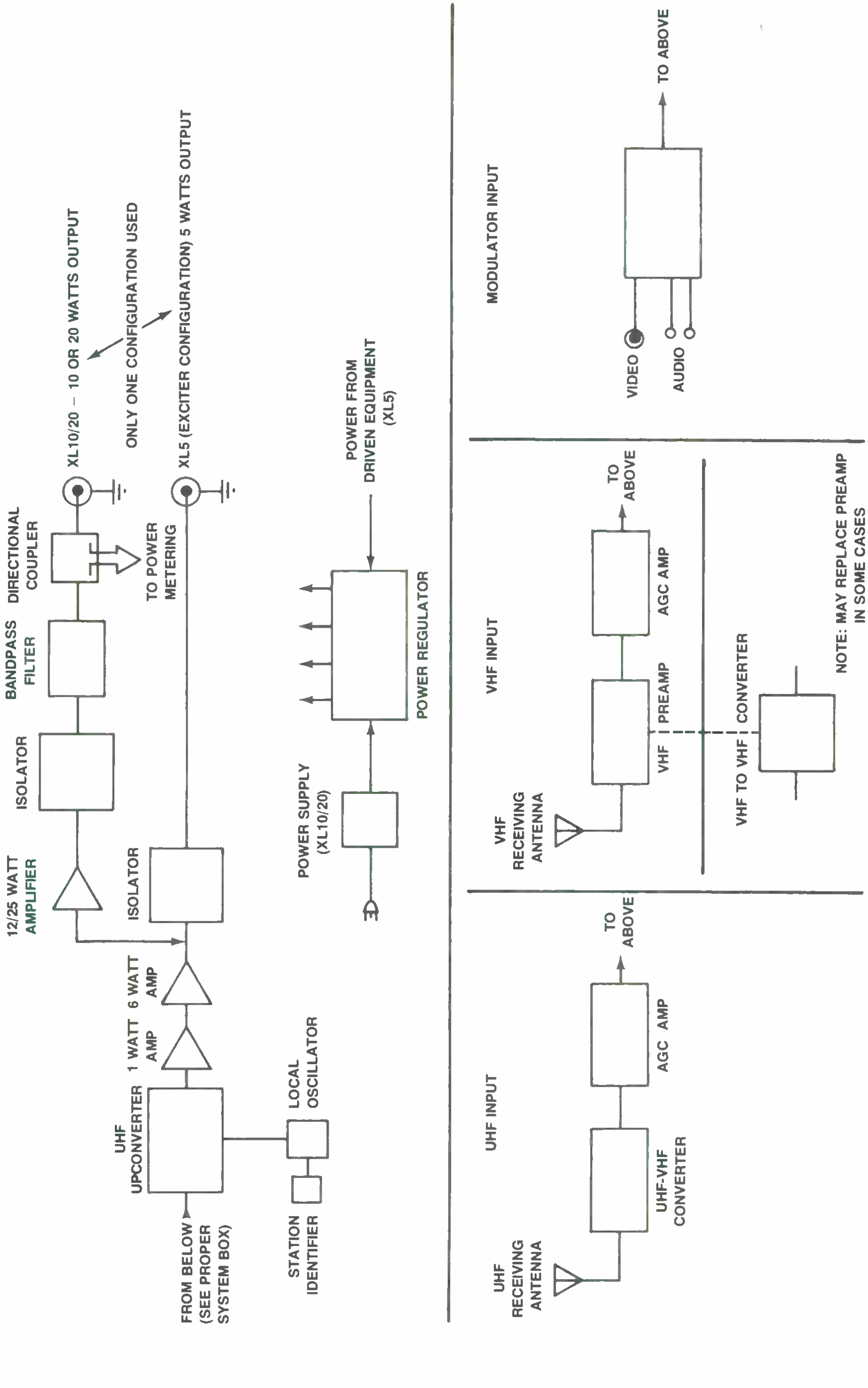

Fig. 9. TTC XL5-10-20U block diagram.

in spurious products that fall inside or close to the output frequency. This converter contains an input preamplifier feeding a double balanced mixer and post amplifier. The local oscillator is generated by a crystal oscillator feeding a multiplier stage (L.O. frequency times 1, 2 or 3). If the VHF input converter is required, it is set to have the same gain as the preamplifier it replaces, thus in either case leaving the balance of the translator identical.

From the input preamplifier or converter the input signal is fed to an AGC amplifier. This module contains most of the gain and filtering required in the translator and provides the necessary AGC. The unit illustrated contains two gain controlled stages separated by a four-pole bandpass filter. From the output of the second stage the signal travels through a variable aural trap circuit which can correct the visual/aural ratio if necessary. The trap is followed by a buffer amplifier. The output of the buffer stage is filtered by a two-pole filter before being amplified by a broadband high power hybrid amplifier. The output of the hybrid amplifier is tapped by a directional coupler before it appears at the AGC amplifier output. The sample of the output thus derived is detected and sent to processing circuitry which monitors both the visual and aural levels and sends corrective signals to the appropriate sections. The illustrated AGC amplifier has a maximum gain of 60 dB and its output level is set to 1.2 volts.

LPTV Application

If the equipment is an LPTV transmitter, the preceding modules are, of course not used. Instead, the RF output from the modulator is fed directly to the UHF upconverter.

The Mixing Process

The output of the translator's AGC amplifier or the transmitter's modulator is connected to a UHF upconverter module, or mixer. This module converts the VHF channel at its input to the assigned UHF output channel. To do this, it requires a local oscillator signal developed, in this instance, by a separate local oscillator module. The mixer's VHF input signal first goes through a variable attenuator after entering the UHF upconverter. This attenuator uses PIN diodes and is controlled by the power output control on the front panel. From the PIN attenuator, the signal is upconverted by a balanced mixer, then amplified to an approximate 50–100 mW level by a two-stage amplifier. The maximum overall gain of the upconverter is more than 12 dB. It requires a nominal 50 mW of drive from the local oscillator.

The local oscillator develops the necessary signal with a synthesizer which uses an 8 MHz crystal oscillator as its reference, followed by a two stage buffer-amplifier between the synthesizer and the output to obtain 50 mW for the upconverter.

Amplifier Stages

The output of the mixer is amplified by a one watt power amplifier which, in this instance, is biased for class A operation and typically has 9 dB gain. The output of this amplifier is between 1/2 and 1 watt depending on the output power required of the translator. The output of the one watt amplifier is supplied to the 5 watt amplifier, which is a Class AB amplifier having a gain of about 7.5 dB. The output of this amplifier enters the final amplifier module. This module is either a 12 watt or a 25 watt amplifier, depending on the output required of the translator. Class A amplifiers have higher power requirements as there is constant output current flow. These three amplifiers run off a 24 volt supply separate from the rest of the translator. This supply, called the 24 volt PA, is switched on from the "turn on" circuitry on the metering interface board.

Output Circuitry

The output of the final amplifier passes through an isolator followed by a bandpass filter before appearing at the output connector. The filter attenuates the intercarrier beat products and any spurious products occurring at the output of the upconverter. The isolator allows the final amplifier to see a constant 50 ohm load regardless of output VSWR or filter tuning. A directional coupler at the output connector monitors both the forward and reverse power and its tap outputs run to the power metering board, which contains the detectors and metering circuitry to measure forward, reverse and aural power. It also contains a splitter that routes a portion of the forward power to a front panel connector for connection of external equipment.

Additional Features

The metering and interface board contains all the metering for the modules within the translator. With the exception of the three UHF output modules, all the subassemblies within the translator plug into this board.

The board also contains a video presence detector that monitors a detected video output of the AGC amplifier and turns on and off the power supply which powers the amplifiers and meets FCC requirements for automatic unattended power shutdown.

There is an automatic Morse code keyer for station identification required on some installations. This keyer is adjustable to several time cycles and programmable to provide automatic frequency shifts to the local oscillator's output frequency.

LPTV Transmitter and Translator Specifications

These products are required to be type accepted by the FCC before they are sold. The Commission's "Radio Equipment List" is a published directory of such equipment. If there is a question regarding type acceptance, the manufacturer can provide the FCC file number of any piece of his type accepted equipment. Many of the specifications of LPTV transmitters and translators are self explanatory, but there are a few which justify explanation here. More detailed explanations of transmission standards can be found earlier in the *Handbook*.

Linear waveform distortion, often listed in specification sheets as "2T K" factor, is a measure of distortion of a picture's fine detail. The 2T sine-squared pulse and the 2T bar are used to define the K factor, which is the actual distortion. LPTV standards are met when the K factor is less than 3%.

Differential gain is the variation in gain of the translator of LPTV system for a small, high frequency signal (chrominance) at two specified levels of a low frequency signal (luminance) upon which the high frequency signal is superimposed. At an average picture level ranging from 10% to 90% the differential gain must not exceed 10%.

Differential phase is the variation in output phase of a signal like that used in differential gain measurements. It should not exceed 7 degrees over the range of blanking to white.

Envelope Delay is the delay within the system of the modulation envelope. It is typically a function of frequency, with higher frequencies having shorter delays. For transmitters, the standard is built on a baseline of the delay within the equipment found between .05 and .2 MHz. Up to 3 MHz that delay is to be maintained. Beyond 3 MHz the delay is to linearly decrease up to 4.18 MHz so that the delay is -170 nanoseconds with respect to the baseline at 3.58 MHz.

For translators, envelope delay should be flat. That is, the translator should not alter the delay relationships of the incoming signal.

TRANSLATOR/LPTV INSTALLATION CONSIDERATIONS

There are several considerations regarding the installation of an LPTV system. The instruction manual accompanying the transmitter or translator should be followed carefully. The requirements for the equipment's safe installation and operation are generally covered within the manual. Some of the more important considerations are discussed below.

Power

Although small transmitters often come equipped with power cords and plugs, the ac input of larger models should be hard-wired. Larger models may require three phase power. Three-phase transmitters are not to be connected to open delta primary power. Such a supply is subject to voltage fluctuations which could damage the equipment.

Special consideration should be given to lightning protection of all systems in view of the vulnerability of most translator or transmitter sites to lightning. Lightning arrestors should be installed in the service entrance. Ground runs of all types should be straight and short, and the electrical service itself well-grounded. For further information on lightning protection, see that chapter in Section 2.

Power circuits within a shelter should be branched. Each translator or transmitter is best connected to its own circuit breaker so a failure in one does not shut off the whole mountaintop. Breakers should be thermal type, capable for handling an inrush current of up to 1650 Amps for 1,000 watt translators. An ample supply of separately protected outlets should be available at the workbench and anywhere test equipment or tools may be needed.

About the Shelter

The quality of the shelter is of great importance for long life, serviceability and accessibility of the transmitter. The building must be kept dry, temperature controlled, clean and secure. The floor space should allow adequate space for each item of equipment, arranged so that all equipment doors can be opened and test equipment moved about. Space for tools, ladders, storage, emergency equipment, first-aid kit, and other required items must be planned.

The shelter should be well-roofed with good material. The cooling load will be lowered with reflective or light-colored roofing material. A sloping roof will tend to develop leaks less rapidly.

Buildings adjacent to towers in locations where icing occurs should be protected or have sufficient roof strength to prevent damage from falling ice.

Many small translators and transmitters are designed to be cooled convectively. This method

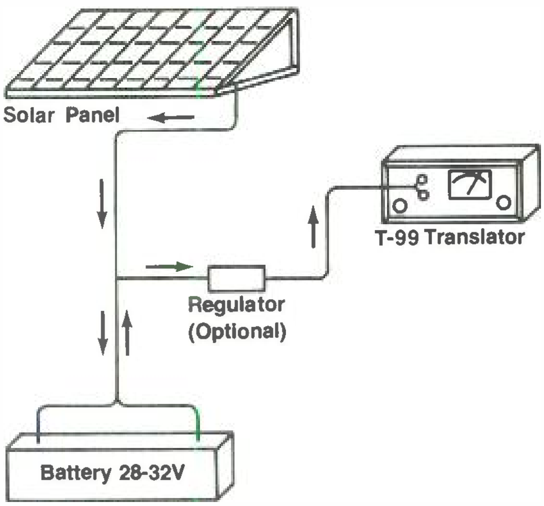

Fig. 10. Solar powered translator—power diagram.

requires substantially less attention to the maintenance of the translator. Convective cooling merely requires that the unit be free of any obstructions to the convection, which generally means that the surfaces and heat sinks of the unit be clear of any extraneous material and that there be some space between the unit and other heat producing units. Additionally, the ambient air temperature must be maintained at a level tolerable to the equipment.

In translators over 100 watts a cooling fan is usually employed. If so, access to the inlet and outlet from the unit's internal airflow must not be restricted. Again, the ambient air temperature must be maintained at a tolerable level.

In both cases, the manufacturer's instructions must be followed for adequate life from the equipment and the building must be temperature controlled if the temperature rise in the building cannot be controlled convectively or through ventilation. The building air intake should be filtered and must have capacity for all airflow in the building plus about 20%. A 1,000 watt transmitter internally exchanges approximately 350 cubic feet of air per minute. Building air intake should be below the roof and away from exhaust to avoid preheated air, but the intake and exhaust must be on the same side of the building to avoid the pressure differential that occurs during windy conditions.

In the event the outside temperature often runs over 90 degrees Fahrenheit, air conditioning may well be required. If so, discuss the situation with a qualified HVAC technician. The sun's heat load requires one ton—or 12,000 BTUs—to cool about 500 empty square feet to a comfortable level. For transmitter buildings, add all the electrical power figures used by all equipment in normal operation and subtract the total combined RF output power. Multiply this number by 3.4 to find the necessary additional BTUs required for the equipment load.

Security

The FCC requires that the transmitter be secure from entry or control by unauthorized persons, and that any hazardous voltages or other dangers (including many tower bases) be protected with fences as necessary to protect personnel and prevent unauthorized operation or tampering. Additionally, the building should be secure from the local wildlife. Other aspects of security for a translator shelter may include its location with respect to the prevailing wind, weather and erosion conditions.

Emergency Situations and Fire Protection

Weather changes, transportation failures or injuries may require an operator to extend his stay at a remote translator site. Prudence indicates the site be equipped with basic survival items to include food, water and related items. Fire is a possibility with unattended operating electrical equipment. If the site is sufficiently extensive as to require automatic fire protection, Halon or CO_2 systems will not destroy equipment as will traditional dry chemical "ABC"-type fire extinguishers, which contain ammonium chloride and will corrode electronic equipment after their use.

Power For the Translator

Power lines in rural areas are subject to interruption and voltage variation to a greater degree than in urban areas. With regard to variations, line regulating transformers are available in all sizes to accommodate transmitting equipment. If the variations are wide, component aging will increase and there will be a point at which the cost curves of protective transformers and of parts replacement will intersect. It is not unwise to so protect the installation.

Automatic utility load control is becoming more commonplace in rural electric power distribution. Such load control allows the utility company to turn off sections of the power distribution grid which may supply power to high capacity pumps or heavy loads. If the translator is connected informally to power available nearby in a farm field, the utility company may unknowingly take it off the air.

Alternate Power Sources

Small translators have often been powered by banks of solar cells. The equipment in such installations is often modified to minimize power requirements. When this is done, metering functions are reduced or made temporarily connectable, pilot lamps are removed, and accessory features may be disconnected. These changes in the equipment must not interfere with its being operated in accordance with the regulations, but are helpful in preserving storage cell life and output power. A solar powered translator is diagrammed in Fig. 10.

Solar power is of varying practicality with location. Particularly in northern areas of the United States, the wintertime output of solar panels may be reduced below a useful level because of the lower angle of the sun. Areas with protracted periods of cloudiness or precipitation may allow discharge of the storage batteries before the solar panels can recharge them. Additionally in solar-powered installations, storage batteries must be kept well-charged to prevent freezing damage. Location limitations of this sort also affect wind generator powered systems. Many areas of the world are subject to almost constant prevailing winds which make the idea of wind generators attractive. The high plains in the central United States is one such area. Conversely, there are many protected areas which do not lend themselves to practical use of wind generators.

Gasoline powered engine driven generators have occasionally been used in translator installations. Their most common application is in the 300 to 3,000 watt range; they require substantial amounts of fuel for extended operation and are not maintenance free. Models are available for gasoline, diesel fuel and propane.

Another type of power supply used occasionally is the thermoelectric generator. These units are most practically applicable to requirements in the 10 to 300 watt range. They provide dc, usually at 12 to 48 volts and catalytically burn propane, butane or natural gas at a low temperature during operation. Their operation is based on the principle that there is electron flow between two dissimilar metals bonded together when one of the metals is heated. They are relatively maintenance free but require about 500 pounds of propane or butane fuel per hundred watts output per month during continuous operation.

PROGRESS INTO THE FUTURE

Stereo TV

Developments in full power television have had their impact on LPTV and translator technology. LPTV stations which originate programming are now confronted with multichannel sound and stereo television. In March, 1984, the FCC adopted a policy on the subject of subcarriers in the aural baseband. The policy does not require a single standard but does require protection of

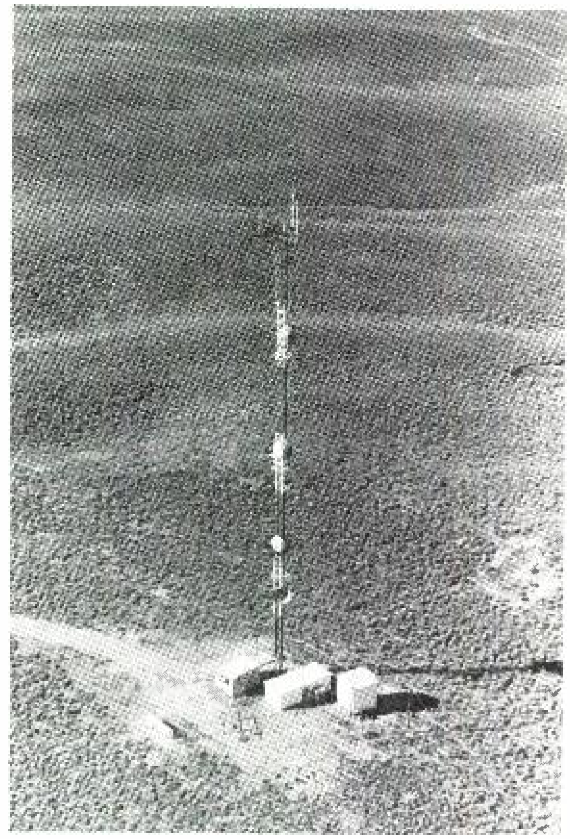

Fig. 11. Translator installation, Colorado.

the system which was recommended by the Broadcast Television Systems Committee of the EIA. The FCC requires protection of the BTSC pilot frequency of 15,734 Hz unless the station is transmitting with that system. Therefore, other systems may be used which do not interfere with BTSC system use. As most LPTV transmitters are internally diplexed, all additional signal components—whether stereo or independent subcarrier—will be within the passband of the transmitter. The aural section of the modulator will, however, have to accomodate a wider baseband and be capable of deviation up to ±73 kHz. Objectionable incidental phase modulation of the additional information by the video sync pulses may occur in transmitters not specifically designed for this more demanding requirement.

SAW Filters

A technology dating back to 1966, Surface Acoustic Wave (SAW) filters are now enjoying increasing use in the LPTV industry. This is expected to grow as their manufacturing cost is now dropping sharply. Computer-driven planar processing techniques used on the ST quartz substrate normally used for filters in the TV range have assured manufacturing repeatability and decreasing costs. For the bandwidth requirements of television broadcasting, SAW filters more closely approximate the ideal rectangular model filter than other designs. Quartz versions of this filter, in particular, have insertion losses averaging around 20 dB and often require buffer amplifiers on either end of the filter. Phase shift within these filters ranges from 2 to 6 degrees.

Offset Operation

As the number of LPTV and translator stations grows, so does the problem of interference. Offset operation has been employed to allow this growth while minimizing the attendant interference by allowing or even requiring a new LPTV applicant to operate at the particular channel with a frequency assignment offset of +10 kHz or −10 kHz from the channel's normal visual and aural carrier frequencies.

The benefit thus achieved is that a new station's signal, when offset, need only be 28 dB below the existing co-channel station's at the existing station's protected contour rather than −45 dB if the offset were not employed. This allows the LPTV applicant a 17 dB benefit when using this approach. The price of this approach is much tighter frequency control. Stations licensed without offset are required to maintain their frequency tolerance to within .02% of the assigned frequency if up to 100 watts and .002% if a transmitter of over 100 watts is used. With offset operation, the station carrier frequency must be maintained to within 1,000 Hz of the carrier frequency regardless of the channel frequency. In a translator so licensed, this is maintained by an AFC system which will hold the output within 1 kHz despite variations in the incoming frequency. In all cases, the relationship between visual and aural carrier frequency remains the same at 4.5 MHz ±1 kHz.

Therefore, to a station licensed at UHF channel 49 (visual carrier 681.25 MHz) operation at 100 watts or less means frequency variation of 136.25 kHz is allowable; operation over 100 watts requires maintenance of a ±13.625 kHz variation but offset operation at any power requires maintenance of the carrier frequency within 1 kHz. Thus, the equipment for offset operation is slightly more expensive, but allows licensing of stations otherwise not possible. Its inclusion in a look at LPTV's future is due to the increasing necessity for its use.

7.5

Instructional Television Fixed Service (ITFS) and Multipoint Distribution Service (MDS)

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INTRODUCTION

Instructional Television Fixed Service (ITFS) and Multipoint Distribution Service (MDS) are television transmission systems authorized by the FCC. ITFS was first authorized in 1963 for educational television. Use of ITFS has grown slowly but steadily and to date there are approximately 250 operating channels. MDS is relatively new. It was first proposed as a two channel service in the early 1970's. It is a "common carrier" service and has been used primarily for the distribution of "pay television" programming. Recently the FCC approved a multiple channel version of this service known as Multi-channel MDS (MMDS), allocating it two groups of four channels of the ITFS band. Additionally, the FCC authorized ITFS licensees to lease excess capacity to operators providing service similar to MMDS.

The technical characteristics of these two services are similar to each other and to broadcast television transmission. In the FCC Rules and Regulations, ITFS is defined in Part 74, Subpart I and MDS is defined in Part 21, Subpart K. The ITFS service originally occupied the 2.5 to 2.686 GHz band. MDS occupied 2.150 to 2.160 GHz, which was later extended to 2.162 GHz. The ITFS band was divided into 32 6 MHz channels and further divided into 8 groups of 4 alternately spaced channels. These 8 groups were identified as A through H. ITFS operators were permitted to operate on an entire group of four channels. The highest frequency channel, H4, was reserved for voice and/or data response communication. Subsequently, H1 through H3 were assigned to Operational Fixed Service (OFS) for the distribution of closed circuit programming.

The original MDS band was divided into 3 channels: Channel 1, which covered 2.150 to 2.156 GHz; Channel 2A, which covered 2.156 through 2.160 GHz; and Channel 2 which covered 2.156 through 2.162 GHz. Channel 2 was assigned only to the top 50 markets. Channel 2A was permitted to handle narrow band television without an aural carrier or other restricted bandwidth transmissions.

In 1983 the FCC allocated E and F groups of the ITFS band to MDS. The FCC is currently considering proposals for the technical standards of this new service and is expected to begin processing applications for construction permits in the near future.

TECHNICAL SYSTEM CONSIDERATIONS

RF System

Currently ITFS and MDS utilize transmitter output powers of 100 W or less per Channel, resulting in relatively low field intensities compared to full service broadcast. Additionally, the use of frequencies above 2,000 MHz requires greater consideration of signal path clearances. These factors tend to make these services primarily dependent upon radio line-of-sight coverage. This imposes upon the receiving system a requirement to have a reasonably high gain antenna and a low noise figure downconverter. The downconverters normally heterodyne convert a block of the ITFS/MDS band to a VHF frequency band, often utilizing standard television channels such as 7, 9, 11 and 13. Paths from transmitter sites to receive sites are often partially obstructed by trees, buildings and terrain. In those cases, received levels cannot easily be predicted without considering the index of refraction, the reflectivity of obstructing surfaces and the amount of defraction occurring near the receive site.

Additional problems the RF System faces are adjacent and co-channel interference. With the ITFS/MDS spectrum becoming more crowded, there is an increasing probability of interference. Adjacent channel systems are being planned in numerous cities, and several field tests of alternately polarized adjacent channel systems, have already taken place. Co-channel interference has been a problem in several Channel 1 MDS systems. It is expected that ITFS will experience this problem to a significant degree as that band becomes more occupied. General engineering principals applicable to VHF and UHF broadcast will often be beneficial to the resolution of these problems. In adjacent channel systems, the suppression of out-of-band products is vital. Older transmission systems often exhibit high degrees of lower side band re-insertion and out-of-band product generation. The use of wave guide filters and externally diplexed linear transmitters can effectively reduce these products to a level that allows operation with undesired adjacent channel levels comparable to the desired channel level. The technology of offset frequency operation can be employed with moderately high levels of co-channel interference. Utilization of this technology will require careful co-ordination of channel offsets and modification of existing transmitters. Frequency control will be more difficult in these services than in standard television broadcast because the percentage frequency error allowed will be smaller at the 2 to 3 GHz range than it was in the VHF and UHF bands.

The area of best signal coverage will be in the range known as radio line-of-site. This extends beyond visible line-of-sight because of the refraction of electromagnetic waves in the atmosphere. On the average, this produces a signal path range that can be approximated by using a profile of the earth with an increased radius, usually 1⅓ times the true radius. See Fig. 1 for a typical ⁴⁄₃ earth profile chart.

To avoid diffraction loss due to path obstructions, a path clearance of 0.6 Fresnel Zone is desirable. To determine the Fresnel clearance on a particular path, the following formula can be used:

$$R = ((\text{wavelength} \times d_1 \times d_2)/(d_1 + d_2))^{1/2}$$

4/3 RADIUS EARTH PROFILE

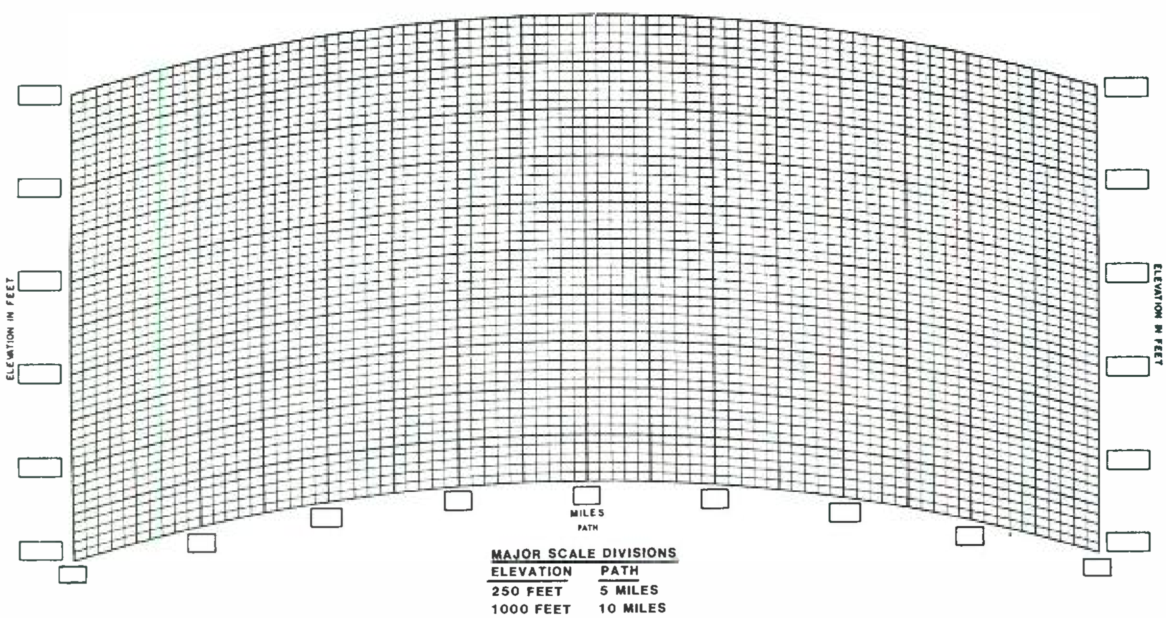

Fig. 1. Path profile chart.

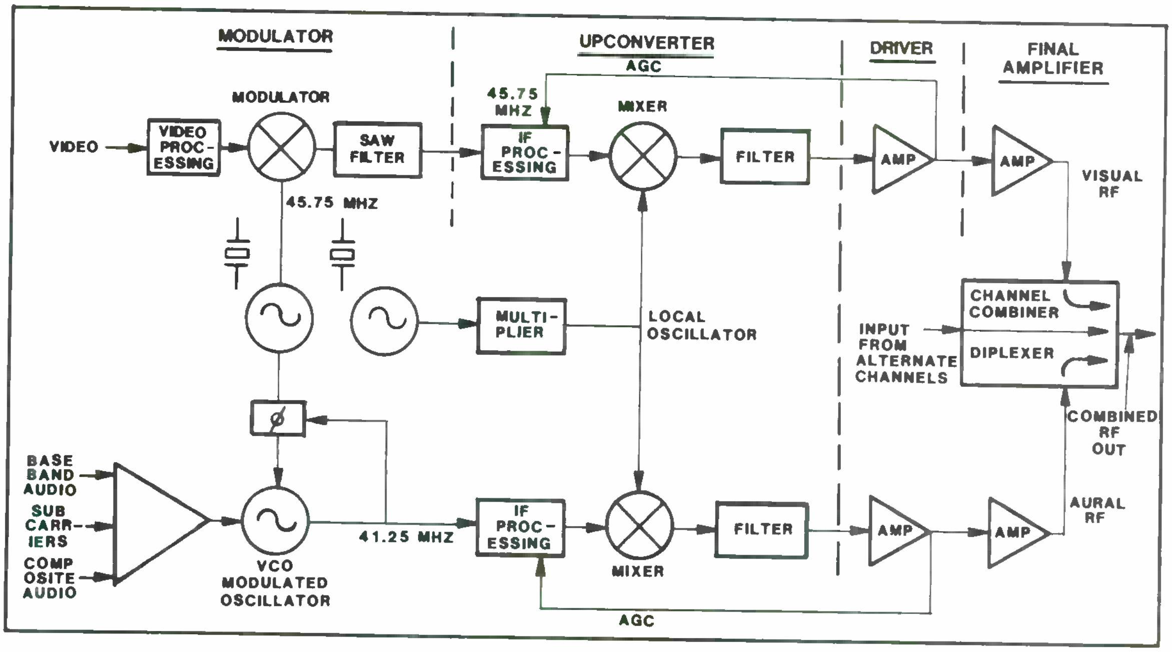

Fig. 2. ITFS/MDS transmitter block diagram.

Where:

d_1 = the distance from the transmitter to the obstruction

d_2 = the distance from the obstruction to the receiver

To determine signal levels in the diffraction region, refer to diffraction loss curves such as those found in *Bell Systems Journal*, Volume XXXVI, No. 3. Path clearances in excess of 1.3 Fresnel Zones can result in multipath propagation, producing nulls in received levels and/or picture ghosts in received pictures. Often it is possible to minimize these problems by moving the receiving antenna slightly to avoid such reflections. Receive levels can also be significantly affected by seasonal foliage, which should be considered in antenna installations.

Transmitters

Transmitters for ITFS and MDS have generally been rated at 10 watts to 100 watts visual power, with 10% aural capability. In the last few years the 10 watt transmitter has become fully transistorized. Amplifiers using triode vacuum tubes are available to reach 50 to 100 watts in both the 2.160 and 2.600 GHz bands. The aural output stages of these transmitters are solid state and operate with up to 10 watts of output power.

Both internally and externally diplexed transmitters are in widespread use. In uncongested areas where adjacent channel difficulties are not likely to occur, low level internally diplexed systems offer a high degree of simplicity and economy. Modern linear amplifier design, coupled with amplitude and phase pre-correction techniques, provides high quality signal performance. In repeater service this avoids the need to perform de-modulation and re-modulation. Externally diplexed transmitters offer higher rejection of products caused by the intermodulation of visual and aural carriers. An additional benefit of externally diplexed systems is the reduction of cross-modulation of video sync components onto the aural carrier. With the advent of multichannel sound and pay television encoding and decoding, aural carrier signal integrity can become an important factor in system performance. One disadvantage of a high level diplexed system is that it can introduce video frequency response errors, group delay variations, and aural bandwith reduction. In lower power ITFS transmitters, the diplexer can be a simple hybrid coupler. Notch diplexers are universally used in higher power versions of the transmitters to avoid the loss incurred in hybrid couplers. Refer to the block diagram (Fig. 2) for the following description of the functions incorporated in a typical ITFS/MDS transmitter.

Transmitters are typically built as combinations of functional trays. These trays, usually 19-inch rack-mount assemblies can be installed in cabinets supplied by the manufacturer or can go directly into the user's cabinet. The trays normally separate the video modulation, upconversion, and amplification functions into separate trays. This provides ease of alignment and shielding through physical separation. The following describes a tray layout for a typical 10 Watt ITFS/MDS transmitter.

Input baseband video and audio are sent to the modulator tray. This tray performs video and audio signal processing and the basic function of modulation. The video signal is back-porch clamped, and group delay pre-corrected. It then modulates a 45.75 MHz crystal oscillator signal to form the double sideband amplitude modulated television waveform. This IF signal is then vestigial sideband filtered in a surface accoustic wave device (SAW) to produce a precise frequency response.

The audio circuitry allows for three different types of inputs: a 600 ohm balanced standard audio base band program channel; a 75 ohm composite audio system comprised of L+R base band, L−R stereo, and second audio program (SAP) input; and a separate 75 ohm high frequency subcarrier input for data or voice communication purposes.

These signals are mixed and used to modulate a wideband aural voltage controlled oscillator (VCO), operating directly at the intermediate frequency of 41.25 MHz. This modulator has wide deviation capability and low harmonic distortion, allowing multi-channel sound operation. The center frequency of this modulated oscillator is phase locked to the 45.75 MHz IF visual oscillator. These two modulated signals are buffered and sent to the upconverter trays for further processing and heterodyne frequency conversion.

The visual upconverter tray provides Automatic Level Control (ALC) of the IF signal (including motorized remote control interface), IF linearity correction, and ICPM correction before upconversion. Additionally, it includes Automatic Gain Control (AGC) from the output of the correctors to the output of a higher power 2GHz RF amplifier stage. This feature insures that gain of the system from the correctors to the RF amplifier stages is held constant, so that the pre-set amounts of amplitude and phase pre-correction remain as correct values under conditions of temperature change. The amplitude pre-correction circuitry provides for correction of differential gain and sync compression occurring in the last amplifier stage in the system. Since the circuit is adjustable, it can be used to correct the changing characteristics as these output tubes age. This is also true of the ICPM corrector. Its purpose is to provide a compliment of the amplitude vs. phase characteristic of the output amplifier stage. These two pre-correctors insure optimum video characteristics of the output signal. This enables multi-channel television sound signals to be transmitted by the aural section without interfering sync buzz or buzz-beat caused by output amplifier ICPM errors. This is especially necessary for high power tube amplifiers that have ICPM errors near white and sync tip. The upconverter tray also includes an oven control crystal oscillator and multiplier chain.

The IF and LO signals are mixed, filtered, and amplified to about the 10 MW level and then sent to the driver amplifier tray for further amplification.

The aural upconverter operates in much the same manner as the visual upconverter, but without the presence of amplitude or phase correctors. The output amplifiers in the aural upconverter tray are similiar to those in the visual driver tray and provide up to 5W of aural output power to the diplexer.

The output of the visual driver tray drives a 10W solid state amplifier, which includes eight transistors operating in parallel. Each device is provided with a video compensated constant current bias source. This amplifier utilizes microstrip transmission line techniques on teflon circuit board and is cooled by forced air.

In the metering/control panel, the output and driver powers are metered and diplayed. The panel also distributes AC and control signals to each tray. The control logic is CMOS for high noise immunity. A "D" connector interface is provided for a remote control system interface.

The visual and aural output signals are diplexed and combined with the ITFS/MDS channels in a three input, one output wave guide channel combiner-diplexer. This device integrates the function of diplexing and channel combining into one assembly and eliminates the jumper losses normally incurred while connecting diplexers to separate channel combiners. Additionally, because it is built entirely of wave-guide, inherent losses are low, especially in the through line wave-guide. This results in an essentially lossless channel combining technique that can be cascaded with other alternately spaced ITFS channels. Because the wave-guide cut off frequency is below 2 GHz, this main line wave-guide can also multiplex Channel 1 or Channel 2 MDS systems onto the same line. Using this device, it is possible to combine up to 17 ITFS/MDS channels on a single wave-guide in a relatively low loss manner. The diplexer sections of these devices utilize directional filter techniques and result in very high isolation from channel to channel and from visual to aural carriers. Since the loss of these filter sections is compensated for in the output amplifier stages, the transmitter can provide a full 10 watts of visual power at the output of the channel combiner. Recent versions of this device incorporate temperature-stabilized specialty steels to provide maximum temperature stability. Refer to Fig. 3 for a photo of a wave-guide diplexer/channel combiner. Other versions of this device have been developed for channel combining internally diplexed repeaters.

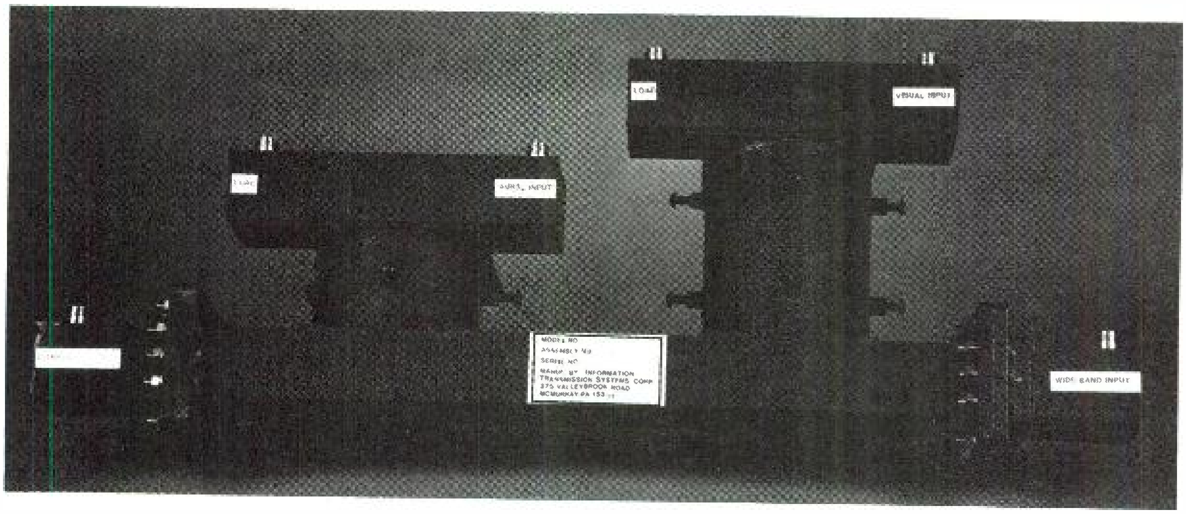

Fig. 3. Diplexer/channel combiner.

Repeaters

ITFS repeaters are usually comprised of ITFS transmitters driven by receivers instead of modulators. In a typical system design an ITFS downconverter "block converts" an entire ITFS group to a VHF band of frequencies. A wide-band splitter then splits this signal to drive the required number of repeaters. Each individual repeater employs a VHF receiver tray to convert the appropriate VHF channel to standard IF. Referring to Fig. 4, a typical downconverter utilizes a remote preamplifier section that is located near the receive antenna. The preamplifier stage is powered from dc supplied by the output co-axial feed line. This pre-amplifying preserves input signal-to-noise ratio and allows the downconverter to be placed in a controlled environment to enhance frequency stability and reliability. The downconverter is a 19 inch rack mount tray that contains an input filter for the desired group, another low noise amplifier stage, a local oscillator, a mixer assembly, and a wide band VHF output amplifier. Since this amplifier stage must handle relatively high level multiple channel signals, it must be designed to produce a minimum of cross-modulation and inter-modulation distortion. The ITS-640 accomplishes this with a wide-band CATV amplifier device. Frequency generation is accomplished by an oven controlled crystal oscillator and multiplier chain, similiar to that in the ITFS upconverter tray.

The receiver tray converts the VHF input channel to the standard IF of 41 to 47 MHz. Another oven controlled oscillator is used for frequency control and a single channel input filter is used to provide selectivity. In the IF strip, the selectivity is further enchanced by a SAW device that provides 60 dB of rejection of adjacent channel signals. This high selectivity insures that other VHF channels are not hetrodyne converted into a desired ITFS output channel. This receiver tray

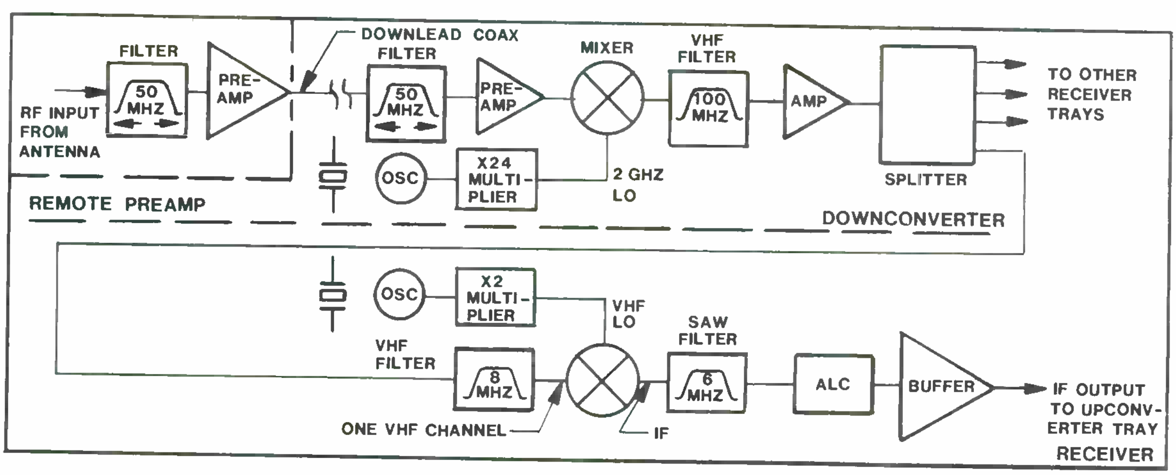

Fig. 4. Downconverter/receiver block diagram.

also includes Automatic Level Control (ALC), and carrier detection circuitry to initiate operation of the output upconverter. There is also a video detection circuit that is utilized to prevent radiation of an unmodulated output signal.

A repeater must be designed to operate with the full range of input signal levels expected. These typically range from −30 to −60 dBm. The input signal handling capability and the system noise figure must be carefully set to handle this wide input dynamic range. Repeaters can be cascaded to more than one hop. Careful consideration must be given to system signal-to-noise ratio, frequency stability and total system distortion since these errors are additive. Channel selection should be done to avoid alternate or adjacent channel operation, if possible. Typical channel selection often reuses the originating channels in the output of a multiple hop system.

Amplifiers

High power amplifiers for MDS and ITFS are available at the 50 watt to 100 watt visual power levels. Higher power level systems are being considered. The present hardware used to produce these power levels is single or parallel planer triode amplifiers. A typical amplifier is shown in Fig. 5. In this unit a Siemens YD1380 triode is operated as a Class AB linear amplifier. The amplifier circuit is a ¾ wavelength output coaxial cavity. It is single tuned for a bandwidth of about 10 MHz at 1 dB. In the ITFS band, this unit provides about 13 dB of gain and in excess of 50 watts of visual or visual plus aural power. This stage produces distortion products that are approximately 50 dB down from the peak visual output power in the internally diplexed mode. This level is easily corrected to more than 56 dB down with the use of the IF correctors previously described. The linearity characteristics of this stage age slowly and require only an occasional (2 to 3 times yearly) pre-correction. Additionally, as the tubes near end-of-life, pre-correction can be employed to effectively extend the tube's operating life. Although this is a relatively low power vacuum tube stage, the delicate nature of this tube's grid structure requires that quick acting protection circuits are included. In this model, optically coupled isolators are used in all of the tube element lines for fault detection. This provides rapid protection in case of a fault. CMOS control logic provides proper delay in application of voltages and automatic re-cycling under fault conditions. Two of these amplifiers can be combined for 100 watt operation.

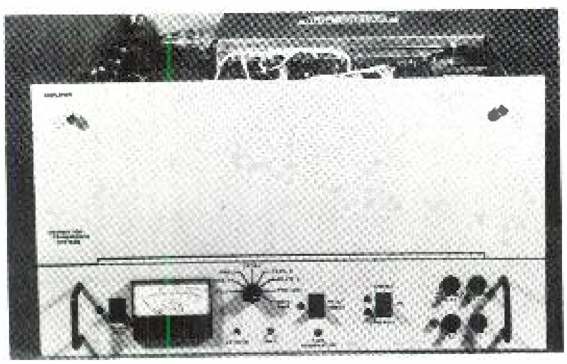

Fig. 5. 50 watt amplifier.

Antennas

The output of the channel combiner feeds a coaxial line or elliptical wave-guide. Normally, this transmission line is pressurized and feeds a pressurized antenna. Transmission line losses can be a significant factor in reducing radiated power. Coaxial transmission lines can only be as large as 1⅝ inch in diameter to avoid mode problems. This size corrugated line has about 1.5 dB per 100 feet of loss in this band. Another common line, ⅞ inch in diameter, has a loss greater than 2 dB per 100 feet. For this reason, elliptical waveguide such as Andrew EW20 is often used. EW20 has less than 0.5 dB of loss per 100 feet. These losses exclude connector transistions and jumper cable losses. Flexible cable as small as ½ inch in diameter is often used for these jumpers, even though this cable has 0.4 dB of loss per 10 foot length. For this reason, jumper cable length should be minimized.

Transmitting antennas are available in both vertical and horizontal polarization, with azimuth patterns of omni or cardioid shapes. Gains range from below 10 dBi to more than 18 dBi. Vertical beam widths range from 13 degrees to less than 3 degrees. These antennas are usually top mounted for the omni pattern case and side mounted for the cardioid pattern, although omni pattern antennas are occasionaly side mounted with some resultant pattern deformation. (See Fig. 6)

Receiving antennas range from small 12 dB gain dipole reflector combinations to large dishes. A very common receive antenna is the disk rod array, which has about 18 dB of gain. For more distant receive points, a 4 ft. dish is often employed with a nominal gain of 28 dB. Some antennas are built directly onto the case of the downconverter to minimize costs and eliminate jumper cable losses. In other cases the downconverter is mounted close to the receive antenna and a short length of flexible coaxial cable interconnects the assemblies.

Downconverters

Receiving converters normally include an RF pre-amplifier stage to preserve signal-to-noise

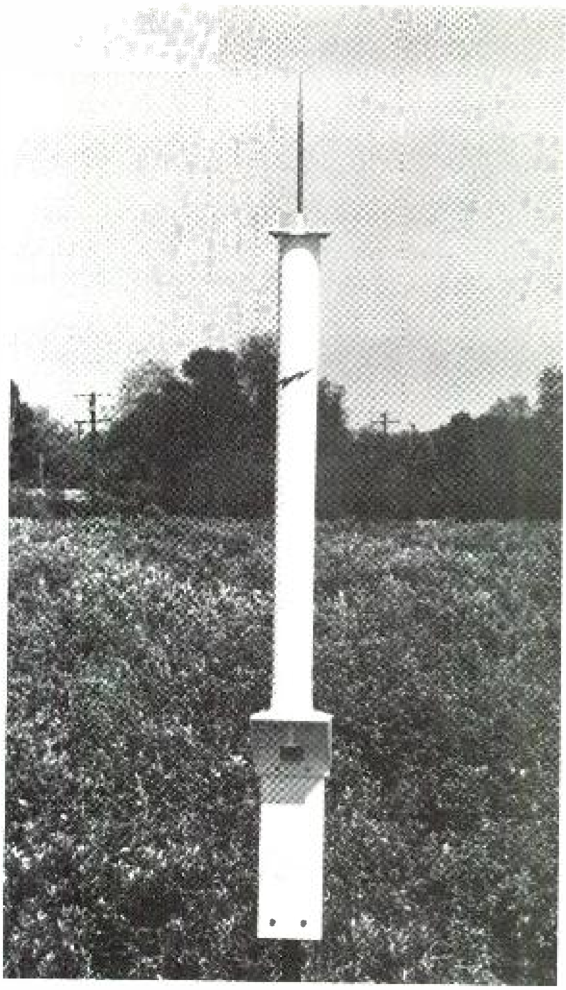

Fig. 6. ITFS/MDS antenna.
(Courtesy of Andrew Corporation).

ratio and a single balanced mixer for frequency conversion. The local oscillator signal is generally derived from a crystal oscillator and multiplier. The VHF output amplifier is usually of discreet component design and often the entire assembly is designed as one printed glass epoxy circuit board to minimize manufacturing costs. Because of the low Q nature of this di-electric material and because of the small physical separation between functions, those devices occasionally have undesired spurious outputs. In multiple channel systems, the single handling capability of the transistor output stage becomes a determining factor is the amount of output signal cross-modulation distortion. In a carefully designed downconverter, input noise figures below 6 dB can be achieved and out-of-band spurious signals can be held 50 dB below typical output levels. When additional input selectivity is required, pre-selector filters are sometimes used before the downconverter section. Since the output of the downconverter often interconnects with other television signal distribution equipment, consideration should be given to the fact that crystal oscillator products and various input signal mixing products may appear on the output, often at levels well above the noise floor. Since the downconverter has a wideband VHF amplifier in its output section, it will produce a broadband noise spectrum independently of the downconverter's oscillator or input signal. Success in interfacing a downconverter in a television signal distribution system may require that VHF filtering be done after the downconverter's output. A typical converter is shown in Fig. 7.

RESPONSE CHANNELS

The ITFS rules also allocate a set of frequencies for voice and/or data transmission. This has most often been used for a return link from a classroom to the main television transmission point. The response channels occupy part of ITFS Channel H4, with each ITFS television channel having an assigned response channel. These response channels are 125 kHz in width and can be used for amplitude or frequency modulation transmissions. Usually, 25 kHz deviation FM is

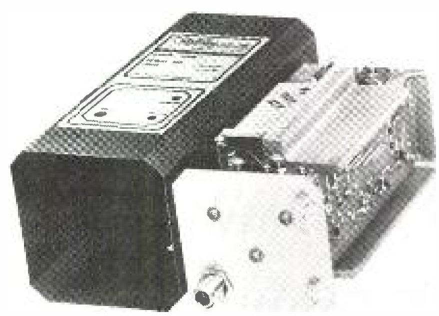

Fig. 7. ITFS down converter.
(Courtesy of MICRO·NOW, Inc.).

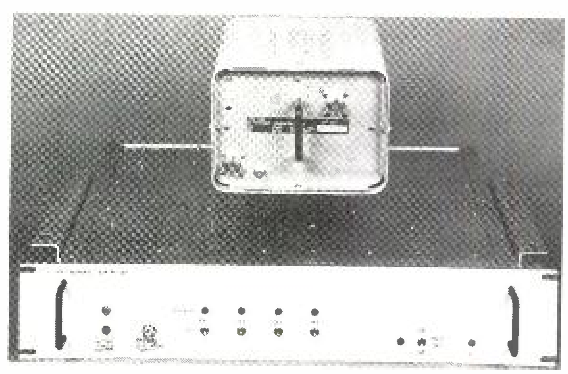

Fig. 8. ITFS response transmitter.

employed. Transmitter output power is normally limited to 0.25 watts. Transmitter power of 2 watts may be permitted, if a need can be shown.

A typical response transmitter is shown in Fig. 8. In this system, a "base unit" consisting of audio processing circuitry, control logic and a frequency modulated crystal oscillator, operating at $\frac{1}{24}$ of final output frequency, drives a "mast unit" that is located near the transmitting antenna. The "mast unit" performs the functions of frequency multiplication, amplification and power level control. At the receiving point, a standard downconverter is used to heterodyne convert the response frequency to a suitable VHF frequency to drive an FM receiver. The FM receiver is normally a crystal controlled unit with squelch. This unit drives an audio amplifier and speaker. In the case of data transmission, it may drive a suitable modem for interfacing with a computer. Preceeding the base unit at the transmitter site is a microphone mixing network and/or modem that originates the input signal. Because of the channel bandwidth limitations, the audio or data bandwidth is usually restricted to less than 15 kHz. Data transmission rates of 300 to 4800 baud have been achieved.

7.6

Broadcast Newsroom Computer Systems

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INTRODUCTION

Computer systems are replacing typewriters increasingly in broadcast newsrooms. These systems enable a station to manage the complex processes involved in broadcast journalism with increased efficiency and speed. The technology of "Electronic News Gathering", the "Global Immediacy" provided by satellite sound and picture transmission, and the competitive pressures of broadcasting demand "state-of-the-art" command and control of the broadcast journalism activity.

Broadcast newsrooms in the 1980s and beyond can benefit from computer-assisted activities in areas such as newsgathering, story development, resource allocation (crews and equipment), on-air broadcast schedules, support functions, and business affairs. This part describes newsroom computer technology and presents a plan for moving a station's news operation into the computer age.

BASIC PRINCIPLES

Newsroom computer systems typically include: one or more computers; *software* (programs) which cause the computers to perform useful tasks; terminals such as VDTs (Video Display Terminals), printers, and prompters which permit people to interact with information in the computer system; data communications which provides access to the newsroom computer from remote locations; newswire services (AP, UPI, Reuters, etc.); and some means to interconnect all the parts.

The Computer(s)

Broadcasters have been using computers for years. Computers control our audio and video editing equipment, pre-roll and switch our on-air program material, monitor and log our RF (radio frequency) emmissions, bill our clients, and even produce our paychecks. The application of computers in broadcast newsrooms is merely another use of an already familiar technology.

Computers come in many shapes and sizes, ranging from shirt-pocket size to large *mainframes* which may occupy thousands of square-feet of floorspace. Newsroom computer equipment tends to be small and flexible. See Figs. 1 through 4.

From the tiniest to the largest, computers share similar architectural elements. See Fig. 5.

The *ALU* (Arithmetic/Logic Unit) is a circuit which performs basic arithmetic and logical operations (typically addition, subtraction, and logical comparisons) on binary numbers represented by the presence or absence of current at designated points in the circuit.

ALUs are characterized by the number of *bits* (binary digits) they process at a time. Typical newsroom computer ALUs process eight or six-

Fig. 1. A battery operated pocket-sized computer which can store a reporter's notes or script. (Courtesy of Sharp Electronics Corporation)

Fig. 2. A battery operated lap-portable computer with built-in software which handles word-processing, contact lists, and a reporter's assignments. The unit includes an internal modem which permits the user to send and/or receive information by telephone dial-in to the main newsroom computer system.

Fig. 3. A desk-top computer system with internal floppy disk and hard disk storage exceeding ten million BYTES. With newswire service input, this system can give a single user most of the functions of a multi-terminal newsroom computer system. Connected to a data communications network, it can perform as a full-featured newsroom workstation. (Courtesy of Basys, Inc.)

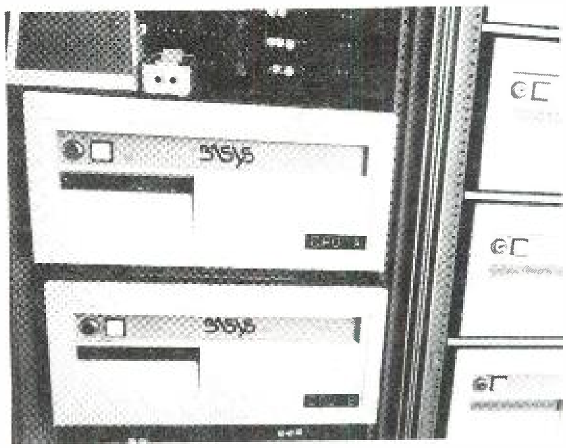


Fig. 4. A mini-computer system with dual CPUs and over eighty million BYTEs of storage. The two CPUs are "tightly linked" and each maintains its own full copy of the database. If either CPU fails, the other can survive with its separate database. The system shown can support up to eighty terminals, printers, dial-ins, and/or newswire feeds when both CPUs are operational; up to forty devices when only one CPU is on-line. (Courtesy of Basys, Inc.)

teen bits at a time. Large mainframes may process 32, 36, or even 64 bits in a single ALU step.

Two concepts: *bus* and *bit-width* apply to many newsroom computer ALUs. The "bus" structure defines the signals—data and control—which pass between the ALU and other internal parts of the computer. "Bit-width" describes the number of bits the bus can pass at a time. A given ALU circuit may be able to process 16 bits at a time internally, but may be constrained by the bus structure to only an 8 bit path through the bus to other internal parts of the computer.

Computer *memory* circuits can store and retrieve binary numbers which represent program instructions and/or data. Program instructions typically cause the ALU to execute a command. Data stored in the computer memory might be tonight's six-o'clock newscast script, a newswire story, or tomorrow's camera crew schedule.

Memories are characterized by the number of *BYTEs* (eight bits of storage) or *WORDs* they can store. A WORD is a measure of the number of bits the ALU processes at a time; an "eight-bit machine" has a word-length of one BYTE (eight bits); a "sixteen-bit machine" has a word-length of two BYTEs (sixteen bits); and a "thirty-two- bit machine" has a word-length of four BYTEs (thirty-two bits).

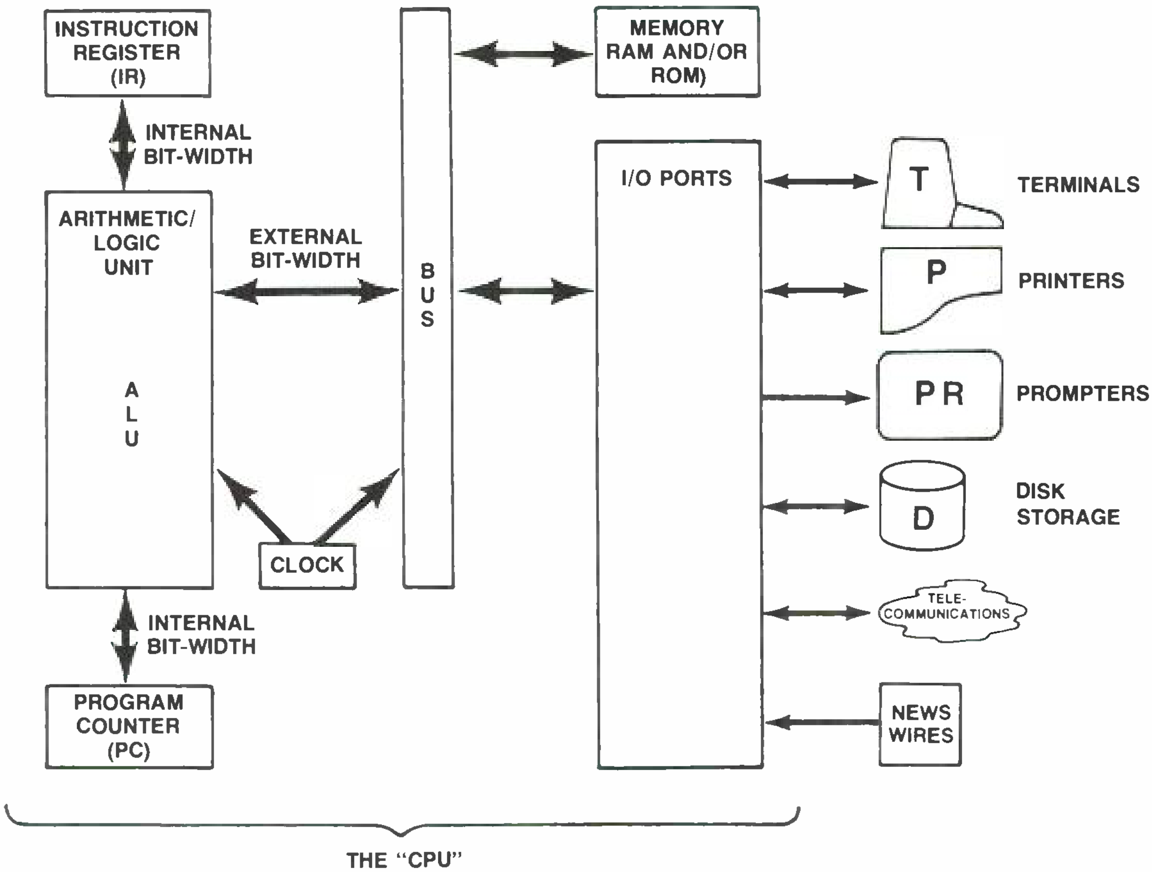


Fig. 5. Conceptual computer.

A BYTE can represent any of 256 (2^8) binary values. Half of these have been assigned standard alphabetic, numeric, punctuation, and "control" designations under the *ASCII* convention. See Appendix A. The remaining binary values are used by some newsroom computer systems for special purposes.

The PC (Program Counter) contains the *address* in memory of the next instruction to be executed by the ALU. An address is a binary number which specifies the location of a program instruction or data item in a computer's memory. See Fig. 6.

The IR (Instruction Register) temporarily holds a binary number which represents an instruction, or command, to be executed by the ALU. Typical instructions are "add a number in memory to the accumulator", "increment the accumulator by 1", "zero the accumulator", "XOR (logical exclusive OR) a number in memory with the accumulator", etc. The binary number in the IR is *decoded* by control circuitry and sent as a command to the ALU which performs the operation.

The I/O (Input/Output) section permits data to be sent to and received from external equipment. This information, typically in ASCII format, might be characters sent to a printer or video display, the "keystrokes" of a video terminal user, the text of a newswire story, or a request for a crew's next assignment from a user in the field. Computers have I/O *ports* which permit the transfer of data to and from external devices such as VDTs, printers, newswires, etc.

The clock controls the transfer of data among the internal parts of the computer. Clock pulses of several "phases" are used to initiate the transfer of an instruction into the IR from memory, to cause the instruction to be decoded and passed to the ALU, to cause the ALU to execute the instruction, and often to store the result of the activity back into memory. The execution of an instruction by the ALU may require one or many of these step-by-step clock pulses.

Newsroom computer equipment is usually based on the technology described above. Newsroom computer *systems*, however, use the technology to support the special purpose tasks news people need to perform.

Commercially available newsroom computer systems fall into two categories:

1. Those which are based on "off-the-shelf" computer *hardware*, typically manufactured by another company; and

2. Those which are based on special purpose computer hardware, usually made by the company selling a newsroom package.

The off-the-shelf approach normally is based on a major computer manufacturer's equipment. This offers well proven hardware, readily available field maintenance and support, and often a range of compatible equipment options from which to choose. The disadvantage in this approach is that off-the-shelf equipment is general-purpose in nature; no use is made of hardware optimized for the newsroom *application*.

In contrast, special purpose newsroom computer equipment is designed specifically for the application. This can lead to a more efficient hardware/software combination which often handles tasks with higher apparent speed than a general purpose system. The disadvantages in special purpose newsroom computer systems stem from their uniqueness. Replacements, *enhancements*, and additions to a special purpose system must usually be done through the system vendor. The local computer store will not be able to supply special purpose system hardware or software off-the-shelf. Another problem is that special purpose equipment which relies on *PROMs* (Programable Read-Only Memory) to store software for each terminal may prove cumbersome when it is time to install a new *software release* (in some cases, every terminal and the central equipment will need PROM chips replaced).

The Software

Software, or programs (lists of commands to be executed by the ALU), give a computer system a kind of "personality". This can be characterized as "user-friendly", "austere", "cumbersome", "fast", "slow", "chaotic", "user-surly", etc.

Typical newsroom software uses features such as "menus", "prompts", "function keys", "cursors", "status messages", and others to guide the user through his or her task.

A menu is a list of items displayed on the user's terminal. The menu may show the set of commands available to the user or a list of newswire story *slugs* or a list of *data files*. The user is expected to choose one of the menu items in order to proceed with his or her work. The software waits for the user to indicate a selection through the terminal's keyboard. Once the selection has been made, the software takes appropriate action.

Some newsroom software "prompts" the user with a message indicating what the user should enter next. Some examples are:

PLEASE ENTER FILE NAME >

PLEASE ENTER DATE >

STRIKE "HELP" KEY FOR MORE INFORMATION

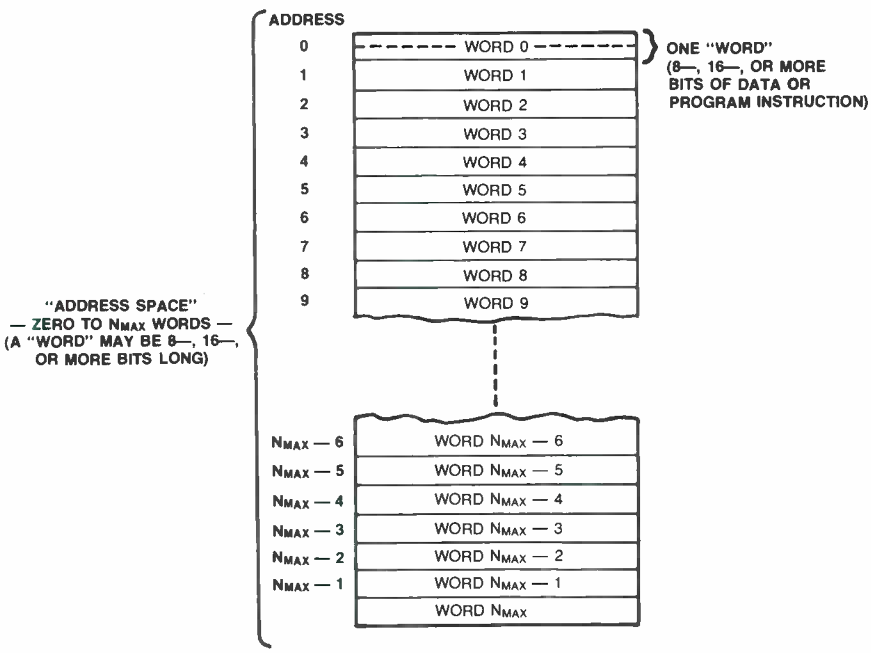


Fig. 6. Memory addresses.

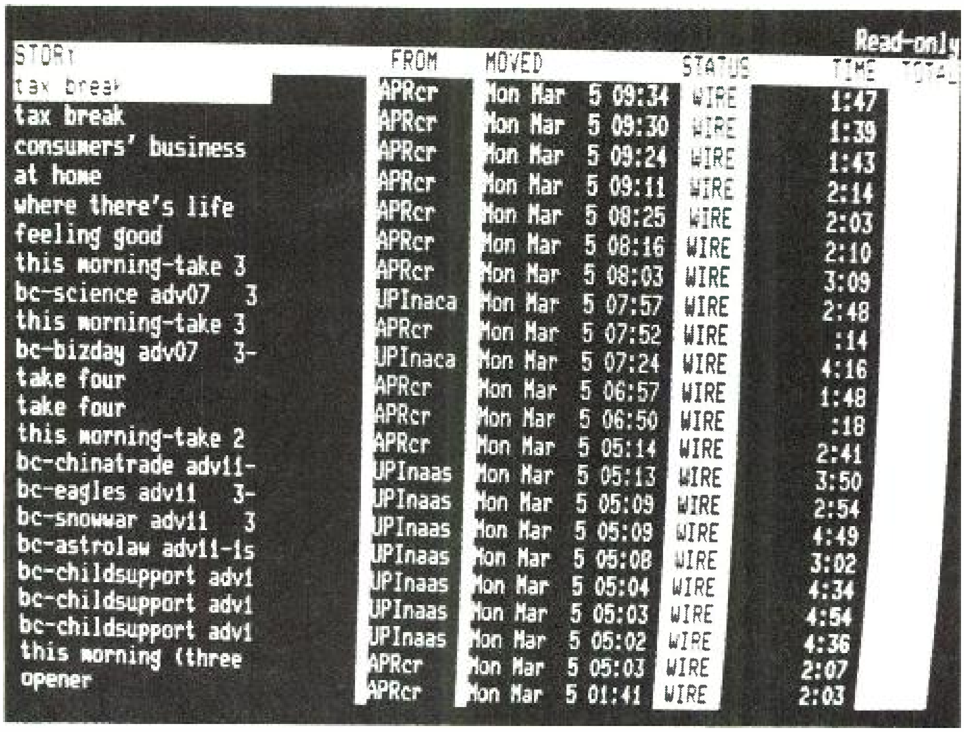


Fig. 7. A menu display presenting a list of newswire stories. The top story in the list, "tax break", has been selected (indicated by the black-on-white story name). To see the full text of the selected story, the user strikes a function key. (Courtesy of Basys, Inc.)

Prompts can also be simply one character such as the greater-than sign (>) or an asterisk (*). These typically appear at the left side of the terminal screen when the user is expected to enter a line of text.

"Function keys" are additions to some terminal keyboards beyond the alphabetic, numeric, and punctuation keys found on a typewriter. In some systems, the function keys have fixed labels such as "PRINT" or "ERASE". In others, they may be labeled as "f5" for function key five. In the latter case, the software can change the function of the function keys to match the user's task. For example, "f3" might mean "PRINT STORY" when the user is reading through the wires, and mean "DELETE SENTENCE" when the user is writing a script. Some software causes the changing meanings of function keys to be displayed as video labels at the bottom of the terminal's screen.

Most newsroom software uses a *cursor* on the video terminal screen to indicate the position of the next character the user enters or one of the items in a menu. Cursors may be a rectangular block of one character size, an underline, or a screen position in reverse video. Often cursors are caused to blink on and off to attract the user's eye. The software usually permits the user to move the cursor around the screen by striking function keys. This gives the user a means of selecting a menu item and is useful when editing text.

"Status messages" are guides and advisories which software displays on the user's screen. In some systems, a section of the screen is reserved for these messages. In others, the messages are displayed as needed. Message content might be a warning that some part of the hardware or software has failed, an indication that a newswire Urgent or Bulletin has been received, or a message from a co-worker at another terminal.

Newsroom software controls the video terminal's *display attributes*. The attributes may apply to single characters, groups of characters, sections of the screen, and the entire screen. Typical attributes controlled by software include "reverse video", "half-intensity video", "high intensity video", "underlining", "blinking", "alternate character fonts", "color displays", and "graphics". These features, when used by a given vendor's software, can give the user a visual indication of what the system is doing and what is next to be done.

Newsroom software is written in one or more computer "languages". Examples are: Pascal, C, FORTRAN, PL1, Assembler, and COBOL. A computer language allows a human computer programmer to write a list of instructions for the computer using human-readable symbols instead of the binary numbers the computer uses. A com-

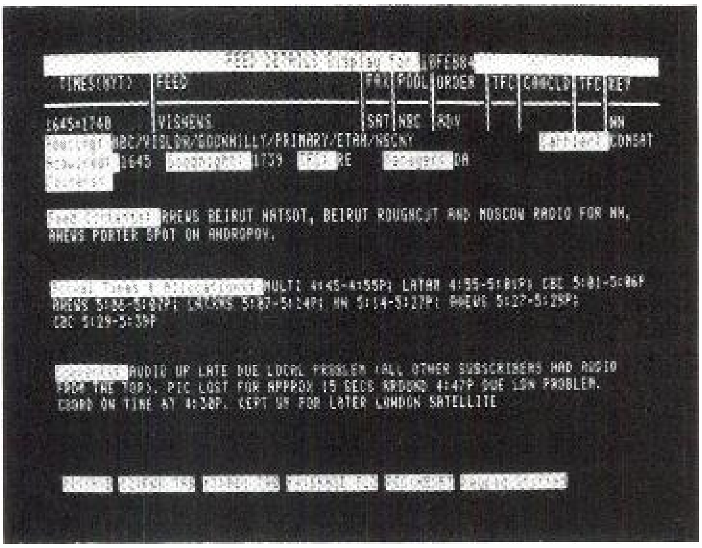
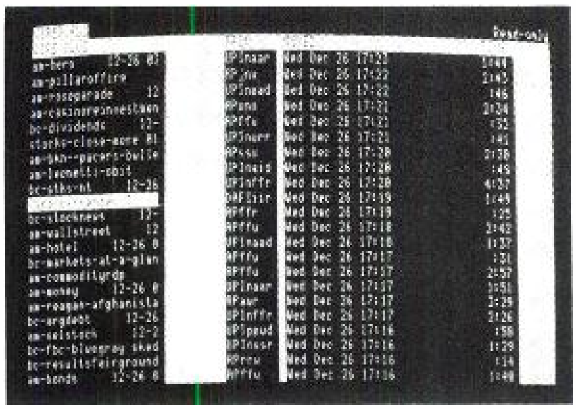
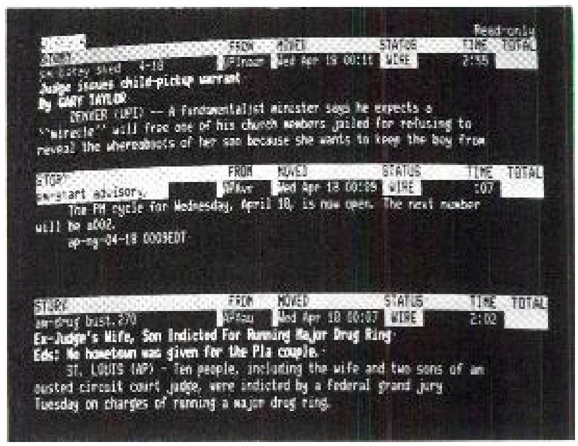


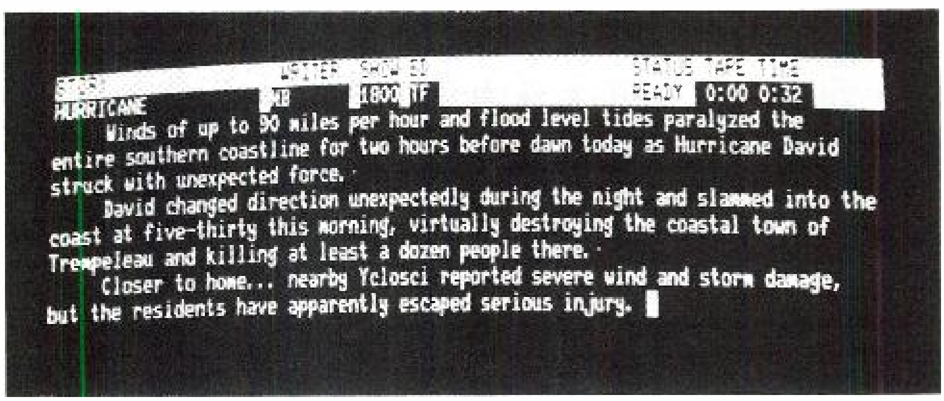
Fig. 8. A video screen showing function key labels on the bottom line. The user selects an action by striking the appropriate key.



(a)

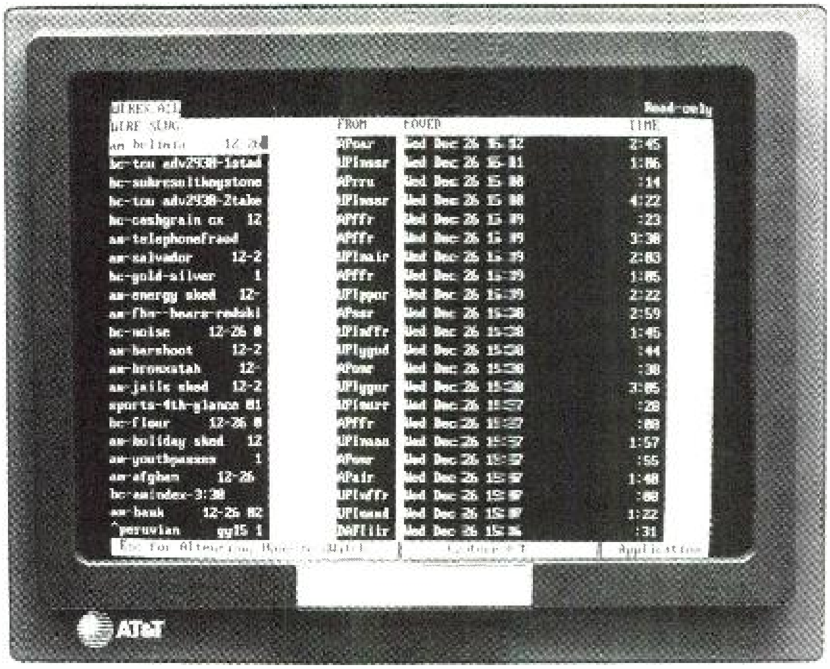


(b)

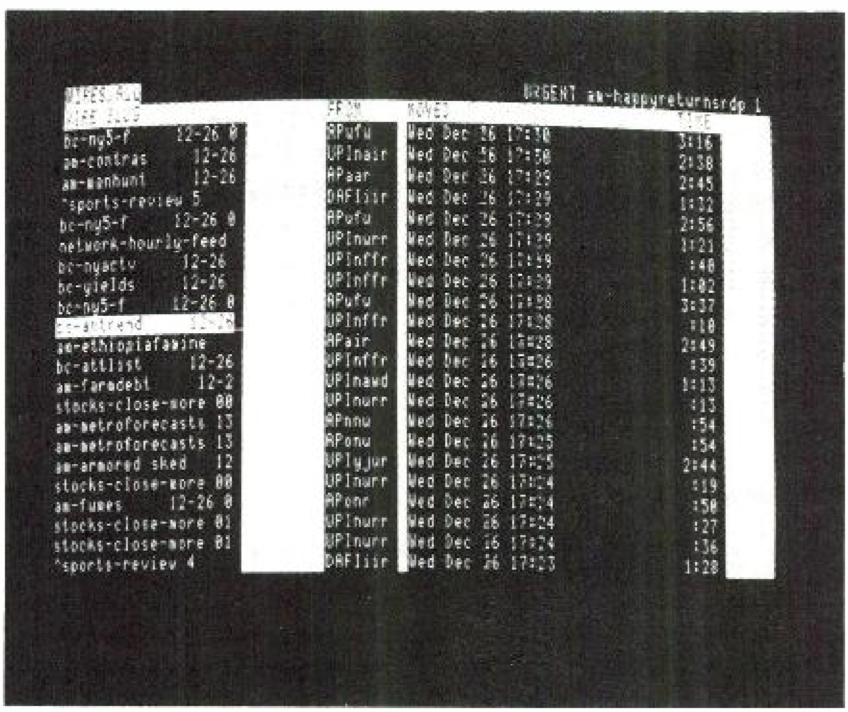


(c)

Fig. 9. Examples of the use of cursors: (a) shows a newswire menu with a "wide-cursor" selecting the "sports-review 3" story; (b) shows a "three-cell" display which presents the first several lines of three stories — the cursor is positioned on the middle story, "pm-start advisory"; (c) shows a "block cursor" which is often used in text entry (the white rectangular block at the end of the story). (Photos courtesy of Basys, Inc.)

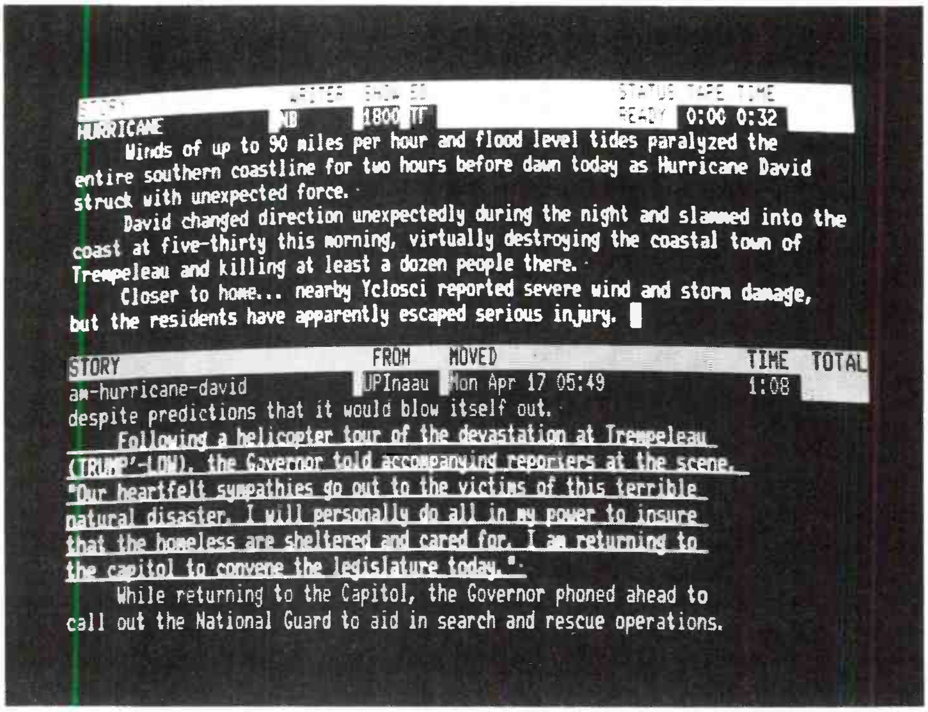


(a)

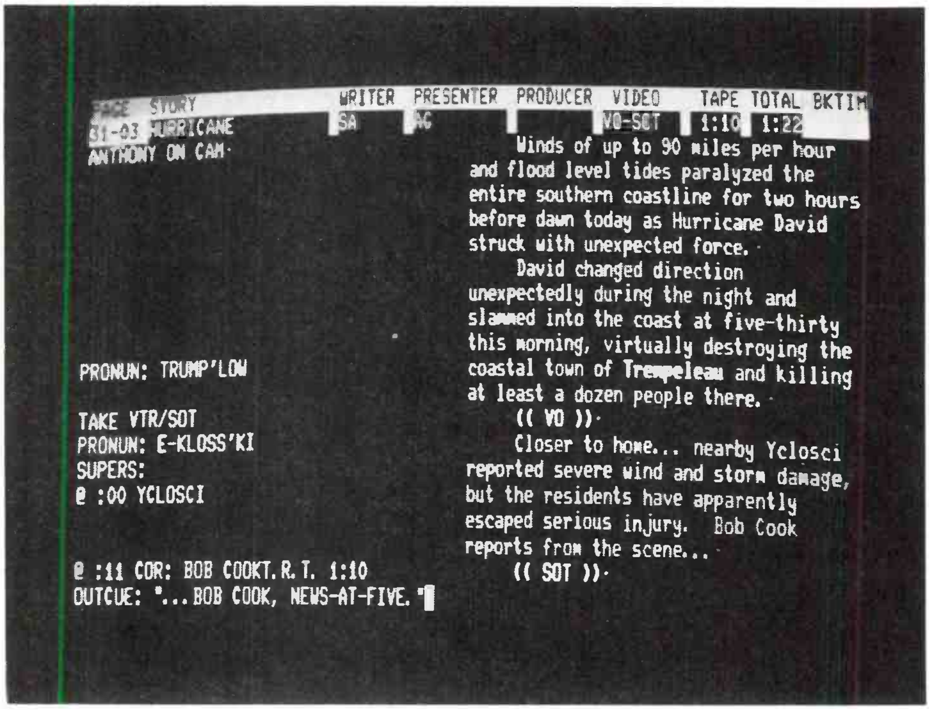


(b)

Fig. 10. Examples of the use of status messages: (a) shows the file label (WIRES.ALL) and the file status (Read-only) on the top line, and on the bottom line, several optional commands which the user can invoke; (b) shows, in the top line at the right, an URGENT story status message which indicates that one of the newswire services has transmitted an urgent story.

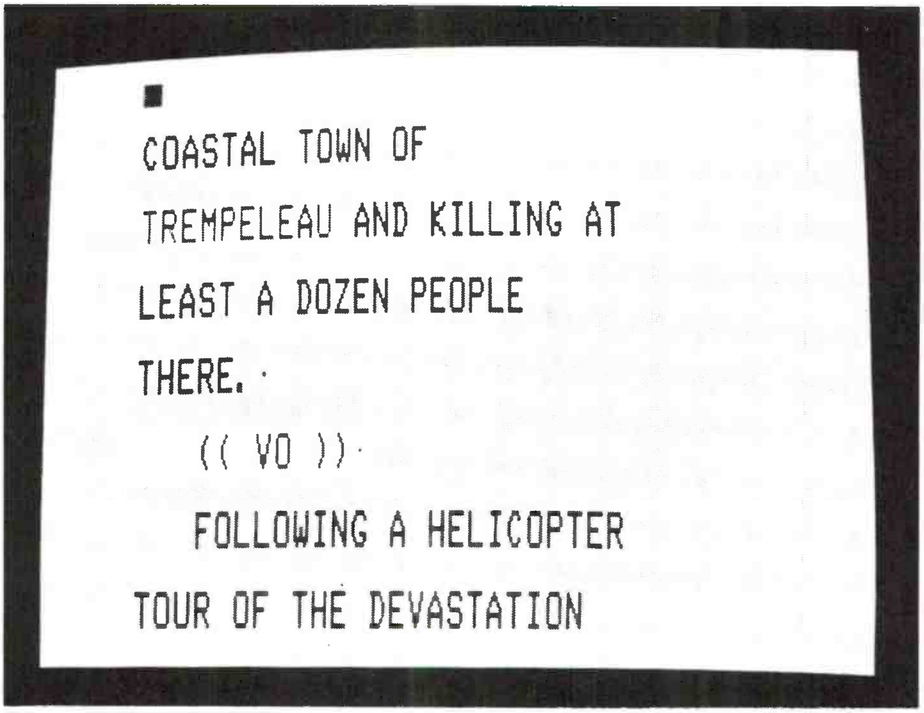


(a)

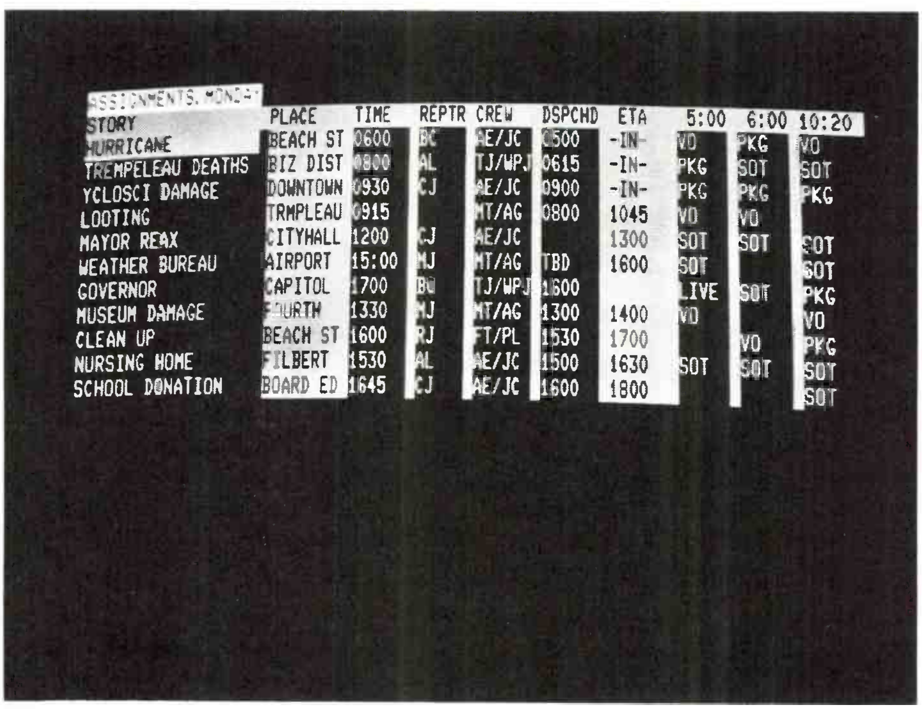


(b)

Fig. 11. Examples of the use of display attributes: (a) shows a mixture of reverse-video, low-intensity video, and underlining; (b) shows a television newscast script display which uses high-intensity video for emphasis;



(c)



(d)

(c) shows an alternate character font in use to simulate a prompter display; (d) shows an assignment menu which uses normal, reverse, and high-intensity reverse video attributes. (Photos courtesy of Basys, Inc.)

puter is then used to translate the human symbols into binary numbers which computers can later use to do the tasks the programmer intended.

The instructions the human programmer writes are called *source code*. The computer translates the source code in a process called *compilation* into binary numbers termed the *object code*.

The object code normally represents only a portion of the newsroom software: an example is the section which prints a selected newswire story. Modern software is written in *modules* which are compiled separately into object code modules. These modules are then *linked* by another computer program to form what is termed the *absolute code* or *executable code*. The absolute code contains all the binary instructions the computer needs to behave as a newsroom computer.

Most newsroom systems based on general purpose hardware and some of those based on special purpose equipment rely on an *operating system*. Operating systems, also known as *system software*, are computer programs supplied with the newsroom computer hardware to handle such tasks as moving data from memory to *disk storage*, moving data from disk storage to memory, controlling the execution of the newsroom software, providing *backup* or *mirror* copies of newsroom data, maintaining *directories* which permit newsroom software to locate stored information, interpreting user requests, etc. A computer's operating system interacts with both the user (processing his or her commands) and with the newsroom vendor's software (to control the flow of information between the computer and the terminal equipment connected to it).

Operating systems are normally the product of a company specializing in this type of software. Newsroom computer system vendors typically acquire an operating system for their customers through a licensing agreement with such a company. License costs are passed on to the customer.

The Terminals

The primary, fixed-site, terminals for a newsroom computer system are normally supplied by the newsroom system vendor. These include the VDTs, printers, and possibly the prompters. Field terminals, such as pocket-sized, "lap-portables", and "carry-ons" are infrequently offered by the vendors; a station is expected to acquire them from the local computer store.

Many computer terminals are controlled by their own internal microcomputers. Most fixed-site newsroom terminals of this type contain a microprocessor which is controlled by a software program stored in ROM (Read-Only Memory). The microprocessor also has access to RAM (Random Access read/write Memory) which holds the data to be displayed on the terminal's video screen and which stores any video attributes or dynamic terminal parameters.

Video terminals typically have a video display unit, a control unit, a keyboard, and I/O port(s). The control unit and I/O ports are often housed in the same enclosure as the video display unit. Keyboards are normally separate, connected to the control unit by a cable. Fig. 13 shows several types of fixed-site newsroom computer terminals.

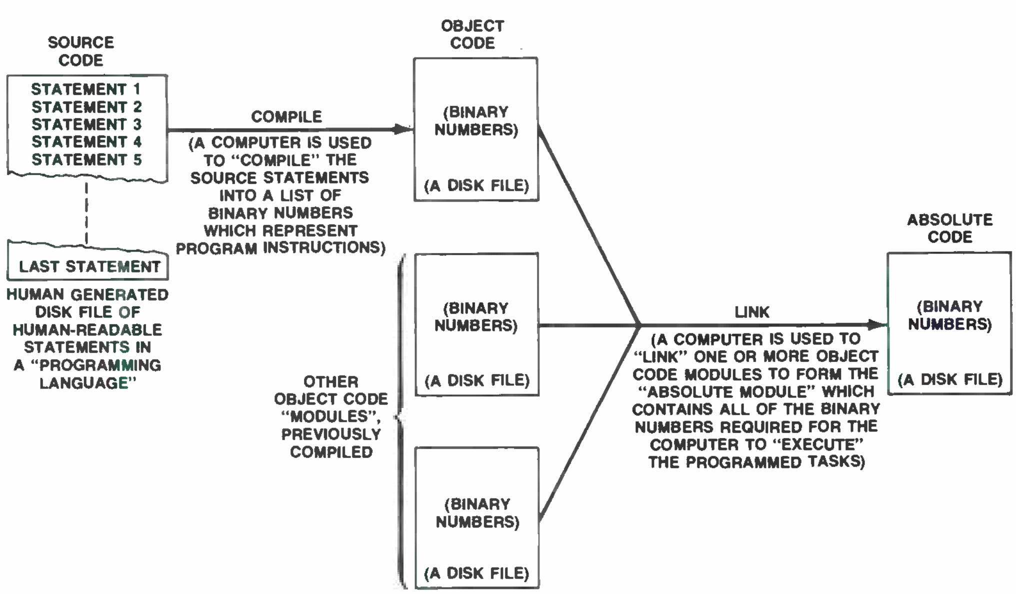


Fig. 12. Source, object, and absolute code.

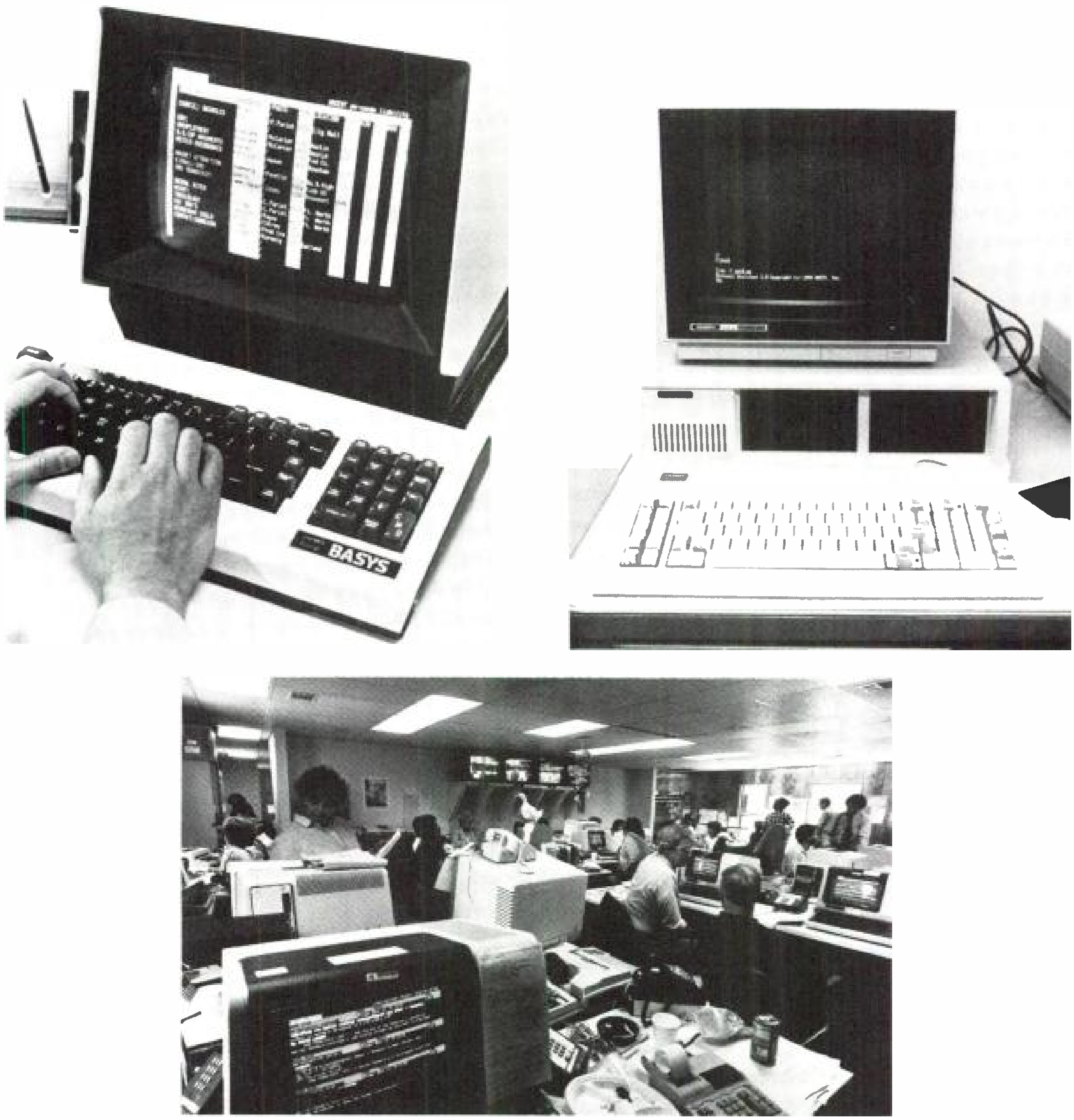


Fig. 13. Typical newsroom computer terminals. (Courtesy of Basys, Inc.)

Fig. 14 shows the relationship between the video display unit (VDU), the terminal control unit (TCU), the keyboard (KBD), the character generator (CG), and the input/output (I/O) ports of a typical newsroom video data terminal.

The VDU is similar to a high quality studio video monitor. Monochrome VDUs can display twenty-five or more eighty-character lines of data. This requires a minimum monitor bandwidth in the 15 to 20 MHz range for acceptable display resolution. Color VDUs either meet such bandwidth/resolution requirements or display fewer characters and/or lines per screen. The high-resolution color VDUs require individual RGB (Red, Green, Blue) video signals since NTSC (National Television Standards Committee) composite video only provides for a bandwidth of about 4.2 MHz.

The TCU controls the flow of data between the keyboard, the display, and the I/O ports. Most newsroom terminal TCUs include a microprocessor, ROM which holds the microprocessor's program instructions, and RAM which stores the VDU's screen contents and video attributes.

There are two types of CGs used in newsroom video terminals. One is a "preset font" type which can display one or more character fonts which are pre-programmed into the CG's ROM when it is manufactured. The other type offers a "user-programmable font" feature which is used to permit the TCU's software to control the appearance of characters and graphics displayed on the terminal's screen. The latter type gives the software vendor more flexibility in designing displays and has been used to simulate prompter-like displays by at least one newsroom system vendor.

Newsroom terminals must have at least one I/O port to permit them to communicate with other devices in the newsroom system. It is desirable to have two or more. The primary I/O port is used to send and receive newsroom system data. The second port is often connected to a nearby printer which can make paper copies of information displayed on the video screen. Additional ports beyond the first two are sometimes used with alternate communications backup circuits, additional printers, prompters, video monitors, etc. Three types of I/O ports are popular—the *serial* I/O port, which sends and/or receives one data bit (binary digit) at a time —the *parallel* I/O port, which sends and/or receives eight bits at a time—and the LAN (Local Area Network) I/O port, which sends and receives serial data through a coaxial cable at more than one-million bits per second. Different newsroom system designs may use one or more types of I/O ports.

Standard electrical specifications exist for several types of I/O ports; these are discussed in the sections on "Data Communications" and "Interconnection" below.

Data Communications

"Data Communications" (here meaning the movement of information among the various parts of a newsroom computer system) is a specialized technology which has evolved from roots in the technologies of computer systems, electrical transmission, and telephony, and the science of information theory.

Practical applications of data communications in newsroom computer systems include: *hard-wired* connections between a newsroom terminal and the nearest computer system port, *modem* (modulator-demodulator) connections between either terminals or *concentrators* and the nearest computer system port, *dial-in* connections, *private-line* connections, and miscellaneous connections. Fig. 15 shows some typical data communications configurations which apply to broadcast newsrooms.

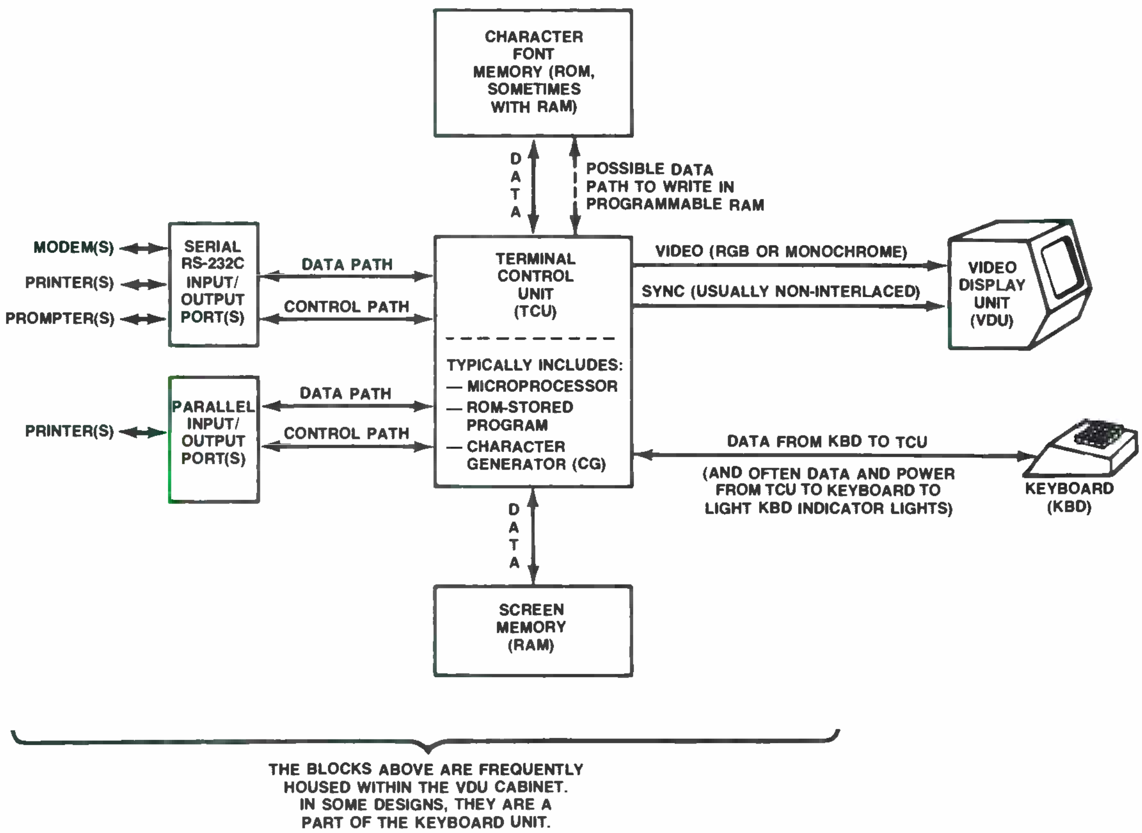


Fig. 14. VDT block diagram.

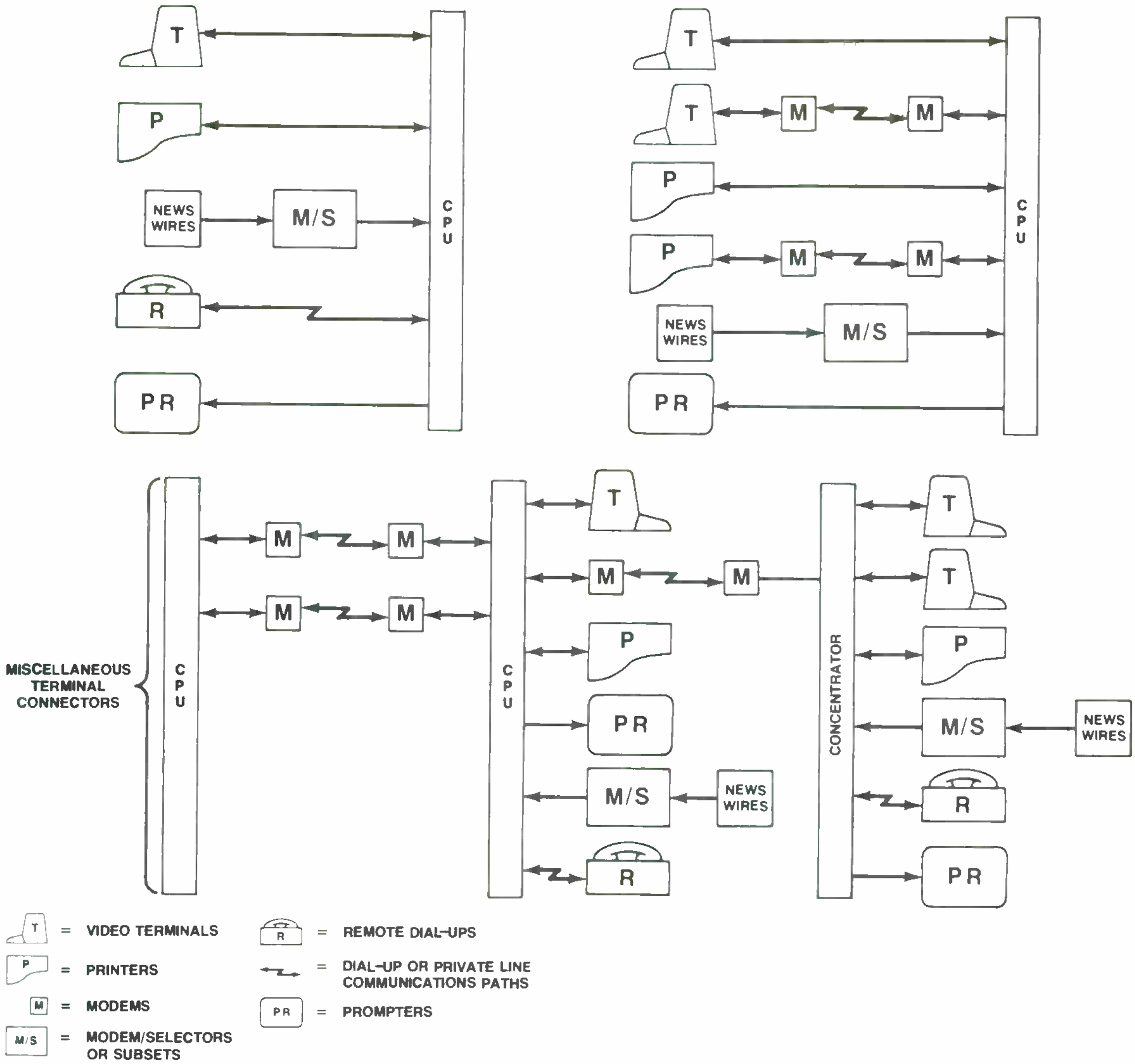


Fig. 15. Typical data communications applications.

Hard-wired connections between terminals and a computer system are employed when the terminals and the system are located within a given number of "cable-feet" between each other. Many newsroom computer systems use the EIA (Electronic Industries Association) standard known as "RS-232C" (see Appendix B) to specify the electrical and physical parameters of such interconnections. Some newsroom computer systems use coaxial cable for hard-wired interconnection. RS-232C interconnection, using special low-capacitance shielded cable, can be used to interconnect terminals and computers up to 500 cable-feet apart. Coaxial cable interconnection schemes often can be used in systems which have terminals 1000 cable-feet or more away from the computer. The choice between RS-232C and coaxial cable is determined by the vendors' newsroom system architectures.

When the distance limits of hard-wired interconnection can not be met (for example, the case of a remote bureau terminal located many miles away from the computer), modem equipment is used. Data communications modems convert digital signals sent from a computer or terminal into an analog audio signal which can be transmitted over telephone lines. Modems also can receive analog signals from a distant modem and convert them into digital signals which are presented to the local terminal or computer port for interpretation. Thus, an analog communications circuit with a modem at each end can interconnect digital devices (computers, terminals, printers, etc.) over longer distances than would be possible with hard-wired connections.

Two types of analog communications paths exist: a "dedicated path" and a "dial-up path."

Dedicated analog paths are *point-to-point* connections which include a transmission mechanism (telephone circuit, satellite circuit, optical fiber circuit, radio circuit, infra-red circuit, etc.) and an "interface" at each end to make the analog signals available to modem equipment for conversion to the digital signals used by the computer or terminal. Dedicated paths are either available on a permanent basis or on a preplanned schedule of usage.

A dial-up path uses the telephone network to establish a connection between a terminal and a computer system on an ad-lib basis. An example would be the dial-up call a correspondent in the field makes from his portable terminal to the station's computer system to file a script or read the newswire services. Dial-up paths can also be used to replace, temporarily, a failed dedicated path.

In addition to analog paths, some communications common carriers offer end-to-end digital services. These digital paths provide a relatively error-free transmission medium between terminals and computer equipment. (Analog transmission paths are subject to incremental degradation due to various factors; while digital technology permits re-generation of the original signal at intermediate points and at the far end of the path.) However, all "end-to-end digital" services are not the same.

Some carriers claim to offer "end-to-end digital" service, but use an analog circuit between the "digital" modems they supply. There is a difference. For true digital transmission, there should be no "analog sections" in the transmission path.

Two types of serial data communications transmission are widely employed—"synchronous transmission" and "asynchronous transmission". Each uses a different scheme to maintain synchronization between the data transmitter and a receiver at the far end of the circuit. Synchronous transmission passes both data signals and a "clock" signal. The clock signal is used by the receiver to determine when to check the data signal for the next bit. Asynchronous transmission passes only a data signal and relies on "start" and "stop" bits to maintain synchronization between the data transmitter and the far-end receiver. Equipment at both ends of an asynchronous data path must be set to the same number of bits-per-second and the same number of bits per character. The receiver waits for a start bit from the incoming path and then counts the data bits as they arrive. When the pre-set number of data bits per character has been received, the receiver awaits a stop bit which causes the character to be processed. The receiver then waits for the start bit of the next character, etc.

Multiplexers, devices which permit several terminals to share a data communications path between a remote location and a computer system, are used in newsroom computer systems to reduce the cost of such communications and, in some cases, to ensure error-free transmission of digital data between the locations.

Multiplexers are installed between a modem and the terminals. The MUX (multiplexer) has "ports" for each of the terminals it serves and gives each terminal access to the communications line through a *protocol* (a set of conventions which determines when and how the terminal can communicate through the MUX to the far end of the path). A multiplexer's purpose is to permit more than one terminal to share a single modem line to a remote computer system. See Fig. 16.

Two schemes for multiplexing several digital devices onto a single line are popular. One is *time-division multiplexing* (TDM) and the other is *statistical multiplexing* (STATMUX).

Time-division multiplexing divides the communications line's data transmission into a number of "time-slots" which are assigned to specific multiplexer ports. An eight-port TDM MUX, for example, would have eight time-slots, one for each port. In rotation, each port is given a chance to transmit and/or recieve data during its assigned time-slot. The data communications path between the TDM MUXs carries a composite signal which includes data from each of the eight ports. The path passes data at a given number of "bits-per-second" (see glossary). In a typical case, a path might be capable of sending and receiving at 9600 BPS (bits-per-second) and be connected to eight-port TDM MUXs at each end. If the eight time-slots were divided equally, each device could pass data at one-eighth of the 9600 BPS rate, or 1200 BPS each. In practical applications, however, time-slots are frequently divided unequally in order to accomodate a mixture of speeds among the MUX ports. Typical examples appear below.

Port #	Example A Bits/sec.	Example B Bits/sec.	Example C Bits/sec.
1	4800	2400	1200
2	2400	2400	1200
3	1200	1200	1200
4	300	1200	1200
5	300	1200	1200
6	300	1200	1200
7	150	—	1200
8	150	—	1200
Totals:	9600	9600	9600

In Example A, half of the data communications path's 9600 BPS transmission rate is assigned to port 1, with the remainder divided among ports 2 through 8. Example B shows an

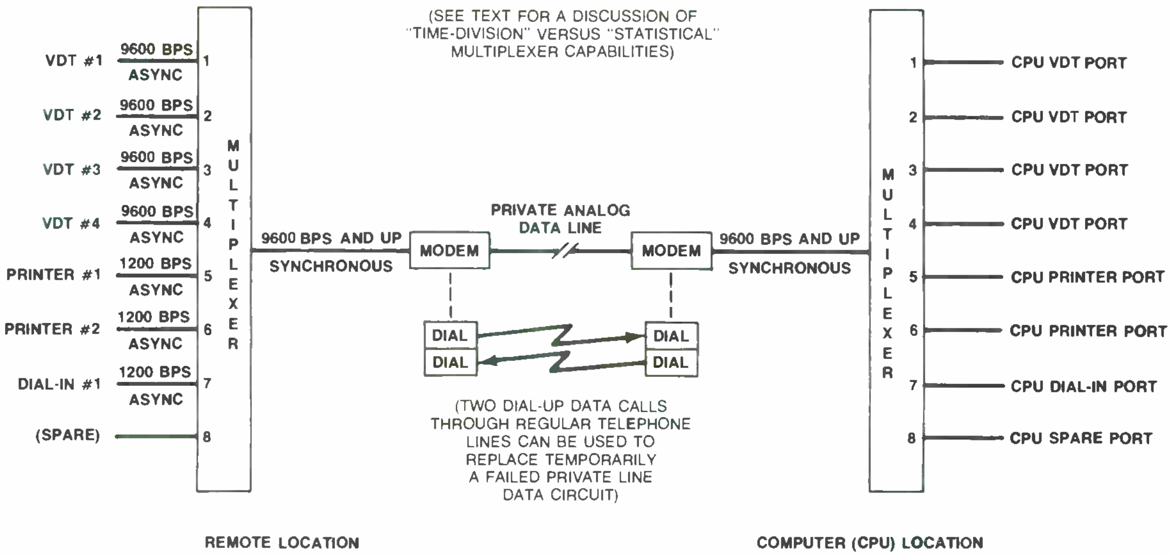


Fig. 16. Conceptual multiplexer application.

eight-port TDM MUX configuration using fewer than eight ports but using the full 9600 BPS capability of the data path. Example C has each of the eight ports using one-eighth of the path's transmission rate. TDM technology permits a maximum combination of port speeds up to the bit-rate at which the data path between the MUXs operates.

Statistical multiplexers, in contrast, offer an apparent data *thruput* (see Glossary) higher than that which would be expected from a data path of a given BPS speed. STATMUXs allocate the data communications path's transmission capacity dynamically. Terminal or computer ports with "nothing to send" are not given a portion of the path between MUXs. If one terminal user is "scratching his or her head" to decide what the next step is and another is actively entering data from the keyboard, the active user's keystrokes will be transmitted over the path normally; the user "looking up the next step" will not be allocated "space" on the communications path until he or she returns to active use of the terminal. Depending on terminal usage patterns, STATMUXs can provide an apparent thruput of two or more times that of a TDM MUX system.

Newswire Services

Most newsroom computer systems permit the various newswire services such as AP, UPI, and Reuters to be "read" and stored in the computer's memory. The newswire stories are then available on video terminals throughout the computer system. Users can "scan" the wires on their screens, print a paper-copy of an interesting story, re-write a wire story to add a local slant, etc.

The more sophisticated newsroom computer systems offer features which can significantly add to productivity in a station's news operation. For example: bulletins, urgents, and flashes from a wire service can cause terminals to "beep" and display the "slug line" of the priority story (interested users may then request a full display of the newswire story). Some systems can interpret the *ANPA* header information sent by most wire services and divide the stories into directories of categories such as "Foreign", "National", "State", "Regional", "Business", "Weather", etc. This permits the user to scan only the stories which interest him or her. In some systems, users can create personal directories of stories which contain specified "key-words". A writer working on a gun-control story might create a personal directory with a key-word of "gun". From then on, all wire stories which contain the word "gun" would be listed in the user's personal directory.

Newswires are delivered to a station through dedicated telephone circuits or satellite receive dishes. Depending on the type of service ordered, the incoming newswire signals may be processed by modems, *selectors*, and/or *subsets* located at the broadcast station. Fig. 17 shows some typical newswire connections.

The modems, normally supplied by the newswire agency, are similar to those discussed under "Data Communications" above. They convert analog audio signals from the wire service into digital signals which can drive a printer and/or be connected to a computer system for processing.

Selectors are often supplied to "filter-out" newswire stories which do not apply to a station's

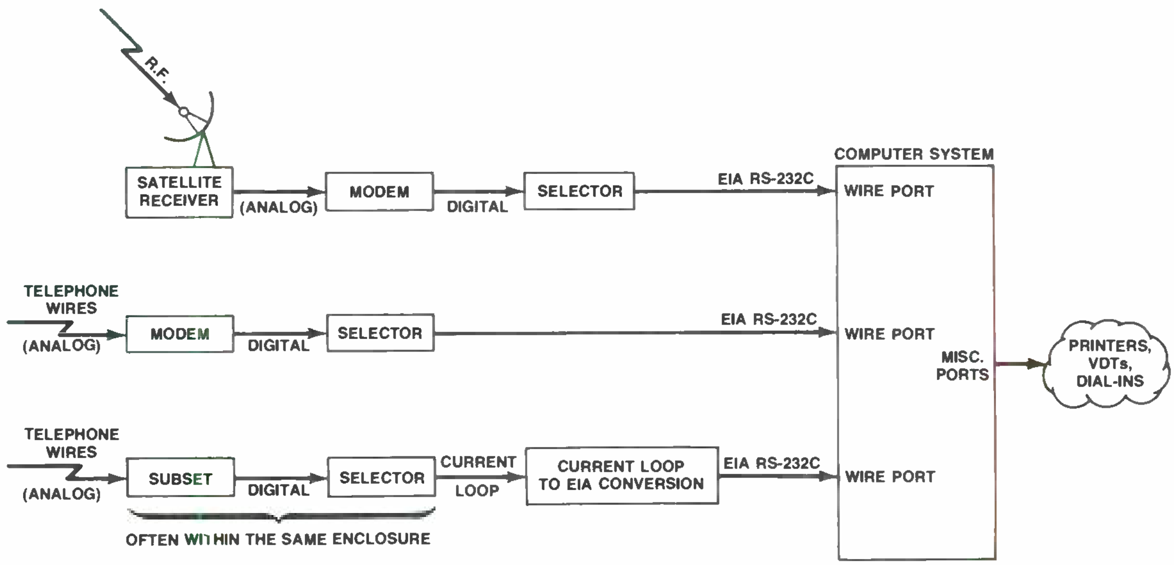


Fig. 17. Typical newswire connections.

coverage area, or information services to which the station has not subscribed. The selector unit is pre-programmed at the time of installation to pass certain classes of stories—based on the ANPA or special wire service headers—to the station's printer or computer. Other stories on the wire are rejected by the selector.

Subsets are typically supplied with low-speed (below 110 BPS) newswire services. These units supply a "current loop interface" to printers and computer systems. Most newsroom computer systems use a conversion device to convert the current loop signals into RS-232C compatible signals before they enter the system.

Interconnection

Cables, wires, modems, multiplexers, subsets, and other facilities are required to interconnect the various parts of a newsroom computer system. Some of these are normally supplied by the newsroom computer system vendor; others are the responsibility of the station.

Typically, a station should expect to supply the following interconnection facilities when converting to a newsroom computer system.

- Cables: either RS-232C or coaxial, to connect to local terminal equipment (VDTs and Printers)
- "Taps" or "drops" of newswire feeds (often a joint venture between the station and the vendor)
- "Dialtone" lines from the local telephone company if dial-in access is required
- Data lines from remote locations, if required

The cables between terminals and the computer system are normally installed by the station, either using station personnel or an outside contractor. The computer system vendor will frequently work with station people in the planning and specification phases of the cable installation. RS-232C cables should have an overall shield wrap with a *drain-wire*, grounded only at the computer end. Cable routes should be planned to minimize the possibility of "noise crossover": keep computer cables away from low-level audio circuits and away from high-level radio frequency equipment where possible.

Two methods of interconnecting newswire feeds to a newsroom computer system are commonly used. The *tap* method assumes that the newsroom has an existing newswire service connected to a printer which will remain in service after computerization. This method uses a *Y-cable* or adaptor to split the newswire feed into two outputs, one for the printer and one for the computer. The splitter is normally supplied by the newsroom computer vendor. The other method uses a separate *drop*, supplied by the newswire service. The dedicated "computer drop" has its own modem, selector, and/or subset. The printer supplied by the newswire service remains on a separate drop which can be continued or disconnected. Since printers are normally supplied with a newsroom computer system, many stations elect to discontinue the newswire printers. Some stations install a transfer switch which permits the newswire to be printed directly on a computer system printer if the computer is not working.

"Dialtone" lines from the local telephone company, to permit field and remote bureau people to dial in to the computer system, are delivered on an "interface unit" supplied by the phone company. An *auto-answer* modem interconnects the dialtone line with the computer system. The newsroom computer system vendor should specify the type of modem needed. In some cases, the vendor supplies modems as part of the newsroom system; in others, the station is expected to acquire the modems.

"Data lines" are used to interconnect relatively permanent remote locations such as bureaus to the newsroom computer. Such lines are special point-to-point circuits which are *conditioned* for data transmission and are available twenty-four hours per day. Modems—and multiplexers, if more than one remote terminal is needed—are installed at both ends of the circuit. Stations use data lines instead of dial-ins when the amount of traffic between a remote point and the computer justifies the cost or when the higher thruput of a data line is needed.

NEWSROOM COMPUTER SYSTEM ARCHITECTURE

The *architecture* of a newsroom computer system describes the way the system's hardware, software, and communications "building blocks" have been assembled to form a useful structure. Several basic structures are presented below; practical system architectures depend on a station's requirements, the newsroom computer vendor's system design, and cost factors. Fig. 18 shows the basic "centralized", "distributed", and "hybrid" architectures.

Centralized Systems

Centralized newsroom computer systems have at least one "computer room" which houses CPU, communications, and frequently test and monitoring equipment. A *computer room* may be anything from a previously unused closet to a large new space with special air-conditioning, power supply, and raised *computer-floor*. The

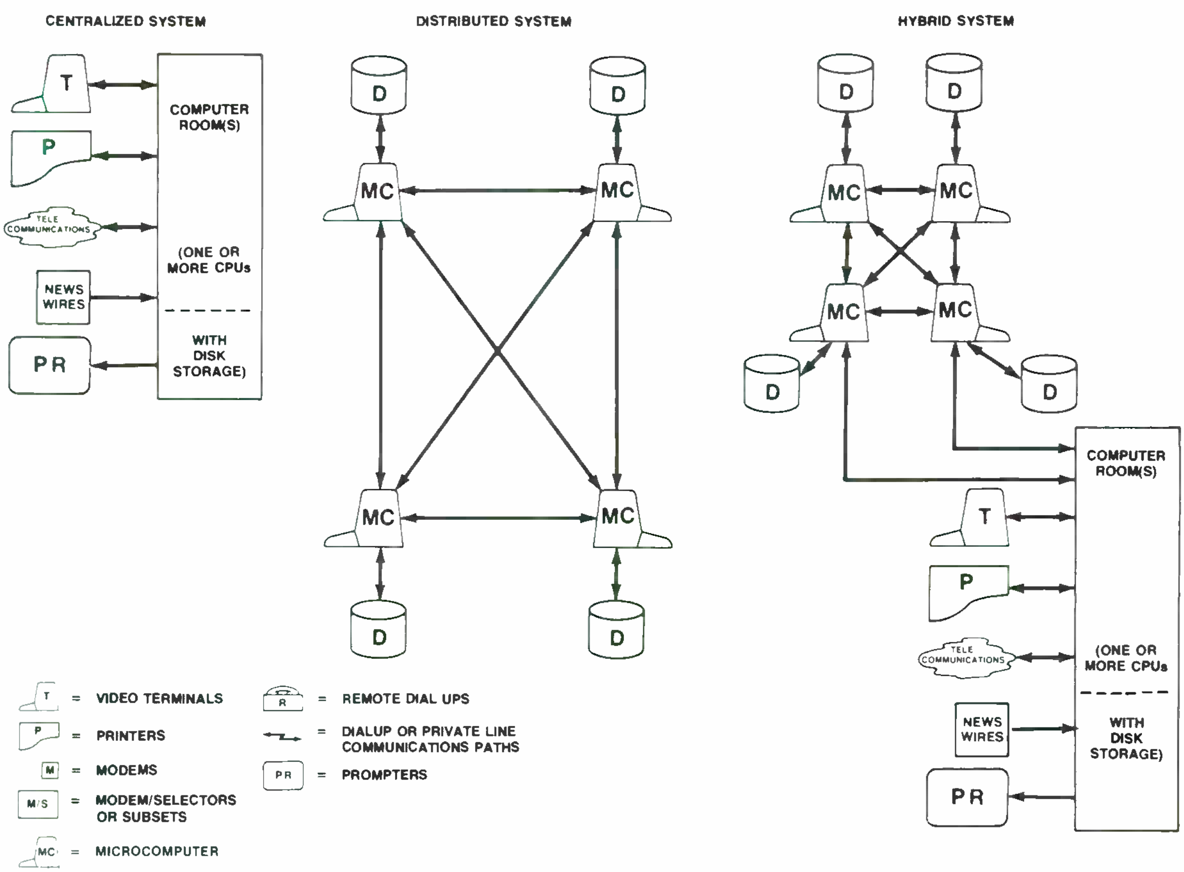


Fig. 18. Newsroom system architectures.

size and requirements of the newsroom system determine what is needed in the centralized site(s).

In centralized newsroom systems, all information flows through the computer room. The terminals, printers, dial-in lines, data lines, and newswire services connect directly to computer equipment in this room. The system's data files reside on magnetic disk or tape devices in this room. The *system console(s)* which permit a *system manager* to control the flow of work through the computer system and to reconfigure the system's hardware or software are located in this room.

The advantages and disadvantages of a centralized computer system architecture stem from centralization.

On the advantage side, centralized systems offer direct control of all system operations from a single location. In the central computer room, an operator can "tune" the system's workflow, make safety copies of the system's data files, install new software, resolve hardware or software or communications problems, monitor system security, etc.

Disadvantages in a centralized system architecture are centered around the "one point of failure" issue. Anything which adversely affects the central computer system can cause problems which may affect some or all terminals connected to the system. The computer room air-conditioning might fail, causing the equipment to overheat and stall; a disk drive which has tonight's newscast script on it might *crash* during the broadcast; the local electric service might go into a "brownout" or "blackout" which could cause a central computer system to lose some or all of its data files; the "cleaning person" might unplug the computer to get an outlet for a vacuum cleaner; or a fire caused by a faulty piece of equipment in the central room might damage the equipment around it.

Distributed Systems

The distributed newsroom computer system architecture places a small computer at each terminal location. The combination of a VDT, a computer, magnetic data storage equipment (usually floppy disks), and possibly a printer is termed a "workstation." At a workstation, the user interacts with his or her own dedicated computer to write scripts, read the newswires, assign crews to stories, or whatever the person's tasks are. Each workstation is a complete computer system, usually serving only one user at a time. Workstations can also be used as terminals for dial-up access to other computer systems.

The workstations, distributed where needed throughout a newsroom system, require some means of inter-communication to permit electronic transfer of one user's information to other users. This need can be satisfied by data lines, a *Local Area Network* (LAN), or a combination of the two. A writer may want to send a copy of a finished script to his or her editor's workstation for review; the news program producer may want to advise the staff of a revised running order for the broadcast; a user may want to send an advisory note to another user; and certainly, the newswire services must be sent to most (if not all) workstations in the system. Distributed architecture links individual *stand-alone* workstations into a *network* which forms the newsroom computer system.

The advantages and disadvantages of a distributed computer system architecture stem from the overall distribution of system resources.

Primary advantages of a distributed architecture include minimal susceptibility to the "single-point-of-failure" syndrome, the capability for each user to maintain direct control of his or her information, and a minimal need for human intervention to keep the system running. Since each user in a distributed system has a dedicated one-user computer system, other parts of the system can fail without having a major effect on the user's capability to perform his or her tasks at the workstation. User tasks which depend on information from other workstations or the newswires may be affected in some types of failures. The typical magnetic storage medium, floppy disks (and sometimes tape cartridges), gives the user direct physical control of his or her information; magnetic storage media can be considered as "portable file-cabinets" which the user is free to lock in a desk or carry along. In contrast to a centralized system, a distributed system normally has no central control console to be staffed (actually, each workstation gives its user the control console functions which apply to his or her own set of tasks).

Disadvantages of a distributed system architecture include lack of centralized control of the *database*, user functions, and data communications; logistical problems in propagating improvements or "bug-fixes" throughout the system; and frequently, higher cost than with other architectures. The lack of centralized control puts the burden of "system-management" on newsroom system users, some of whom will have no interest in or aptitude for such tasks. News writers want to write their scripts; the news program producer wants to control the program's running order; the technicians want to know what items to playback when; etc. Under the pressures of the broadcast news environment, these people may not be willing or able to make "backup-disk copies", to "restart" a neighboring terminal which has stopped communicating with its user or the rest of the network, to "re-boot" their own dedicated computer system, or to "challenge" an outside person attempting to access the system by dial-in telephone line.

Inevitable modifications to the system, whether to fix problems or to make improvements, are frequently difficult to achieve within a distributed system. Systems which use PROM (Programable Read-Only Memory) or ROM (Read-Only Memory) chips to store the newsroom system software will require a technician to change chips at each workstation whenever software upgrades are required. Some upgrades require all system units to be modified at the same time. In such a case, installation of the upgrade may require more than one technician, major pre-planning, and some *downtime* for the overall system.

Costs for a distributed newsroom system are typically higher on a per-workstation basis than with other architectures. Since each workstation contains its own one-user computer system and often a separate micro-computer-based communications processor, there is more hardware (and cost) associated with a distributed system workstation than with a terminal or printer connected to a central computer. However, cost-factor comparisons between a distributed system and other system architectures should include the "effective-cost-per-workstation" (divide the total system cost by the number of users who can be supported simultaneously).

Hybrid Systems

Hybrid newsroom computer system architectures attempt to combine the best features of both the centralized and distributed approaches. They have one or more central computer locations, terminals and communications connected to the central location(s), and workstations which connect to the central site(s) (which also may process newswires, dial-in lines, LAN communications with other distributed workstations, etc.).

Two types of hybrid newsroom computer systems are defined below; additional hybrid architectures can be expected in the future.

The first hybrid architecture combines *dumb terminals* and *intelligent workstations* into a newsroom computer network. The dumb terminals connect directly to a central computer system and can do nothing without the central computer services. The intelligent workstations also connect directly to the central newsroom computer network, but can operate in the stand-alone mode if connection to the central system is broken.

The second hybrid architecture places a portion of the computer "intelligence" in a central location and the remainder in the individual terminals connected to the central location. Each terminal normally relies on the central computer system to handle user functions, but if connection to the central equipment is interrupted, these "semi-intelligent" terminals can continue to handle a limited set of the users' tasks.

PLANNING A NEWSROOM COMPUTER SYSTEM

Like other technical projects, the installation of a newsroom computer system requires planning. The better the plan, the better are chances for successful project completion. This section addresses planning issues associated with the installation of a broadcast newsroom computer system.

Define Objectives

The first step in planning a newsroom computer system is to define the objectives of the change to a computerized news operation. This includes descriptions of current (probably manual) means of handling news information, of the proposed computerized means (possibly in several stages over time), of the anticipated benefits through computerization, and of the estimated effect on the station's business.

The definition of objectives should include both quantitative and qualitative factors. A quantitative example would be a station which currently processes fifty news stories a day through manual means and needs to process eighty stories per day to compete effectively in its market. Qualitative factors which tend to improve the newscast product include more rapid distribution of story and news program development information throughout the news operation, greater efficiency for writers and editors through automated *word-processing* features, and with these a productivity increase which can provide the newsroom staff more time to concentrate on broadcast journalism rather than the "mechanics" of getting a story on the air.

A useful tool in this stage of planning is the *work-flow diagram*. One should be done to show how information flows through the current newsroom; another should depict the flow after computerization. These diagrams should include items such as how the newswire stories are sorted and distributed, how crews and correspondents get their assignments, how the content and running order of news programs are created, how contact information is maintained, etc. The resulting drawings may be as simple or complex as the scope of a news operation warrants. They are useful in discussions with computer system vendors, station management, and the news operation staff.

Determine Workstation Requirements

The number of workstations, printers, and other devices to be connected to the newsroom computer system should be determined through careful analysis of the work-flow diagrams. Generate a list of functions and allocate the appropriate equipment to each function. An example is presented below.

TV News Workstation Requirements

Function	VDTs	Printers	Misc.
Assignment Desk	2	1	2 modems
Editor's Desk	1		
Writers	3	1	
Producer's Desk	1		
Anchorperson Office	1		
Studio A Control Room	1	1	
Studio A Anchor-person Set	1		3 prompters
Tape Room	2	1	1 label printer
Tape Library	1	1	1 label printer
Graphics	1	1	
Reporters and Crews	3	1	2 portable terminals
News Director	1	1	
Totals:	18	8	

Miscellaneous:
- 2 Modems
- 3 Prompters
- 2 Label Printers
- 2 Portable Terminals

Make a drawing or list of relationships between the terminals and the peripheral equipment. For example, the list above shows only one printer for two Assignment Desk VDTs and no printer for the Editor's Desk VDT. Most systems will permit a single printer to make printouts for several VDTs. In the case above, it might be logical to have the Assignment Desk printer serve both the Assignment Desk's and the Editor Desk's printing needs. Definition of such relationships is part of determining workstation requirements.

Special requirements such as unusual environmental conditions (temperature, humidity, altitude, salt-spray), non-standard electrical power, high RF (radio frequency) fields, etcetera should be defined.

Determine Newswire Requirements

Most newsroom computer systems excel at sorting and distributing incoming newswire stories. The computerized newsroom needs fewer newswire printers, uses less wire printer paper, and provides faster access to stories which "move" on the wire. Planning should answer three questions: "Which wire services are required?"; "How will they be distributed?"; and "How will newswires be processed in the event of a computer failure?".

Which newswire services to buy is normally determined by past practice at a station. However, computerization of a news operation frequently offers cost reduction through elimination of newswire printers and paper supplies. The savings might be used to offset the cost of computerization, or to add additional newswire services which could not be cost-justified previously.

Distribution requirements should be determined from the work-flow diagrams. Newswire stories on most wire services contain "header" information which specifies the story's classification: state, regional, national, business, sports, weather, etc. The computer "reads" each story header and can be instructed to route the story to one or more newsroom users. This can replace the "wireroom clerk" who used to tear, sort, and deliver printed newswire stories to specified newsroom desks. In a computerized newsroom, the users are alerted to an incoming story which relates to their function. The local editor is advised of local stories, the weatherman gets weather stories, sports gets sports, etc. Flashes, bulletins, urgents, and other advisories are frequently distributed to all terminals in a newsroom computer system. A distribution plan should be developed for each terminal in the system.

If the newsroom computer fails, some backup means of processing newswire stories should be available. One approach is to retain at least one newswire printer for each wire in the newsroom. Another, offered by several newsroom computer vendors, is to use the computer system printers to print the newswire stories while the computer is out of service. A switch is provided for each printer which transfers it between the computer system and an incoming newswire line. Newsroom computer system planning should include either, or a combination, of these approaches to keep the newswires flowing when the computer system is unavailable.

Determine Data Communications Requirements

Data communications lines are required in newsroom computer systems whenever terminals, printers, or other computer peripherals are remotely located. Direct interconnection of computer equipment through twisted-pair or coaxial cable is limited to maximum runs of up to several thousand feet at best. Station newsroom requirements for intercommunication with bureaus or field personnel beyond such cable limitations must include a data communications *network specification*.

A network specification can be as simple as one dial-in auto-answer modem for a tiny station, or as complex as a worldwide communication system serving hundreds of workstations for a major broadcast news organization. It should include, per each location, the quantities and types of equipment required. The location's work-flow diagrams, estimates of remote workstation data communications character-counts over time, and relative costs can then be used by the computer system vendor and/or an outside communications common carrier to define a data communications network architecture which meets station requirements.

CHOOSE A VENDOR

Few, if any, broadcast organizations can commit the resources in manpower, equipment, time, and materials required to create a newsroom computer system "from scratch." Fortunately, there are a number of newsroom computer system vendors active in the marketplace. This section presents suggestions on choosing a broadcast news computer system vendor.

Request for Proposals (RFP)

A "Request for Proposals" (RFP) describing the station's requirements and desired features of a newsroom computer system should be created. This might be a few pages for a single small station or several hundred pages for a group of stations or a major network. At a minimum, the RFP should include the newsroom's present and proposed work-flow diagrams, a description of the broadcasts supported by the newsroom, and an estimate of the workstation requirements. If possible, the RFP should include a job-by-job breakdown of the work done by each person in the news operation, sample forms and documents used in the current manual newsroom, floorplans showing the layouts of the newsroom and studios, descriptions of the station's technical facilities which might be connected to the newsroom computer, timetable requirements for the conversion to a computerized news operation (initial installation and possible phased expansion), business considerations, procurement terms and conditions, etc. Extensive detail in an RFP gives the responding vendors a better chance to propose a system which will meet the station's needs.

Proposal Analysis

The analysis of vendor proposals is more an art than a science. Some vendors will respond to an RFP with specific proposals; others may respond with few specifics but many sales brochures, testimonials from current customers, and a stream of sales-oriented correspondence directed at a station's "decision makers"; still other vendors may not respond at all. Sorting the "wheat from the chaff", discovering and understanding the specific benefits a proposed system can offer a station is important, but often difficult and time-consuming.

Whether a station receives a proposal from one vendor or several, the preparation of a "scoring matrix" will aid proposal analysis. The scoring matrix should show detailed station requirements, one line for each, at the left of the page. A column for each vendor responding should then be established further to the right, leaving space for a score or a "YES/NO" entry for each requirement line item. A short example appears on page 7.6-144; a real station's list of requirements would probably be longer.

A numerical scoring system (a scale of 0 to 10 or 0 to 100%) might be used instead of the "YES/NO" approach in the example above. If a computerized "spread sheet" system is available, it may be useful in proposal analysis based on numerical scoring.

Visit Vendor Installations

Key people in the station's News, Engineering, Financial, and/or Purchasing departments should visit at least one of the leading vendor's newsroom installations and possibly the vendor's plant. Discoveries made in such visits may reinforce or alter tentative vendor selection decisions based on RFP responses alone. Choose a vendor's newsroom of similar size and with similar requirements to those in the RFP.

Demonstration System

Some vendors may be willing to install a small "demonstration system" at a station for evaluation on a no-charge or "token payment" basis —if the station indicates a strong interest in the vendor's system. Such an arrangement is beneficial for several reasons. First, the station can evaluate the vendor's system under actual operating conditions, using the station's own newsroom procedures and information. Second, the vendor will have an opportunity to learn more about the station's news operation and possibly be able to

Radio News Scoring Matrix

RFP Requirement	Vendor A	Vendor B	Vendor C
Workstation Quantities:			
Initially 20	20	20	20
Expansion to 50?	YES	YES	max. 40
Remote Terminal Support:			
Lap-portables	YES	NO	YES
Fixed-site Workstations	YES	YES	YES
Data Communications	YES	limited	YES
Newsroom Functions:			
Assignments	YES	YES	YES
Script Preparation	YES	NO	YES
Newswires	YES	YES	YES
Desk Logs	YES	NO	YES
Studio Functions:			
Change Running Order	YES	n/a	YES
Prompter	YES	n/a	NO
On-line Bulletin Alert	YES	n/a	YES
Installation and Maintenance:			
Installation by Vendor	YES	3rd. pty.	YES
Hardware Maintenance	GOOD	limited	GOOD
Software Maintenance	GOOD	n/a	limited
Costs:			
Turnkey 20 Workstations	$ ________	$ ________	$ ________
Hardware Maintenance/mo.	$ ________	$ ________	$ ________
Software Maintenance/mo.	$ ________	$ ________	$ ________

suggest better ways of using the system when the full computerized newsroom is implemented. Third, the demonstration system can be used to train the newsroom staff prior to cutover to the full system. Finally, vendor and station personnel will gain experience in working together; a rapport or the lack of it will become obvious.

INSTALLATION

The sections below present some guidelines and considerations appropriate to the installation phase of a computerized newsroom. By the time installation is about to begin, the station people responsible should have had a chance for extensive exposure to the vendor's system's capabilities and requirements. Since no two news operations are exactly the same, installation requirements and plans must be tailored to match the station's needs.

Develop Interconnection Plan

Whether the station has chosen a system based on RS-232C, coaxial, or a mixed interconnection scheme, a complete plan of the cable runs should be developed. The plan should show each terminal, printer, workstation, newswire feed, dial-in modem, private line modem, computer port, and the relationship between them. Such a "cable list" can be used by station, vendor, or third party installation personnel to provide the connections between the various equipment in the newsroom system.

Develop Architectural Plan

Newsroom workstations and terminals normally will replace typewriters. Typically, the workstations and terminals require more desk-space than a typewriter and also have interconnection requirements to the rest of the newsroom system. Architectural adjustments to the physical layout of a station's newsroom may be required to accommodate computerization.

This may be a blessing, a curse, or may lie somewhere in between. Stations about to refurbish their newsroom facilities will find the architectural adjustments required for a computerized news operation fairly easy to accomodate. Others may discover that major physical changes will be required to support a computerized news operation.

In any event, the vendor and the station's architectural people should develop a plan to be approved, and possibly modified by the newsroom management and/or staff. This plan should address changes in furniture layout, lighting, HVAC (Heating, Ventilation, and Air Conditioning), electrical requirements, telephone communications, newswire-room facilities, etc.

Develop Installation Schedule

Once the interconnection and architectural plans are finalized, the station and the vendor(s) should develop an installation schedule which specifies the work to be done by each party and establishes "milestone" completion date targets for all project tasks. This schedule should be dynamic; tasks may be completed earlier or later than originally planned, causing inevitable revisions as the work progresses.

Project review meetings between all parties involved should be held on a regular basis to monitor progress and identify and solve problems. These meetings might be informal or formal, depending on the complexity of the newsroom system installation.

Develop Training Schedule

A formal training schedule should be developed by the station and the vendor's instructors. This is important no matter how tiny or large the newsroom system will be. Without proper training, the people who are expected to use the computer equipment can become fearful, confused, disgruntled, or at best, may not be able to use the system efficiently. A good training program can help to avoid these problems.

The station should prepare a training roster which lists each person's name, position, and a brief description of tasks they will need to perform on the computer. Plan to train not only the regular users, but also, their supervisors, engineering personnel, and even station management. The roster should be discussed with the newsroom system vendor to establish a schedule of classes which address specific job functions. Separate sessions might be dedicated to assignment desk people, writers, producers, reporters, etc.

Training sessions should be limited to two to three hours at a time for most people. Lengthier sessions tend to produce diminishing returns. People with several different tasks or with complex tasks will need more sessions than casual users or those with only a primary task or two. If possible, everyone should be scheduled for a minimum of two sessions to permit "learning reinforcement" and to resolve any retrospective questions that may have arisen since the previous session.

The classes should be held in a special training area apart from the trainees' work areas. A conference room with several terminals, a blackboard, chairs and tables would be ideal. The "classroom" is normally a temporary facility just for initial training. However, some of the larger news operations may maintain it permanently.

MAINTENANCE

Newsroom computer systems require several types of continuing maintenance. Hardware failures require either replacement of the failed equipment or a repair technician's attention. Software maintenance includes the installation of *fixes* for *bugs* and the *migration* from one software version to a newer, enhanced *release-level*. The system's data file maintenance includes creation of backups, restoration of damaged files, control of access permissions and user lists, and administration of data archives.

Hardware Maintenance

Hardware maintenance may be done by the vendor, a third-party maintenance organization, the station's engineers, or a combination of the three. Vendors normally offer several hardware maintenance plans from which the station can choose.

Several newsroom computer system vendors offer a 24-hour "Help Line" service which station personnel can call in the event of problems with the computer system. The vendor people staffing such a telephone line will guide station personnel, whether technical or non-technical, through a series of tests which should be able to isolate the cause of the malfunction. Depending on what is discovered and what maintenance arrangements have been made between the vendor and the station, the Help-Line operator may ask for a faulty unit to be returned to the vendor, may dispatch a repair person, and/or may ask that the station exchange the failed equipment with a spare device on hand at the station.

Most vendors propose a regular schedule of preventive maintenance which may include cleaning air filters, vacuuming or spraying circuit cards, wiping video screens, cleaning tape heads, tightening cable connectors, etc. These tasks are usually the responsibility of a station-designated *key operator* from among the newsroom or engineering staff.

Software Maintenance

Newsroom computer software—the programs which cause the hardware to perform as a newsroom computer system—will require maintenance. Few, if any, software systems are without "bugs" (problems which can adversely affect the user's ability to perform his or her tasks through the computer system). Most software systems are *enhanced* periodically to provide new features and functions for their users. Stations using newsroom computer systems will need to be aware of and/or participate in "software maintenance" both to eliminate bugs and to add enhancements to newsroom systems.

Software updates are delivered in various forms. Some systems use magnetic tape; others use magnetic disks; others use PROM chips; some use a combination of the above *media*. Station personnel may or may not be involved in the installation and maintenance of software, but should be fully advised of any changes proposed by the vendor. The station should approve and schedule installation of such alterations, in advance.

System File Maintenance

A station is normally responsible for maintaining its own system data files. The newsroom computer system usually provides hardware and/or software "tools" to aid the station in this task. Some systems provide extensive file maintenance facilities, while others expect individual users to maintain control of their own data files.

One or more station people may be assigned file maintenance tasks. These people may be termed "Super-users", "Key Operators", "Database Administrators", or "SYSOPs (System Operators)". Their function is to keep the system's information files free of *data corruption* caused by hardware and software problems or user mistakes. Frequently, the SYSOP also controls the *access permission file* which lists the users, their passwords, and their *security levels*.

In most systems, the data files are periodically copied to backup disks or tapes. Later, if a file is damaged or erased, the SYSOP can restore the original file by copying from the backup disk or tape into the active system memory. The backup file copies are often retained long after their contents are outdated. These *data archives* are usually maintained by the SYSOP.

SECURITY

Computer systems are vulnerable to damage from several sources. The system may occasionally damage itself when hardware or software fails. However, external threats are a more frequent cause of harm. Appropriate security measures can reduce a computer system's exposure to damage from sources outside the system.

Passwords

While a computer system exists to serve people, people are a frequent cause of damage to the system that serves them. The damage may be accidental or malicious. Most newsroom computer systems offer *password security* to limit such occurrences.

Password security systems require that each user desiring access to the computer system enters an identifying name. The system then requests entry of a password (a set of letters and/or digits which are known only by the user and the computer system). If the name and the password the user enters match an entry in the system's "access permission file", the user gains access to the system; if not, the user is denied access. Most newsroom systems give a potential user several chances to enter a valid name/password combination to allow for mis-strikes on the keyboard.

The name/password combination is used in some newsroom systems to determine the *file access privileges* of the user. These systems can limit the access of individual users or groups to only certain data files. Some can also limit a given user or group to *read-only* status (no update capability) for specified files.

Telephone Lines

Most newsroom computer systems use dial-in telephone lines to provide computer access for a station's people in the field. These lines are a potential pathway into the system for unauthorized users who may simply be "curious" or who may have malicious intent.

Password security provides a measure of protection, but can be thwarted. Several precautions can be taken. First, users should be encouraged to change their passwords frequently. Second, the SYSOP should maintain tight control of the user access permission list; users leaving employment at the station should be deleted from the list upon termination. Third, the dial-in telephone numbers should be changed periodically.

An additional approach uses *call-back modems*. These units accept incoming data calls and request the caller's identification and/or the caller's telephone number. Some of these devices have their own internal "user lists" which they check for access permission; others *log* the request; both types return the potential user's call, if valid, and establish a data communications path between the user and the computer system. The user then must pass the computer system's password security test.

Some newsroom computer systems provide a log of all users entering and leaving the system, as well as abortive entry attempts. This information can be helpful in the identification and containment of security breaches.

Equipment

Computer equipment should be secured from three types of damage. The ac (alternating current) power supply, the environment, and inappropriate human activities can damage a computer system.

The ac power supply should be free of *spikes*, *noise*, RF energy, and remain at a constant voltage throughout *brownouts*, *power dips*, etc. The station may wish to install power-conditioning equipment such as *spike-suppressors* or UPSs (Uninterruptable Power Supplies) to provide clean power to the newsroom computer system. Such equipment permits the computer system to survive during temporary commercial power problems.

Environmental security requirements depend on the equipment types. Most newsroom systems can function in any environment in which a human is comfortable. However, some systems (especially those employing floppy disks) are susceptible to damage from air-borne particles which a human would seldom notice.

Newsroom computer system equipment, where possible, should be kept in a separate, secure area. In the case of centralized or hybrid systems, the central "computer room" should be the secured area. Only people with a valid task to perform should be permitted physical access to the equipment. Distributed systems present a greater security risk; there is no central computer room to lock-up.

Database

Database security is primarily the responsibility of the SYSOP. The backup/restore procedure permits damaged or missing files to be replaced. The user access permission list keeps outsiders out of the system and gives valid users access only to the files they need to do their jobs. The log of access attempts permits speedy detection of potential security breaches. An effective SYSOP uses these tools to maintain database security.

CONCLUSION

This brief overview has concentrated on some of the issues unique to broadcast newsroom computerization. For more information, talk with stations who have computerized their news operation. Talk with the newsroom computer vendors. And finally, talk with the station's own news people.

It has been said that "The question is not *whether* to computerize a newsroom, but *when*".

APPENDIX A

ASCII Code Chart

ASCII Name	Description	Decimal Value	Octal Value
NUL	Null	0	000
SOH	Start of Heading	1	001
STX	Start of Text	2	002
ETX	End of Text	3	003
EOT	End of Transmission	4	004
ENQ	Enquiry	5	005
ACK	Acknowledge	6	006
BEL	Bell	7	007
BS	Backspace	8	010
HT	Horizontal Tabulation	9	011
NL (LF)	New Line (Line Feed)	10	012
VT	Vertical Tabulation	11	013
FF	Form Feed	12	014
RT (CR)	Return (Carriage Return)	13	015
SO	Shift Out	14	016
SI	Shift In	15	017
DLE	Data Line Escape	16	020
DC1	Device Control 1	17	021
DC2	Device Control 2	18	022
DC3	Device Control 3	19	023
DC4	Device Control 4	20	024
NAK	Negative Acknowledgement	21	025
SYN	Synchronous Idle	22	026
ETB	End Transmission Block	23	027
CAN	Cancel	24	030
EM	End of Medium	25	031
SUB	Substitute	26	032
ESC	Escape	27	033
FS	File Separator	28	034
GS	Group Separator	29	035
RS	Record Separator	30	036
US	Unit Separator	31	037
SP	Space	32	040
!	Exclamation Point	33	041
"	Quotation Mark	34	042
#	Pound Sign	35	043
$	Dollar Sign	36	044
%	Percent Sign	37	045
&	Ampersand	38	046
'	Apostrophe	39	047
(	Opening Parenthesis	40	050
)	Closing Parenthesis	41	051
*	Asterisk	42	052
+	Plus Sign	43	053
,	Comma	44	054
-	Hyphen (Minus Sign)	45	055
.	Period (Decimal Point)	46	056
/	Slash	47	057
0	Zero	48	060
1	One	49	061
2	Two	50	062
3	Three	51	063
4	Four	52	064
5	Five	53	065
6	Six	54	066
7	Seven	55	067
8	Eight	56	070
9	Nine	57	071
:	Colon	58	072

;	Semi-colon	59	073
<	Less-than Sign	60	074
=	Equal Sign	61	075
>	Greater-than Sign	62	076
?	Question Mark	63	077
@	At-the-rate ("At Sign")	64	100
A	Uppercase A	65	101
B	Uppercase B	66	102
C	Uppercase C	67	103
D	Uppercase D	68	104
E	Uppercase E	69	105
F	Uppercase F	70	106
G	Uppercase G	71	107
H	Uppercase H	72	110
I	Uppercase I	73	111
J	Uppercase J	74	112
K	Uppercase K	75	113
L	Uppercase L	76	114
M	Uppercase M	77	115
N	Uppercase N	78	116
O	Uppercase O	79	117
P	Uppercase P	80	120
Q	Uppercase Q	81	121
R	Uppercase R	82	122
S	Uppercase S	83	123
T	Uppercase T	84	124
U	Uppercase U	85	125
V	Uppercase V	86	126
W	Uppercase W	87	127
X	Uppercase X	88	130
Y	Uppercase Y	89	131
Z	Uppercase Z	90	132
[	Left square bracket	91	133
\	Back slash	92	134
]	Right square bracket	93	135
↑	Circumflex ("Up Arrow")	94	136
_	Underscore	95	137
`	Grave Accent	96	140
a	Lowercase a	97	141
b	Lowercase b	98	142
c	Lowercase c	99	143
d	Lowercase d	100	144
e	Lowercase e	101	145
f	Lowercase f	102	146
g	Lowercase g	103	147
h	Lowercase h	104	150
i	Lowercase i	105	151
j	Lowercase j	106	152
k	Lowercase k	107	153
l	Lowercase l	108	154
m	Lowercase m	109	155
n	Lowercase n	110	156
o	Lowercase o	111	157
p	Lowercase p	112	160
q	Lowercase q	113	161
r	Lowercase r	114	162
s	Lowercase s	115	163
t	Lowercase t	116	164
u	Lowercase u	117	165
v	Lowercase v	118	166
w	Lowercase w	119	167
x	Lowercase x	120	170
y	Lowercase y	121	171
z	Lowercase z	122	172
{	Opening brace	123	173
|	Vertical line	124	174
}	Closing brace	125	175
~	Tilde	126	176
DEL	Delete	127	177

APPENDIX B

Publications

EIA RS-232C Specification

The EIA RS-232C specification details the electrical and physical parameters of a standard interface between Data Communications Equipment (DCE) and Data Terminal Equipment (DTE), which includes computer systems. Copies of this document are available from:

EIA Engineering Department
Standards Orders Office
2001 Eye Street, N.W.
Washington, DC 20006

Newswire Protocols

Specifications of the communications protocols used by newswire services are presented in "Wire Service Transmission Guidelines" (Special Report Number 84-2) and in "Low-speed Wire Service Transmission Guidelines" (Bulletin #1220), American Newspaper Publishers Association. Copies of these documents are available from:

ANPA, The Newspaper Center
Box 17407
Dulles International Airport
Washington, D.C. 20041

GLOSSARY

The terms and "computerese buzz-words" defined below represent only a portion of the jargon used by computer people (especially the sales persons). When in doubt, require them to "define their terms".

Absolute Code

A computer file containing binary numbers which represent the instructions and data a CPU needs to execute a given program.

Access Permission File

A computer file containing lists of users and the areas of the system to which each has access.

Address

A number which identifies a specific memory location or I/O port in a computer system.

ALU(Arithmetic/Logic Unit)

The circuit which performs mathematical and logical operations on binary numbers as directed by the computer's programming.

Analog

Signals which vary smooothly as opposed to digital signals which vary in steps. In data communications, modems are used to convert computer and terminal digital signals into modulated analog signals which are compatible with telephone lines and other transmission circuits.

ANPA Standards

A set of guidelines published by the American Newspaper Publishers Association (ANPA) defining standard protocols for newswire data transmissions. (See Appendix B)

Applications

In "computerese", a computer program or set of programs which perform a specific function. Functions as large as "a complete newsroom system" or as small as "print an audio-cart label" may be termed "applications".

Architecture

A plan which specifies how hardware, software, and/or communications "building blocks" fit together to form a computer system.

ASCII(American Standards Committee on Information Interchange)

The specification of the binary codes which represent numeric, alphabetic, and special control characters for data transmission. (See Appendix A)

Asynchronous

In data communications, a scheme to maintain synchronization between a data transmitter and far-end receivers through adding special "start" and "stop" bits to each character transmitted. The transmitter and the receiver must have been previously configured to the same bit-rate and number of bits per character. The receiver detects the start bit, counts the data bits as they arrive, and then awaits a stop bit on a per-character basis.

Auto-answer

A device, typically a modem, which detects "ring signal" on a telephone line and automatically goes "off-hook" to answer an incoming data call.

Backup

Redundancy—duplicate hardware, software, and/or data which permits graceful recovery from system faults.

Baud

In data communications, the number of signal states transmitted per second. This is not to be confused with "bits-per-second"; some transmission schemes send two or more bits in every change of signal state. A communications path with a thruput of 9600 bits-per-second may be signalling at only 2400 BAUD, communicating 4 bits of data within each signal transition.

Binary Digit

A numerical digit in the radix 2 numbering system which is based on only two values per digit (zero and one, or "off" and "on"). The binary numbering system is extensively used in computer systems because of the ease with which electronic circuits can assume the two states of "off" or "on".

Bit

An acronym for "Binary digit".

Bit-rate

The number of bits transmitted in a given time period, typically per second.

Bit-width

The number of bits communicated at a time on a given parallel path. Parallel paths are typically used within an ALU, between the ALU and the bus, and between the ALU and I/O ports. An ALU may have a 16-bit internal bit-width but only an 8-bit path to the bus and external I/O devices.

Bits-per-second

In data communications, the number of binary digits transmitted per second; not to be confused with BAUD.

BPS

(See BITS-PER-SECOND)

Bug

Primarily, a term used to characterize mistakes made by software authors which cause the computer system to malfunction or to perform in unanticipated ways; sometimes used in reference to hardware or communications faults.

Bus

Electrical connections which permit various modules of a computer system to share system resources. A CPU bus may interconnect the CPU with memory, I/O ports, controllers, etc. LANs with a bus structure connect workstations through a common communications link.

Byte

Eight bits of data (serial or parallel)—a character.

Call-back-modem

A modem which receives an incoming call requiring access to a computer system, requests a password or the caller's phone number, checks a list of authorized passwords, and, if the call is valid, returns the user's call to establish a data communications path.

Carry-on-terminal

A terminal which will fit under an airline seat.

Character

A five to eight bit binary number representing a "printable" or "non-printable" transmission character in any of several communications codes. (See Appendix A for the frequently-used ASCII codes)

Chip

An integrated circuit.

Clock

The circuit which generates timing pulses used by computer hardware to maintain synchronization among the computer system's modules. Or, a name for the pulse-train which permits such synchronization.

Command

Hardware commands are typically program instructions which the hardware executes in response to the binary numbers in an absolute code module. User commands are usually "mnemonic" (intended to be easily recalled) words or phrases which the computer software interprets and acts upon.

Common-carrier

In communications, a "telephone company", a "long-distance company", an International Record Carrier (IRC), or a Postal/ Telegraph/ Telephone (PTT) administration in a foreign country.

Computer

Variously refers to the hardware, the hardware/ software combination, and (to some users) to the terminals connected to a computer system.

Computer-floor

Typically, a raised-floor arrangement which permits computer equipment to be interconnected by running the interconnecting cables under a segmented floor-tile arrangement. The "computer-floor" tiles (usually two-by-two feet square) can each be lifted for access to the under-floor cableway.

Concentrator

Equipment which, with internal program capabilities, handles multiple devices (VDTs, printers, and communications) and appears to a CPU as a single device.

Conditioned line

In data communications, a circuit with transmission parameters adjusted specifically to pass analog data signals at a given speed with a minimum error rate.

CPU

A computer's Central Processing Unit—the ALU, the equipment in a "computer room", or a user's concept of "the computer". Any of these concepts are valid.

Crash

A disastrous failure of computer system hardware and/or software.

Cursor

On a VDT screen, an indicator which points to the current screen selection or the next character position. (See Fig. 9)

Data

In a computer system, information stored and/ or manipulated by the system.

Data archives

Storage, typically on magnetic disk or tape, of outdated computer data for historical purposes. Usually in newsroom computer systems, this archival information is stored separately from the computer system. When needed, archival files can be reloaded into the system for on-line access. Some newsroom systems offer on-line archives: old scripts, a morgue, and/or content descriptions for filed video and audio materials.

Data corruption

Incorrect, missing, or jumbled computer information.

Data file

Information stored in a computer system under a specific heading or title (equivalent to a physical file folder containing one or more pages of information written on paper).

Data line

An electrical, radio, and/or optical path between parts of a computer system which permits the transfer of data signals among the parts.

Database

A collection of data files, sometimes including descriptions of how the files are organized and how they relate to each other.

Database administrator

A person responsible for the maintenance of a database.

Decode

The conversion of information from one representation to another.

Dial-in

A software feature and/or equipment which permits a potential user to access a computer system through a dial telephone network.

Dialtone line

A regular telephone line, supplied by the local telephone company, which permits a user to dial other telephones throughout the country or the world (also known as POTS—Plain Old Telephone Service). It is prudent when using data communications on a dialtone line to use direct "central office" lines instead of those which pass through a switchboard or PBX (Private Branch Exchange). Switchboard and PBX lines often suffer from transmission degradations which can cause errors in data transmission.

Digital

Signals which vary in discrete steps as opposed to analog signals which vary smoothly.

Directory

A list of data files which can be accessed by the user.

Disk

A magnetic storage medium which contains data files and/or programs.

Disk storage

Storage of data or program files on a disk.

Display

A visual presentation of computer-generated information to the user —typically on a CRT (Cathode Ray Tube) or LCD (Liquid Crystal Display) device.

Display attributes

Various forms of video presentations, including: reverse-video, underscored text, high-and low-intensity displays, italics, bold characters, "blinking" fields, colored areas, etc.

Downtime

The duration of a failure (hardware, software, or communications) which affects a computer system's users.

Drain-wire

Typically a bare-wire conductor which maintains electrical contact with an enveloping shield surrounding one or more signal conductor wires within a multi-conductor cable.

Drop

A connection at the end of a data line which services a computer port, a modem, or terminal equipment.

Dumb terminal

Terminal equipment which permits a user, only when connected to a computer system, to perform his or her tasks. This type of equipment does not allow the user to do useful work in a "stand-alone" mode.

Enhancement

An improvement in hardware and/or software which adds new features or functions to the computer system.

Executable code

(See Absolute code)

File

Information stored in a computer system under a specific heading or title. Files either contain program instructions or data.

File access privilege

Permission to use a file. Users are assigned access privilege "levels" which the system uses to determine whether to grant a user access to a data file.

Fixes

Repairs to software intended to eliminate bugs. Sometimes used to refer to hardware or communications repairs.

Floppy disk

A removable magnetic storage medium shaped like a 45 RPM record and housed in a protective carrier. Floppy disks come in several physical sizes ranging from three-inch to eight-inch diameters. The amount of computer data they can store ranges from about one hundred thousand bytes to several million bytes.

Function key

In a terminal keyboard, one or more buttons which when pressed cause actions to be performed either within the terminal or through the computer's program. Examples are "ERASE", "CURSOR UP", "CLEAR SCREEN", "DELETE LINE", etc.

Graphics

Visual presentations of computer information such as charts, graphs, drawings, and pictures; anything displayed or printed other than the alphabetic, numeric, and punctuation characters found on a normal typewriter.

Hard-wired

A term used to describe the direct electrical connection of two parts of a computer system through metallic conductor(s).

Hardware

The physical equipment in a computer system, including computers, concentrators, terminals, modems, disk drives, and other devices.

Help-line

A telephone number users can call to get human assistance in the use of a computer system or to report equipment or software problems.

I/O

Input/Output; the movement of information into (input) or out of (output) a computer device.

Instruction

A binary number which causes the ALU to perform a function. Or, the mnemonic name a human programmer uses to represent such a binary number.

Instruction register

A circuit within the CPU which holds a binary number representing an instruction to be executed.

Integrated circuit

A microelectronic component, typically containing many semiconductor junctions arranged to perform complex functions.

Intelligent workstation

Typically a desk-top computer system with a communications link to other computer devices throughout a newsroom system. Intelligent workstations have internal microprocessors, memory, and often either disk or tape storage devices.

Interface

A scheme for connecting one part of a computer system to another; or, the hardware and/or software implementation of such a connection.

Key operator

A person responsible for maintaining a useful computer system and aiding users who have questions or problems with the system. Key operators typically deal with relatively non-technical aspects of a computer operation; they call in hardware or software experts when major problems are encountered.

Keyboard

A set of buttons (keys) which a user strikes to cause a character or command to be transmitted from a terminal to other parts of the computer system. Most terminal keyboards have a set of keys similar to a typewriter. Some have additional keys which are used to invoke computer system features and/or provide a "numeric keypad" which is a set of keys arranged in calculator format.

LAN

A "Local Area Network" which interconnects terminals, workstations, printers, and other computer system devices through relatively short runs of "twisted-pair", coaxial, or optical cables.

Language

In computer programming, a structured syntax which permits a human to manipulate mnemonic symbols instead of binary numbers when creating a list of instructions (a program) for a computer system.

Lap-portable

A microcomputer or terminal which can be operated conveniently while resting on the user's lap.

Link

A data communications path which interconnects two parts of a computer system. Links may be established through hardware, software, or a combination of the two.

Local Area Network

(See LAN)

Log

A record of activities or performance. News people may use the computer system to maintain logs of their activities; most computer systems keep a log of their internal activities and performance.

Mainframe

A central computer system, frequently a large facility serving many users with varied requirements; seldom used to satisfy the requirements of a news operation.

Media

Magnetic disks or tapes which provide data storage.

Memory

In a computer system, the circuits which store binary numbers representing data or program instructions. Two types of memory are prevalent: ROM (Read-Only Memory) and RAM (Random Access read/write Memory).

Menu

A list of choices presented by a computer system's software from which a user can select a computer function to be invoked.

Microcomputer

A computer designed around a microprocessor chip.

Microprocessor

An integrated circuit chip which functions as an ALU. The term is sometimes used to refer to a device which contains a microprocessor.

Migration

The movement toward installation of enhanced or more powerful hardware and/or software in a computer system.

Mini-computer

A computer system on a scale somewhere between a microcomputer and a large mainframe.

Mirror

A backup process which stores data simultaneously on two separate magnetic disk systems so that each has a full copy of the database. If one disk fails, the other will still have a good copy of the data.

Modem

A modulator-demodulator. In data communications, equipment which converts digital signals from a computer or terminal into modulated analog signals which can pass through telephone lines or other transmission paths.

Module

Part of a system, usually with a definable purpose. In software, a list of computer instructions in source, object, or absolute code format which will perform a specific task. In hardware, an assembly of electronic components with a specific function.

Multiplexer

A device which permits more than one signal to pass through a single transmission path. In data communications, the equipment which permits a number of terminals to share a single communications link.

Network

In data communications, the interconnection of computers and terminals through some combination of facilities such as data lines, modems, multiplexers, hard-wired cable, LANs, and/or dial-in telephone lines.

On-line

A module or system configured and/or connected to perform its function. Sometimes used to refer to a person using a computer system, as in: "John Smith is on-line".

Operating system

Software which logically interconnects the hardware of a computer system and provides the utility functions needed for an application program to be executed by the system. An operating system only makes the computer available as a general-purpose system; in order for the computer to perform newsroom tasks, the newsroom application software must be executed under the auspices of the operating system. Users seldom interact directly with an operating system; their interaction is with the newsroom application software. Key operators and SYSOPs may need to understand parts of the operating system to be able to do their jobs.

Output

Data flowing outward from a hardware or software module. Also, the results of that flow—printed pages, video displays, etc.

Parallel

In hardware interconnection, the simultaneous communication of more than one data bit between equipment modules. Examples are: a printer interface which uses eight conductors to move an entire BYTE of data (eight bits) to the printer at a time, or an internal bus within a CPU which passes sixteen bits simultaneously to the modules connected to the bus.

Password security

A scheme for limiting access to all or portions of a computer system by requiring a potential user to enter a previously established set of keystrokes before the system will permit such access.

Peripheral

A device connected to a computer system. Examples are: printers, terminals, disk storage units, modems, multiplexers, prompters, etc.

Point-to-point

A direct communications link between two parts of a computer system.

Port

In hardware, a module which permits the transfer of data to and/or from a computer system or peripheral; in software, the process through which applications are converted to be able to "run" on different computer hardware or operating systems.

Printer

A terminal device which converts incoming data signals to printed pages.

Private line

In data communications, a dedicated (as opposed to a dial-in) telephone line for transmission of modem analog signals between two or more points.

Program

In computer systems, a list of instructions to be executed by the ALU. A program may be in source, object, or absolute formats.

Program counter

A storage circuit within a CPU which holds the address of an instruction to be executed by the ALU.

Program module

A list of computer instructions in source, object, or absolute code format which performs a specific task.

PROM

Programmable Read-Only Memory. A type of memory chip which is used to store relatively unchanging software and/or data.

Prompt

A character or phrase displayed by software to solicit a response from the user.

Protocol

A set of rules for the interaction between hardware and/or software modules within a computer system.

RAM

Random Access read-write Memory; a computer's "scratch-pad" memory circuits which are used to store both programs and data.

Register

A storage circuit which temporarily holds a binary number representing data, an instruction, or an address—may be part of the ALU or a general purpose module.

Release

An improved, updated, or enhanced version of software and/or hardware.

Reverse video

A video display attribute which reverses the normal "white-on-black" or "black-on-white" screen presentation.

ROM

Read-Only Memory; a memory circuit containing chips which store programs and/or data imprinted at the time of their manufacture.

RS-232C

A protocol specifying the physical and electrical characteristics of a widely-used serial interface between data communications equipment and data terminal equipment.

Screen

The CRT (Cathode Ray Tube) display in a video terminal. Also, the information displayed on the CRT.

Scroll

The process by which more than one screen-full of information is displayed to a user. Most newsroom computer systems permit a user to "scroll down" (see the next one or more lines of a video display longer than the screen can contain) or "scroll up" (see one or more lines previous to the currently displayed data presentation).

Security level

A "permission" attribute associated with the user's name and password which is used by the system to determine which commands and which data files the user can invoke and access.

Selector

Equipment, normally supplied by a newswire service, which permits a station to read (on a printer or through a computer system) only those wire stories which fall under the categories of service to which the station has subscribed.

Serial

In hardware interconnection and data communications, the bit-by-bit communication between modules through a single digital signal path.

Slug

A title phrase and/or story number transmitted by a newswire service to identify a transmitted story.

Software

Lists of binary numbers which represent instructions to be executed by the ALU.

Software release

A new version of software which might include enhancements and/or fixes to either the application or the operating system, or to both.

Stand-alone

In computer systems, a module which can perform all or a subset of its intended functions even when normal interconnection to the rest of the system is disrupted.

Statistical multiplexer

A multiplexer which dynamically allocates a data transmission path's capacity, depending on user needs and pre-set priorities.

Status message

An advisory to a user from software—sometimes from hardware—which describes a situation or event possibly of interest to the user. Status messages may advise the user of a hardware or software problem, announce the arrival of a message from another user, alert the user to a bulletin from a newswire service, display function key labels, or simply inform the user that the "CAPS LOCK" key is depressed and all further keystrokes will produce upper-case characters.

Step

A discrete action to be performed by a CPU, or the program instruction(s) which cause such action—sometimes, a user activity which results in the completion of a discrete user task.

Subset

A device, normally supplied by a newswire service, which provides a current-loop interface for printers and/or computers from a "low-speed" (110 BPS or less) wire.

Super-user

A person responsible for some or all of a computer system's normal maintenance tasks, such as: adminstration of user lists and access permissions, archiving the database, interacting with operating system software to alter configurations or recover from problems, etc.

Synchronous

In data communications, a transmission approach which maintains synchronization between a transmitter and a receiver by passing a clock signal in addition to the data bits.

Sysop

System operator; a person responsible for smooth operation of a system. (Also see KEY OPERATOR and SUPER-USER.)

System

A collection of hardware and/or software modules which performs a specific function.

System console

A terminal with direct access to a computer's operating system for use by key operators, super-users, and the SYSOP to control system operation. System console configurations often include a printer which produces a log of events affecting the system.

System manager

A administrator responsible for the planning, installation, operation, and maintenance of a computer system. In small systems the system manager may also function as the super-user and/or the SYSOP.

System software

The operating system. Occasionally, the term is incorrectly used to refer to applications software.

Tap

A means of connecting an existing newswire circuit to a computer system by "bridging" the circuit.

Terminal

Equipment connected to a computer system which permits a human user to enter and/or receive information stored in the system. Examples are: VDTs, printers, prompters, and the portable devices which have a keyboard and either a screen or a printing unit.

Thruput

A measure of work or traffic processed by a module or system within a given period. Examples are: a newsroom system whose thruput on March 9th was 127 stories; a modem with a maximum thruput of 120 characters-per-second.

Time division multiplexer

A multiplexer which allocates a data line's transmission rate to several lower speed channels by dividing the line's thruput into discrete "time slices" during which a given channel's data is transmitted.

Transmission

The movement of information from one point —the transmitter—to other point(s)—the receiver(s).

User

A person who interacts with a computer system.

VDT

Video Display Terminal; a device which displays computer output on a video screen and usually includes a keyboard which permits a user to enter information and control the display.

Word

In describing computer architecture, the number of bits processed at a time by the ALU.

Word-length is frequently expressed in BYTEs: an eight-bit ALU's word-length is one BYTE, a sixteen-bit ALU's word-length is two BYTEs, etc.

Word processor

A feature of applications software which permits the user to create, manipulate, and update text stored in the computer system.

Work-flow diagram

A graphical representation of the interactions between the various members of a news operation; a drawing showing "who does what", "when they do it", and the sources of the information they use to do their jobs.

Workstation

An equipment configuration which permits a single user to interact with a computer system. The term is most frequently used in reference to a desk-top computer system connected to others through a LAN, but may also be used to refer to a terminal connected to a central computer system.

Y-cable

An adaptor cable which permits two devices to be connected to the same RS-232C pathway.

7.7

Weather Radar Systems and Radar Displays

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Radar History

The principles of radar were discovered at the Naval Research Laboratory (NRL) in 1930, almost accidentally, by Lawrence H. Hyland. Hyland noticed that radio signals, transmitted from the ground, were reflected back by passing aircraft. Another member of NRL, Leo Young, used the information, and he paved the way for accurate detection of aircraft. Young developed a system which scanned the sky with high frequency beams of short pulses, each of which was separated by relatively long intervals. The bearing of the reflected beam gave the bearing of the aircraft. By determining the time it took the pulse to go out to the target and return, the distance from the transmitter could be determined. This was the beginning of Radio Detection And Ranging, or RADAR.

The use of radar for detecting weather was developed after World War II. In 1953, the use of radar in tracking severe weather began with the detection, by the Illinois State Water Survey, of a hook shaped echo from a thunderstorm which produced a tornado. Since then, radar has been adapted for use by the National Weather Service and by private concerns for tracking storms, and providing increasingly better warnings in hazardous weather situations.

Radar Principles

Radar is defined as "the art of detecting, by means of radio echoes, the presence of objects, determining their direction and range, recognizing their character, and employing the data thus obtained."

A radar wave is an electromagnetic beam of energy which travels at the speed of light, 2.998×10^8 m/sec. The speed of light varies only slightly in the atmosphere. Those variations are based on the index of refraction of the atmosphere, and they are predictable.

The radar beams will bounce back to their transmitter from objects they hit. The wavelength of the beam determines the smallest size of the object which will reflect it. The smaller the wavelength, the smaller the object will be that reflects the beam. Examples of meteorological objects, or targets, are raindrops, cloud droplets, ice particles, snowflakes, atmospheric nuclei, insects and birds.

The radar microwave spectrum is traditionally divided into the following bands:

BAND	WAVELENGTH	FREQUENCY
K	1 cm	30.0 GHz
X	3 cm	10.0 GHz
C	5 cm	6.0 GHz
S	10 cm	3.0 GHz
L	20 cm	1.5 GHz

An S-band radar can detect rain but not cloud droplets. A K-band radar can "see" many clouds even if they are not producing any rain, and it is useful for studying microphysical processes in clouds. Generally, the frequency (and, thus, wavelength) of each radar is fixed.

The wavelength and frequency of a radar beam are related by the equation:

Speed of light = frequency x wavelength

A radar set consists essentially of a transmitter, an antenna, a receiver, and a scope or television screen. The transmitter produces the beam power at a given frequency (wavelength). The antenna both radiates the power and detects the reflected signals. The receiver detects, amplifies and transforms the received signals into video form. The scope displays the returned signals in a meaningful form.

Most radars employ the same antenna for both transmitting and receiving signals. An automatic switch turns off the receiver while the transmitter is sending the beam out, and then it turns on the receiver so that it can detect the reflected beam.

The power of a transmitted radar beam can be as high as 10^6 watts, while the received reflected power can be as low as 10^{-13} watts, which is close to the noise level of radiation. An important characteristic of a radar, in addition to the smallest detectable target size, is the minimum detectable signal. Several methods can be used for detecting very weak signals.

To summarize up to this point, a radar will transmit a beam of electromagnetic radiation, it may or may not be reflected back to the antenna (receiver), and then, if reflected, the returned signal must be displayed so that it can be studied.

Radar Displays

There are two main displays on a meteorological radar, the plan-position indicator (PPI scope), and the range-height indicator (RHI scope). Both of these displays are cathode ray tubes.

The PPI scope is the most widely used display in radar meteorology. It displays the reflected signals on a horizontal polar coordinate system. That is, the bearing and distance from the radar are given. The bearing is determined by the angular direction from true north of the antenna when it receives the reflected signal. The distance from the radar is determined by timing the round trip (at $3x10^8$ m/sec) of the transmitted and reflected beam.

The RHI scope is used with radars which have vertical scanning antennae. The antenna scans vertically by sending out beams at different angles. The RHI scope has an abscissa (horizontal axis) of range, and an ordinate (vertical axis) of height.

Both the PPI and RHI scopes use intensity modulation, which means that the brightness of the returned signal on display is directly proportional to its strength.

In most meteorological applications of radar, it is useful to quantify the precipitation rate of the weather system being observed, over the full intensity range of the radar. This means that a signal strength handling capability in excess of 60 dB, representing precipation rates from 0.01 inch per hour to over 5 inches per hour, is necessary; this requires a fixed gain logarithmic receiver. Passive fixed attenuators cannot readily perform precipitation rate quantification with a log receiver, therefore an active signal processor becomes necessary. The Digital Video Integrator Processor, or DVIP, performs this function.

The DVIP accepts the video (high frequency data) output of the radar logarithmic receiver, digitizes and processes the data, and produces contoured logarithmic (C-log) data for CRT or color monitor display. Typically, C-Log data are in the form of six precipation levels. Level one is greater than receiver noise, and less than 0.1 inch per hour, while level 6 might represent any precipitation rate greater than 5 inches per hour. The remaining four levels would represent specific rates between 0.1 and 5 inches per hour. When displayed on a CRT or on a color monitor, these levels form the contour bands of the weather system, much like pressure and temperature are presented on conventional charts.

The processing functions of the DVIP include range averaging, pulse interval integration, and range normalization. Range averaging produces a digital value representing the average rainfall rate for a number of samples, each taken at every ¼ km, would be averaged to produce a value representing a 1 km range "bin". Each of these range bins is integrated, on a pulse-to-pulse basis, to smooth the data (minimize the fluctuations common to radar echoes from rainfall droplets), and the averaged and integrated data are then normalized with respect to range. Range normalization corrects the data such that a given precipitation rate will be properly contoured regardless of of the distance of target from the radar antenna.

There are two families of radar: non-coherent (conventional) and coherent (Doppler). Conventional radars supply information about a target's position and strength (reflectivity). Movement of areas of targets can also be determined. Doppler radars can obtain the same information as conventional radars, but, in addition, they can also determine the radial movement of targets.

This can be done because the Doppler radar measures the shift in the frequency of the radar beam as it is reflected by a moving target. Beams directed toward a target that is approaching the sending unit will return at a higher frequency than they would if the target were moving away. Since this technique is not effective if the target is moving at right angles to the radar unit, two or more units are used. Doppler radar is thus capable of seeing not only the movements of storms, but the movement of tiny particles within the storm. Changes in wind direction and velocities within individual thunderstorm cells can be detected and thus give a better picture of the severity of a storm and its likelihood of producing a tornado. The relationship between the Doppler shift and the radial velocity is demonstrated below.

Let r be the radial distance of a target from the radar, which is operating at a frequency of f. Then the total distance traveled by a reflected pulse is $2r$. Translating this into wavelength, we get a distance of $2r/L$, where L is the wavelength of the beam. Converting this to radians gives a distance of $(2r/L)\ 2\pi$ or $4\pi r/L$. If the radar beam has an initial phase of ϕ_0, then its phase after reflection back to the radar is

$$\phi = \phi_0 + 4\pi r/L$$

Then the change of phase in time is

$$\frac{d\phi}{dt} = \frac{4\pi dr}{Ldt}$$

But dr/dt is simply the radial velocity of the target. If the target is not moving along the radius of the beam, then $V = dr/dt = O$, and there is no phase shift.

Now $d\phi/dt$ is the angular frequency, and $d\phi/dt = 2\pi F$, where F is the frequency.

So $d\phi/dt = 4\pi dr/Ldt$ becomes

$$F = \frac{2vr}{L} \qquad [1]$$

Equation [1] gives the relationship between the frequency shift and the radial velocity. The frequency shifts are very small with respect to the beam frequencies of Doppler radars, but it is possible, using sophisticated techniques, to determine the Doppler shift frequencies. It is then easy to convert the shifts into radial movements using [1].

The Pulse Pair Processor (PPP) is one method of estimating the mean velocity of rainfall, using the Doppler effect. To perform this function, the dynamic phase relationship between the transmitted RF pulse and the received (and Doppler shifted) echo is compared, on a pulse-to-pulse basis, to determine the amount of phase change from one transmitted pulse to the next. This change in phase between pairs of transmitted pulses is a measure of the Doppler shift caused by target radial velocity, hence the name Pulse Pair Processor. The real (in phase) and imaginary (quadrature, or 90 degree out-of-phase) components of phase change are translated to target velocity by applying an arc tangent function to the imaginary component divided by the real component. A group of these velocity estimates, e.g. 32, 64, or 128 pulse intervals, is averaged in order to smooth the data. Once the PPP has produced an estimate of radial velocity, the variance (or spectral width) of the Doppler shift may be readily determined.

The PPP will produce accurate estimation of radial velocity up to the point where the pulse-to-pulse change in phase is the equivalent to 180 degrees of the pulse repetition frequency of the radar. For example, with a 5 cm radar a radial velocity of 8 meters per second will cause a Doppler shift of 320 Hertz; if the PRF of the radar is 650 pulses per second, the velocity estimate produced by the PPP will be accurate. If the PRF should be 630, or less than double the Doppler frequency, then the PPP will produce an ambiguous (erroneous) estimate. Therefore, selection and control of the PRF becomes an important tool in the interpretation of PPP data.

The Fast Fourier Transform (FFT) signal processor is another method employed to estimate the radial velocity of rainfall echoes. Where the PPP estimates only velocity and variance directly from the real and the imaginary components of phase change, the FFT first performs an analysis of the spectral analysis to velocity and spectral width. A multi-point Fourier transform is employed, with 32, 64, or 128 point analysis typical. The FFT processor can, among other functions, reduce ground clutter.

The FFT suffers the same PRF vs. target velocity ambiguity as the PPP, because change in phase from pulse-to-pulse is the input data common to both.

History of Colorizers and Remoting

The use of radar remoting and color displays of PPI information came into being in the middle of the 1970s. Technical Services Corporation (TSC) in southern California developed some color displays for local radars there, but the most extensive development was done by Enterprise Electronics Corporation (EEC) in Enterprise, Alabama.

In October 1976, they installed the first remoting of a PPI display from the Athens, Georgia NWS radar to WJBF-TV in Augusta. The data was sent over telephone lines, and that is still the medium of transferring radar data at this time.

In May, 1977, they installed the first real-time color display at KTVY-TV in Oklahoma City using the data from the radar at the station.

In August, 1977, Enterprise combined the above two concepts by installing a remote color display at the FAA Control Center near Atlanta using the data from the NWS Athens radar. Enterprise introduced a meterological Doppler radar system using both pulse-pair and fast fourier transform (FFT) processing in 1980. Since then, EEC has offered modification kits for existing MET radars to provide Doppler data in addition to intensity information.

At this time, the Enterprise and Kavouras (in Minneapolis) have data repeater transmitters at many radar sites, primarily at NWS radars. Collins Air Transport Division of Rockwell International in Cedar Rapids, Iowa, currently has introduced in 1984 a new low-cost Doppler radar system. Collins does not sell direct, but uses authorized dealers including ColorGraphics Systems, Inc. (Madison, Wisconsin); Advanced Designs, Inc. (Bloomington, Indiana); Kavouras, Inc.; and Environmental Satellite Data (Washington, D.C.).

Typical Applications

There are several reasons for the purchase of a radar system. Improving the quality of the weathercast is the overall objective. This can be done in two different ways. First the introduction of a new radar system into the weathershow lends a visual benefit. It presents the viewer with a very sophisticated and impressive looking display which helps promote a state-of-the-art image for the weather department.

Secondly, it will upgrade the quality of short-term weather forecast, and provide more reliable and up-to-the-minute tracking of potentially severe storms. A properly used and well maintained weather radar system can give the station an edge over competitors in providing accurate forecasts of when and where storms are about to strike. It can depict possible duration of the event, and approximately how much of a certain type of precipitation will accumulate.

The advantages of owning and using a weather radar system are numerous. Although cost may be a problem in the smaller stations or smaller markets, competition often dictates stations can ill-afford *not* to have "live" local radar. It is, however, often difficult to justify expensive radar equipment.

One means of lowering the financial burden is to share the costs, and thus the benefits of the radar system with other weather-sensitive operations.

One possible partner is the electric power utility. Radar can benefit them by tracking lightning storms that often cause power outages. Knowing where the storms are can help the utility to pinpoint where power outages may occur. This will help them to better direct their repair crews, and thus save time in restoring service—and also save money.

Another possible cost sharer would be smaller municipal or private airports without the benefit of National Weather Service radar.

Any weather-sensitive operation, such as shipping, mining, heavy industry and many others, could potentially aid in cutting costs. Especially helpful for use in radio (and in some cases, television) are regularly scheduled and sponsored radar weather reports where part of the advertising revenue generated would be applied to the costs of radar equipment.

Another widely used alternative is a joint television and radio station ownership in which a local radio station would share the costs in return for a set number of weather reports from the weathercaster(s) at the television station, as well as special reports when weather conditions justify.

Once the decision has been made to purchase a system, it then must be decided what type of system to buy, and from what manufacturer. In general, all weather radars work on the same principles, sending out microwave radiation pulses which bounce off precipitation particles in the atmosphere and return an "echo" to the antenna, which acts as both transmitter and receiver.

The time elapsed between the pulse and return is used in computing the position of the precipitation, while the strength of the return indicates its intensity. A wavelength of 3.2 cm is most often used, with frequency and power differing with each individual type of system. The 3.2 cm wavelength is the X band, while C Band (5 cm) and S Band (10 cm) are used by the National Weather Service. The X Band has a higher resolution than the C and S Bands due to the shorter wavelength, but for the same reason, it will also have a higher attenuation. Recent technological advances have decreased the attenuation of some units using the X Band, thereby further enhancing its appeal.

The power and range of individual radar units varies widely. Marine radar systems now being marketed as weather radars typically operate at a lower power with shorter range, up to about 64 miles. One major drawback with a marine radar is that its initial development treated weather as a detriment to shipping interests, concentrating on large targets such as bridges, ships, aircraft, etc. In general, marine radar makes a poor weather radar, and a weather radar makes a poor marine radar. The most attractive feature of the marine radar system is its relatively low price. Typical prices range near $10,000.

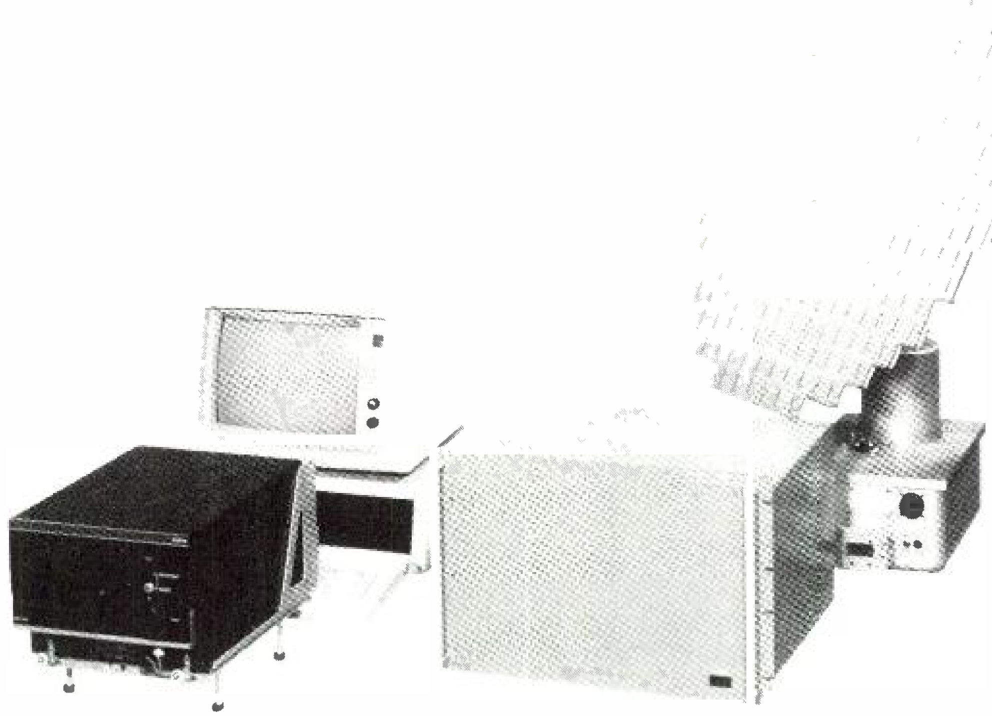

Fig. 1. Doppler hardware—note flat plate antenna. (Photo courtesy of Collins Radar, Rockwell International).

Higher power radar units can attain ranges in excess of 200 miles. Due to the curvature of the earth, anything over 200 miles is of limited use in that precipitation cannot be detected at longer ranges except in extreme cases. Price ranges of these systems can run from less than $30,000 to in excess of $80,000. Most of these systems are designed to interface directly with television inputs with non-fading square display, a sweeping-line synchronized with this antenna position, range scale selection and typical four intensity levels displayed. Some systems feature as many as six levels of rainfall intensity.

Doppler radar is now becoming widely used because of the capability for indicating severe winds and possible tornadoes. Doppler systems are somewhat more costly than conventional systems, with typical prices in the order of $80,000 to $100,000.

Any radar, regardless of type and size, radiates RF energy and, therefore, must be licensed by the FCC before it can be put into operation. This simply entails filling out the proper forms and submitting them to the FCC for approval. Information on FCC procedures is covered in Section 1 of this Handbook.

Siting radar equipment can usually be done on existing structures. The weight of the transmitting equipment can range from less than 50 pounds to nearly 1000 pounds. A high flat roof makes a suitable position. Most antennae are mounted on a tripod and can be bolted onto a flat plate. Smaller units can be affixed to existing towers. Available in most cases is a radome assembly for protection of the antenna from strong winds. The tower's designer should be consulted on the effects of weight and wind loading before a radar unit is selected.

Choosing a site for the radar transmitter-receiver may also be dictated in part by your station's location. One consideration is nearby terrain. Hills and other masses will reflect the radar signal and show up on the screen as the perpetual "ground clutter". The antenna should be located high enough to clear these sources of clutter. And, although a filter is employed to avoid interference with other microwave sources, it is still best to locate the radar antenna as far as possible from other satellite or terrestrial communication dishes. A high location is preferable but going too high, more than 100 to 200 feet, can reduce the accuracy of some information, and it puts the antenna in jeopardy from strong winds or airborne debris. However, the only part of the unit that needs to be situated outdoors is the antenna dish or plate, and its motor drive, which can be covered by a fiberglass radome, while the transmitter and associated hardware are safely indoors.

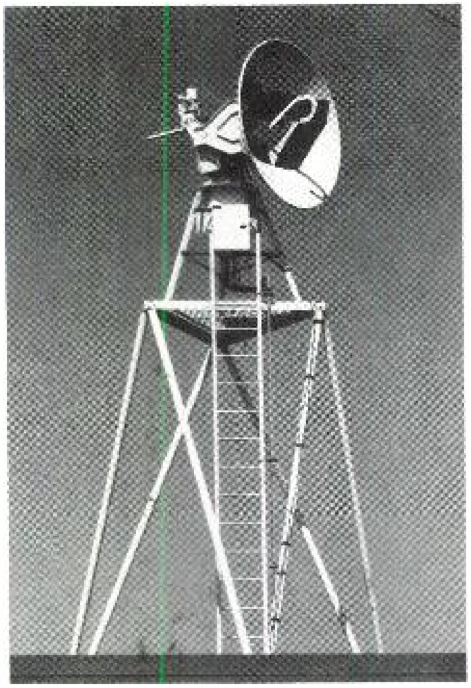

Fig. 2. Typical radar dish antenna—roof mount Vitro Model #1.

Power needed to operate the radar unit is minimal, on the order of 8 to 9 amps; although older radar units drain more electricity than newer units currently on the market.

Since the radar unit is set up outside the station, with the exception of the transmitter, few problems occur having to do with overheating of any of the internal hardware. Most of the internal transmitter components are solid state and have a low failure rate.

A broadcast interface is necessary to tie the radar unit into the central station switcher, and it usually includes a colorizer. Basically, the interface accepts station sync and formats the information obtained by the radar unit available to show the viewer on a plan position indicator or similar cathode ray tube.

All personnel who repair and adjust radar must have or work under the supervision of someone with an FCC General Class license. National Weather Service sites usually employ an engineer around the clock in case of unit malfunction, as do most television stations making use of a C or S Band radar. It is expected that the engineer will have some knowledge of how the radar unit works, and this knowledge can be obtained through a variety of ways. Learning from other engineers is often the case. The manual which comes with the unit is also useful but may be comparatively difficult when employed by a novice. There are also schools where the engineer may learn about the specific unit. Any radar manufacturer can provide such training. If the station's engineering staff are not familiar with radar, it may be possible to locate someone in the area who has the experience. An airport, military base or communications company may have someone willing to work part-time or on-call as needed.

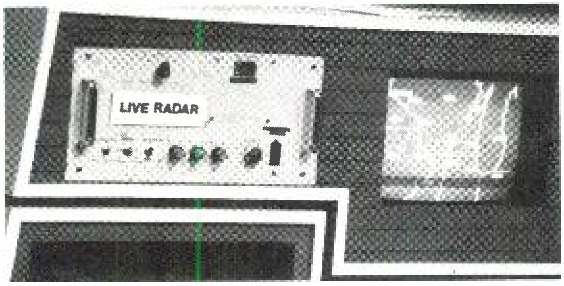

Fig. 3. Studio components and display monitor—by TSC.

Aside from regular lubrication of the moving parts, there is little that has to be maintained on a typical radar unit. Consult the manual for the schedule as well as the parts to oil and grease. Generally, lubrication once per year is necessary. Of course, the older the radar, the more care required. Besides lubrication, it is necessary to check the power or pulse frequency being emitted by the transmitter. This can be done by employing a Voltage Standing Wave Ratio (VSWR) test, which determines the condition of the pulse. This should be done every month, but performing this test quarterly will help the engineer avoid most trouble.

Most of the actual radar transmitter is solid state, which keeps the failure rate low; however, most systems include two vacuum tubes. These are the Magnetron and the transmit-receive (T-R) tube.

The Magnetron is the heart of the radar transmitter, and it delivers radio frequency power on the order of 2,000 to 5,000,000 instantaneous peak watts for each emitted pulse. A common value for broadcast weather units is in the range of 250,000 watts peak, and the typical duty cycle is on the order of 0.0001 or 0.01%, giving an average power on the order of 250 watts. These Magnetrons generally last 2-3 years and can be expensive to replace. It is highly recommended to keep a spare Magnetron available if the budget allows. Cost for each Magnetron is approximately $3,000 to $4,000.

The T-R tube generally lasts much longer. This tube is a high speed switch which effectively couples and decouples the transmitter and receiver alternately to the antenna as dictated by the emitted pulse and pulse interval. If this switch fails, the unit will not function, and it is highly recommended to keep a spare on hand. Besides lubrication, annual expense would depend on the use of the radar and whether the two main components, magnetron and T-R tube, need replacement.

It has generally been proven that the radar antenna is adequately insulated and durable to last through most weather situations. If your climate is adverse and your unit is subject to high winds or falling debris, it would be wise to purchase a radome for the external parts. This is a plastic of fiberglass dome which completely encompasses the outside unit and is sufficiently large enough to allow the radar disk to turn. Generally speaking, most adverse weather will not be sufficient to damage the radar unit. It is recommended, though, to turn the radar unit off when winds hit 50 miles per hour or higher. Of course, with a radome, this is unnecessary. Some TV stations have towers or cables elevated over the building, and in the winter, ice can form on these cables. Thus, when a warming trend commences, the ice starts to fall off in large chunks. If one of these strikes the radar unit, it may cause damage. A radome is the only protection.

When installing or working around radar equipment, precautions should always be taken to avoid exposure to the beam. Power levels for weather radar are not as high as those used in some aircraft tracking or communications applications; however, the transmitter should be turned off any time someone is near the antenna unit. Antennas are usually installed in areas of limited access, roof tops or towers, so it is unlikely that anyone would be near the unit casually. On the other hand, someone, such as a tower maintenance or air conditioning repair worker, could be near a radome-covered unit without being aware that it is operating or even what it is.

In planning a new installation or making changes in an existing one, current information about standards and precautions regarding exposure to non-ionizing radiation should be consulted.

Dial-up Weather Radar Data

An alternative to purchasing a radar unit is a "dial-up" radar system. This allows the user access to National Weather Service radar sites all over the country. For the price of a phone call (in addition to a receiving unit and a subscription fee), the user can reach a nearby radar or one of the other 117 National Weather Service S and C Band sites in the contiguous 48 states.

A typical system includes a color graphic video terminal to display data from their transmitters at NWS sites. Voice-grade telephone lines carry the data, which are then displayed in 6 color images. These images are coded according to precipitation intensity and can be stored for later use.

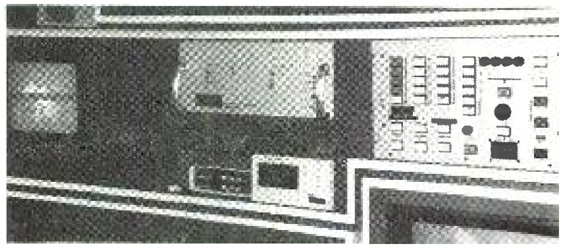

Fig. 4. Studio components Radac Model 1000 by Kavouras.

Units range in price from around $10,000 to $30,000, depending on features and functions. That price includes a maintenance fee for the transmitter units and for the use of express dial-up facilities out of their headquarters. Service is available whenever the particular NWS site is in operation.

The Radar Remote Weather Display System (RRWDS) is a next generation dial-up alternative now being made available to owners of computers with graphics display capabilities. Many television weather departments make use of such computers to generate and air their weather maps. Now they can contract with several vendors for an annual fee, and access any of 77 NWS radar sites. This alternative does not require the user to buy additional hardware if they already have a graphics computer and a telephone modem. Image resolution is 4 times higher than previously available from the dial-up radar systems available before 1984.

The RRWDS images are not processed and distributed instantaneously. Data are approximately 5 minutes behind real-time. There is also the capability, through the use of the graphics computer, to combine several images on a single map to show storms over a wider area, and to time-lapse a series of images. Vendors supplying RRWDS interfaces (as of mid-1984) include ColorGraphics Systems, Inc.; ESD, Inc.; and Kavouras, Inc.

In contrast to the locally owned unit, filters and echo timing are not necessary with RRWDS. There are no special power or cooling requirements either. A standard broadcast interface is needed to connect with the studio and control room. A "clean" ordinary business phone line (either dial-up or dedicated) is a necessity, though, for both types of dial-up radars.

Summary

Perhaps the ideal system in today's competitive broadcast market is a combination of all of the above in a state-of-the-art weather center. The locally owned radar unit and the new advancements in Doppler technology are certainly useful in providing real-time warnings to listeners and viewers. The dial-up systems available can provide a "double check" for stations which have a problem spotting nearby storms lost in the ground clutter in their vicinity. Cost is certainly a factor in determining how far a station can go. Other factors affecting any such purchase are the needs of the market and its concerns about weather and also the geographic size of the market area... not to mention whatever gear the station down the street is using.

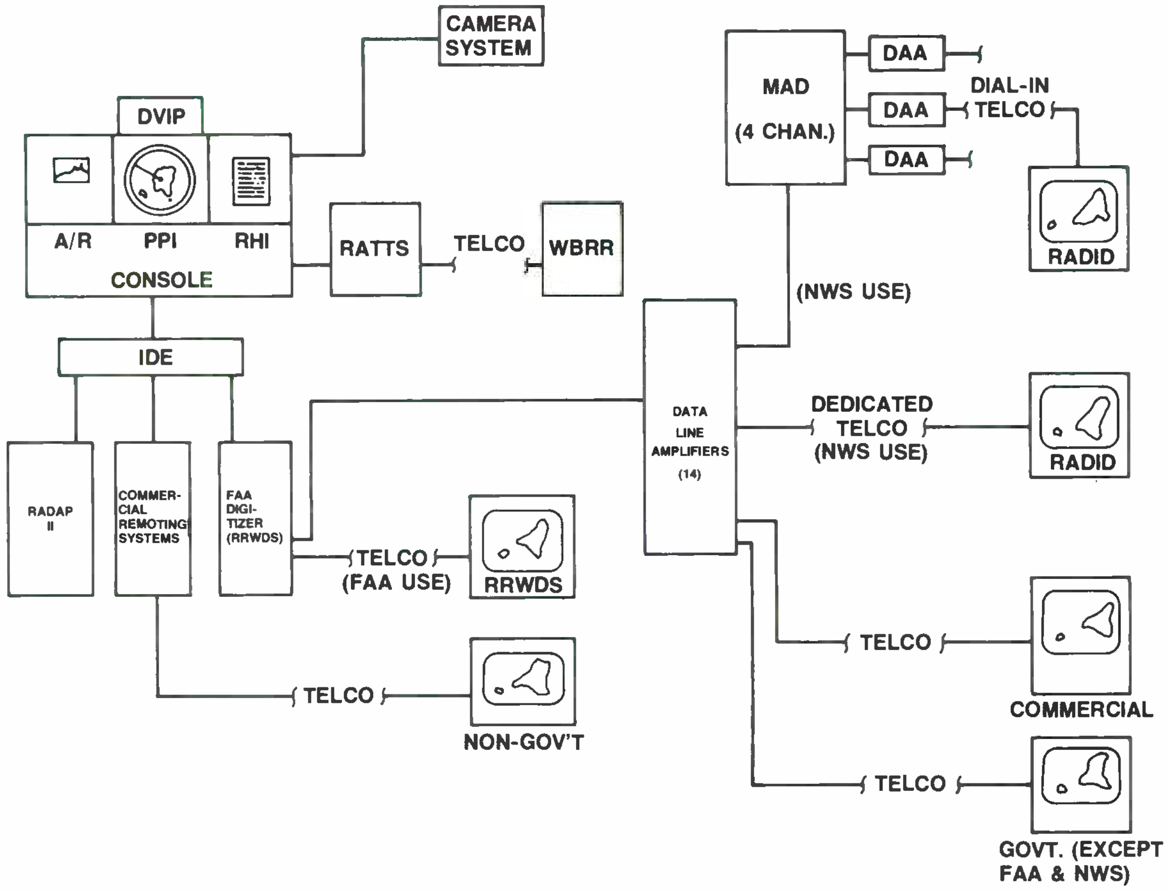

Fig. 5. Radar Remote Weather Display System.

7.8

The Emergency Broadcast System

Raymond Seddon
Chief, Emergency Communications Division
The Federal Communications Commission
Washington, DC

The role of communications in defending the Nation and protecting the life and property of its citizens has been recognized since the Federal Communications Commission was established in 1934. Over the intervening years, as the international situation has changed and as the Nation's communications systems have vastly expanded and improved, the role of communications in promoting the national defense and protecting life and property has likewise undergone farreaching changes.

Today when the United States has capability of responding to a national emergency in a matter of minutes, it is imperative that the President be able to communicate with the entire Nation on a few moments' notice. Similarly, other federal officials, as well as state and local authorities, must be able to quickly transmit vital information to the public in times of emergency.

The Emergency Broadcast System (EBS) has been devised to provide the President and the federal government, as well as heads of state and local governments, or their designated representatives, with a means of communicating with the general public during emergency situations. Every home, business and institution will be able, when the EBS is activated, to receive Presidential messages and other pertinent announcements and news by tuning to an emergency broadcast station serving their local area.

The responsibility of the broadcast industry for providing emergency communications capability had its origins a number of years ago with the birth of CONELRAD, and acronym for *CO*ntrol of *EL*ectromagnetic *RAD*iation utilizing specially authorized standard broadcast stations. It was developed by the Federal Communications Commission during the period 1951-1953 at the joint request of the USAF Air Defense Command and the Federal Civil Defense Administration and remained in effect until early 1964. It was designed to satisfy the following two requirements:

1. Warn the general public and transmit emergency information during a period of declared national emergency (i.e., imminent threat of war, attack warning).

2. Minimize any radio navigational aid that the signals of the participating stations might furnish to attacking enemy aircraft.

Navigational aid denial was accomplished by restricting all authorized stations to operate on only two channels in the standard broadcast band (640 kHz and 1240 kHz). All nonparticipating stations were required to cease operations during such emergencies, and no transmissions were permitted on the remainder of the standard broadcast channels. In addition, the authorized stations transmitted intermittently. The combination of intermittent operation from any given station, plus the high concentration of signals originating from many different directions rendered radio direction-finding techniques practically useless.

However, the high degree of co-channel interference that resulted from this operational mode severely limited the service areas of the participating stations. Intitially, there were approximately 200 broadcast stations participating operationally in CONELRAD. This figure increased to approximately 1300 by late 1953 and stayed constant for the remainder of the program. In 1961, as a result of the development of ballistic missiles and the consequent diminishing importance of the tactical role of manned bombers, the Air Defense Command dropped the stringent technical restrictions they had imposed upon CONELRAD operation, and agreed that the authorized stations could operate with their regularly licensed facilities (power, frequency, etc.). The resulting increased service areas produced an improved emergency communication facility.

In 1964, a new and improved system designated as the *Emergency Broadcast System* (EBS) was implemented. This name change was accomplished in order to differentiate the former (CONELRAD) two-channel 640 and 1240 kHz restricted communication system from station operation with regularly assigned facilities. It was during this change-over period that provision was made for FM broadcast stations to participate in the establishment of State Defense (relay) Networks.

Prior to 1972, in the event of a national emergency, participants in CONELRAD and the later EBS operation were required to possess a special emergency operating authorization called a National Defense Emergency Authorization (NDEA). Stations desiring to participate had to submit an informal application for an NDEA to the Commisssion, accompanied by a documentary assurance that the station would comply with certain qualifying criteria set forth in the Basic EBS Plan.

In early 1972, all outstanding NDEAs were cancelled and replaced by new emergency operating authorizations called Emergency Broadcast System Authorizations, and the former qualifying criteria were abolished. All existing broadcast stations (unlike during the CONELRAD and early EBS periods which did not include television and all FM Station) were furnished with new EBS Authorizations, accompanied by a memorandum advising them if they elected not to actively participate in the EBS they were instructed to return their authorizations, accompanied by a written request that they be cancelled. Similarly, all new broadcast stations licensed subsequent to the initial authorization period have been tendered EBS Authorizations, again accompanied by a letter advising that the authorizations should be returned with a written request for cancellation, in event the licensee does not want to actively participate. The abolishment of stringent EBS authorization qualifying criteria plus the expedited authorization distribution procedures have resulted in an increase in active station participation in the EBS from approximately 40 percent to over 94 percent of the total broadcast stations in the United States.

The term "key station" has no official status, and is not formally defined in the Commission's EBS Rules. However, the Number 1 Common Program Control Station (CPCS-1) in an EBS Operational Area is a key station in the system.

Current State Emergency Broadcast System (EBS) Operational Plans have been completed for the 50 states, the District of Columbia, and the four territories (American Samoa, Guam, Puerto Rico, and Virgin Islands). These plans are subdivided into at least 575 Operational Areas, each area containing at least one Common Program Control Station (CPCS). There are other CPCSs in an Operational area but they are considered backups. Therefore, there are 575 CPCS-1 stations in the Emergency Broadcast System that may be considered key stations.

589 broadcast stations participate in the EBS Broadcast Station Protection Program. They maintain government loaned auxiliary power generating and other equipment in a fallout protected enviroment. There are 214 of these stations which are not the CPCS-1. Thus it may be said that there is a total of 799 key stations in the Emergency Broadcast System; 575 stations who are in the BSPP and are also the CPCS-1 station, 214 stations who are only in the BSPP.

SYSTEM ORGANIZATION

The Emergency Broadcast System (EBS) uses the facilities and personnel of the entire communications industry—broadcast stations, telephone companies and national press services—on a voluntary, organized basis to establish an emergency broadcasting network. This network is operated by the industry under government regulations and procedures and in a manner consistent with national security requirements. Broadcast station licensees participating in the EBS have been issued Emergency Broadcast System (EBS) Authorizations by the Federal Communications Commission. Under peacetime conditions, Presidential broadcasts are handled by existing nongovernment radio and television facilities. Under conditions that would call for the activation of the EBS the normal flow of communications could be disrupted, altered, or destroyed.

A national-level EAN will be released only upon Presidential authority, and the White House will direct release of the Emergency Action Notification (EAN) which constitutes the notice to all broadcast stations and participating radio and television networks of an emergency situation. Both the Emergency Action Notification and Termination are transmitted only over the Emergency Broadcast System. Upon activation of the National-Level EBS, the White House Communication Agency (WHCA), which is responsible for providing all communications for the President under all conditions, will deliver the Presidential messages to selected originating points. From these points, the Presidential messages or broadcast will be distrubuted to participating EBS stations via the nationwide Radio and Television Broadcast Network program distribution facilities.

The Federal Communications Commission has been assigned the overall responsibility for the development of the Emergency Broadcast System. The FCC ensures effective coordination between that agency, the Federal Emergency Management Agency (FEMA), other required government agencies and nongovernment entities concerned. The National Industry Advisory Committee (NIAC) has been organized to advise and assist the FCC and other appropriate authorities. It is to study and submit recommendations for emergency communications policies, plans, systems, and procedures for all licensed and regulated communications in order to provide continued emergency communications service during emergency situations.

Key in development of the EBS is the National Level Emergency Broadcast Services Subcommittee. This subcommittee, with the assistance of Special Working Groups, provides the NIAC and the FCC with continuing advice and recommendations to ensure a workable EBS. Members are responsible for providing advice and assistance in programming guidance, production, and other operations of the National-Level interconnecting facilities and systems voluntarily participating in the EBS.

A State Emergency Communications Committee (SECC) has been organized in each of the 50 States, American Samoa, Guam, Puerto Rico, Virgin Islands, and the District of Columbia. The function of the SECC is to prepare coordinated operational emergency communications plans, systems, and procedures for their areas. A Broadcast Services Subcommittee is responsible for a state EBS Plan. State plans must be consistent with the approved National-Level plans.

An Operational Area Emergency Communications Committee, which functions as a subcommittee of the SECC, has been organized within geographical Operational (Local) Areas designated in coordination between SECC and State authorities. An Operational (Local) Area may include one or more communities; portions of two or more states may be included in borderline situations. The function of a Broadcast Services Subcommittee of the Operational Area Emergency Communication Committee is to develop operational emergency communications systems, plans, and procedures for inclusion in the state EBS Plans for use during local level day-to-day emergency situations.

Again, participation in the EBS by FCC licensees is on a voluntary basis. The FCC sends new licensees an EBS authorization and a letter requesting their voluntary participation in the EBS. Licensees subsequently receive an appropriate EBS checklist, an Operational Area Mapbook, relevant state and local EBS plans, a special instruction card to be posted at AP/UPI teletypewriter machines and the EBS Rules and Regulations.

Participating stations that remain on the air during a National-Level emergency situation must carry Presidential messages "live" at the time of transmission. Activities of the National-Level EBS will preempt operation of the state or operational (Local) area EBS.

National programming and news which is not broadcast at the time of original transmission will be recorded locally by the Common Program Control Station (CPCS) for broadcast at the earliest opportunity consistent with operational (Local) area requirements.

SYSTEM OPERATION

National Level Activation and Termination (Fig. 1)

Implementation

The Emergency Action Notification (EAN) will be released at the National level upon request of the White House. When the White House directs activation of the National-Level EBS, the White House Communications Agency (WHCA), after a series of interim steps, issues instructions to implement the EBS. The Emergency Action Notification (EAN) message is then released and is eventually received by the Nation's broadcast stations. A dedicated teletypewriter net connecting the radio and television broadcasting networks and wire services transmits these messages. Following the EAN, there is a one-minute pause to allow time for the broadcasting networks to transmit a message over their internal alerting facilities, alerting stations that normal programming will be preempted by the EBS. Simultaneously, the EAN is transmitted over the respective Radio Wire Teletype Networks to alert those stations equipped to receive this service. Broadcast stations not equipped to receive either network alerting information or Radio Wire Teletype Network transmissions must rely on receipt of the EAN

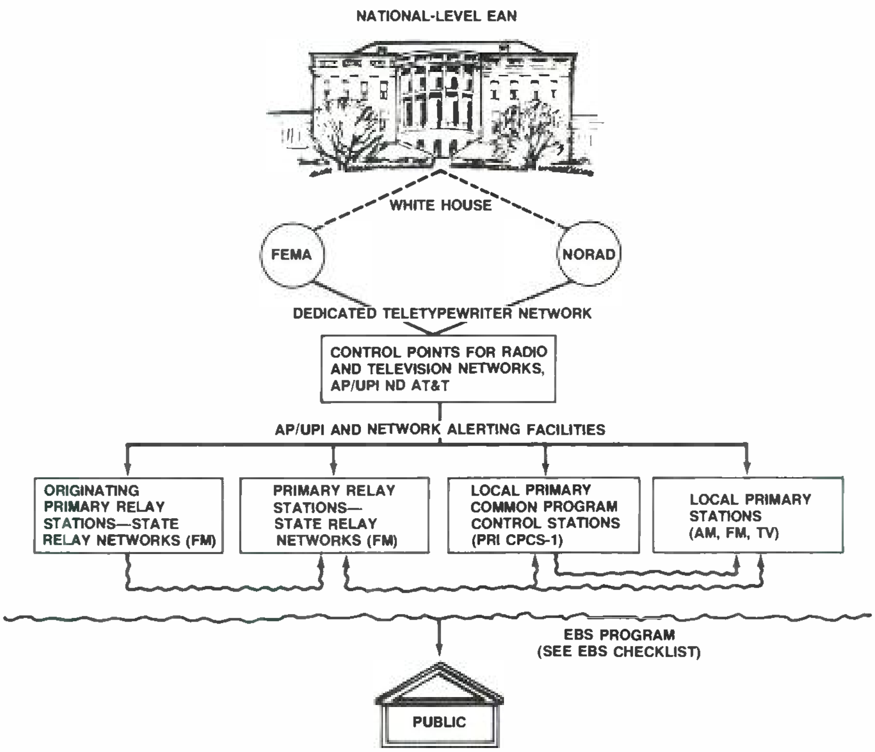

Fig. 1. Off-the-air-monitoring.

via off-the-air monitoring from other stations. Receipt of the EAN by any one of the methods discussed above is sufficient for the broadcast stations to commence emergency actions.

Station Responsibility

Upon receipt of the EAN certain actions are taken by all stations. These actions are:

a. Authenticate the EAN.

b. Discontinue normal programming and broadcast a special announcement alerting the public to the fact that important instructions are forthcoming.

c. Transmit the Attention Signal.

d. Broadcast the message which informs the public of the fact that an emergency situation exists, that some stations will remain on the air, and that additional news and information will follow. Those stations required to cease transmitting will so inform their listeners.

The actions taken by the broadcast stations following transmission of the attention signal depend on the station designation. Stations fall into the categories of:

a. Primary Station (Primary)

b. Primary Relay Station (PRI Relay)

c. Common Program Control Station (CPCS)

d. Originating Primary Relay Station (Orig. PRI Relay)

e. Nonparticipating Station (Non-EBS)

Participating stations monitor the CPCS or PRI Relay station in their area or radio and television broadcasting networks for further instructions and broadcast emergency programming when it becomes available. Nonparticipating stations remove their carriers from the air and monitor for the termination of the emergency. Should it become apparent the CPCS or PRI Relay stations may not be able to provide appropriate emergency program feed, other participating stations may elect to assume the duties by providing program feed.

When the National-level EBS is no longer needed, the Emergency Action Termination Message is transmitted. Broadcast stations receive the notification in the same manner as activation. The Common-Carriers then return the networks to normal configuration, and broadcast stations resume normal programming in accordance with their regular station authorization.

System Tests

Periodic Teletype Test Transmissions. The wire services will separately conduct test transmission to AM, FM, and TV broadcast stations on their Radio Wire Teletype Networks, a maximum of twice a month on a random basis at times of their choice. The subscribing broadcast stations enter the date and time of receipt of these tests consistently in their logs or records.

Closed Circuit Tests . These tests of the EBS will be conducted on a random or scheduled basis not more than once a month and not less than once every three months but only after FCC approval. Scheduled Closed Circuit Tests will be conducted at a time selected by the White House, the National Industry Advisory Committee (NIAC) representatives, and the FCC Defense Commissioner. The Closed Circuit Test Activation Message is disseminated to the various radio stations by:

1. The internal alerting facilities of the radio networks.
2. The Radio Wire Teletype Networks to all subscribers.

The common-carriers do not add participating independent stations to any of the Radio Networks during a Closed Circuit Test, unless ordered by the FCC.

During a Closed Circuit Test, broadcast stations do not interrupt programming and do not broadcast the message. The radio stations are required to:

a. Monitor the Radio Network for the Test Program;

b. Check the wire services teletype;

c. Authenticate the message and;

d. Record the time of the test consistently in station logs or records.

Because of the limited time available for the Closed Circuit Test, the **Termination** of the test will occur on the following Closing Cue as it appears in the text of the program:

"This concludes the Closed Circuit Test of the Emergency Broadcast System."

Weekly Transmission Tests. All radio and TV stations are required to conduct a weekly test of the Attention Signal. This must be done once a week at a random day and time between 8:30 am and local sunset. *Note:* Activation of the EBS may be substituted for the weekly test during the week the activation occurred.

State Level EBS Operation (Fig. 2)

Implementation

Upon receipt of a State-Level EAN all broadcast stations, including stations operating under equipment or program test authority, may, at the discretion of management, conduct operations in accordance with the provisions of the state-level EBS Plan. Day-to-day emergencies posing a threat to the safety of life and property which could cause activation of the State-Level EBS include tornadoes, hurricanes, floods, tidal waves, earthquakes, icing conditions, heavy snows, widespread power failures, industrial explosions,

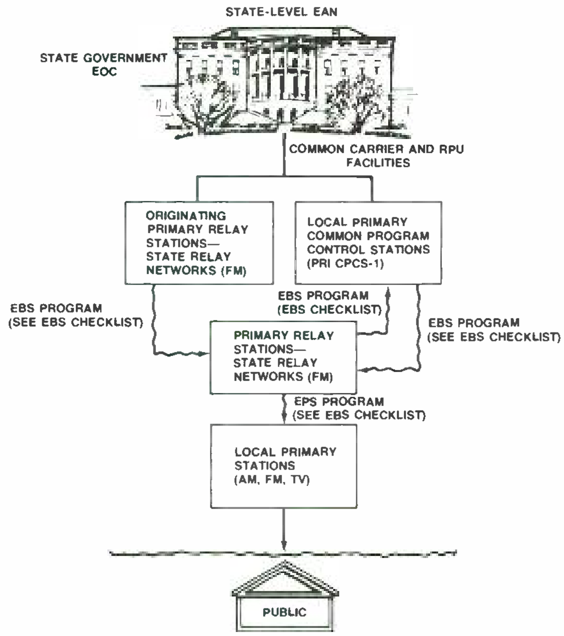

Fig. 2. Off-the-air-monitoring.

and civil disorders. In most instances the State-Level EAN will be released from the State Emergency Operations Center (EOC). Common-Carrier or Remote Pickup Units (RPU) are used to provide communications from the EOC. An FCC EBS authorization is not required for a broadcast station to participate in the operation of the State-Level EBS. Receipt of the State-Level EAN will be through the means of Off-the-Air Monitoring or as otherwise stipulated in the State EBS Plan.

Station Responsibility

Actions to be taken by the broadcast stations after receipt of the EAN are as follows:

a. Monitor the State Relay Network (PRI Relay Stations) for receipt of any further instructions from the original PRI Relay Station.

b. Monitor the Primary Station designated as the CPCS-1 for your Operational (Local) Area for receipt of any further instructions.

c. Discontinue normal program operation and broadcast the alert message.

d. Transmit the Attention Signal.

e. Broadcast the State-Level EBS-EAN Message.

f. Upon completion of the above transmission, resume normal programming until receipt of the cue from the CPCS for the Operational (Local) Area, or Primary Relay Station for the State EBS Network. Then begin broadcasting the common state-level program.

Upon receipt of notification of the termination of the State-Level EBS, participating broadcast stations will resume regular operations in accordance with the station authorization.

Operational (Local) Area EBS (Fig. 3)

Implementation

Upon receipt of an Operational (Local) Area EAN, all broadcast stations, including stations operating under equipment or program test authority, which are voluntarily participating, may, at the discretion of management, conduct operations in accordance wtih the provisions of the local EBS Plan. Day-to-day emergencies posing a threat to the safety of life and property which could cause activation of the Operational (Local) Area EBS include tornadoes, hurricanes, floods, tidal waves, earthquakes, icing conditions, heavy snows, widespread power failures, industrial explosions, and civil disorders. The Operational (Local) Area EAN will be released from the local government Emergency Operations Center (EOC) or a National Weather Service (NWS) office. Common Carrier or Remote Pickup Units (RPU) are used to provide communications from the EOC. An FCC EBS Authorization is not required for a broadcast station to participate in the operation of the Operational (Local) Area EBS. Receipt of the Operation (Local) Area EAN will be through the means of Off-the-Air Monitoring or as otherwise stipulated in the State and local EBS Plans.

Station Responsibility

Actions to be taken by the broadcast stations after receipt of the EAN are as follows:

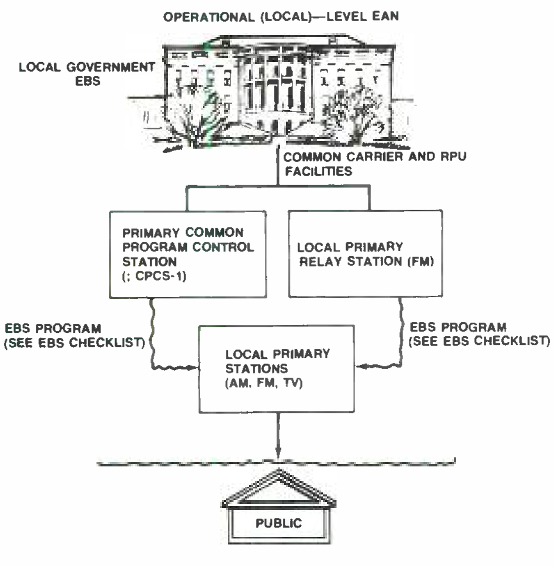

Fig. 3. Off-the-air-monitoring.

a. Monitor the Primary Station designated as the CPSC-1 for the Operational (Local) Area for the receipt of instructions.

b. Discontinue normal program operation and broadcast the alert message contained in the EBS Checklists.

c. Transmit the Attention Signal.

d. Broadcast the Operational (Local) Area EBS EAN Message.

e. Upon completion of the above transmission, resume normal programming until receipt of the cue from the CPCS-1 for the Operational (Local) Area. Then begin broadcasting the common program.

Upon receipt of the termination of the Operational (Local) Area-Level EBS, participating broadcast stations will resume regular operations in accordance with the station authorization.

State and Local Tests

Tests of implementing procedures developed at the state and local level may be conducted on a day-to-day basis as indicated in the State EBS Operational Plans. Coordinated tests of EBS operational procedures for an entire State or Operational Area may be conducted in lieu of the weekly transmission tests.

EMERGENCY BROADCAST SYSTEM (EBS) CHECKLIST FOR PARTICIPATING STATIONS

The following checklist is a condensation of the Basic Emergency Broadcast System Plan, and contains simpified instructions for each type of situation. The checklist contains step-by-step procedures for stations to follow when receiving a National-Level Emergency Action Notification. Also the termination procedures to be followed by all licensees at the conclusion of the National-Level Emergency. The checklist provides detailed procedural information as to what action must be taken when in receipt of National-Level Closed Circuit Tests, the periodic Teletype Tests, and the Weekly Transmission Tests. Lastly, step-by-step instructions are included for state and local level procedures and tests. More detailed information may be found, concerning these simplified instructions, by referring to Part 73 of the Commission's Rules and Regulations.

National Level Instructions

When EBS is activated by the White House, all broadcast stations must take the following actions. Stations should record all emergency broadcasts (including notification) and log or record all significant events.

Activation Procedures— All Stations

1 RECEIVE EMERGENCY ACTION NOTIFICATION—EAN

(This is the notice which activates EBS—Presidential messages may be received as soon as 5 minutes.)

Notification by one of the following methods is sufficient to commence action:

- **AP and UPI TELETYPE**—Preceded and followed by a line of "X's" and 10 bell alarm.
- **RADIO-TV NETWORKS**—Affiliates only—preceded by network alerting signal—Continue to monitor for further instructions.
- **EBS MONITOR RECEIVER**—Preceded by Two-Tone Attention Signal—Step 5 for message format—Continue to monitor for further instructions—Your EBS Monitoring assignment is specified in the State EBS Operational Plan.

EMERGENCY ACTION NOTIFICATION MESSAGE—AP AND UPI SUBSCRIBERS /NETWORK AFFILIATES ONLY

"This is an Emergency Action Notification requested by the White House. The AUTHENTICATOR WORD for this notification is (—). All stations follow procedures in the EBS Checklist for national level emergency. The President of the United States or his designated representative will shortly deliver a message over the EMERGENCY BROADCAST SYSTEM. The Authenticator Word is (—)."

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2 AUTHENTICATE NOTIFICATION

AP and UPI Subscribers/Network Affiliates Only

Compare authenticator words in notification with words on current EBS authenticator list. *(Red envelope inside front cover of EBS checklist.)* Take no further action if words do not match.

Different activation and termination words are provided for each date. Words are effective 12:01 a.m., Washington, D.C. time.

3 DISCONTINUE NORMAL PROGRAMMING AND BROADCAST ANNOUNCEMENT

(TV Stations shall display an appropriate EBS slide and transmit all following announcements visually and aurally in the manner required by Section 73.1250(h) of the FCC Rules. Foreign language stations report all announcements in foreign language.)

"We interrupt this program; this is a national emergency. Important instructions will follow."

4 TRANSMIT ATTENTION SIGNAL

Broadcast the Two-Tone Attention Signal (see section 73.906 of the Rules) for 20 to 25 seconds. *Note.* Noncommercial educational FM broadcast stations of 10 watts or less, and low power TV stations, which are exempt from having the capability to transmit the Two-Tone Attention Signal.

Primary Stations Only

(Including PRI CPCS Stations)

5 BROADCAST ANNOUNCEMENT

"This is an Emergency Action Notification. All stations shall broadcast this Emergency Action Notification Message. This station has interrupted its regular program at the request of the White House to participate in the Emergency Broadcast System. During this emergency, some stations will remain on the air broadcasting news and official information to the public in assigned areas. This is station (call letters). **We will remain on the air to serve the** (operational area name) **area. If you are not in this area, you should tune to other stations until you hear one broadcasting news and information for your area. You are listening to the Emergency Broadcast System serving the** (operational area name) **area. Do not use your telephone. The telephone lines should be kept open for emergency use. The Emergency Broadcast System has been activated to keep you informed. I repeat..."** (Repeat Announcement)

6 MONITOR FOLLOWING SOURCES FOR FURTHER INSTRUCTIONS AND BROADCAST EMERGENCY PROGRAMMING AS SOON AS AVAILABLE:

Sources

- Common Program Control Station for Operational Area
- Radio-TV Network Lines
  Affiliates & Non-affiliates serviced by participating communications common carriers
- Primary Relay Station of State Relay Network
- Any other source that may be available

Priorities

Record lower priority programming for rebroadcast at earliest opportunity.

First—Presidential messages—Must be carried "live"
Second—Operation Area (LOCAL) Programming
Third—State Programming
Fourth—National Programming and News

7 USE THIS STANDBY SCRIPT UNTIL EMERGENCY PROGRAMMING AVAILABLE—LATER AS FILLER

"We interrupt our program at the request of the White House. This is the Emergency Broadcast System. All normal broadcasting has been discontinued during this emergency. This is station (call letters). **This station will continue to broadcast, furnishing news, official information and instructions, as soon as possible, for the** (operational area name) **area. If you are not in the** (operational area name) **area, tune to a station furnishing information for your area. I repeat—We interrupt our program at the request of the White House. This is the Emergency Broadcast System. All normal broadcasting has been discontinued during this emergency. This station will continue to broadcast, furnishing news, official information and instructions, as soon as possible, for the** (operational area name) **area. If you are not in the** (operational area name) **area, tune to a station furnishing information for your area."** (Repeat as needed.)

8 MONITOR FOR EMERGENCY ACTION TERMINATION

Same methods as for notification—Upon receipt, proceed to termination procedures.

Primary Relay Stations Only

(Including Originating Primary Relay Stations)

1-4 See above

5 BROADCAST ANNOUNCEMENT

"This is an Emergency Action Notification. All stations shall broadcast this Emergency Action Notification Message. This station has interrupted its regular program at the request of the White House to participate in the Emergency Broadcast System. During this emergency, some stations will remain on the air broadcasting news and official information to the public in assigned areas. This is station (call letters). **We will be serving as a program distribution and relay channel to other stations. We will remain on the air to serve the** (operational area name) **area. If you are not in this area, you should tune to other stations until you hear one broadcasting news and information for your area. Do not use your telephone. The telephone lines should be kept open for official use. The Emergency Broadcast System has been activated to keep you informed. I repeat. . ."** (Repeat Announcement.)

6 MONITOR FOLLOWING SOURCES FOR FURTHER INSTRUCTIONS AND BROADCAST EMERGENCY PROGRAMMING AS SOON AS AVAILABLE

Sources

- Common Program Control Station for Operational Area
- Radio-TV Network Lines
  Affiliates & Non-affiliates serviced by participating communications common carriers
- Primary Relay Station of State Relay Network
- Any other source that may be available

Priorities

Record lower priority programming for rebroadcast at earliest opportunity.

First—Presidential messages—Must be carried "live"
Second—Operation Area (LOCAL) Programming
Third—State Programming
Fourth—National Programming and News

7 USE THIS STANDBY SCRIPT UNTIL EMERGENCY PROGRAMMING AVAILABLE—LATER AS FILLER

"We interrupt our program at the request of the White House. This is the Emergency Broadcast System. All normal broadcasting has been discontinued during this emergency. This is station (call letters). **This station will continue to broadcast, furnishing news, official information and instructions, as soon as possible, for the** (operational area name) **area. If you are not in the** (operational area name) **area, tune to a station furnishing information for your area. I repeat—We interrupt our program at the request of the White House. This is the Emergency Broadcast System. All normal broadcasting has been discontinued during this emergency. This station will continue to broadcast, furnishing news, official information and instructions, as soon as possible, for the** (operational area name) **area. If you are not in the** (operational area name) **area, tune to a station furnishing information for your area."** (Repeat as needed.)

8 MONITOR FOR EMERGENCY ACTION TERMINATION

Same methods as for notification—Upon receipt, proceed to termination procedures.

Termination Procedures— All Stations

1 RECEIVE EMERGENCY ACTION TERMINATION

(Same methods as for notification)

EMERGENCY ACTION TERMINATION MESSAGE—AP/UPI SUBSCRIBERS/ NETWORK AFFILIATES ONLY

"This is an Emergency Action Termination. The AUTHENTICATOR WORD for this termination is (—). All stations follow the EBS Checklist for termination procedures. The Authenticator Word is (—)."

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2 AUTHENTICATE TERMINATION

Compare authenticator words in termination with words on current authenticator list. Do not initiate termination if words do not match. *(Red envelope contained in pocket on inside front cover of EBS checklist.)*

3 BROADCAST ANNOUNCEMENT:

"This concludes operations under the Emergency Broadcast System. All broadcast stations may now resume normal broadcast operations." (Repeat announcement.)

4 RESUME NORMAL PROGRAMMING

(In accordance with regular station authorization)

National Level Tests

National interconnecting arrangements and facilities (Networks, Key Stations, AP/UPI, AT&T) will be tested periodically. See Basic EBS Plan for detailed instructions. Procedures for tests which affect all stations are described below.

Closed Circuit Tests

(Radio Network Affiliates and AP/UPI Subscribers)

DO NOT INTERRUPT PROGRAM—DO NOT BROADCAST TEST MESSAGE

Notification Methods

- **RADIO NETWORKS:** Affiliates only—Preceded by network alerting signal
- **AP and UPI TELETYPE**—Preceded and followed by a line of "X's" and 10 bell alarm.

CLOSED CIRCUIT TEST ACTIVATION MESSAGE—AP/UPI SUBSCRIBERS/ RADIO NETWORK AFFILIATES ONLY

"This is notification of a closed circuit test of the the EMERGENCY BROADCAST SYSTEM. The test program will begin at -----, Washington, D.C. time. Radio stations do not broadcast this message and do not broadcast the audio program. The test Authenticator Word is ----. This message authorizes a closed circuit test of the Emergency Broadcast System. Broadcast stations monitor radio network lines for closed circuit test program. All stations follow procedures in the EBS Checklist for closed circuit test. The test Authenticator Word is -----."

Action By Station:

1 MONITOR RADIO NETWORK FOR TEST PROGRAM

2 CHECK AP AND UPI TELETYPE

3 AUTHENTICATE TEST MESSAGE

Compare Authenticator Words with test words printed on outside of EBS AUTHENTICATOR LIST (Red envelope). If words do not match, take no further action.

4 RECORD TIME TEST RECEIVED IN STATION LOG OR RECORDS

Termination Methods:

- **RADIO NETWORKS**—Affiliates only—receive following aural Closing Cue: *"This concludes the Closed Circuit Test of the Emergency Broadcast System."*
- **AP and UPI TELETYPE**—Preceded and followed by a line of "X's" and 10 bell alarm.

Closed Circuit Test Termination Message (AP and UPI Subscribers Only)

"This is an EBS Closed Circuit Test Termination. The Authenticator Word for this termination is (—). The Closed Circuit Test was terminated at (Date and Time), Washington, D.C. Time. The Authenticator Word is (—)."

Action By Station:

1 RADIO NETWORK AFFILIATES MONITOR NETWORK FOR CLOSING CUE

2 AP AND UPI SUBSCRIBERS CHECK TELETYPE FOR CLOSED CIRCUIT TEST TERMINATION MESSAGE

3 AUTHENTICATE TEST TERMINATION MESSAGE

Compare Authenticator Word with test words printed on outside of EBS Authenticator List (Red Envelope). If words do not match, take no further action.

4 RECORD TIME TEST TERMINATION MESSAGE RECEIVED IN STATION LOG OR RECORDS

Periodic AP and UPI Test Transmissions

(AP AND UPI SUBSCRIBERS ONLY)

DO NOT INTERRUPT PROGRAM—DO NOT BROADCAST TEST MESSAGE.

Notification Method

- **AP and UPI TELETYPE**—Preceded and followed by a line of "X's" and 10 bell alarm.

Periodic Teletype Test Message

"This is a test of the Emergency Action Notification Procedures. If this were not a test, you would receive an Emergency Action Notification Message containing Authenticator Words. This is a test of the Emergency Action Notification Procedures. All stations follow procedures in EBS Checklist for periodic teletype tests."

Action by Station:

1 RECORD TIME TEST RECEIVED IN STATION LOG OR RECORDS
(NO AUTHENTICATION PROVIDED)

Weekly Transmission Test of the Attention Signal and Test Script

ALL RADIO AND TV STATIONS MUST PERFORM THIS TEST A MINIMUM OF ONCE A WEEK AT RANDOM DAYS AND TIMES BETWEEN 8:30 A.M. AND LOCAL SUNSET UNLESS THEY HAVE PARTICIPATED IN ONE OF THE FOLLOWING ACTIVITIES DURING THE TEST WEEK PERIOD: (1) A STATE OR LOCAL EBS ACTIVATION OR (2) A COORDINATED STATE OR LOCAL EBS TEST

Action By Station:

1 DISCONTINUE NORMAL PROGRAMMING

2 BROADCAST ANNOUNCEMENT

(TV stations shall display an appropriate EBS slide and transmit all following announcements visually and aurally in the manner described by Section 73.1250(h) of the FCC Rules. Foreign language stations repeat all announcements in foreign language.)

"This is a test. This station is conducting a test of the Emergency Broadcast System. This is only a test."

---

3 TRANSMIT ATTENTION SIGNAL

BROADCAST THE TWO-TONE ATTENTION SIGNAL (SEE SECTION 73.906 OF THE RULES)

4 BROADCAST ANNOUNCEMENT:

"This is a test of the Emergency Broadcast System. The broadcasters of your area in voluntary cooperation with Federal, State and local authorities have developed this system to keep you informed in the event of an emergency. If this had been an actual emergency, the Attention Signal you just heard would have been followed by official information, news or instructions. This station serves the (operational area name) **area. This concludes this test of the Emergency Broadcast System."**

---

5 RESUME REGULAR PROGRAMMING

6 RECORD TIME TEST CONDUCTED IN STATION LOG OR RECORDS

State and Local Level Instructions

These procedures may be amended or altered as set forth in procedural guides, SOP's, and other implementing instructions which are considered an appendix to the State EBS Operational Plan.

1 ACTIVATION

• **STATE LEVEL**—A request for activation may be directed to the Originating Primary Relay Station by the Governor, his designated representative, the National Weather Service, the State Civil Defense or State Office of Emergency Services.

• **LOCAL LEVEL**—A request for activation may be directed to the Common Program Control Station (CPCS-1) by the Weather Service, local Civil Defense, and local government or public safety officials.

2 AUTHENTICATION

The Originating Primary Relay Station and/or Common Program Control Station will authenticate request for activation according to the State EBS Operational Plan and associated implementing instructions.

3 IMPLEMENTATION

(a) Record emergency program material (Optional)

(b) Broadcast the following announcement:
"We interrupt this program because of a (state/local) emergency. Important information will follow."

(c) Transmit the EBS Attention Signal for 20 to 25 seconds.

(d) Broadcast the following announcement:
"We interrupt this program to activate the (name of State or Operational Area) Emergency Broadcast System at the request of (activating official) at (time)."

(e) Broadcast emergency program material (from (a) above).

Note: TV stations participating in the State or local level EBS shall display an appropriate EBS slide and transmit all announcement visually and aurally in the manner required by Section 73.1250(h) of the FCC Rules. Foreign language stations may transmit emergency announcements in the foreign language prior to broadcasting such announcements in English.

4 TERMINATION

(a) Upon receipt of the termination notice from activating official, make the following announcement:
"This concludes operations under the (name of State of Operational Area) Emergency Broadcast System. All broadcast stations may now resume normal broadcast operations."

(b) Record emergency operation in station operating or program log. Send brief summary to FCC (Optional).

State And Local Tests

Tests of implementing procedures developed at the State and local levels may be conducted on a day-to-day basis as indicated in State EBS Operational Plans. Coordinated tests of EBS operational procedures for an entire State or Operational Area may be conducted in lieu of the Weekly Transmission Tests of the Attention Signal and Test Script required by Section 73.961(c) of the Rules.

Station Notes

NONPARTICPATING STATION

National Level Instructions

When EBS is activated by the White House, all broadcast stations must take the following actions. Stations should record all emergency broadcasts (including notification) and log all significant events in the event these records are required at a later date.

**Activation Procedures—
All Stations**

1 RECEIVE EMERGENCY ACTION NOTIFICATION—EAN

(This is the notice which activates EBS—Presidential messages may be received as soon as 5 minutes.)

Notification by one of the following methods is sufficient to commence action:

- **AP and UPI TELETYPE**—Preceded and followed by a line of "X's" and 10 bell alarm.
- **RADIO-TV NETWORKS**—Affiliates only—preceded by network alerting signal—Continue to monitor for further instructions.
- **EBS MONITOR RECEIVER**—Preceded by Two-Tone Attention Signal—Step 5 for message format—Continue to monitor for further instructions.

Your EBS Monitoring assignment is specified in the State EBS Operational Plan.

EMERGENCY ACTION NOTIFICATION MESSAGE—AP UPI SUBSCRIBERS/ NETWORK AFFILIATES ONLY

"This is an Emergency Action Notification requested by the White House. The AUTHENTICATOR WORD for this notification is (—). All stations follow procedures in the EBS Checklist for national level emergency. The President of the United States or his designated representative will shortly deliver a message over the EMERGENCY BROADCAST SYSTEM. The Authenticator Word is (—)."

---

2 AUTHENTICATE NOTIFICATION AP AND UPI SUBSCRIBERS/NETWORK AFFILIATES ONLY

Compare authenticator words in notification with words on current EBS authenticator list. Take no further action if words do not match.

Different activation and termination words are provided for each date. Words are effective 12:01 a.m., Washington, D.C. time.

3 DISCONTINUE NORMAL PROGRAMMING AND BROADCAST ANNOUNCEMENT

(TV Stations shall display an appropriate EBS slide and transmit all following announcements visually and aurally in the manner required by Section 73.1250(h) of the FCC Rules. Foreign language stations repeat all announcements in foreign language.)

"We interrupt this program; this is a national emergency. Important instructions will follow."

---

4 TRANSMIT ATTENTION SIGNAL

Broadcast the Two-Tone Attention Signal (see section 73.906 of the Rules).

Note: Noncommercial educational FM broadcast stations of 10 watts or less, and low power TV stations, which are exempt from having the capability to transmit the Two-Tone Attention Signal.

5 BROADCAST ANNOUNCEMENT

"This is an Emergency Action Notification. All stations shall broadcast this Emergency

Action Notification Message. This station has interrupted its regular program at the request of the White House to participate in the Emergency Broadcast System. During this emergency, most stations will remain on the air broadcasting news and official information to the public in assigned areas. This is station (call letters). **We will be leaving the air. You should now tune to other stations until you hear one broadcasting news and information for your area. Do not use your telephone. The telephone lines should be kept open for official use. The Emergency Broadcast System has been activated to keep you informed. I repeat..."**
(Repeat Announcement)

---

6 **REMOVE CARRIER FROM AIR**

7 **MONITOR FOR EMERGENCY ACTION TERMINATION**

Same methods as for notification—Upon receipt, proceed to termination procedures.

Termination Procedures—All Stations

1 **RECEIVE EMERGENCY ACTION TERMINATION**

(Same methods as for notification)

Emergency Action Termination Message

AP/UPI Subscribers/Network Affiliates Only)

"This is an Emergency Action Termination. The AUTHENTICATOR WORD for this termination is (—). All stations follow the EBS Checklist for termination procedures. The Authenticator Word is (—)."

---

2 **AUTHENTICATE TERMINATION**

Compare authenticator words in termination with words on current authenticator list. Do not initiate termination if words do not match. (Red envelope contained in pocket on inside front cover.)

3 **BROADCAST ANNOUNCEMENT**

"This concludes operations under the Emergency Broadcast System. All broadcast stations may now resume normal broadcast operations." (Repeat Announcement)

---

4 **RESUME NORMAL PROGRAMMING**

(In accordance with regular station authorization)

STATE AND LOCAL LEVEL INSTRUCTIONS

Note: All the above National Level Tests and State and Local Level Instructions also apply to Non-participating stations.

EBS Monitoring Requirements

All stations can obtain their monitoring assignments from the FCC.

Over-the-air EBS Station Monitoring

In order to insure the effectiveness of the Emergency Broadcast System, all licensees must have installed and in operating condition, equipment capable of transmitting and receiving the Attention Signal. The receiving equipment must be maintained in operating condition, including arrangements for human listening or automatic alarm devices and shall be installed at the designated transmitter control point and/or studio location in such a way that it enables the broadcast station staff, at normal duty locations, to be alerted instantaneously upon the receipt of Attention Signal and to immediately monitor the emergency programming.

The Attention signal consists of the simultaneous transmission of two audio tones for not less than 20 seconds nor more than 25 seconds. The characteristics of the two-tone signaling system are as follows:

Encoder

Function. To give an alert by demuting a monitoring receiver at the station receiving the signal. The monitor is continuously tuned to the sending station for EBS information.

Signal. Two simultaneous audio frequencies, 853 Hz and 960 Hz, each +/- 0.5 Hz.

Harmonic Distortion. Not to exceed 5 percent of each tone at encoder output.

Minimum level of modulation. Each tone must be capable of modulating the transmitter to not less than 40%, with all equipment ordinarily used in the audio line between the encoder and transmitter. To assure this, the specification further says that the output at each audio tone shall be at least +8 dBm into a 600-ohm load. The unit shall allow calibration of each tone separately.

Time period. On activation, the two tones shall be generated for not less than 20 seconds nor more than 25 seconds.

Operating temperature. All foregoing specs maintained in ambient temperature 0 degrees to 50 degrees Centigrade.

Humidity. All specs must be maintained up to 95 percent relative humidity.

Supply voltage variation. Operation must be within tolerances with supply voltage from 85 percent to 115 percent of the rated value.

Testing conditions. Must maintain the frequency, distortion, and time period specs in a minimum RF field of 10 v/M at a frequency in the AM broadcast band, and with a minimum RF field of 0.5 v/M in either the FM or TV frequency band.

Indicator device. A visual and/or aural indicator must show clearly that the device has been activated.

Switch guard. The activation switch must have protection which will prevent accidental operation; this must include remote-control switches.

Decoder

The decoder must be activated only on *simultaneous detection* of the two audio tones, 853 Hz and 960 Hz. This simultaneous reception must demute the monitoring receiver. The additional capability of activating an external alarm is not *required*, but has obvious value.

To prevent falsing, the decoder must have: a time delay not less than 8 seconds, and not more than 16 seconds; must have bandwidth such that there is no response to tones that vary more than +/- 5 Hz from each of the frequencies, 853 Hz and 960 Hz.

The decoder must have a reset switch, for returning the receiver to a muted state after activation.

The decoder must maintain all the foregoing specifications in ambient temperature from 0 degrees to 50 degrees Centigrade.

For the convenience of operating personnel, the EBS decoder is in most cases muted for normal periods of operation. Such devices are, of course, activated upon receipt of the alert signal.

Special Reception Techniques

In certain instances either where stations are at a critical distance from another station or where receiving conditions are generally difficult by reason of directional operation, atmospherics, etc., extraordinary means are sometimes necessary to ensure the reception of the alert signal from another station. The Federal Communications Commission has provided information concerning the use of special receiving antennas which are applicable for such purposes. The application of this information, in many situations, will enable satisfactory reception of stations which ordinarily are completely unintelligible.

Shielding and Filtering

In cases where applicable, it is advisable to locate the antenna as far from a source of interference (or radio transmitter antenna) as possible and use coaxial or shielded transmission line to the receiver input terminals. Appropriate filtering and bypassing of power leads in order to eliminate the possible effect of high RF fields on the reception of the desired signal may be required. The antenna transmission line to the receiver may have to incorporate trap circuits to filter out the local transmitter radiation. For low-impedance receiver input, the circuit may be a parallel-resonant trap connected in series with the inner conductor of the coax. For high-impedance receiver input, the trap will perform most satisfactorily if connected directly across the input terminals, tuned to the frequency of the local station. Sometimes, both traps are required when the local RF field is high and/or when the cross-modulation products produced in a superheterodyne receiver cause adverse reception effects or when the undesired radiation is on a difference frequency from the desired frequency.

Loop Antenna

When the desired and undesired stations are on the same or very near the same frequencies, a directional antenna is often necessary. Such an antenna is also necessary in areas of weak signal strength from the desired station. A simple type of such antenna is the loop antenna, which is of maximum effectiveness only when the signals under consideration are within the ground-wave area. When this antenna is used, the null (obtained broadside to the plane of the loop) is oriented toward the undesired station. Maximum voltage is induced in the loop when the plane of the loop points toward the desired station. Since the antenna is bidirectional, a station on the back side may produce sufficient signal to cause interference, in which case a more elaborate directional receiving antenna may be required. (Fig. 5)

Beverage, or "Wave", Antenna

A very effective receiving directional antenna is the Beverage type. The theory of this antenna has been well covered in texts for many years and is not included here. Among the desirable properties of the Beverage, or the "wave," antenna for the reception are:

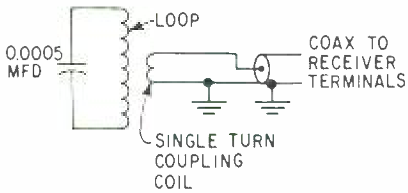

Fig. 5. Simplified schematic of a loop antenna with construction details. ***Loop dimensions:*** **13 turns of No. 20 wire wound on a 12-in. square form, with 1/8 in. spacing between turns. The coupling coil is a single turn wound inside the loop and spaced approximately 1 in. from the loop. The mechanical mounting is optional, but for best results the loop should be mounted in the clear and away from metallic objects. Experiments with various turns in the coupling coil and using a coaxial cable from the loop to the receiver might prove beneficial. Shielding the loop is important in direction-finding work but is not important for ordinary reception.**

1. It delivers a stronger signal over the entire standard broadcast band than a good, simple antenna of the single-wire variety.

2. When terminated, it is unidirectional but can be used as a bidirectional antenna either by switching the termination or by being unterminated.

3. Atmospherics and industrial interference are considerably reduced, especially when the source is in a direction other than that of the main lobe of the antenna.

4. The antenna is low in cost, has long life, and is usually easy and simple to erect provided the space is available.

National Industry Advisory Committee

Introduction

A National Industry Advisory Committee (NIAC) has been organized to advise and assist the Federal Communications Commission, and

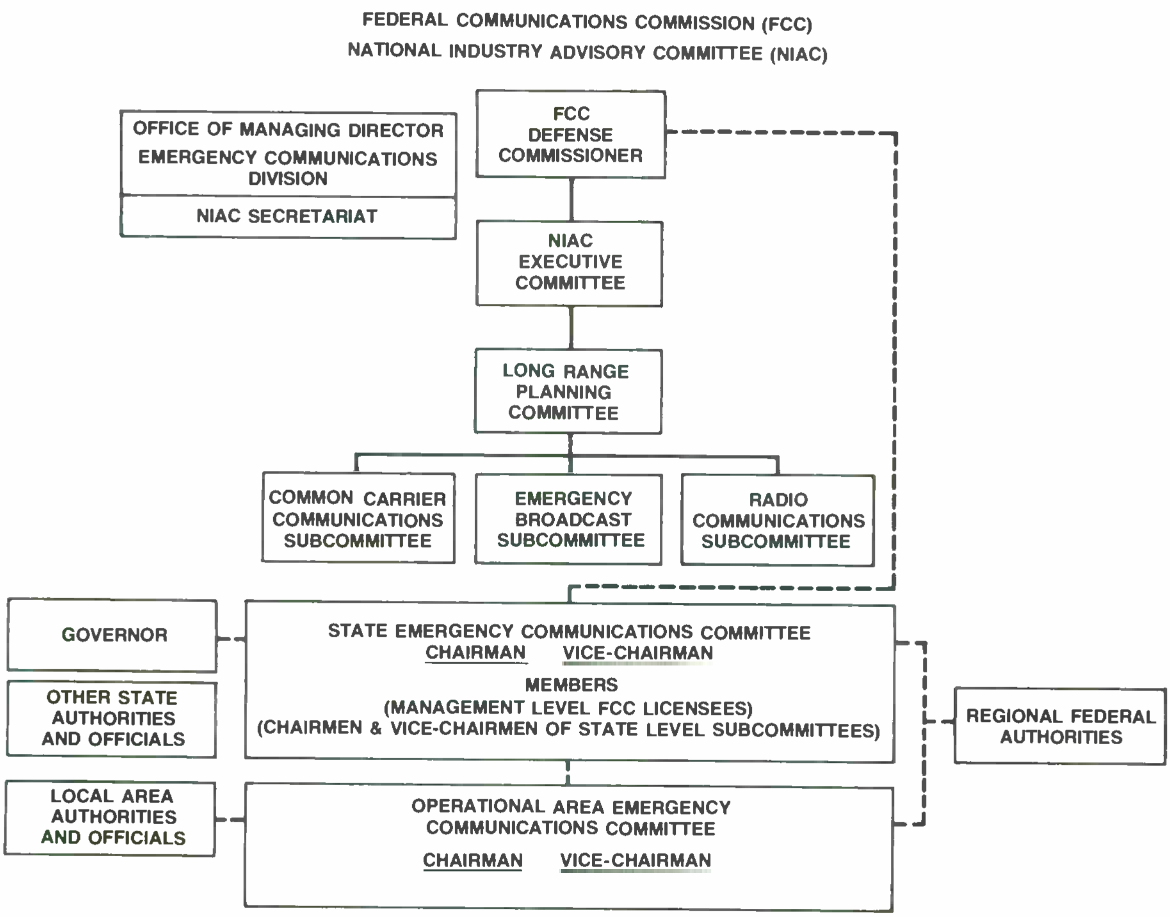

Fig. 4. Industry Advisory Committee organization chart.

other appropriate authorities. NIAC's function is to study and submit recommendations for emergency communications policies, plans, systems, and procedures, for all FCC licensed and regulated communications in order to provide continued emergency communications services under conditions of crisis or war. In addition, NIAC considers the adaptation and use of the systems, arrangements, and interconnecting facilities set forth in approved Operational Plans on a voluntary, organized basis during national, state, and operational (local) situations posing a threat to the safety of life and property. Included also are those conditions constituting a state of public peril or disaster. Such use of these capabilities during emergency situations is in accordance with the Commission's emergency and preparedness responsibilities, as defined in sections 1, 4(o), 301, 308(a) and 606 of the Communications Act of 1934, as amended, and Executive Order 11490.

Organization

The National Industry Advisory Committee:
Chairman
Vice Chairman
Executive Secretary
Executive Committee partly composed of the Chairman and Vice Chairman of National Level Subcommittees
Long Range Planning Committee
National Level Subcommittees:
Emergency Broadcast Services Subcommittee
Private Radio Service Subcommittee
Common Carrier Communications Service Subcommittee

Members of the NIAC are appointed for a term not exceeding two years by the Federal Communications Commission, subject to appropriate security clearance when warranted. Membership in the NIAC and its subcommittees is restricted to officers and employees of nongovernment Federal Communications Commission licensees (communications industry), subject to formal waiver when it is deemed in the public interest, convenience, and necessity. ("Nongovernment," as used herein, excludes federal government but includes state and local government agencies which are not licensed by the Federal Communications Commission.) Since all appointees serve at the pleasure of the Commission, any appointment may be terminated without cause. Such termination will be effective upon receipt of written notification from the Commission.

The Executive Secretary serves as the official correspondent for the National Industry Advisory Committee.

Functions and Responsibilities

The NIAC is concerned with operational emergency communications policies, plans, systems and procedures to fulfill stated requirements under a broad range of emergency contingencies posing a threat to the safety of life and property. The principal functions and responsibilities include but are not limited to:

a. Studying and submitting recommendations to the Federal Communications Commission concerning operational emergency communications.

b. Providing advice and recommendations through the Federal Communications Commission to appropriate federal, national, state and local authorities and organizations to enhance emergency communications operations.

c. Maintaining liaison with the nongovernment communications industry.

d. Maintaining liaison with all subcommittees, Special National Industry Advisory Committee Working Groups, and ad hoc committees to coordinate and assist in the planning for the utilization of nongovernment communications facilities during emergencies.

e. Coordinating with the Federal Communications Commission in the establishment of authentication procedures for use during emergencies.

f. Advising the Federal Communications Commission concerning industry opinion relative to any proposed test or exercise of emergency communications systems, plans, and procedures. Also assisting, observing and evaluating the effectiveness of such activities.

g. Evaluating proposals for the development and use of operational emergency communications systems, plans, and procedures.

h. Encouraging studies and research directed towards the improvement of existing and development of new systems, plans, and policies which will improve the overall effectiveness of emergency communications.

i. Maintaining liaison with State Emergency Communications Committees.

Procedures

Detailed procedures with respect to operation, management, and functioning of the National Industry Advisory Committee, Subcommittees and Working Groups are published in separate documents and are available from the Executive Secretary, National Industry Advisory Committee, Federal Communications Commission, Washington, D.C. 20554.

REFERENCES

1. FCC Rules and Regulations, Subpart G, Emergency Broadcast System.

2. Broadcasting Emergency Information, FCC Rules Section 73.1250.
3. Detailed State EBS Plans.
4. Operational (Local) Area EBS Plans.
5. EBS checklist

7.9

Broadcast Audio Measurement

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AUDIO MEASUREMENT

The ability to quantify audio signals in terms of characteristics and qualities is paramount in audio engineering. This allows comparisons to be made with reference to established standards and requirements. Of interest include measurements relating to amplitude, frequency content, distortion, noise, relative loudness, and phase. The observation of such attributes allows complete characterization of an electrical audio system.

In the broadcast environment, audio measurements are used to gauge the overall quality of equipment such as amplifiers, tape recording systems, transcription equipment, mixing consoles, and other networks including the overall broadcast signal path. These types of measurements are detailed below. Other common audio measurements are of an acoustic nature and relate to the characteristics of microphones and speakers. These are not covered in this section.

Amplitude Measurement

The most basic of needs in audio measurement is to determine a value relating to the size, or amplitude, of an audio signal. Since an audio waveform is rapidly changing, methods have been developed to convert peak, r.m.s. and average values of the changing waveform into corresponding proportional dc voltages which can then be more easily observed.

There are specific cases where the peak value is the most direct measure of magnitude. It gives an indication of the largest excursions (either positive or negative) of an audio waveform. As is shown in Fig. 1, the signal is applied to an absolute value circuit, which rectifies the waveform such that the output is all positive. A diode is then used to couple into C and R. These serve as memory and decay time elements, respectively, which can then be adjusted in value to conform to the ballistics desired. Although the output is still changing with time, along with the input, the excursions corresponding to the peak values of the original waveform are much slower and more easily observed on metering devices. As the value

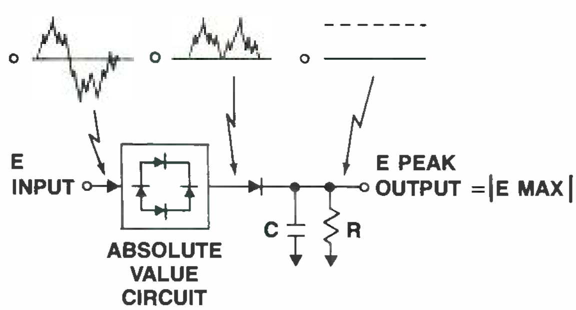

Fig. 1. Peak value detection.

NOTE: Superscript numbers refer to references at the end of this chapter.

of resistor R is increased, the decay time of the output is proportionally increased as well. If the resistor is completely removed, a "peak hold" circuit results.

Peak (actually "peak to peak") functions can also be observed on an oscilloscope, although this technique is often impractical because of the difficulty in reading the random waveforms typical in most audio material. Storage oscilloscopes can perform a "peak-to-peak hold" function.

While there are many cases where the peak value is of considerable use, the r.m.s. value of a signal is generally most meaningful since it gives indication of the energy content of the signal without regard to its waveform. In audio measurement, however, it is usually simpler to detect the average amplitude of a given waveform and relate it to an associated r.m.s. value, with reference to a sine wave. The r.m.s., or "root mean square" level can be defined as follows:

$$E_{r.m.s.} = \sqrt{\frac{E_1(t)^2 + E_2(t)^2 + \ldots + E_n(t)^2}{n}} \quad [1]$$

where E_1 through E_n are successive measurements over time of a total of n samples. As can be seen from its name, the value is computed by taking the average of n samples of E squared. Performing the square root function completes the calculation. This is also commonly referred to as "true r.m.s.".[1] Fig. 2 shows how this is accomplished electrically.

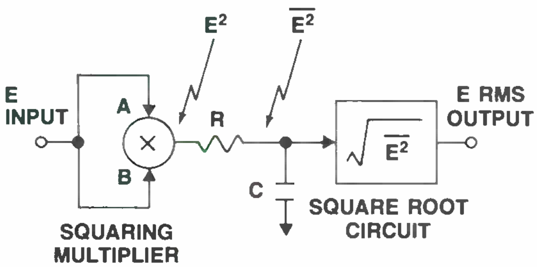

Fig. 2. True RMS detection.

Through the use of the absolute value circuit of Fig. 1 and the R/C configuration found in the r.m.s. detector of Fig. 2, an average detector can be made. This is shown electrically in Fig. 3 and mathematically below:

$$E_{\text{average}} = \frac{E_1(t) + E_2(t) + \ldots + E_n(t)}{n} \quad [2]$$

In terms of audio perception, the average value of an audio signal is related to program material

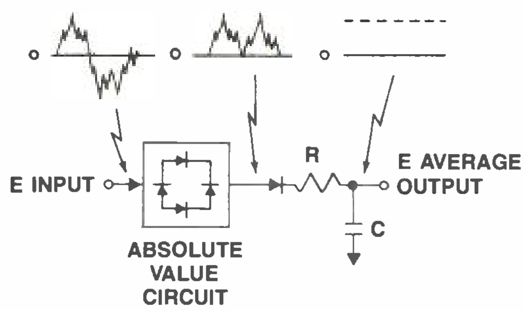

Fig. 3. Average value detection.

density, where the peak value described earlier relates to a maximum. Since the peak value defines the upper limit of allowable modulation in a transmission system, it is often desirable that the peak to average ratio be as low as possible to attain highest perceived loudness and signal to noise ratio.

The decibel, or dB, is a unit for comparing relative levels of voltage or power signals in transmission systems. In broadcast audio systems, the most common representation of decibels is dBm. This is the value of a signal with reference to 1 mW into 600 ohm load. The level in dBm of a signal can be found using the following relation:

$$dBm = 20 \log \left(\frac{E}{0.775}\right) \quad [3]$$

where E is the voltage level to convert. The number 0.775 represents the voltage level found at the reference. Quantities from the peak, r.m.s., and average circuits described above can be used for possible values of E. When this is done, some common types of metering can be synthesized to observe the activity of audio material.

Metering

Two popular types of metering for the characterization of program audio are the standard volume indicator, commonly known as the "vu meter," and the peak program meter (referred to as ppm). Although vu metering has been the more common in U.S. broadcast equipment, the standard ppm indicator is gaining popularity.

The vu meter (see Fig. 4) was introduced in 1939 to serve as a standard program level indicating device.[2] Its original purpose was to be the reference between broadcasters (as well as other programming suppliers) and the telephone company. A vu meter is the combination of a bridge rectifier, a resistive attenuator, and an ammeter with an approximately voltage linear scale to produce an average responding ac voltmeter. The vu meter is calibrated such that it reads 0 vu across

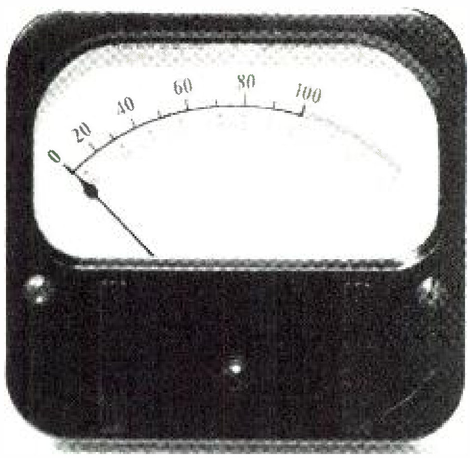

Fig. 4A. VU meter.

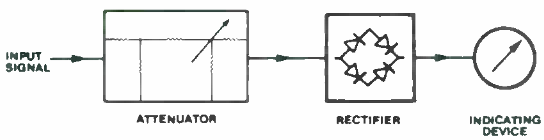

Fig. 4B. Block diagram of the stages of a typical volume unit indicator.

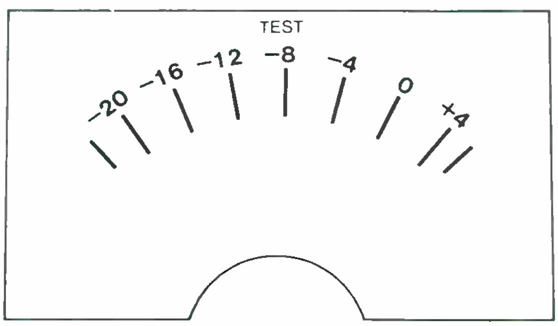

Fig. 4C. Arrangement of a typical peak-program meter scale.

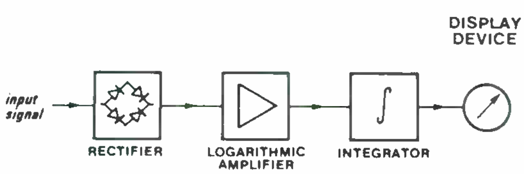

Fig. 4D. Block diagram of the stages of a typical PPM.

a circuit in which sinusoid develops 1 mW in a resistance equal to the circuit impedance (e.g., 0.775 volts r.m.s. across 600 ohms). This allows the meter to be powered directly by a 600 ohm program line, with the attenuator typically set to read 0 vu at +8 dBm.

Beyond reading continuous tones, the dynamic characteristics are set so that it will display 99 percent of its steady-state reading on a sine wave tone burst 300 milliseconds long, with a fall to 5 percent of the reading in 300 milliseconds. Essentially an average responding device, the vu meter will not respond to short duration program peaks. Therefore, levels should be set with a 10 dB margin (headroom) to the point of clipping.[3]

The peak program meter (ppm) is designed to read nearly the full peak value of the audio signal (See Figs. 4C, 4D). It uses a rectifier and an integrator producing a fast rise and slow fall effect on the display device. Typical standards require the ppm to read −2 dB, ± 0.5 dB of the steady state value for a tone burst of 10 mS, and take 2.8 seconds for the pointer to fall 20 dB.[4]

Typically, a ppm exhibits flat frequency response and are calibrated such that the nominal peak program level corresponds to a 0 dB meter reading near full scale (generally +16 dBm).

Other types of metering devices have been developed to read wide band audio in a simultaneous mode. One such system consists of an LED bar graph display exhibiting peak program content. "Riding" upon this is a brighter display (utilizing the same display elements) corresponding to vu standards. Such an indicator allows continuous monitoring of program material compression and dynamic characteristics. Another system combines a vu movement meter with peak indicating LED flashers. A "hold" function is sometimes associated with these to allow an operator sufficient time to observe the approximate peak content.

Frequency Analysis

Amplitude analysis methods as described in the previous section are generally used to provide an indication of signal levels simultaneously over the entire audio range. It is sometimes more desirable however, to be able to measure discrete frequencies in an audio system. This allows frequency response measurement as well as dynamic measurement of energy content throughout the audio spectrum.

Simply stated, frequency response is the capability of a device or system to pass or amplify equally, all frequencies within a specified range.[5] As far as audio in the broadcast environment is concerned, the range of interest is generally 50 Hz to 15 kHz. Although few musical instruments produce fundamental frequencies greater than 4 kHz and the human voice much above 1 kHz, the reproducing device or system must be able to pass the harmonics which accompany the fundamental frequency. Without adequate bandwith or with uneven frequency response, an unnatural "coloration" of the perceived sound becomes evident. To solve this, a great deal of care is taken to construct amplifiers with very flat frequency response to high frequencies. Since the responses of series-connected amplifiers are additive, care must be taken to verify the flatness of each in a system.

Several methods are available to measure audio frequency response. They include discrete measurement and swept frequency methods. Parallel analysis and Fast Fourier Transform (FFT) techniques can also be used.

The discrete frequency measurement method is uncomplicated and inexpensive. A simple measurement system consists of a low distortion audio frequency oscillator and a wide band ac voltmeter. The oscillator output is connected to the input of the device or system to be characterized. The voltmeter is used to observe the level at the output of the device or at a desired intermediate point in a system.

The measurement is done by first setting the generator output level to a value which represents nominal input operating level of the device. Generally, a 1 kHz frequency is chosen initially in high fidelity audio systems. The output level is read on the ac voltmeter, and this quantity is noted as a zero dB relative reference. Provided the generator itself has a flat frequency response, measurements at frequencies through the audio band can be measured while recording the corresponding dB output levels with respect to the reference. A convenient and commonly used technique is to increment the frequency in a 1, 2, 5 sequence (i.e., 20 Hz, 50 Hz, 100 Hz, 200 Hz, etc.). This permits plotting the final response data on 4-cycle "Log/Lin" graph paper providing regularly spaced frequency increments horizontally. The logarithmic amplitude data are plotted along the horizontal axis, with the zero dB relative reference placed in a convenient position as the linear vertical axis.

Although the discrete frequency measurement technique is straightforward, it is also often tedious and time-consuming. Numerous frequency measurements must be made to insure adequate testing. This method is most usable in the response measurement of single ended devices which do not have suitable input ports for connection to an audio generator. Transcription equipment, such as turntables and compact disc players are examples of these types of devices. Test recordings supplied by the equipment manufacturer and others are used to provide the tones necessary for discrete frequency response characterization.

Swept Frequency

A faster and more efficient means of measuring frequency response is the *swept frequency* method. This process employs a sweep frequency generator as a signal source and measures response over the entire range of interest in one sweep. The detector for these measurements is most often a tracking type which follows the signal source and measures a narrow band of frequencies centered around the source frequency. Use of a tracking detector is a better guarantee that the amplitude measured is that of the tone generator and is not influenced by spurious tones, noise, or harmonics.

Devices specifically designed to do swept frequency measurements include wave analyzers and spectrum analyzers. Wave analyzers must be used with plotters to provide a hard copy data plot, while spectrum analyzers directly produce response images on a built-in display. A representative spectrum analyzer is shown in Fig. 5 while the one displayed in Fig. 6 is specifically intended for audio frequency use.

Fig. 7 shows a typical setup for measuring amplifier frequency responses using the swept frequency method. The signal source used to drive the test device is the tracking oscillator output

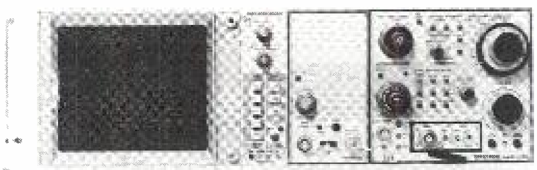

Fig. 5. Spectrum analyzer suitable for audio and low frequency RF use.

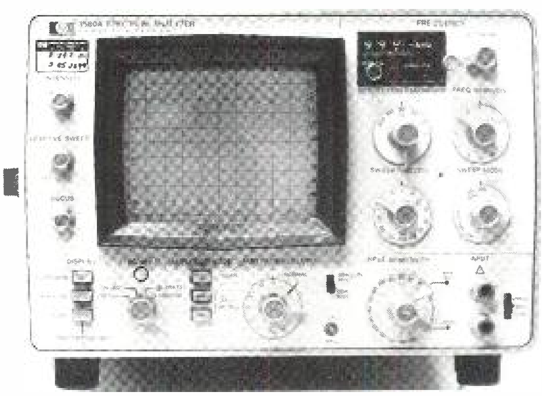

Fig. 6. Spectrum analyzer intended for audio use.

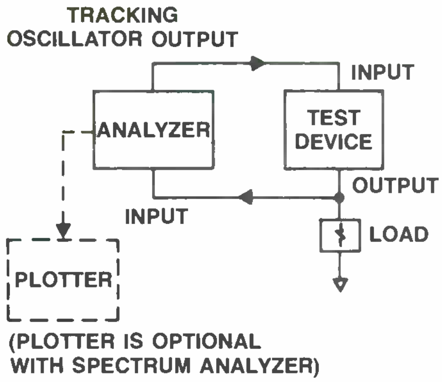

Fig. 7. Frequency response measurement using swept method.

of the analyzer. The device's output is terminated with an appropriate characteristic load impedance and connected to the analyzer input. Measurement of the frequency response is made by manually or automatically sweeping the analyzer across the frequency range of interest. A plotter connected to either type of analyzer or a scope-type camera used with the spectrum analyzer can provide a permanent record of the device's response characteristics.

The swept frequency method can also be used to measure overall frequency response of multiple-head tape recorders. The tracking oscillator signal is connected to the record amplifier input and the output is taken from the playback amplifier output. This allows recording and playback frequency response measurement to be done all at once and eliminates the necessity of synchronizing the analyzer sweep to the recorded signal. But a time delay between input and output signals exists, caused by the physical displacement between record and playback heads. This can be corrected simply by using a very slow sweep speed or a wider measurement bandwidth.

Real Time Analyzer

A real time audio analyzer (RTA) consists of a sequential collection of one octave or one-third octave filters having individual detectors and indicators at each output. The program audio is simultaneously fed to the inputs of all the filters. The output signal of each filter is proportional to the amount of energy occurring in that particular frequency band. This is also referred to as *parallel analysis*.

A simplified version of an RTA is presented in Fig. 8. As shown, it is intended to break the audio band into three sections using low, mid-band, and high-pass filtering. Signal detectors are then used to condition the audio for display on a suitable indicator, one set for each of the three bands. The detectors can be (and often are) the same peak, r.m.s. or average circuits described earlier. Typically, readout indicators are bar graph displays with dB-calibrated scales. When arranged side by side, the readouts provide a graphical presentation of amplitude versus frequency, just as the spectrum analyzer does. Unlike the spectrum analyzer, however, an RTA does not rely on a fixed sweep speed. An advanced audio analysis system with RTA function is shown in Fig. 9. Fig. 10 shows a typical RTA display of the same unit.

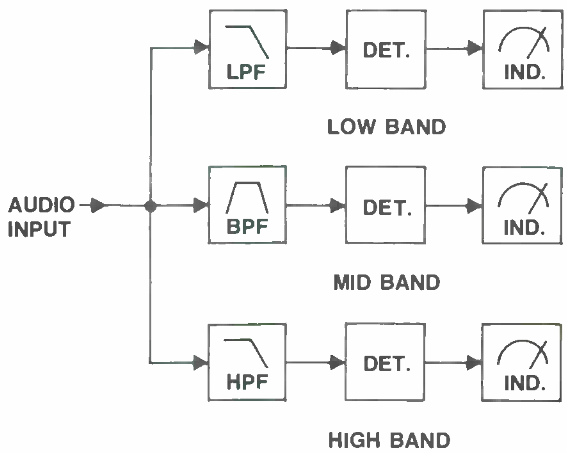

Fig. 8. Basic real-time analyzer.

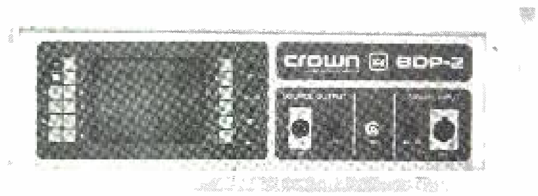

Fig. 9. Advanced audio analyzer with RTA functions and CRT display.

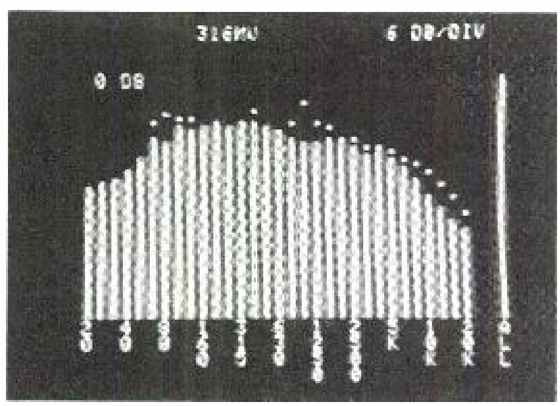

Fig. 10. Typical RTA display.

Parallel techniques using the RTA are often used for dynamic program material and room acoustics analyses.[6] This type of analyzer is also useful for measuring frequency response of audio devices when used in conjunction with a "pink" noise source. Pink noise has a constant mean squared voltage per octave. This makes it popular in audio work since it allows correlation between successive octaves by ensuring the same voltage amplitude is available as a reference. By connecting the pink noise source to the input of a device to be characterized, and the RTA to its output, a response curve can be displayed.

Although often prohibitive in cost, network and FFT analyzers are also exceptionally useful in audio frequency domain measurements. Network analyzers are swept-analysis instruments and used to characterize 2-port networks (i.e., devices having an input and output) as to frequency, phase, and delay responses. They are employed where substantial accuracy in the measurement of these parameters is required. RF sub-system and semiconductor device design have been the major application for network analyzers, although some newer generation equipment includes audio-frequency coverage. This allows precision response measurement of amplifier and filter designs.

FFT (Fast Fourier Transform) analyzers have the ability to convert a snapshot sampling of an audio or other time-varying source and mathematically transform the result into a display of the frequency components present. Because the conversion process is done by a specialized microcomputer, an FFT analyzer can often produce a spectrum display as much as an order of magnitude faster than conventional swept-spectrum analyzers. This is most helpful in low frequency measurement, where a swept analyzer would require a very slow sweep time to resolve closely spaced components. Although often helpful in audio system measurements, FFT analyzers are used mostly in industry for vibrational analysis and other mechanically-oriented testing.

Distortion Measurement

When a device is driven beyond its range of linear operation, or through areas of discontinuity, signal distortion occurs. As a result, additional frequencies appear at the output which are not present at the input. In cases where distortion becomes extreme, it can be identified through listening. Odd-order distortion (commonly "clipping" distortion) can become audible around 1.25 percent. Even-order distortion, characterized by a "coloration" of the program material, becomes audible at about 5 percent. Generally, systems with a wider frequency response capability need lower distortion levels to be acceptable. Since distortion is not always obvious to many people, techniques are available to measure its various types.

Distortion can be characterized in two basic ways: harmonic distortion and intermodulation distortion. While the two associated methods produce uncorrelated measurement values, each gives a quantitative result of the device's quality in terms of a single number. Although total harmonic distortion (THD) content is determined by only one method, intermodulation distortion (IMD) has several accepted measurement practices. These include the SMPTE and CCIF methods. Transient Intermodulation Distortion (TIM) is another commonly measured type of IMD.

Harmonic Distortion

Harmonic distortion is a measure of individual harmonic amplitudes with respect to the amplitude of the fundamental frequency. In practice, harmonics greater than the third often add little to the resultant value because of their negligible amplitude. THD is defined as:

$$THD\% = 100\ \frac{\sqrt{A_2^2 + A_3^2 + A_4^2 + \ldots + A_n^2}}{A_1} \quad [4]$$

where A_2 through A_n are the amplitudes of the individual harmonics and A_1 is the amplitude of the fundamental. As seen in Fig. 11, a 1 kHz signal with harmonic distortion can display only minor differences when it is overlaid with an undistorted signal. The amplitude and slope errors do not lead directly to a numeric result. But when a spectrum photo of the same waveform is observed (Fig. 12), the relation above can be applied. With the fundamental at 0 dBm (0.775V), the second harmonic at -26 dBm (38.8 mV), and

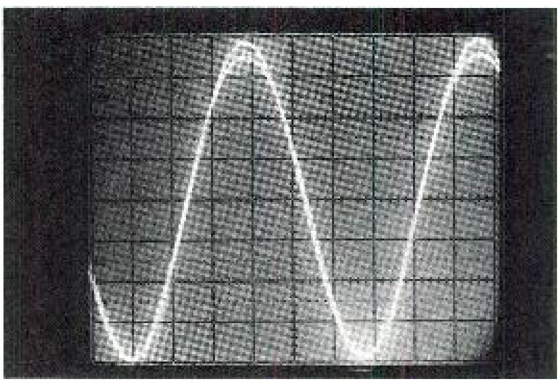

Fig. 11. Comparing the distorted output with an undistorted 1 kHz tone with its undistorted component.

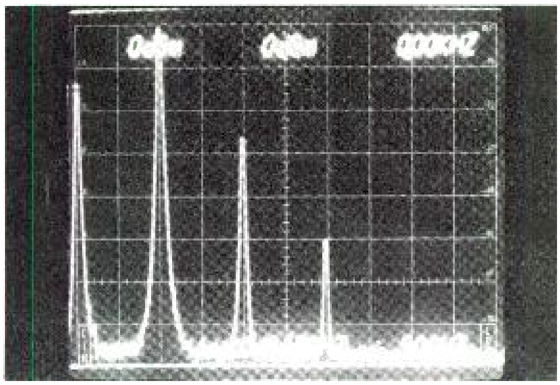

Fig. 12. Measuring THD with a spectrum analyzer. (V:10dB/div.; H:500Hz/div)

the third harmonic at -50 dBm (2.5 mV), the harmonic distortion can be calculated:

$$THD\% = 100\frac{\sqrt{(0.0388)^2 + (0.0025)^2}}{0.775} = 5.0\%[5]$$

Although spectrum analysis can produce accurate THD measurement results, a simpler and more cost effective procedure which produces a direct numeric quantity is the most popular method.

Fig. 13 shows the block diagram of a typical THD analyzer. An oscillator (having much less harmonic distortion than the device or system to be measured) is connected to the device's input. The distorted output signal of the device is filtered to remove A_1, the fundamental component. This produces a signal which, when r.m.s. detected, is proportional to the THD imposed by the device being tested.

THD measurement is often done over the same 1,2,5 sequence of frequencies as mentioned for discrete response measurement. The THD results can be plotted on the same graph to characterize better the device under test. THD measurements may be taken over various input levels, but as the level is reduced, noise characteristics will affect the readings. In such a case, the spectrum analyzer method produces more meaningful results.

Intermodulation Distortion

The intermodulation method of measuring distortion uses a test signal composed of two sinusoidal signals of different frequencies (except for TIM measurement, to be covered shortly). After summation, they produce the effect of an amplitude modulated carrier when applied to a circuit having IM distortion. The intermodulation method is useful because the harmonic distortion of the signal sources do not affect the measurement.

The SMPTE method uses a low frequency (f_1) and a relatively high frequency (f_2) signal (usually 60 Hz and 7 kHz, respectively) which are mixed at a four to one amplitude ratio (see Figs. 14 and 15). This method involves the measurement of the relative amplitude of the modulation sidebands of the higher frequency signal. For diag-

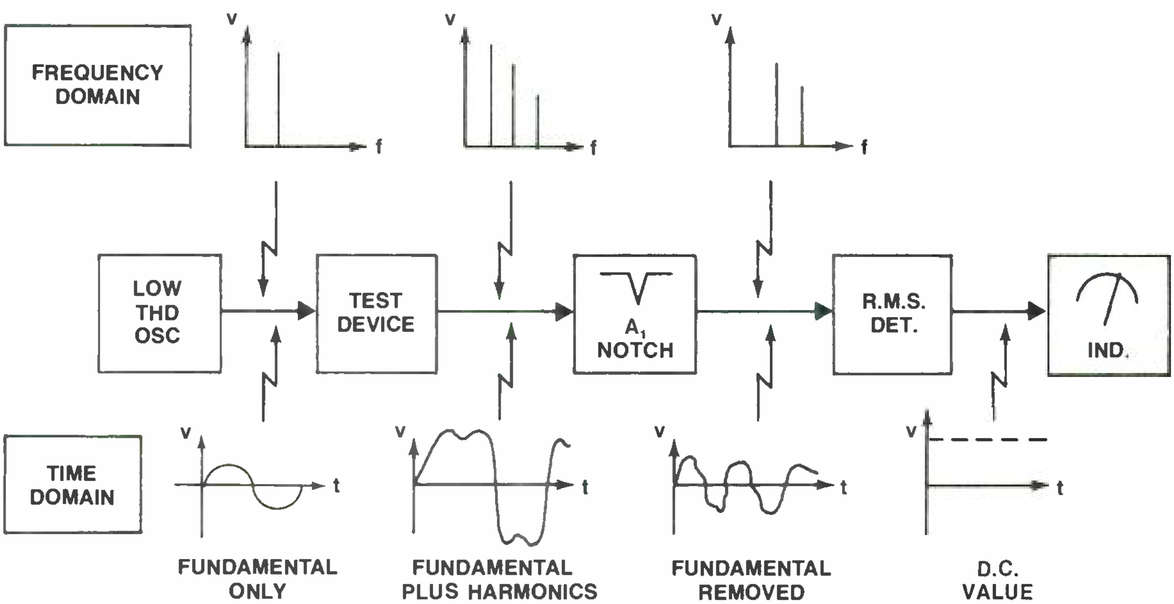

Fig. 13. THD analyzer.

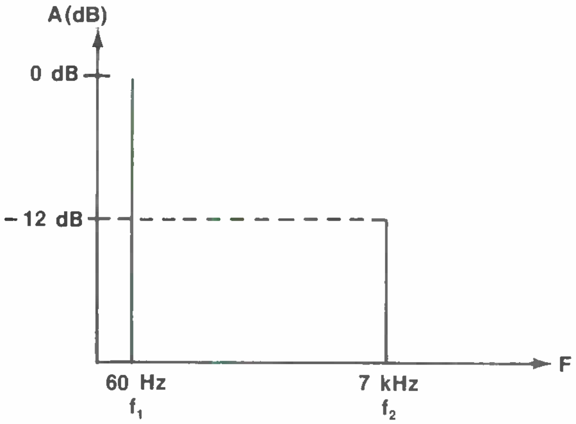

Fig. 14. Spectrum of SMPTE IM input test signal ratios.

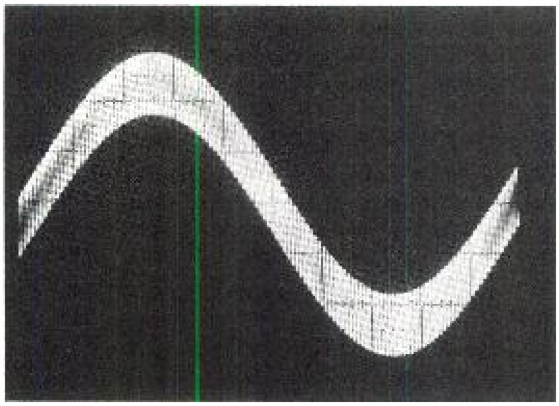

Fig. 15. SMPTE IM test signal.

nostic purposes, it is often useful to determine even-order and odd-order distortions separately, although this is best done by spectrum measurement techniques. Even-order distortion usually can be characterized by the ratio of the sum of the amplitudes of only the two second-order spurious frequencies, $f_2 - f_1$ and $f_1 + f_2$, to the amplitude of the "carrier" signal, f_2:

$$\text{SMPTE IMD\%}_{\text{(second order)}} = \left[\frac{A_{(f_2 - f_1)} + A_{(f_1 + f_2)}}{A_{f_2}}\right] \times 100 \qquad [6]$$

In a similar manner, odd-order distortion can be characterized by the ratio of the sum of the amplitudes of the two third-order spurious frequencies, $f_2 - 2f_1$ and $2f_1 + f_2$, to the amplitude of f_2:

$$\text{SMPTE IMD\%}_{\text{(third order)}} = \left[\frac{A_{(f_2 - 2f_1)} - A_{(2f_1 + f_2)}}{A_{f_2}}\right] \times 100 \qquad [7]$$

Fig. 16 shows the output signal of an amplifier with IM distortion as viewed on an oscilloscope.

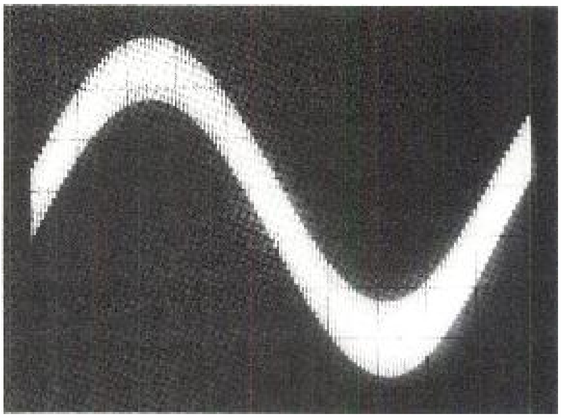

Fig. 16. SMPTE IMD measurement - time domain output signal.

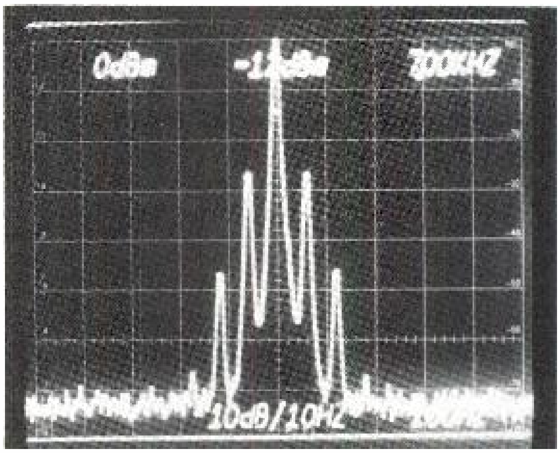

Fig. 17. SMPTE IM distortion measurement. (V:10dB/div; H:100Hz/div.)

Note the elongated trough as compared to Fig. 15. As in THD, spectrum analysis can be used to determine the numerical amount of distortion present. Intermodulation sidebands can be seen around f_2 in the spectrum photo of Fig. 17. Second and third order distortion percentages for this example are calculated as follows:

$$A_{f_2} = -12\ dBm = 195\ mV$$

$$A_{(f2 - f1)} = A_{(f_1 + f_2)} = -38\ dBm = 9.76\ mV$$

$$\text{SMPTE IMD\%}_{\text{(second order)}} = \left[\frac{9.76 + 9.76}{195}\right] \times 100 = 10.0\%$$

$$A_{(f2 - 2f1)} = A_{(2f_1 + f_2)} = -58\ dBm = 0.98\ mV$$

$$\text{SMPTE IMD\%}_{\text{(third order)}} = \left[\frac{0.98 + 0.98}{195}\right] \times 100 = 1.0\% \qquad [8]$$

As is shown, the contribution of even-order distortion products is usually greater than that of the odd order. To express the result as a single quantity, the vector sum of the two quantities is taken:

$$\text{SMPTE IMD\% (total)} = \sqrt{((IMD\%\ Even)^2 + (IMD\%\ Odd)^2} = \sqrt{10^2 + 1^2} = 10.05\% \quad [9]$$

As with THD, SMPTE IM has a direct method of numeric solution, as shown in the block diagram of Fig. 18. The two test frequency oscillators are summed to produce the $f_1 + f_2$ signal which is applied to input of the device to be tested. The distorted output signal is high-pass filtered to remove the f_1 fundamental component leaving only the amplitude modulated f_2 component. Using a standard a.m. demodulator and low-pass filter, the residual f_1 component is obtained. After r.m.s. detection, a dc level proportional to the distortion is present and can be viewed on a direct-reading indicator.

"Wow and Flutter" is a term which describes a special case of IM distortion normally associated with analog tape recorders. It is caused by variations in tape velocity across the recording and/or reproduction heads due to imperfections in the mechanical drive system. These variations result in frequency modulation of the recorded and reproduced signal. The frequency spectrum obtained is similar to that of the SMPTE IM distortion measurement method, except the f_1 low frequency signal is generated by fluctuations in tape speed and is not of any set amplitude.[5]

To measure wow and flutter, a test tape containing a prerecorded 3 kHz tone is played. Using an audio spectrum analyzer, for example, the amplitude of the first sideband (A_m) with reference to the 3 kHz amplitude (A_o) is measured. The frequency of the flutter (F_m) must also be known. Then the following relation can be used to approximate the percent of wow and flutter present:

$$\text{WOW \& FLUTTER \% (peak-to-peak)} = \frac{2\,(A_m)\,(F_m)}{(A_o)\,(3\,kHz)} \times 100 \quad [10]$$

For example, if the first sideband (either upper or lower) amplitude is 10 dB below the 3 kHz maximum amplitude (0.316 volts with reference to an arbitrary 1 volt 3 kHz level) and is at a frequency of 4 Hz, the wow and flutter would be 0.084 percent.

The CCIF intermodulation method uses a combination of two higher frequency sinusoidal signals (f_3, f_4) of equal amplitude. They are typically 1 kHz apart and found at 5/6 kHz, 14/15 kHz, or 19/20 kHz in most applications. One of the spurious frequencies generated is low in frequency while others are gathered around the two driving frequencies. Fig. 19 and 20 spectrally show the driving frequencies before and after

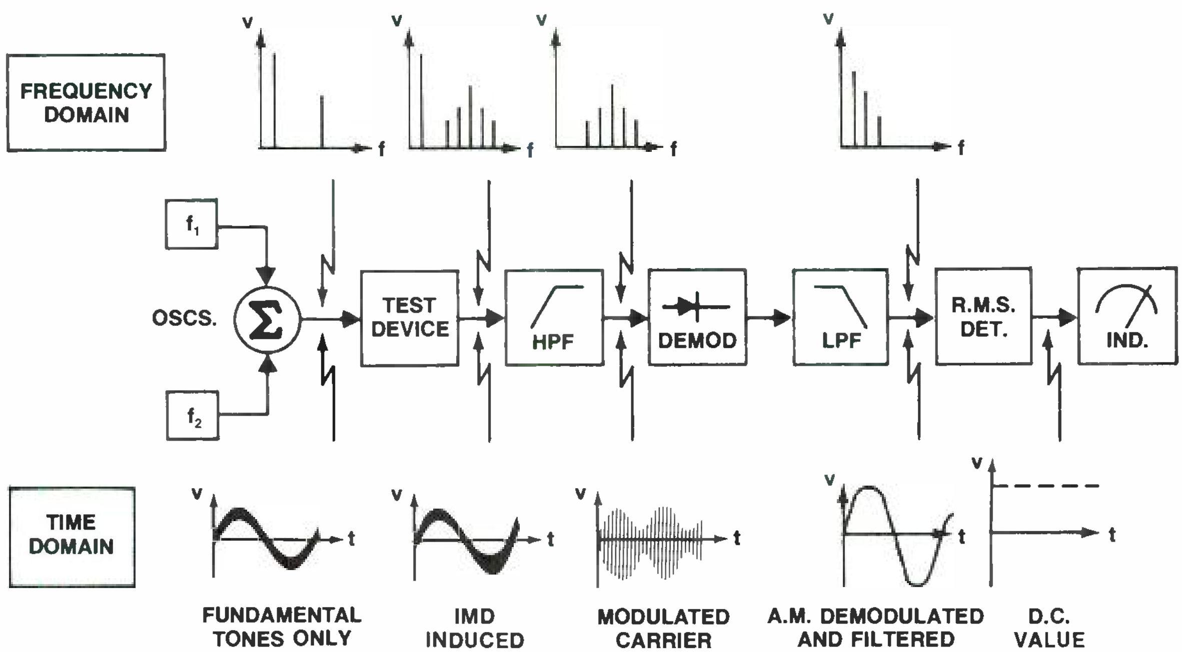

Fig. 18. SMPTE IMD analyzer.

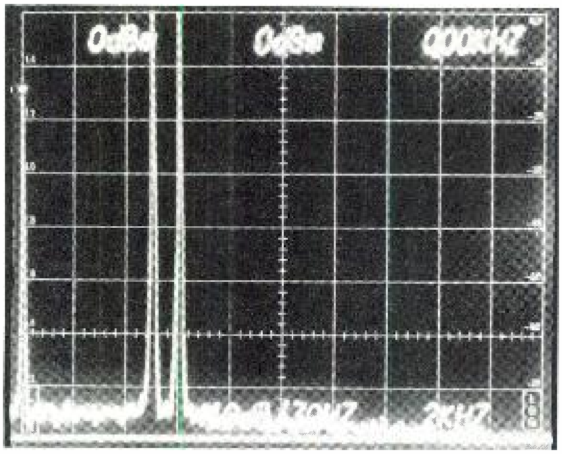

Fig. 19. CCIF IM test signals. (V:10 dB/div.; H:2 kHz/div.)

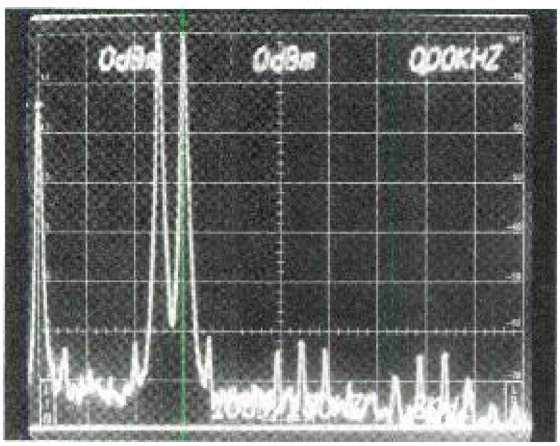

Fig. 20. CCIF IM distortion measurement. (V:10 dB/div.; H:2 kHz/div.)

passing through a test amplifier. As with SMPTE IMD measurement, the generated spurious products can be classified as even-order or odd-order. Even-order distortion is expressed as the ratio of the amplitude of the difference component $(f_4 - f_3)$ to the sum of the two driving frequencies (f_3, f_4):

$$\text{CCIF IMD\% (second order)} = \left[\frac{A\,(f_4 - f_3)}{Af_3 + Af_4}\right] \times 100 \qquad [11]$$

Odd-order distortion is determined by calculating the ratio of the sum of the amplitude of the two third-order products, $2f_3 - f_4$ and $2f_4 - f_3$, to the sum of the amplitudes of the two driving frequencies, f_3 and f_4:

$$\text{CCIF IMD\% (third order)} = \left[\frac{A\,(2f_3 - f_4) + A(2f_4 - f_3)}{Af_3 + Af_4}\right] \times 100 \qquad [12]$$

In the case of Fig. 20, the driving frequencies f_3 and f_4 are at 5 kHz and 6 kHz, even-order product at 1 kHz, and third-order products at 4 and 7 kHz, respectively. Distortion percentages for this example are calculated below:

$$Af_3 = Af_4 = 0\ dBm = 775\ mV$$

$$A(f_4 - f_3) = -64\ dBm = 0.49\ mV$$

$$\text{CCIF IMD\% (second order)} = \left[\frac{0.49}{775 + 775}\right] \times 100 = 0.032\%$$

$$A(2f_3 - f_4) = -62\ dBm = 0.62\ mV$$

$$A(2f_4 - f_3) = -61\ dBm = 0.69\ mV$$

$$\text{CCIF IMD\% (third order)} = \left[\frac{0.62 + 0.69}{775 + 775}\right] \times 100 = 0.085\% \qquad [13]$$

It is a common practice for direct-reading metered analyzers to measure only the amplitude of the difference product $(f_4 - f_3)$ with respect to the driving signal amplitudes. A device which performs this task is called a CCIF second-order difference frequency distortion analyzer. Fig. 21 shows how the measurement is made.

Transient Intermodulation (TIM) distortion is found only in amplifiers that utilize negative feedback which, when excessive, causes a fast-rising transient signal applied to the input of the amplifier to produce an internal overshoot which saturates the circuits in the amplifier.

The most popular procedure used to measure TIM distortion is called the "Sine-Square Wave Method". The test signal employed uses a square wave (f_{sq}) to induce nonlinearity in the test device by saturating the amplifier's internal current, caused by its alternate rises and falls. Mixed with this square wave is a low level, high frequency sine wave (f_{si}), which is unrelated harmonically. As defined, the frequency of the square wave is 3.18 kHz and that of the sine wave 15 kHz, where the peak-to-peak amplitude ratio of the former to the latter is four to one. Before summation, the square wave is low-pass filtered using a first order design having a cutoff frequency of 30 kHz. This reduces the harmonics outside of the band of interest which could damage the device being tested. The composite waveform produced is shown in Fig. 22 and spectrally in Fig. 23.

Using the test setup shown in Fig. 24, an amplifier can be measured for TIM. Mathematically, TIM distortion produced by the sine-square wave method is defined as:

$$TIM\% = \frac{\sqrt{A1^2 + A2^2 + \ldots + A9^2}}{A_{si}} \times 100, \qquad [14]$$

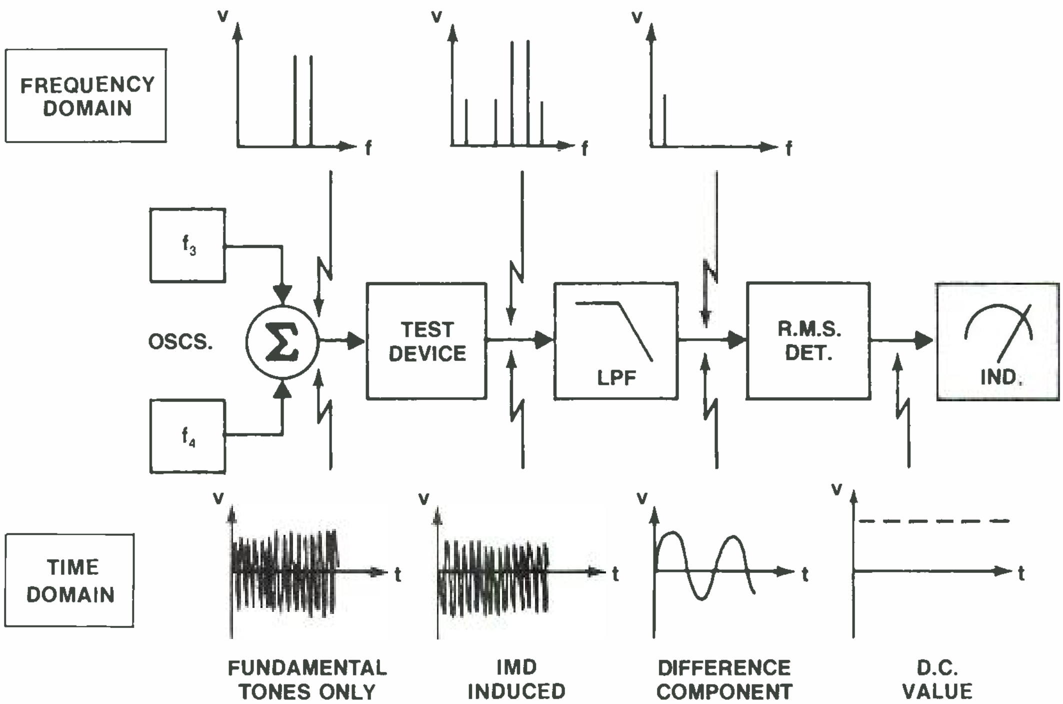

Fig. 21. CCIF second-order IMD analyzer.

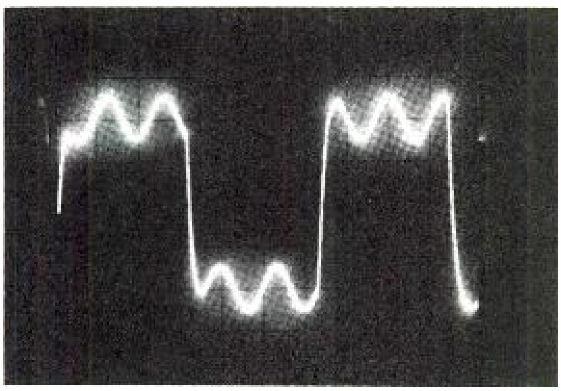

Fig. 22. TIM test signal.

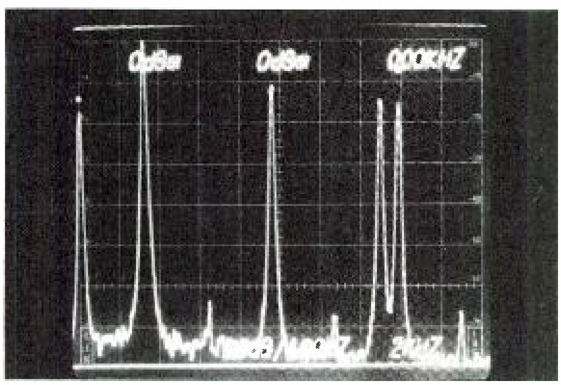

Fig. 23. TIM test signal, spectral view. V:10 dB/div.; H:2 kHz/div.)

where *A1* through *A9* represent the amplitudes of the distortion products present in the audio band and A_{si} is the amplitude of the sine wave. Values for the *A1*—*A9* components are shown in the table below:

Component	Relation	Frequency,kHz
A1	fsi—fsq	11.82
A2	fsi—2fsq	8.64
A3	fsi—3fsq	5.46
A4	fsi—4fsq	2.28
A5	$\lvert$fsi—5fsq$\rvert$	0.90
A6	$\lvert$fsi—6fsq$\rvert$	4.08
A7	$\lvert$fsi—7fsq$\rvert$	7.26
A8	$\lvert$fsi—8fsq$\rvert$	10.44
A9	$\lvert$fsi—9fsq$\rvert$	13.62

Fig. 25 shows the TIM distortion products produced by an amplifier that only displayed negligible THD, SMPTE IMD and CCIF IMD percentages. By using equation 14, it can be determined that this amplifier is producing about 20% TIM distortion.

Other TIM measurement methods include a sawtooth wave method which takes amplifier slew rate into account and a noise-square wave method where the sine wave of the sine-square wave method is replaced by a narrow-band noise spectrum.[8] These have not been as commonly used as the sine-square wave method at the time of this writing.

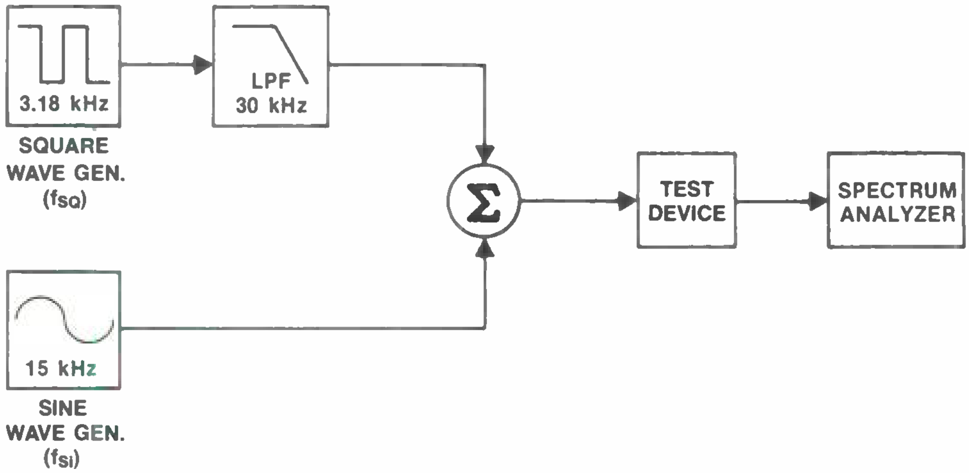

Fig. 24. TIM distortion analysis.

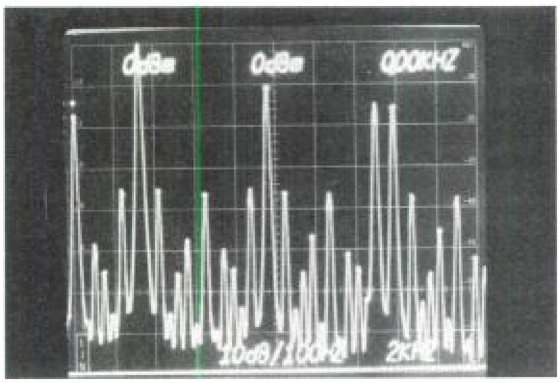

Fig. 25. TIM distortion products. (V:10 dB div.; H:2 kHz/div.)

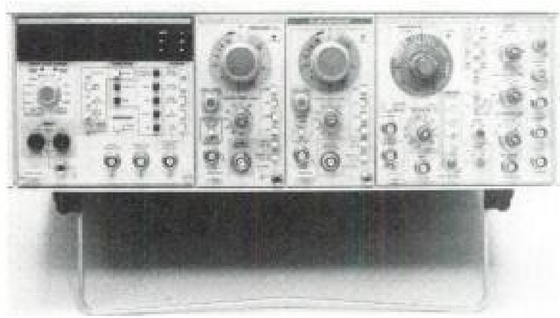

Fig. 26. Audio measuring set.

Filtering as part of distortion measurement is often useful to remove components which are of little interest and as a diagnostic aid.[9] This is especially true with THD measurement. A 20 or 30 kHz high-pass filter placed in series with the output of the device being measured is useful in testing broadcast equipment. This is often acceptable to do since the harmonics produced outside the transmission bandwidth can be eliminated, producing a more realistic result.

A high-pass filter also can serve as an important analytical aid. With a cutoff frequency in the 400 Hz range, it can be placed in series with the test device's output and used to determine the contribution of line frequency hum (60 Hz) to a THD measurement utilizing a fundamental frequency of 1 kHz or greater. Verification of adequate grounding used in the test setup can also be observed.

Care must be taken, however, when filtering is used in IM measurement. It is important to verify that in-band distortion components are not inadvertently removed. Also, extremely sharp cutoff filter designs may produce overshoot components which could affect measurement results.

A device capable of performing many of the distortion tests described above, as well as frequency response measurements, is shown in Fig. 26.

Noise Measurement

In audio engineering, noise is random energy where individual spectral components are not clearly resolved. Primary sources of noise are in the resistive elements from which amplifiers are made.[10] It is important to control noise in amplifiers as their gain increases to preserve a high signal to noise ratio, which is the ratio of the operating signal level to the noise level inherent in the amplifier itself.

To understand the origin of noise, we can model a passive resistive element as a noiseless resistor in series with a noise voltage generator, E_r:

$$E_r = \sqrt{4KTBR} \quad \text{(volts)} \qquad [15]$$

Where K = Boltzman's constant (1.38×10^{-23} W-Sec/°K)
T = temperature in degrees Kelvin
B = noise bandwidth (Hz)
R = resistance in ohms

Although noise bandwidth is not equivalent to amplifier 3 dB bandwidth, it can be related.

As can be seen from the above equation, noise voltage is a physical phenomenon which can be worsened by an increase in any of the variable factors. Therefore, noise cannot be eliminated but it can be reduced. This is often done by proper selection of the resistive components used, because an additional factor known as excess noise, which is proportional to the voltage drop across the resistor and related to the material from which it is made. Carbon composition resistors are prone to the most excess noise contribution while metal-film devices show the least.

At times the actual spectral distribution of noise is of less importance than the noise voltage in a given bandwidth for comparison purposes. For audio frequencies, a 15 or 20 kHz bandwidth is of interest. With a low-pass filter in this range connected in series with an amplifier output, and the input of the amplifier grounded, an unweighted but band-limited noise measurement can be made. When the noise output level is obtained, it can be related logarithmically to a standard operating level and reference frequency. This produces an indication of the amplifier's signal-to-noise (S/N) ratio.

When the gain of the amplifier is known, this same technique can be used to determine equivalent input noise voltage, i.e., the voltage of the noise which would be found at the input of the amplifier if the amplifier were completely noiseless.[10]

The measurement of a noise voltage quantity over a given frequency bandwidth in order to determine a S/N ratio does not provide a complete characterization. This is because the noise spectrum can occupy all or part of the same bandwidth.[11] For example, two amplifiers with identical S/N ratios can sound very different because one may have a uniform noise spectrum and the other may have most of the noise concentrated over a limited frequency range. Hence, the latter amplifier would sound "noisier" than the other. This has to do with the way the ear perceives the loudness of a signal which is uniform in amplitude across the audio band. To make comparative noise measurements more meaningful, several weighting filters have been used to alter noise spectra over the frequency band of interest.

NAB A weighting is based on the inverse of early measurements by Fletcher and Munson of the ear's sensitivity at low sound pressure levels.

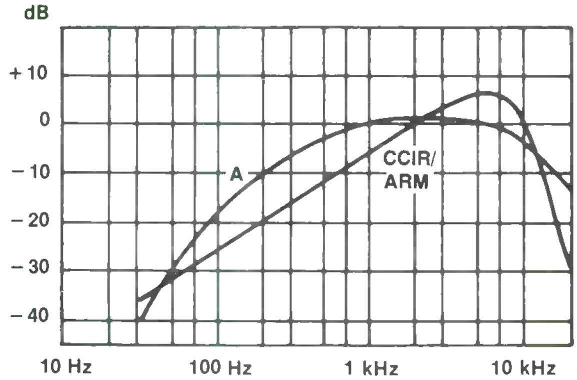

Fig. 27. Noise measurement weighting schemes.

A more recently developed weighting curve utilizes the CCIR/ARM method, an updated scheme which places the zero dB reference at 2 kHz instead of 1 kHz.[12] It is believed that this method, which is based on the obtrusiveness as well as the levels of different kinds of noise, provides a more commercially acceptable result when used to characterize modern, wide-range audio equipment. Fig. 27 compares the two curves.

Noise on telephone circuits has been investigated in detail by the Bell System (now AT&T) and others.[13] Terms used to describe this type of noise correspond to the use of specially developed noise meters which incorporate weighting filters specifically intended to characterize communications channels of 3 kHz bandwidth.

The abbreviation dBrn stands for dB above reference noise. It was introduced when the Bell System released the 2A noise meter. The meter is calibrated so that a 1 kHz, zero dBm tone will produce a reading of +90 dBrn. The same energy produces a reading of +82 dBrn when spread over a 300 to 3400 Hz band, subjected to "144-line" weighting.

A more recent standard is incorporated into the 3A noise measuring set which includes a "C-Message" weighting to suit the characteristics of newer handsets. The unit used is dBrnc; a zero dBm, 1 kHz tone will read +90 dBrnc. The weighting is flatter than "144-line" and therefore the 3 kHz band of noise will read +88.5 dBrn.

Relative Program/Loudness Measurement

Broadcasters and the FCC have received numerous complaints concerning loud commercials being broadcast on radio and television. Until recently, little was known about either what makes commercials loud or how to control this loudness. Since individual listeners vary in their judgments of loudness, the matter becomes further complicated. Indicators such as vu meters proved to be of little use in loudness measurement.

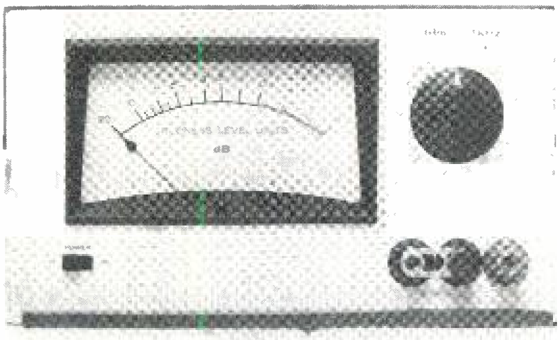

Fig. 28. Original CBS loudness meter.

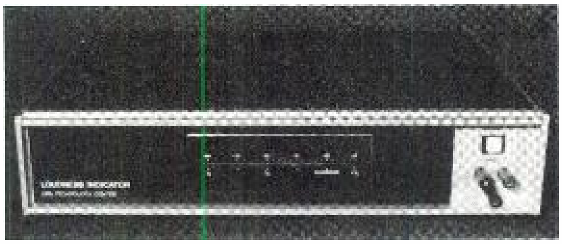

Fig. 29. Current CBS loudness indicator. (Courtesy CBS, Inc.)

The CBS Technology Center in Stamford, Connecticut has been working for many years on methods to measure and control loudness.[14] The first loudness monitor developed by CBS had the ability to perform loudness level additions on wide spectrum signals. This was done in accordance with studies performed investigating the characteristics of human hearing. Fig. 28 shows this original system.

In further research, the spectrum of hearing was separated into "critical bands". By definition, a critical band is that maximum bandwidth below which loudness does not diminish as the bandwidth is decreased. Subjective testing revealed a total of 24 critical bands. CBS felt that an ideal loudness measuring device should sample energy in each band to process and display a result. However, the hardware would require 24 filtering and processing sections. The critical band concept was used, but every three of the bands were combined to produce a total of 8 bands. The latest loudness indicator has a frequency response weighted in accordance with a subjectively derived frequency response of the human ear at a reference level (see Fig. 29). A block diagram of this meter is shown in Fig. 30.

Another device intended for real-time program analysis is the Audio Program Analyzer pictured in Fig. 31. It allows material from devices such as receivers, modulation monitors and audio processing equipment to be characterized in several ways. Peak-to-average ratios are quickly determinable, as well as maximum peak levels. Peak density can be measured which allows evaluation of audio processing effectiveness. The unit also contains a four band RTA; analysis of tonal balance and pre-emphasis characteristics can be done using this function. Provisions are also available for the monitoring of stereo program material.[3]

Phase Monitoring and Measurement

L + R is the monophonic compatible signal for AM, FM, and TV stereo. Separation information is transmitted via an L-R signal. Since these two signals are created through a summation and difference process of the original left and right channel stereophonic source, it is important that they be recombined properly at the receiver.[15] To accomplish this, amplitude and *phase* errors must be minimized in the transmission system. Phase measurement is important in accomplishing this task. [For further information see Chapter 3.4 of this *Handbook* and reference 15.]

In a stereo system, if left and right audio information is correlated but delayed in phase, the error would not be evident on a stereophonic receiver. A monophonic signal, however, will be degraded because of inexact summation. This problem is most common in audio tape recording. Periodic azimuth adjustment or "phasing" of the heads is often done. A test tape containing a high frequency tone is played while azimuth is adjusted to minimize the difference between the two channels.

A phase meter can be used to simplify this task. A simple version would take phase and amplitude variances into account simultaneously by functioning as a two-input subtractor. When both characteristics are identical in each of the channels, the output becomes zero. A meter which

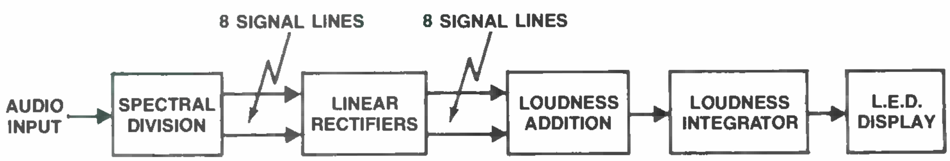

Fig. 30. 2nd generation CBS loudness indicator. (Courtesy CBS, Inc.)

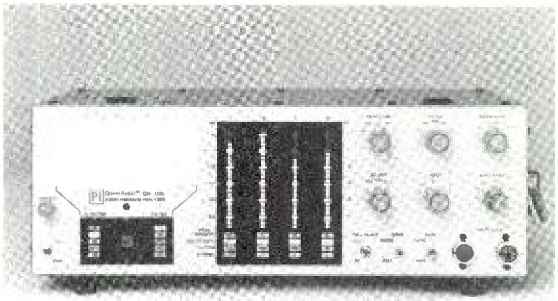

Fig. 31. Audio program analyzer. (Courtesy Potomac Instruments, Inc.)

measures only phase compares the zero-crossing times of the two signals, and time difference is used to generate a dc voltage proportional to the phase difference.[16] Phase detectors which operate in this manner often limit the input signals in order to remove all amplitude information.

More popular, however, is the "Lissajous Figure" method, involving the use of an oscilloscope in the x-y mode. The patterns produced are shown in Fig. 32. An oscilloscope is connected such that the left channel audio causes an x-axis sweep and right channel audio produces a y-axis sweep as shown in Fig. 32A and 32B respectively. When each channel is producing the same program material, the pattern of Fig. 32C is produced. This is the "L + R" axis. If one of the channels is inverted, the pattern of Fig. 32D becomes evident. This is often called the "L-R" axis. Program material which follows this axis is said to be "inverted in phase", because no sum or L + R information is present.

During alignment of tape reproduction equipment when discrete tones are used, the patterns of Fig. 32E, F, and G are often seen when phase errors exist between the two channels. Stereo program material, in unprocessed form, generally modulates the L + R axis while simultaneously deviating in the L-R direction to a lesser amount as shown in Fig. 32H.

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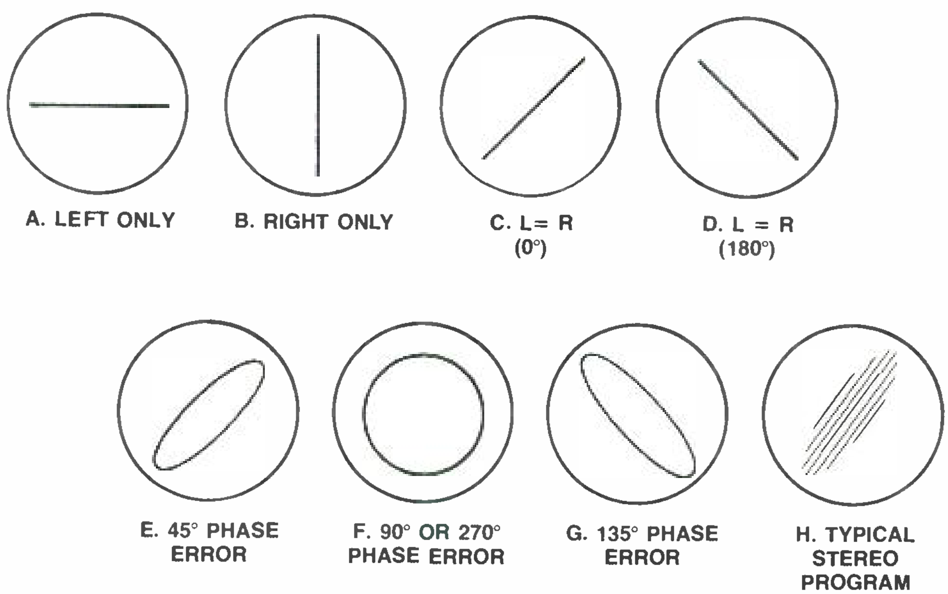

Fig. 32. Interpretation of Lissajous patterns.

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