

INTRODUCTION TO TELEVISION

1.0 HUMAN PERCEPTION OF MOTION

A television system involves equipment located at the source of production, equipment located in the home of the viewer, and equipment used to convey the television signal from the producer to the viewer. The purpose of all of this equipment is to extend the human senses of vision and hearing beyond their natural limits of physical distance. A television system is designed, therefore, to embrace the essential capabilities of these senses, particularly the sense of vision. The aspects of vision that must be considered include the ability of the human eye to distinguish the brightness, colours, details, sizes, shapes, and positions of objects in a scene before it. Aspects of hearing include the ability of the ear to distinguish the pitch, loudness, and distribution of sounds. In working to satisfy these capabilities, television systems must strike appropriate compromises between the quality of the desired image and the costs of reproducing it. They must also be designed to override, within reasonable limits, the effects of interference and to minimize visual and audial distortions in the transmission and reproduction processes. The particular compromises chosen for a given television service—e.g., broadcast or cable service—are embodied in the television standards adopted and enforced by the responsible government agencies in each country.

Television technology must deal with the fact that human vision employs hundreds of thousands of separate electrical circuits, located in the optic nerve running from the retina to the brain, in order to convey simultaneously in two dimensions the whole content of a scene on which the eye is focused. In electrical communication, however, it is feasible to employ only one circuit (i.e., the broadcast channel) to connect a transmitter with a receiver. This fundamental disparity is overcome in television practice by a process known as image analysis, whereby the scene to be televised is broken up by the camera's image sensors into an orderly sequence of electrical waves and these waves are sent over the single channel, one after the other. At the receiver the signals are translated back into a corresponding sequence of lights and shadows, and these are reassembled in their correct positions on the viewing screen.

This sequential reproduction of visual images is feasible only because the visual sense displays persistence; that is, the brain retains the impression of illumination for about one-tenth of a second after the source of light is removed from the eye. If, therefore, the process of image synthesis takes less than one-tenth of a second, the eye will be unaware that the picture is being reassembled piecemeal, and it will appear as if the whole surface of the viewing screen is continuously illuminated. By the same token, it will then be possible to re-create

more than 10 pictures per second and to simulate thereby the motion of the scene so that it appears to be continuous.

In practice, to depict rapid motion smoothly it is customary to transmit from 25 to 30 complete pictures per second. To provide detail sufficient to accommodate a wide range of subject matter, each picture is analyzed into 200,000 or more picture elements, or pixels. This analysis implies that the rate at which these details are transmitted over the television system exceeds 2,000,000 per second. To provide a system suitable for public use and also capable of such speed has required the full resources of modern electronic technology.

2.0 TELEVISION IMAGE ANALYSIS

2.1 Flicker

The first requirement to be met in image analysis is that the reproduced picture shall not flicker, since flicker induces severe visual fatigue. Flicker becomes more evident as the brightness of the picture increases. If flicker is to be unobjectionable at brightness suitable for home viewing during daylight as well as evening hours, the successive illuminations of the picture screen should occur no fewer than 50 times per second. This is approximately twice the rate of picture repetition needed for smooth reproduction of motion. To avoid flicker, therefore, twice as much channel space is needed as would suffice to depict motion.

The same disparity occurs in motion-picture practice, in which satisfactory performance with respect to flicker requires twice as much film as is necessary for smooth simulation of motion. A way around this difficulty has been found, in motion pictures as well as in television, by projecting each picture twice. In motion pictures, the projector interposes a shutter briefly between film and lens while a single frame of the film is being projected. In television, each image is analyzed and synthesized in two sets of spaced lines, one of which fits successively within the spaces of the other. Thus the picture area is illuminated twice during each complete picture transmission, although each line in the image is present only once during that time. This technique is feasible because the eye is comparatively insensitive to flicker when the variation of light is confined to a small part of the field of view. Hence, flicker of the individual lines is not evident. If the eye did not have this fortunate property, a television channel would have to occupy about twice as much spectrum space as it now does.

It is thus possible to avoid flicker and simulate rapid motion by a picture rate of about 25 per second, with two screen illuminations per picture. The precise value of the picture-repetition rate used in a given region has been chosen by reference to the electric power frequency that predominates in that region. In Europe, where 50-hertz alternating current is the rule, the television picture

rate is 25 per second (50 screen illuminations per second). In North America the picture rate is 30 per second (60 screen illuminations per second) to match the 60-hertz alternating current that predominates there. The higher picture-transmission rate of North America allows the pictures there to be about five times as bright as those in Europe for the same susceptibility to flicker, but this advantage is offset by a 20 percent reduction in picture detail for equal utilization of the channel.

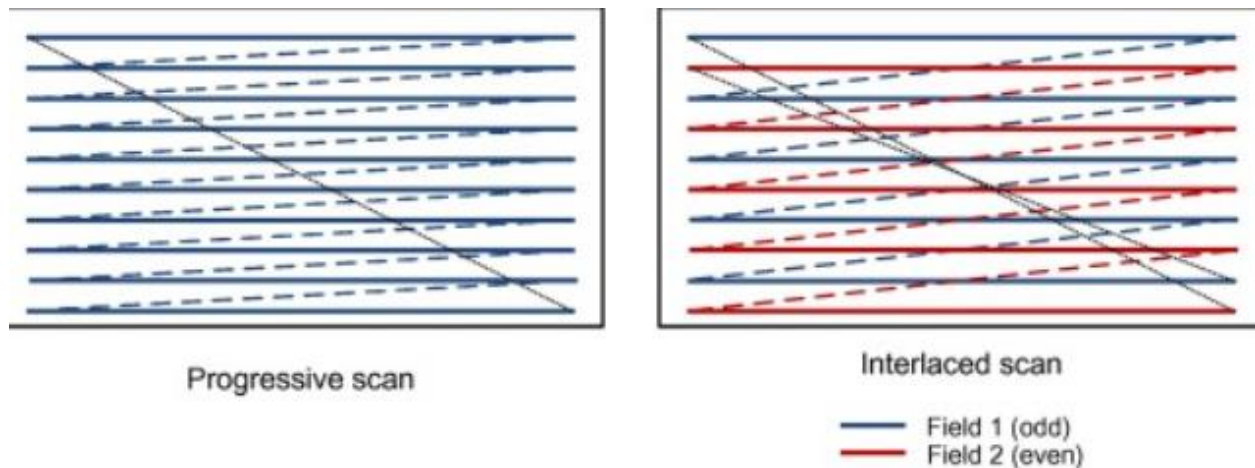


Figure 1. Progressive and Interlaced Scanning

2.2 Resolution

The second aspect of performance to be met in a television system is the detailed structure of the image. A printed engraving may possess several million halftone dots per square foot of area. However, engraving reproductions are intended for minute inspection, and so the dot structure must not be apparent to the unaided eye even at close range. Such fine detail would be a costly waste in television, since the television picture is viewed at comparatively long range. Standard-definition television (SDTV) is designed on the assumption that viewers in the typical home setting are located at a distance equal to six or seven times the height of the picture screen—on average some 3 metres (10 feet) away. Even high-definition television (HDTV) assumes a viewer who is seated no closer than three times the picture height away. Under these conditions, a picture structure of about 200,000 picture elements for SDTV (approximately 800,000 for HDTV) is a suitable compromise.

The physiological basis of this compromise lies in the fact that the normal eye, under conditions typical of television viewing, can resolve pictorial details if the angle that these details subtend at the eye is not less than two minutes of arc. This implies that the SDTV structure of 200,000 elements in a picture 16 cm (0.5 foot) high can just be resolved at a distance of about 3 metres (10 feet), and the HDTV structure can be resolved at about 1 metre (3 feet). The structure of both pictures may be objectionably evident at short range—e.g., while tuning the receiver—but it would be inappropriate to require a system to assume the heavy costs of transmitting detail that would be used by only a small part of the audience for a small part of the viewing time.

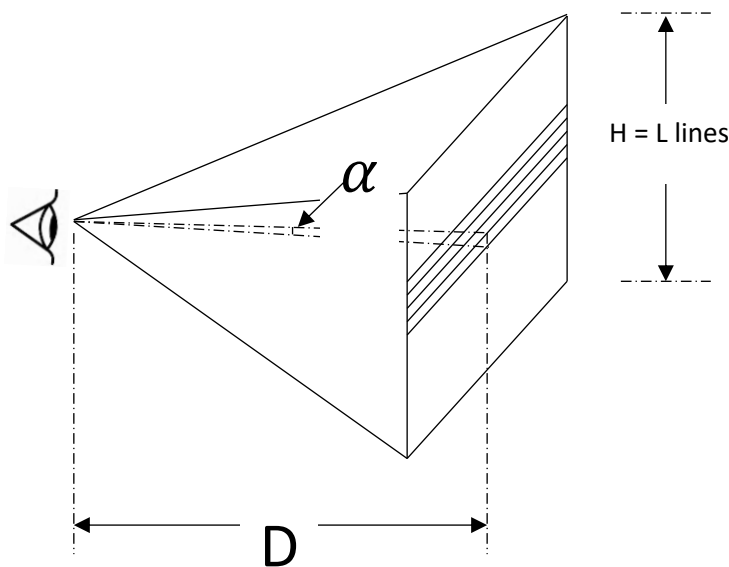


Figure 2 Resolution vs viewing distance

2.3 Picture shape

The third item to be selected in image analysis is the shape of the picture. For SDTV, as is shown in the figure, the universal picture is a rectangle that is one-third wider than it is high. This 4:3 ratio (or aspect ratio) was originally chosen in the 1950s to match the dimensions of standard 35-mm motion-picture film (prior to the advent of wide-screen cinema) in the interest of televising film without waste of frame area. HDTV sets, introduced in the 1980s, accommodate wide-screen pictures by offering an aspect ratio of 16:9. Regardless of the aspect ratio, in both SDTV and HDTV the width of the screen rectangle is greater than its height in order to incorporate the horizontal motion that predominates in virtually all televised events.

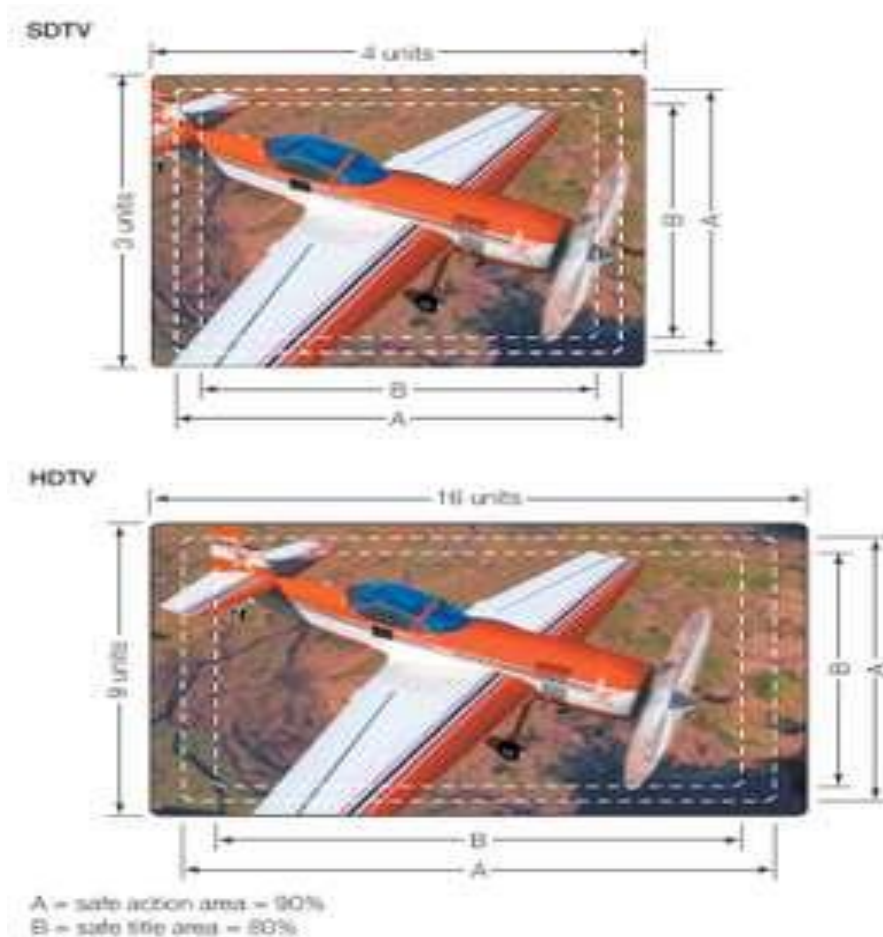


Figure 3. Picture tube aspect ratios for SDTV and HDTV. Since some of the picture information flows off the top, sides, and bottom of a television screen, the safe action area (A) is actually 90% of the transmitted picture. The safe title area (B) is the 80% of the transmitted picture that is assumed not to be hidden behind the decorative mask around the receiver tube.

2.4 Scanning

The fourth determination in image analysis is the path over which the image structure is explored at the camera and reconstituted on the receiver screen. In standard television, the pattern is a series of parallel straight lines, each progressing from left to right, the lines following in sequence from top to bottom of the picture frame. The exploration of the image structure proceeds at a constant speed along each line, since this provides uniform loading of the transmission channel under the demands of a given structural detail, no matter where in the frame the detail lies. The line-by-line, left-to-right, top-to-bottom dissection and reconstitution of television images is known as scanning, from its similarity to the progression of the line of vision in reading a page of printed matter. The agent that disassembles the light values along each

line is called the scanning spot, in reference to the focused beam of electrons that scans the image in a camera tube and recreates the image in a picture tube. Tubes are no longer employed in most video cameras (see the section Television cameras and displays), but even in modern transistorized cameras the image is dissected into a series of “spots,” and the path of dissection is called the scanning pattern, or raster.

3.0 THE SCANNING PATTERN

3.1 Interlaced lines

The geometry of the standard scanning pattern as displayed on a standard television screen is shown in the figure. It consists of two sets of lines. One set is scanned first, and the lines are so laid down that an equal empty space is maintained between lines. The second set is laid down after the first and is so positioned that its lines fall precisely in the empty spaces of the first set. The area of the image is thus scanned twice, but each point in the area is passed over only once. This is known as interlaced scanning, and it is used in all the standard television broadcast services of the world. Each set of alternate lines is known as a scanning field; the two fields together, comprising the whole scanning pattern, are known as a scanning frame. The repetition rate of field scanning is standardized in accordance with the frequency of electric power, as noted above, at either 50 or 60 fields per second; corresponding rates of frame scanning are 25 and 30 frames per second. In the North American monochrome system, 525 scan lines are transmitted about 30 times per second, for a horizontal sweep frequency of $525 \times 30 = 15,750$ hertz. In the colour television system, the 525 scan lines are retained, but the sweep frequency is adjusted to 15,734 hertz and the field rate reduced to a small amount below 60 hertz. This is done to assure backward compatibility of the colour system with the older black-and-white system—a concept discussed in the section Compatible colour television.

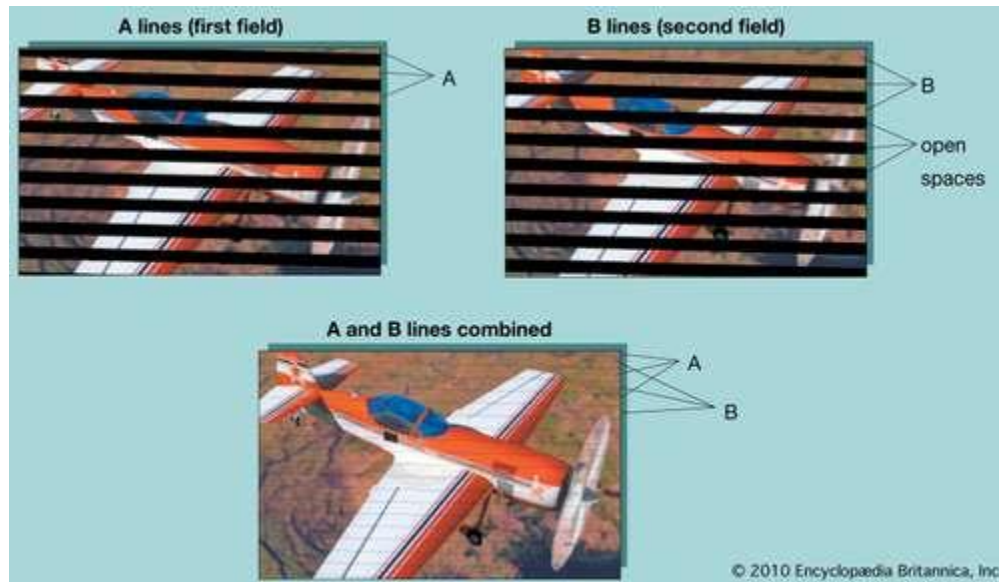


Figure 3. Interlaced scanning for standard television display. The first field, made up of evenly spaced scan lines (A), is followed by the second field, whose scan lines (B) fall between the A lines of the first field. The interlaced fields follow each other so rapidly that they combine in the viewer's eye to form a complete picture.

For SDTV, the total number of lines in the scanning pattern has been set to provide a maximum pictorial detail on the order of 200,000 pixels. Since the frame area is four units wide by three units high, this figure implies a pattern of about 520 pixels in its width (along each line) and 390 pixels in its height (across the lines). This latter figure would imply a scanning pattern of about 400 lines (one line per pixel), were it not for the fact that many of the picture details, falling in random positions on the scanning pattern, lie partly on two lines and hence require two lines for accurate reproduction. Scanning patterns are designed, therefore, to possess about 40 percent more lines than the number of pixels to be reproduced on the vertical direction. Actual values in use in television broadcasting in various regions are 405 lines, 525 lines, 625 lines, and 819 lines per frame. These values have been chosen to suit the frequency band of the channel actually assigned in the respective geographic regions.

The relationship between the ideal and actual scanning patterns is shown in the diagram of aspect ratios. The part of the pattern beyond the dashed lines of A (the “safe action area”) is lost as the scanning spot retraces. The remaining area of the pattern is actively employed in analyzing and synthesizing the picture information and is adjusted to have the 4:3 or 16:9 aspect ratio of SDTV or HDTV. In practice, some of the safe action area may be hidden behind the decorative mask that surrounds the picture tube of the receiver, as shown by the dashed lines of B, leaving programmers to work with what is known as the “safe title area.”

3.2 Deflection signals

The scanning spot is made to follow the interlaced paths described above by being subjected to two repetitive motions simultaneously (see the figure). One is a horizontally directed back-and-forth motion in which the spot is moved at constant speed from left to right and then returned as rapidly as possible, while extinguished and inactive, from right to left. At the same time a vertical motion is imparted to the spot, moving it at a comparatively slow rate from the top to the bottom of the frame. This motion spreads out the more rapid left-to-right scans, forming the first field of alternate lines and empty spaces. When the bottom of the frame is reached, the spot moves vertically upward as rapidly as possible, while extinguished and inactive. The next top-to-bottom motion then spreads out the horizontal line scans so that they fall in the empty spaces of the previously scanned field. Precise interlacing of the successive field scans is facilitated if the total number of lines in the frame is an odd number. All the numbers of lines used in standard television were chosen for this reason.

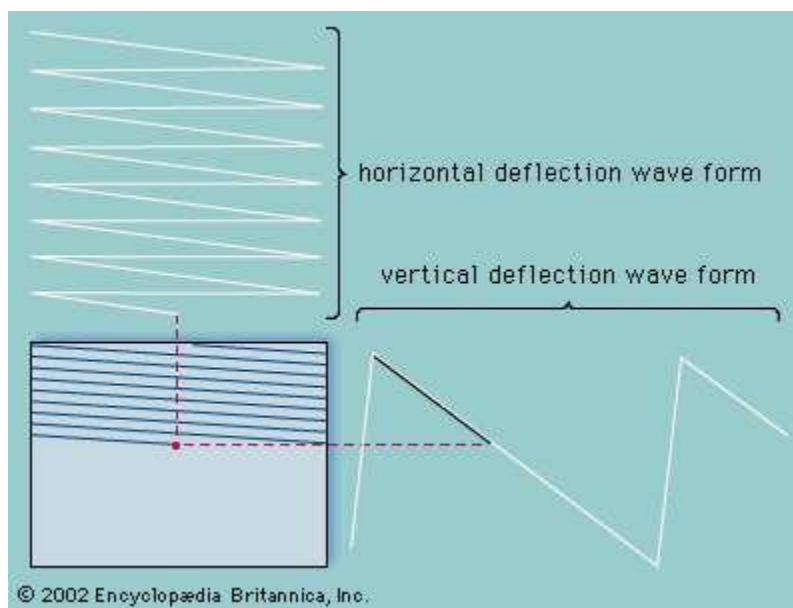


Figure 5. Wave forms for horizontal and vertical deflection of the scanning spot in sequential scanning.

3.3 Synchronization signals

The return of the scanning spot from right to left and from bottom to top of the frame, during which it is inactive, consumes time that cannot be devoted to transmitting picture information. This time is used to transmit synchronizing control signals that keep the scanning process at the receiver in step with that at the transmitter. The amount of time lost during retracing of the spot proportionately reduces the actual number of picture elements that can be reproduced. For instance, in the 525-line scanning pattern used in North

America, about 15 percent of each line is lost in the return motion, and about 35 out of the 525 lines are blanked out while the spot returns from bottom to top of two successive fields. The scanning area that is actually in use for reproduction of the picture therefore contains a maximum of about 435 pixels along each line, and it has 490 active lines capable of reproducing 350 pixels in the vertical direction. The frame can therefore accommodate at most about 350×435 , or 152,000, picture elements.

The time taken by the scanning spot to move over the active portion of each scanning line is on the order of 50 microseconds. In the American system, 525 lines are transmitted in about one-thirtieth of a second, which is equivalent to about 64 microseconds per line. Up to 15 percent of this time is consumed in the horizontal retrace motion of the spot, leaving 54 microseconds (54×10^{-6} second) for active reproduction of as many as 435 pixels in each line. This represents a maximum rate of $435 \div (54 \times 10^{-6}) \cong 8,000,000$ pixels per second. Since two pixels can be approximately represented by one cycle of the transmission signal wave, the signal must be capable of carrying components as high as four megahertz (4 million cycles per second). The American six-megahertz television channel provides a sufficient band of frequencies for this picture signal, leaving an additional two megahertz to transmit the sound program, to protect against interference, and mostly to meet the requirements of vestigial side-band transmission.

4. THE PICTURE SIGNAL

4.1 Television Wave form

The translation of the televised scene into its electrical counterpart results in a sequence of electrical waves known as the television picture signal. This is represented graphically in the diagram as a wave form, in which the range of electrical values (voltage or current) is plotted vertically and time is plotted horizontally. The electrical values correspond to the brightness of the image at each point on the scanning line, and time is essentially the position on the line of the point in question.

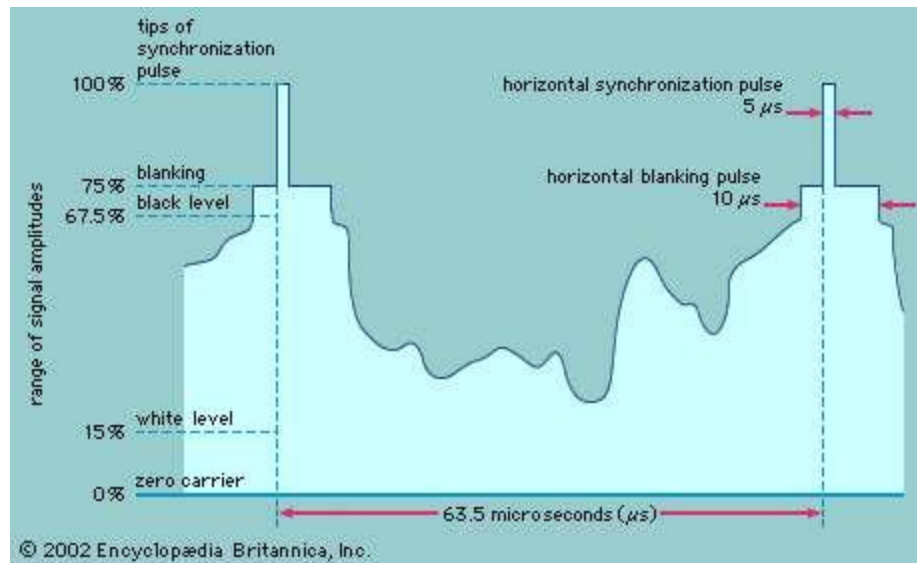


Figure 6. Wave form of the monochrome (black-and-white) television picture signal.

The television signal wave form is actually a composite made up of three individual signals, as is shown in the figure comprising:

1. **Luminance** - a continuous sequence of electrical values corresponding to the brightnesses along each line. This signal contains what is known as the luminance information.
2. **blanking** - the times during which the scanning spot is inactivated and retraced from the end of one line to the beginning of the next.
3. **synchronization** - causes the scanning spots at the transmitter and receiver to retrace to the next line at precisely the same instant.

These three individual signals—luminance, blanking, and synchronization—are added together to produce the composite video signal.

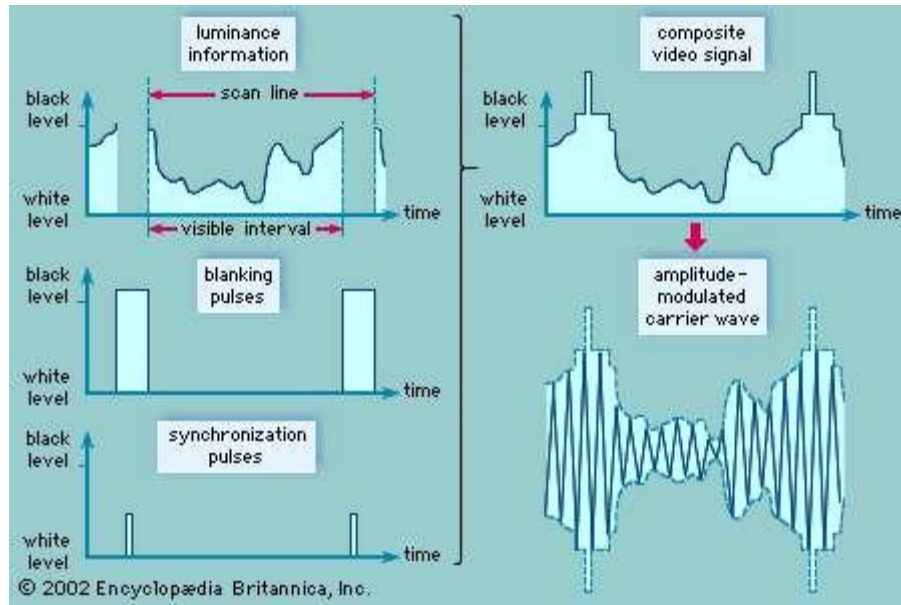


Figure 5. The composite television signal and modulated carrier wave. The luminance information is obtained as the image of the scene to be televised is scanned horizontally. Blanking pulses are transmitted to extinguish the scanning spot on the receiver screen at the end of each scan line. The receiver is precisely aligned with the transmitter by a series of short synchronization pulses. These three signals are added together to produce the composite video signal, which then amplitude modulates a radio-frequency carrier wave for transmission.

A blank interval also occurs twice every 525 lines (or twice every 625 lines, depending on the system) when the scanning spot, having reached the bottom of the frame, retraces to the top. This movement is guided by the vertical synchronization signal, a serrated series of impulses (shown in the diagram) that occurs shortly after the scanning spot has reached the bottom of the frame. The vertical synchronization signal is followed by a series of horizontal synchronizing impulses at black level with no luminance information. The interval of time allocated for the reproducing beam to travel from the bottom of the picture to the top is called the vertical blanking interval. During this time, no picture information is transmitted. In the American system, the vertical blanking interval is equivalent to the time necessary to trace a total of 21 scan lines for each field. The reproducing beam in television receivers actually gets to the top of the screen more quickly than the allocated 21 scan lines, but it is not visible since it falls off the screen. Some of these scan lines can then be used to send other information, such as a vertical interval reference signal to calibrate colour receivers, text information, i.e. teletext.

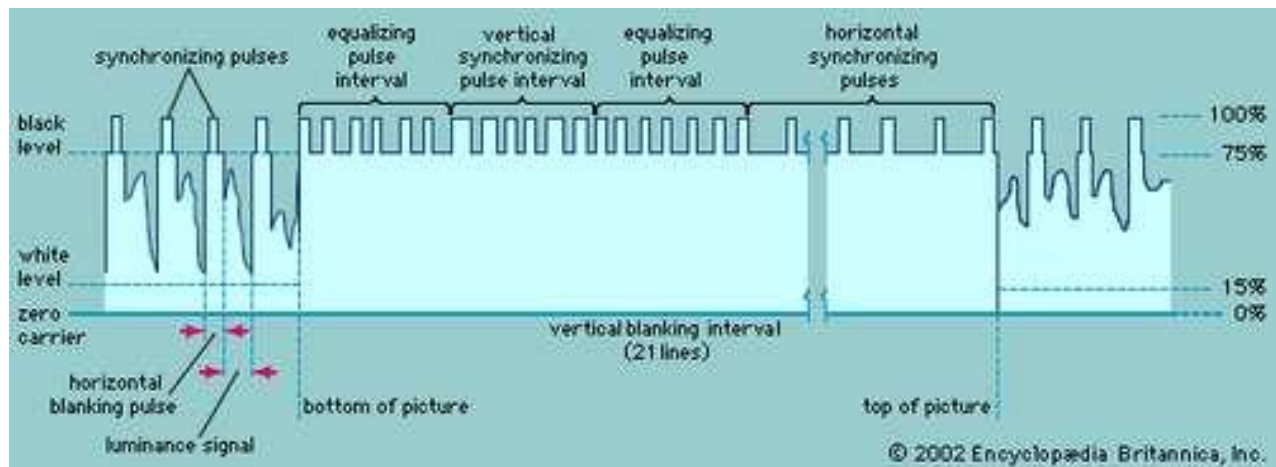


Figure 8. Wave form of the vertical synchronization signal transmitted at the end of each field, a series of pulses returns the scanning spot to the top of the television screen. The time required to return the inactive spot is known as the vertical blanking interval.

4.2. Distortion and Interference of TV signal

The signal wave form that makes up a television picture signal embodies all the picture information to be transmitted from camera to receiver screen as well as the synchronizing information required to keep the receiver and transmitter scanning operations in exact step with each other. The television system, therefore, must deliver the wave form to each receiver as accurately and as free from blemishes as possible. Unfortunately, almost every item of equipment in the system (amplifiers, cables, transmitter, transmitting antenna, receiving antenna, and receiver circuits) conspires to distort the wave form or permits it to be contaminated by “noise” (random electrical currents) or interference.

Among the possible distortions in the signal producing the picture are

- (1) failure to maintain the rapidity with which the wave form rises or falls as the scanning spot crosses a sharp boundary between light and dark areas of the image, producing a loss of detail, or “smear,” in the reproduced image;
- (2) the introduction of overshoots, which cause excessively harsh outlines;
- (3) failure to maintain the average value of the wave form over extended periods, which causes the image as a whole to be too bright or too dark.

Throughout the system, amplifiers must be used to keep the television signal strong relative to the noise. These random currents, generated by thermally induced motions of electrons in the circuits, cause a speckled “snow” to appear in the picture. Pictures received from distant stations are subject to this form of interference, since the radio wave by then is so weak that it cannot override

random currents in the receiving antenna. Other sources of noise include electrical storms and electric motors. Distortions of a striated type may be caused by interference from signals of stations other than that to which the receiver is tuned.

Another form of distortion arises when a broadcast television signal arrives at the receiver from more than one path. This can occur when the original signal bounces or is reflected off large buildings or other physical structures. The time delays in the different paths result in the creation of “ghosts” in the received picture. These ghosts also can occur in cable television systems from electrical reflections of the signal along the cable. Care in the design of the receiver tuner and amplifier circuits is necessary to minimize such interference, and channels must be allocated to neighbouring communities at sufficient geographic separations and frequency intervals to protect the local service.

4.2. Bandwidth Requirements

The quality and quantity of television service are limited fundamentally by the rate at which it is feasible to transmit the picture information over the television channel. If, as is stated above, the televised image is dissected, within a few hundredths of a second, into approximately 200,000 pixels, then the electrical impulses corresponding to the pixels must pass through the channel at a rate of several million per second. Moreover, since the picture content may vary, from frame to frame, from simple close-up shots having little fine detail to comprehensive distant scenes in which the limiting detail of the system comes into play, the actual rate of transmitting the picture information varies considerably. The television channel must be capable, therefore, of handling information over a continuous band of frequencies in MHz. This is testimony to the extraordinary comprehension of the human sense of sight. By comparison, the ear is satisfied by sound carried over a channel only 10KHz.

In the United States, the television channel, occupying six megahertz in the radio spectrum, is 600 times as wide as the channel used by each standard amplitude modulation (AM) sound broadcasting station. In fact, one television station uses nearly six times as much spectrum space as all the commercial AM sound broadcasting channels combined. Since each television broadcast must occupy so much spectrum space, a limited number of channels is available in any given locality. Moreover, the quantity of service is in conflict with the quality of reproduction. If the detail of the television image is to be increased (other parameters of the transmission being unchanged), then the channel width must be increased proportionately, and this decreases the number of channels that can be accommodated in the spectrum. This fundamental conflict between quality of transmission and number of available channels dictates that the quality of reproduction shall just satisfy the typical

viewer under normal viewing conditions. Any excess of performance beyond this ultimately will result in a restriction of program choice.

5. COLOUR TELEVISION

5.1 Compatible Colour Television

Colour television represents electronic technology at its pinnacle of achievement, carefully balancing the needs of human perception with the need for technological efficiency. The transmission of colour images requires that extra information be added to the basic monochrome television signal, described above. At the same time, this more complex colour signal must be “compatible” with black-and-white television, so that all sets can pick up and display the same transmission. The design of compatible colour systems, accomplished in the 1950s, was truly a marvel of electrical engineering. The fact that the standards chosen at that time are still in use attests to how well they were designed.

The first compatible colour system was designed in 1950–51 by engineers at the Radio Corporation of America (RCA) and was accepted in 1952 by the National Television Systems Committee (NTSC) as the standard for broadcast television in the United States. The essentials of the NTSC system have formed the basis of all other colour television systems. Two rivaling European systems, PAL (phase alternation line) and SECAM (système électronique couleur avec mémoire), are modifications of the NTSC system that have special application to European conditions. One or the other of these three systems has been adopted by all countries of the world (see the table). All are discussed in this section, with the American (NTSC) system being used to describe the basic principles of colour television.

Television systems of the world					
system (region or country)	number of lines per frame	number of pictures per second	maximum detail (picture elements per frame)	available picture bandwidth (MHz)	channel bandwidth (MHz)
NTSC (North America, South America, Japan)	525	30	130,000	4	6
PAL (United Kingdom, Germany)	625	25	210,000	6	8

SECAM (France, eastern Europe)	625	25	210,000	6	8
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5.2 Basic Principles Of Compatible Colour: The NTSC System

The technique of compatible colour television utilizes two transmissions. One of these carries information about the brightness, or luminance, of the televised scene, and the other carries the colour, or chrominance, information. Since the ability of the human eye to perceive detail is most acute when viewing white light, the luminance transmission carries the impression of fine detail. Because it employs methods essentially identical to those of a monochrome television system, it can be picked up by black-and-white receivers. The chrominance transmission has no appreciable effect on black-and-white receivers, yet, when used with the luminance transmission in a colour receiver, it produces an image in full colour.

Historically, compatibility was of great importance because it allowed colour transmissions to be introduced without obsolescence of the many millions of monochrome receivers in use. In a larger sense, the luminance-chrominance method of colour transmission is advantageous because it utilizes the limited channels of the radio spectrum more efficiently than other colour transmission methods.

To create the luminance-chrominance values, it is necessary first to analyze each colour in the scene into its component primary colours. Light can be analyzed in this way by passing it through three coloured filters, typically red, green, and blue. The amounts of light passing through each filter, plus a description of the colour transmission properties of the filters, serve uniquely to characterize the coloured light.

The fact that virtually the whole range of colours may be synthesized from only three primary colours is essentially a description of the process by which the eye and mind of the observer recognize and distinguish colours. Like visual persistence (the basis of reproducing motion in television), this is a fortunate property of vision, since it permits a simple three-part specification to represent any of the 10,000 or more colours and brightnesses that may be distinguished by the human eye. If vision were dependent on the energy-versus-wavelength relationship (the physical method of specifying colour), it is doubtful that colour reproduction could be incorporated in any mass-communication system.

By transforming the primary-colour values, it is possible to specify any coloured light by three quantities:

- (1) its luminance (brightness or “brilliance”);
- (2) its hue (the redness, orangeness, blueness, or greenness, etc., of the light); and
- (3) its saturation (vivid versus pastel quality).

Since the intended luminance value of each point in the scanning pattern is transmitted by the methods of monochrome television, it is only necessary to transmit, via an additional two-valued signal, supplementary information giving the hue and saturation of the intended colour at the respective points.

Chrominance, defined as that part of the colour specification remaining when the luminance is removed, is a combination of the two independent quantities, hue and saturation. Chrominance may be represented graphically in polar coordinates on a colour circle (as shown in the diagram), with saturation as the radius and hue as the angle. Hues are arranged counterclockwise around the circle as they appear in the spectrum, from red to blue. The centre of the circle represents white light (the colour of zero saturation), and the outermost rim represents the most saturation. Points on any radius of the circle represent all colours of the same hue, the saturation becoming less (that is, the colour becoming less vivid, or more pastel) as the point approaches the central “white point.” A diagram of this type is the basis of the international standard system of colour specification.

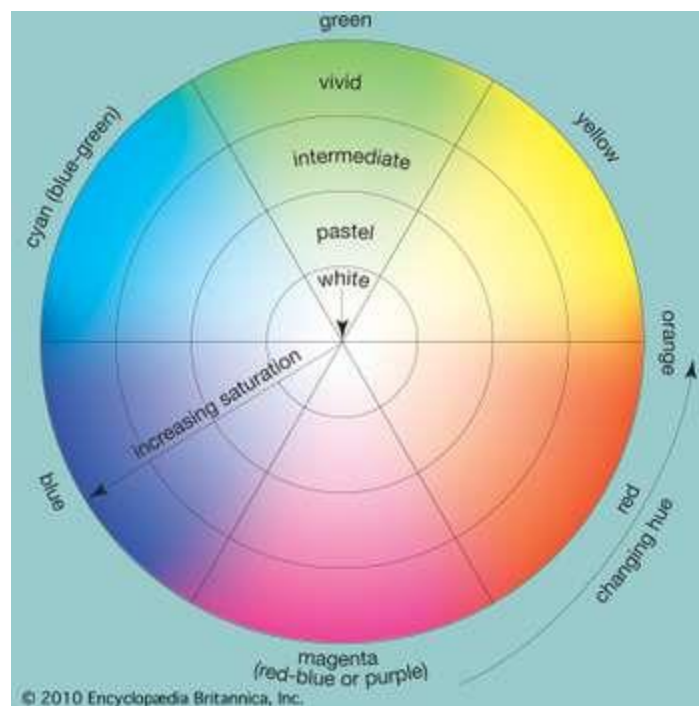


Figure 7. Colour wheel in which hue changes with location around the circle and saturation changes with distance from the centre or circumference. Hue and saturation, perceived together, make up the chrominance value of an image.

In the NTSC system, the chrominance signal is an alternating current of precisely specified frequency (3.579545 ± 0.000010 megahertz), the precision permitting its accurate recovery at the receiver even in the presence of severe noise or interference. Any change in the amplitude of its alternations at any instant corresponds to a change in the saturation of the colours being passed over by the scanning spot at that instant, whereas a shift in time of its alternations (a change in “phase”) similarly corresponds to a shift in the hue. As the different saturations and hues of the televised scene are successively uncovered by scanning in the camera, the amplitude and phase, respectively, of the chrominance signal change accordingly. The chrominance signal is thereby simultaneously modulated in both amplitude and phase. This doubly modulated signal is added to the luminance signal (as shown in the diagram of the colour signal wave form), and the composite signal is imposed on the carrier wave. The chrominance signal takes the form of a subcarrier located precisely 3.579545 megahertz above the picture carrier frequency.

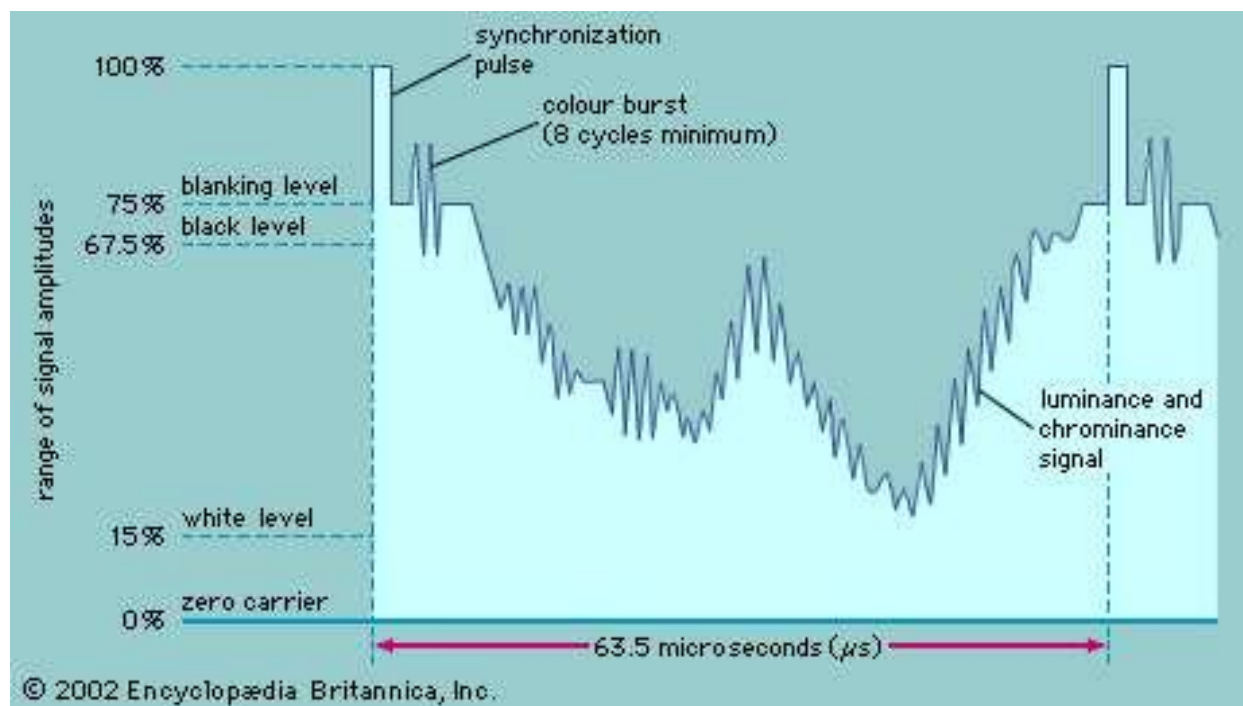


Figure 8. Wave form of the colour television picture signalThe chrominance signal, which carries the hue and saturation information, is added to the luminance signal, which carries the brightness information. Detection of the hue information by the receiver is aided by the addition of a short colour burst to the back porch of the blanking pulse.

The picture carrier is thus simultaneously amplitude modulated by (1) the luminance signal, to represent changes in the intended luminance, and (2) the chrominance subcarrier, which in turn is amplitude modulated to represent changes in the intended saturation and phase modulated to represent changes in the intended hue. When a colour receiver is tuned to the transmission, the picture signal is recovered in a video detector, which responds to the amplitude-modulated luminance signal in the usual manner of a black-and-white receiver. An amplifier stage, tuned to the 3.58-megahertz chrominance frequency, then selects the chrominance subcarrier from the picture signal and passes it to a detector, which recovers independently the amplitude-modulated saturation signal and the phase-modulated hue signal. Because absolute phase information is difficult to extract, the hue signal is made easier to decode by a phase reference transmitted for each horizontal scan line in the form of a short burst of the chrominance subcarrier. This chrominance, or colour, burst consists of a minimum of eight full cycles of the chrominance subcarrier and is placed on the “back porch” of the blanking pulse, immediately after the horizontal synchronization pulse (as shown in the diagram).

When compatible colour transmissions are received on a black-and-white receiver, the receiver treats the chrominance subcarrier as though it were a part of the intended monochrome transmission. If steps were not taken to prevent it, the subcarrier would produce interference in the form of a fine dot pattern on the television screen. Fortunately, the dot pattern can be rendered almost invisible in monochrome reception by deriving the timing of the scanning motions directly from the source that establishes the chrominance subcarrier itself. The dot pattern of interference from the chrominance signal, therefore, can be made to have opposite effects on successive scanings of the pattern; that is, a point brightened by the dot interference on one line scan is darkened an equal amount on the next scan of that line, so that the net effect of the interference, integrated in the eye over successive scans, is virtually zero. Thus, the monochrome receiver in effect ignores the chrominance component of the transmission. It deals with the luminance signal in the conventional manner, producing from it a black-and-white image. This black-and-white rendition, incidentally, is not a compromise; it is essentially identical to the image that would be produced by a monochrome system viewing the same scene.

The television channel, when occupied by a compatible colour transmission, is usually diagrammed as shown in the figure. The luminance information modulates the chrominance subcarrier in the form of two orthogonal components, the I signal and the Q signal. This form of quadrature modulation accomplishes the simultaneous amplitude and phase modulation of the chrominance subcarrier. The I signal represents hues from the orange-cyan

colour axis, and the Q signal represents hues along the magenta-yellow colour axis. The human eye is much less sensitive to spatial detail in colour, and thus the chrominance information is allocated much less bandwidth than the luminance information. Furthermore, since the human eye has more spatial resolution to the hues represented by the I signal, the I signal is allotted 1.5 megahertz, while the Q signal is restricted to only 0.5 megahertz. To conserve spectrum, vestigial modulation is used for the I signal, giving the lower sideband the full 1.5 megahertz. The quadrature modulation used for the chrominance information results in a suppressed carrier.

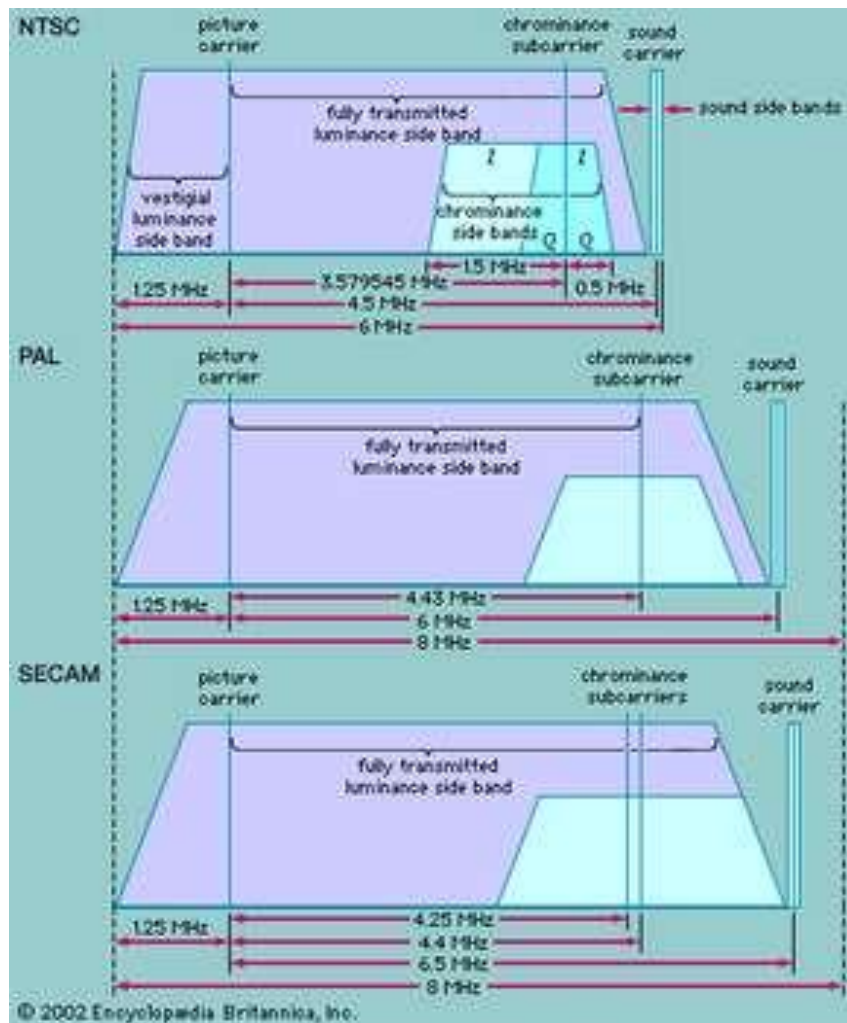


Figure 9. Spectrum allocations for television channels in the NTSC, PAL, and SECAM systems.

When used by colour receivers, the channel for colour transmissions would appear to be affected by mutual interference between the luminance and chrominance components, since these occupy a portion of the channel in common. Such interference is avoided by the fact that the chrominance subcarrier component is rigidly timed to the scanning motions. The luminance

signal, as it occupies the channel, is actually concentrated in a multitude of small spectrum segments, by virtue of the periodicities associated with the scanning process. Between these segments are empty channel spaces of approximately equal size. The chrominance signal, arising from the same scanning process, is similarly concentrated. Hence it is possible to place the chrominance channel segments within the empty spaces between the luminance segments, provided that the two sets of segments have a precisely fixed frequency relationship. The necessary relationship is provided by the direct control by the subcarrier of the timing of the scanning motions. This intersegmentation is referred to as frequency interlacing. It is one of the fundamentals of the compatible colour system. Without frequency interlacing, the superposition of colour information on a channel originally devised for monochrome transmissions would not be feasible.

5.3. European Colour Television Systems

In the United States, broadcasting using the NTSC system began in 1954, and the same system has been adopted by Canada, Mexico, Japan, and several other countries. In 1967 the Federal Republic of Germany and the United Kingdom began colour broadcasting using the PAL system, while in the same year France and the Soviet Union also introduced colour, adopting the SECAM system.

PAL and SECAM embody the same principles as the NTSC system, including matters affecting compatibility and the use of a separate signal to carry the colour information at low detail superimposed on the high-detail luminance signal. The European systems were developed, in fact, to improve on the performance of the American system in only one area, the constancy of the hue of the reproduced images.

It has been pointed out that the hue information in the American system is carried by changes in the phase angle of the chrominance signal and that these phase changes are recovered in the receiver by synchronous detection. Transmission of the phase information, particularly in the early stages of colour broadcasting in the United States, was subject to incidental errors arising in broadcasting stations and network connections. Errors were also caused by reflections of the broadcast signals by buildings and other structures in the vicinity of the receiving antenna. In subsequent years, transmission and reception of hue information became substantially more accurate in the United States through care in broadcasting and networking, as well as by automatic hue-control circuits in receivers. Since the late 1970s a special colour reference signal has been transmitted on line 19 of both scanning fields, and circuitry in the receiver locks onto the reference

information to eliminate colour distortions. This vertical interval reference (VIR) signal includes reference information for chrominance, luminance, and black.

PAL and SECAM are inherently less affected by phase errors. In both systems the nominal value of the chrominance signal is 4.433618 megahertz, a frequency that is derived from and hence accurately synchronized with the frame-scanning and line-scanning rates. This chrominance signal is accommodated within the 6-megahertz range of the fully transmitted side band, as shown in the figure. By virtue of its synchronism with the line- and frame-scanning rates, its frequency components are interleaved with those of the luminance signal, so that the chrominance information does not affect reception of colour broadcasts by black-and-white receivers.

5.3.1 Phase Alternation Line (PAL)

PAL (phase alternation line) resembles NTSC in that the chrominance signal is simultaneously modulated in amplitude to carry the saturation (pastel-versus-vivid) aspect of the colours and modulated in phase to carry the hue aspect. In the PAL system, however, the phase information is reversed during the scanning of successive lines. In this way, if a phase error is present during the scanning of one line, a compensating error (of equal amount but in the opposite direction) will be introduced during the next line, and the average phase information (presented by the two successive lines taken together) will be free of error.

Two lines are thus required to depict the corrected hue information, and the vertical detail of the hue information is correspondingly lessened. This produces no serious degradation of the picture when the phase errors are not too great, because, as is noted above, the eye does not require fine detail in the hues of colour reproduction and the mind of the observer averages out the two compensating errors. If the phase errors are more than about 20° , however, visible degradation does occur. This effect can be corrected by introducing into the receiver (as in the SECAM system) a delay line and electronic switch.

5.3.2 SECAM

In SECAM (système électronique couleur avec mémoire) the luminance information is transmitted in the usual manner, and the chrominance signal is interleaved with it. But the chrominance signal is modulated in only one way. The two types of information required to encompass the colour values (hue and saturation) do not occur concurrently, and the errors associated with simultaneous amplitude and phase modulation do not occur. Rather, in the SECAM system (SECAM III), alternate line scans carry information on luminance and red, while the intervening line scans contain luminance and blue. The green information is derived within the receiver by subtracting the

red and blue information from the luminance signal. Since individual line scans carry only half the colour information, two successive line scans are required to obtain the complete colour information, and this halves the colour detail, measured in the vertical dimension. But, as noted above, the eye is not sensitive to the hue and saturation of small details, so no adverse effect is introduced.

To subtract the red and blue information from the luminance information and obtain the green information, the red and blue signals must be available in the receiver simultaneously, whereas in SECAM they are transmitted in time sequence. The requirement for simultaneity is met by holding the signal content of each line scan in storage (or “memorizing” it—hence the name of the system, French for “electronic colour system with memory”). The storage device is known as a delay line; it holds the information of each line scan for 64 microseconds, the time required to complete the next line scan. To match successive pairs of lines, an electronic switch is also needed. When the use of delay lines was first proposed, such lines were expensive devices. Subsequent advances reduced the cost, and the fact that receivers must incorporate these components is no longer viewed as decisive.

Since the SECAM system reproduces the colour information with a minimum of error, it has been argued that SECAM receivers do not have to have manual controls for hue and saturation. Such adjustments, however, are usually provided in order to permit the viewer to adjust the picture to individual taste and to correct for signals that have broadcast errors, due to such factors as faulty use of cameras, lighting, and networking.

9. TELEVISION TRANSMISSION AND RECEPTION

Transmission and reception involve the components of a television system that generate, transmit, and utilize the television signal wave form (as shown in the block diagram). The scene to be televised is focused by a lens on an image sensor located within the camera. This produces the picture signal, and the synchronization and blanking pulses are then added, establishing the complete composite video wave form. The composite video signal and the sound signal are then imposed on a carrier wave of a specific allocated frequency and transmitted over the air or over a cable network. After passing through a receiving antenna or cable input at the television receiver, they are shifted back to their original frequencies and applied to the receiver’s display and loudspeaker. That is the process in brief; the specific functions of colour television transmitters and receivers are described in more detail in this section.

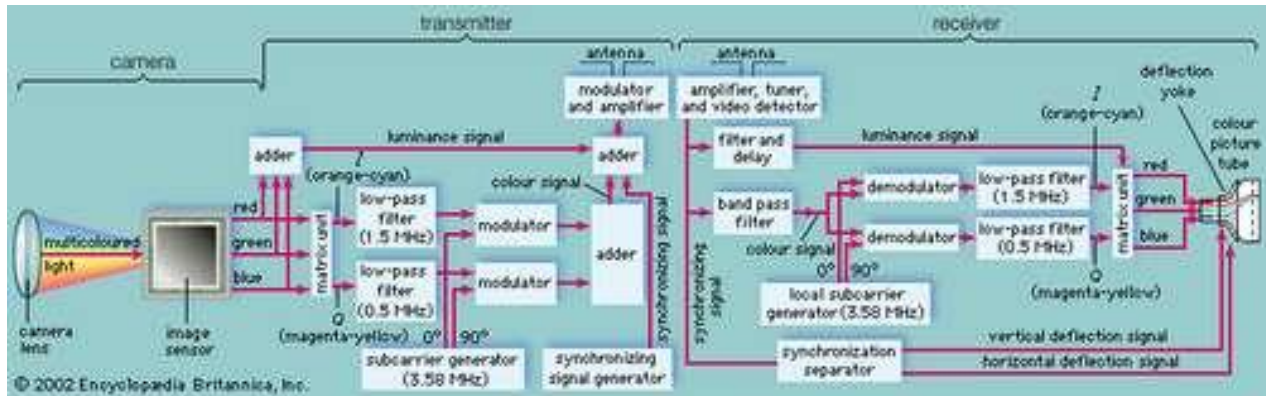


Figure 8. Components of the colour television transmitter and receiver.

9.1 Generating the colour picture signal

As is pointed out in the section Compatible colour television, the colour television signal actually consists of two components, luminance (or brilliance) and chrominance; and chrominance itself has two aspects, hue (colour) and saturation (intensity of colour). The television camera does not produce these values directly; rather, it produces three picture signals that represent the amounts of the three primary colours (blue, green, and red) present at each point in the image pattern. From these three primary-colour signals the luminance and chrominance components are derived by manipulation in electronic circuits.

Immediately following the colour camera is the colour coder, which converts the primary-colour signals into the luminance and chrominance signals. The luminance signal is formed simply by applying the primary-colour signals to an electronic addition circuit, or adder, that adds the values of all three signals at each point along their respective picture signal wave forms. Since white light results from the addition (in appropriate proportions) of the primary colours, the resulting sum signal represents the black-and-white (luminance) version of the colour image. The luminance signal thus formed is subtracted individually, in three electronic subtraction circuits, from the original primary-colour signals, and the colour-difference signals are then further combined in a matrix unit to produce the I (orange-cyan) and Q (magenta-yellow) signals. These are applied simultaneously to a modulator, where they are mixed with the chrominance subcarrier signal. The chrominance subcarrier is thereby amplitude modulated in accordance with the saturation values and phase modulated in accordance with the hues. The luminance and chrominance components are then combined in another addition circuit to form the overall colour picture signal.

The chrominance subcarrier in NTSC systems is generated in a precise electronic oscillator at the standard value of 3.579545 megahertz. Samples of this subcarrier are injected into the signal wave form during the blank period between line scans, just after the horizontal synchronizing pulses. These samples, collectively referred to as the “colour burst,” are employed in the receiver to control the synchronous detector, as mentioned in the section Basic principles of compatible colour: The NTSC system. Finally, horizontal and vertical deflection currents, which produce the scanning in the three camera sensors, are formed in a scanning generator, the timing of which is controlled by the chrominance subcarrier. This common timing of deflection and chrominance transmission produces the dot-interference cancellation in monochrome reception and the frequency interlacing in colour transmission, noted above.

9.2 The carrier signal

The picture signal generated as described above can be conveyed over short distances by wire or cable in unaltered form, but for broadcast over the air or transmission over cable networks it must be shifted to appropriately higher frequency channels. Such frequency shifting is accomplished in the transmitter, which essentially performs two functions: (1) generation of very high frequency (VHF) or ultrahigh frequency (UHF) carrier currents for picture and sound, and (2) modulation of those carrier currents by imposing the television signal onto the high-frequency wave. In the former function (generation of the carrier currents), precautions are taken to ensure that the frequencies of the UHF or VHF waves have precisely the values assigned to the channel in use. In the latter function (modulation of the carrier wave), the picture signal wave form changes the strength, or amplitude, of the high-frequency carrier in such a manner that the alternations of the carrier current take on a succession of amplitudes that match the shape of the signal wave form. This process is known as amplitude modulation (AM) and is shown in the context of monochrome transmission in the diagram of the composite video signal.

9.3 The sound signal

The sound program accompanying a television picture signal is transmitted by equipment similar to that used for frequency-modulated (FM) radio broadcasting. In the NTSC system, the carrier frequency for this sound channel is spaced 4.5 megahertz above the picture carrier and is separated from the picture carrier in the television receiver by appropriate circuitry. The sound has a maximum frequency of 15 kilohertz (15,000 cycles per second), thereby assuring high fidelity. Stereophonic sound is transmitted through the use of a subcarrier located at twice the horizontal sweep frequency of 15,734 hertz. The

stereo information, encoded as the difference between the left and right audio channel, amplitude modulates the stereo subcarrier, which is suppressed if there is no stereo difference information. The base sound signal is transmitted as the sum of the left and right audio channels and hence is compatible with nonstereo receivers.

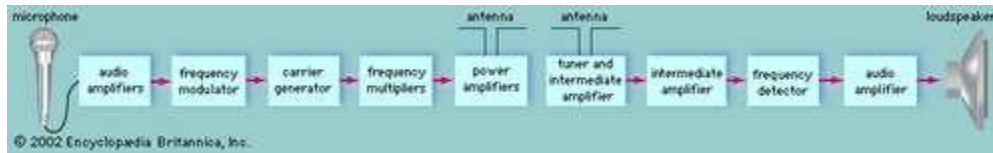


Figure 5. Components of television sound transmission and reception.

9.4 The television channel

When the band of frequencies in the picture signal is imposed on the high-frequency broadcast carrier current in the modulator of the transmitter, two bands of frequencies are produced above and below the carrier frequency. These are known as the upper and lower side bands, respectively. The side bands are identical in frequency content; that is, both carry the complete picture signal information. One of the side bands is therefore superfluous and, if transmitted, would wastefully consume space in the broadcast spectrum. Therefore, the major portion of one of the side bands (that occupying frequencies below the carrier) is removed by a wave filter, and the other side band (occupying frequencies above the carrier) is transmitted in full. Complete removal of the superfluous side band is possible, but this would complicate receiver design; hence, a vestige of the unwanted side band is retained to serve the overall economy of the system. This technique is known as vestigial side-band transmission. It is universally employed in the television broadcasting systems of the world.

The television channel thus contains the picture carrier frequency, one complete picture side band (including the complete chrominance subcarrier), and a vestigial portion of the other picture side band. (See the diagram of spectrum allocations for compatible colour channels.) In addition, the carrier for the sound transmission and its side bands is included within the channel. Since the band of frequencies needed to convey the sound is much narrower than that needed for the picture, it is feasible to include both sound-carrier side bands. To avoid mutual interference between sound and picture, the picture and sound side bands must not overlap. Moreover, some space must be allowed at the edge of the channel to avoid interference with the transmissions of stations occupying adjacent channels. These requirements are met in the

colour television channels of the NTSC, PAL, and SECAM systems shown in the figure.

Each channel in the NTSC system contains the following bands: 4.2 megahertz for the fully transmitted picture side band, 1.25 megahertz for the vestige of the other picture side band, 0.2 megahertz for the sound carrier and its two side bands, and the remaining 0.15 megahertz to guard against overlap between channels. The chrominance subcarrier is included within the fully transmitted picture side band.

The standard broadcast television channels of the United States are assigned 6 megahertz each in the following segments of the spectrum: VHF channels 2, 3, and 4, 54–72 megahertz; 5 and 6, 76–88 megahertz; 7 through 13, 174–216 megahertz; and the UHF channels, 14 through 83, 470–890 megahertz. These channels are allocated to communities according to a master plan established and administered by the Federal Communications Commission. No more than seven VHF channels are provided in any one area; many smaller cities must be content with one or two channels. In the major cities of Europe, fewer channels (typically two to four per city) are provided, because the higher population density and closer spacing of cities precludes more assignments within the available spectrum.

9.5 Broadcast Television

After the signal wave form and carrier current are combined in the modulator, the modulated carrier current is amplified (typically to 10,000 watts or more) and passed to the transmitter antenna, which is designed to direct radio waves along the surface of the Earth and to minimize radiation toward the sky. The antenna must be placed to stand as high and in as exposed a location as possible, since the radio waves tend to be intercepted by solid objects that stand in their path, including the Earth's surface at the horizon. Reception beyond the horizon is possible, but the signal at such distances becomes rapidly weaker as it passes to the limit of the service area.

In the transmitting antenna, the amplified carrier current produces a radio wave of the same frequency that travels through space. This wave induces a considerably weaker, but otherwise identical, current in any receiving antenna located within the service area. The signal picked up by a receiving antenna is typically as low as 0.00000001, or 10^{-8} , watt, yet even this low power is capable of producing reception of excellent quality, since the amount of amplification conferred on the picture and sound currents by a typical television receiver is extremely large. Indeed, when tuned to a station at a distance of 80 km (50 miles), the power picked up by an antenna can be as low as 10^{-11} watt, whereas the signals fed to picture tube and loudspeaker are on

the order of 1 watt. In other words, the receiver produces a faithful amplification on the order of 100 million times.

9.6 Cable television

In the United States, about two-thirds of homes obtain their broadcast television over coaxial cable systems. Cable television actually began as a service for people living far from the large cities where most broadcasting took place. The solution for rural consumers was a single master antenna located high on a hill to pick up the faint signals, which would then be amplified and retransmitted over coaxial cables to the homes of viewers. Thus community antenna television (CATV) was invented, with the earliest system being installed in 1948. Later, CATV systems were installed in large cities to provide an improved picture by avoiding ghosts and other forms of noise and distortion. Today, cable systems offer many more programs and services than can be obtained from television broadcast over the air. Most cable television programs are distributed over communications satellites.

A cable television system begins at the head end, where the program is received (and sometimes originated), amplified, and then transmitted over a coaxial cable network. The architecture of the network takes the form of a tree, with the “trunk” carrying signals to the neighbourhoods and “branches” carrying the signals closer to the homes. Finally, “drops” carry the signals to individual homes. Coaxial cable has a bandwidth capable of carrying a hundred six-megahertz television channels, but the signals decay quickly with distance. Hence, amplifiers are required periodically to boost the signals. Backbone trunks in a local cable network frequently use optical fibre to minimize noise and eliminate the need for amplifiers. Optical fibre has considerably more capacity than coaxial cable and allows more programs to be carried.

The tuners of most television receivers are capable of receiving cable channels directly. However, many programs are encrypted for premium rates, and hence a cable convertor box must be installed between the cable and the television receiver.

9.7 Direct broadcast satellite television

Communications satellites located in geostationary orbit about the Earth are used to send television signals directly to the homes of viewers—a form of transmission called direct broadcast satellite (DBS) television. Transmission occurs in the Ku band, located around 12 gigahertz (12 billion cycles per second) in the radio frequency spectrum. At these high frequencies, the receiving antenna is a small dish only 46 cm (18 inches) in diameter. More than 100 programs are available over a single DBS service. Since competing

services are not compatible, separate equipment is needed for each. Also, the receiving antenna must be carefully aimed at the appropriate satellite.

DBS transmission is digital. Normally, considerable bandwidth would be required for a digital television signal; however, by capitalizing on the redundancies inherent in a series of moving pictures, compression techniques reduce the transmission rate to 2–4 million bits per second. Decoding of the signal is performed by a set-top convertor box that is also connected to a telephone line. The telephone connection is used to send data about which shows are being watched and also to obtain permission to receive premium programs.

9.8 Teletext

Although relatively unknown in North America, teletext is routine throughout Europe. Teletext uses the vertical blanking interval (see the section The picture signal: Wave form) to send text and simple graphic information for display on the picture screen. The information is organized into pages that are sent repetitively, in a round-robin fashion; a few hundred pages can be sent in about one minute. The page selected by the viewer is recognized by electronic circuitry in the television receiver and then decoded for display. The information content is mostly of a timely, general interest, such as weather, news, sports, and television schedules. Graphics are formed from simple mosaics. The British Broadcasting Corporation (BBC) developed teletext and initiated teletext transmission in 1973. The BBC ended the service in 2012, but teletext is still used in several European countries.

9.9 Reception

At the television receiver the sound and picture carrier waves are picked up by the receiving antenna, producing currents that are identical in form to those flowing in the transmitter antenna but much weaker. These currents are conducted from the antenna to the receiver by a lead-in transmission line, typically a 12-mm (one-half-inch) ribbon of plastic in which are embedded two parallel copper wires. This form of transmission line is capable of passing the carrier currents to the receiver, without relative discrimination between frequencies, on all the channels to which the receiver may be tuned. Television signals also are delivered to the receiver over coaxial cable from a cable service provider or from a videocassette recorder. In addition, some television receivers have an input that bypasses the tuner and detector so that an unmodulated video signal can be viewed directly, in effect making the television receiver into a video display terminal.

9.10 Basic receiver circuits

At the input terminals of the receiver, the picture and sound signals are at their weakest, so particular care must be taken to control noise at this point. The first circuit in the receiver is a radio-frequency amplifier, particularly designed for low-noise amplification. The channel-switching mechanism (tuner) of the receiver connects this amplifier to one of several individual circuits, each circuit tuned to its respective channel. The amplifier magnifies the voltages of the incoming picture and sound carriers and their side bands in the desired channel by about 10 times, and it discriminates by a like amount against the transmissions of stations on other channels.

From the radio-frequency amplifier, the signals are passed to a superheterodyne mixer that transposes the frequencies of the sound and picture carriers to values better suited to subsequent amplification processes. The transposed frequencies, known as intermediate frequencies, remain the same no matter what channel the receiver is tuned to. In typical receivers they are located in the band from 41 to 47 megahertz. Since the tuning of the intermediate-frequency amplifiers need not be changed as the channel is switched, they can be adjusted for maximum performance in this frequency range. Two to four stages of such amplification are used in tandem, increasing the voltage of the picture and sound carriers by a maximum of 25 to 35 times per stage, representing an overall maximum amplification on the order of 10,000 times. The amplification of these intermediate-frequency stages is automatically adjusted, by a process known as automatic gain control, in accordance with the strength of the signal, full amplification being accorded to a weak signal and less to a strong signal. After passage through the intermediate amplifiers, the sound and picture carriers and their side bands reach a relatively fixed level of about one volt, whereas the signal levels applied to the antenna terminals may vary, depending on the distance of the station and other factors, from a few millionths to a few tenths of a volt. Intermediate-frequency amplifiers are especially designed to preserve the chrominance subcarrier during its passage through these stages.

From the last intermediate amplifier stage, the carriers and side bands are passed to another circuit, known as the video detector. From the detector output, an averaging circuit or filter then forms (1) a picture signal, which is a close replica of the picture signal produced by the camera and synchronizing generator in the transmitter, and (2) a frequency-modulated sound signal. At this point the picture and sound signals are separated. The sound signal is passed through a sound intermediate amplifier and frequency detector (discriminator, or ratio detector) that converts the frequency modulation back to an audio signal current. This current is passed through one or two additional audio-frequency amplifier stages to the loudspeaker (see the figure).

The video detector develops the luminance component of the picture signal and applies it through video amplifiers simultaneously to all three electron guns of the colour picture tube. This part of the signal thereby activates all three primary-colour images, simultaneously and identically, in the fixed proportion needed to produce white light. When tuned to monochrome signals, the colour receiver produces a black-and-white image by means of this mechanism, the chrominance component being absent. The separation of the luminance information from the composite picture signal can be accomplished through the use of a comb filter, so called because a graph of its frequency response looks like the teeth of a comb. This comb filter is precisely tuned to pass only the harmonic structure of the luminance signal and to exclude the chrominance signal. The use of a comb filter preserves the higher-frequency spatial detail of the luminance signal.

When the receiver is tuned to a colour signal, the chrominance subcarrier component appears in the output of the video detector, and it is thereupon operated on in circuits that ultimately recover the primary-colour signals originally produced by the colour camera. Recovery of the primary-colour signals starts in the synchronous detector, where the synchronizing signals are passed through circuits that separate the horizontal and vertical synchronizing pulses. The pulses are then passed, respectively, to the horizontal and vertical deflection generators, which produce the currents that flow through the electromagnetic coils in the picture tube, causing the scanning spot to be deflected across the viewing screen in the standard scanning pattern. (See the section Picture tubes.)

The synchronous detector is followed by circuits that perform the inverse operations of the addition and subtraction circuits at the transmitter. The end result of this manipulation is the production of three colour-difference signals that represent, respectively, the difference between the luminance signal (already applied to all three electron guns of the picture tube) and the primary-colour signals. Each colour-difference signal reduces the strength of the corresponding electron beam to change the white light, which would otherwise be produced, to the intended colour for each point in the scanning line. The net control signal applied to each electron gun bears a direct correspondence to the primary-colour signal derived from the respective camera sensor at the studio. In this manner, the three primary-colour signals are transmitted as though three separate channels had been used.

In addition to the amplifiers, detectors, and deflection generators described above, a television receiver contains two power-converting circuits. One of these (the low-voltage power supply) converts alternating current from the power line into direct current needed for the circuits; the other (high-voltage

power supply) produces the high voltage, typically 15,000 to 20,000 volts, needed to create the scanning spot in the picture tube.

9.11 Controls

Receivers are commonly provided with manual controls for adjustment of the picture by the viewer. These controls are (1) the channel switch, which connects the required circuits to the radio-frequency amplifier and superheterodyne mixer to amplify and convert the sound and picture carriers of the desired channel; (2) a fine-tuning control, which precisely adjusts the superheterodyne mixer so that the response of the tuner is exactly centred on the channel in use; (3) a contrast control, which adjusts the voltage level reached by the picture signal in the video amplifiers, producing a picture having more or less contrast (greater or less range between the blacks and whites of the image); (4) a brightness control, which adjusts the average amount of current taken by the picture tube from the high-voltage power supply, thus varying the overall brightness of the picture; (5) a horizontal-hold control, which adjusts the horizontal deflection generator so that it conforms exactly to the control of the horizontal synchronizing impulses; (6) a vertical-hold control, which performs the same function for the vertical deflection generator; (7) a hue (or “tint”) control, which shifts all the hues in the reproduced image; and (8) a saturation (or “colour”) control, which adjusts the magnitudes of the colour-difference signals applied to the electron guns of the picture tube. If the saturation control is turned to the “off” position, no colour difference action will occur and the reproduction will appear in black and white. As the saturation control is advanced, the colour differences become more accentuated, and the colours become progressively more vivid.

Since the late 1960s, colour television receivers have employed a system known as “automatic hue control.” In this system, the viewer makes an initial manual adjustment of the hue control to produce the preferred flesh tones. Thereafter, the hue control circuit automatically maintains the preselected ratio of the primary colours corresponding to the viewer’s choice. Thus, the most critical aspect of the colour rendition, the appearance of the faces of the performers, is prevented from changing when cameras are switched from scene to scene or when the receiver is tuned from one broadcast to another. Another enhancement is a single touch-button control that sets the fine tuning and also adjusts the hue, saturation, contrast, and brightness to preset ranges. These automatic adjustments override the settings of the corresponding separate controls, which then function over narrow ranges only. Such refinements permit reception of acceptable quality by viewers who might otherwise be confused by the many maladjustments possible when ordinary manual controls are used.

Modern remote controls, employing infrared radiation to send signals to the receiver, are descended from earlier models of the 1950s and '60s that used electric wire, visible light, or ultrasound to control the power, channel selection, and audio volume. Today's television sets have no knobs; instead, their features are controlled through on-screen displays of parameters that are adjusted by the remote control.