Chapter

1

Basics of Television

Conventional television, as is currently broadcast to home viewers, was developed in the 1930s, which was a time of rapid advance in the various techniques of telecommunication, among them, the transmission of sound and pictures. Conventional television standards are the result of these early developments. They reflect the technological limitations of the times, as well as human vision characteristics, and were a compromise between cost and performance. Given the large number of television receivers throughout the world, any technological advance has to be compatible in some manner with the existing standards.

1.1 Historical Background

After experimentation with unsatisfactory mechanical image-scanning methods, the electronic scanning method was adopted in the middle 1930s. Regular "high-resolution" television transmissions began almost simultaneously in England, Germany, and France. The picture definition of the day was about 400 lines per picture, for example, 441 lines in Germany and France and 405 lines in England. The horizontal-to-vertical aspect ratio of the picture was 4:3 and is still being used today in conventional television systems.

In 1941, after years of experimenting with various 300-line and 400-line picture formats, the United States adopted the 525-line National Television System Committee (NTSC) standard. This standard is still in use today with minor backward-compatible modifications.

After World War II, England continued with its 405-line broadcasts and France with its 441-line broadcasts. In 1948, France adopted the 819-line national television standard. The rest of Europe adopted the 625-line standard. For a while, there were no fewer than three scanning standards, two color standards [phase-alternating line (PAL) and séquential couleurs à mémoire (sequential colors with memory, or SECAM)], and seven incompatible transmission standards in simultaneous operation in Europe. The situation was corrected in the early 1980s when the French 819-line transmissions and the English 405-line transmissions were phased out. Currently, Europe shares a single scanning standard (625/50), two color standards (PAL and SECAM), and only four incompatible transmission standards.

1.2 The Eye-Brain Mechanism

1.2.1 The characteristics of visible light

Light is usually identified by wavelength rather than by frequency. Visible light is confined to a relatively narrow range of wavelengths, from about 380 to 760 nm (1 nm = 10^{-7} cm). The eye perceives various wavelengths as color hues. The wavelengths corresponding to the three primary colors are

- Red: 700.0 nm
- Green: 546.1 nm
- Blue: 435.8 nm

1.2.2 The light perception

The retina, upon which the image looked at is focused, consists of two types of receptors known as rods and cones. There are between 110 million and 130 million rods and between 6 and 7 million cones.

- The rods predominate in the periphery of the retina, are more sensitive to light than the cones, and are responsible for night (scotopic) colorless vision. The rods have limited visual acuity.
- The cones predominate in the central area (fovea) of the retina, respond to higher levels of light intensity than the rods, and are responsible for daylight (photopic) color vision. At high light intensity levels the cones have a high colorless visual acuity and a diminished color visual acuity. As the light intensity decreases, the perception is shifted to the periphery of the retina where rods are more numerous.

The information received by the retina is transmitted to the brain through the optic nerve, which consists of about 800,000 individual fibers. Each fiber is fed by a dedicated ganglion cell. Almost every ganglion cell has connections to hundreds of rod cells and tens of cone cells. In the fovea region each cone has a direct connection to a dedicated ganglion cell in addition to sharing other ganglion cells with groups of cones and rods. This accounts for the high acuity of vision in the center of the visual field. This acuity diminishes as the light intensity decreases.

The information generated by the rods and cones is fed simultaneously to the brain, where the process of perception takes place. Figure 1.1 shows a simplified "block diagram" of the eye-brain mechanism outside of the fovea region.

The eye-brain mechanism results in two consequences:

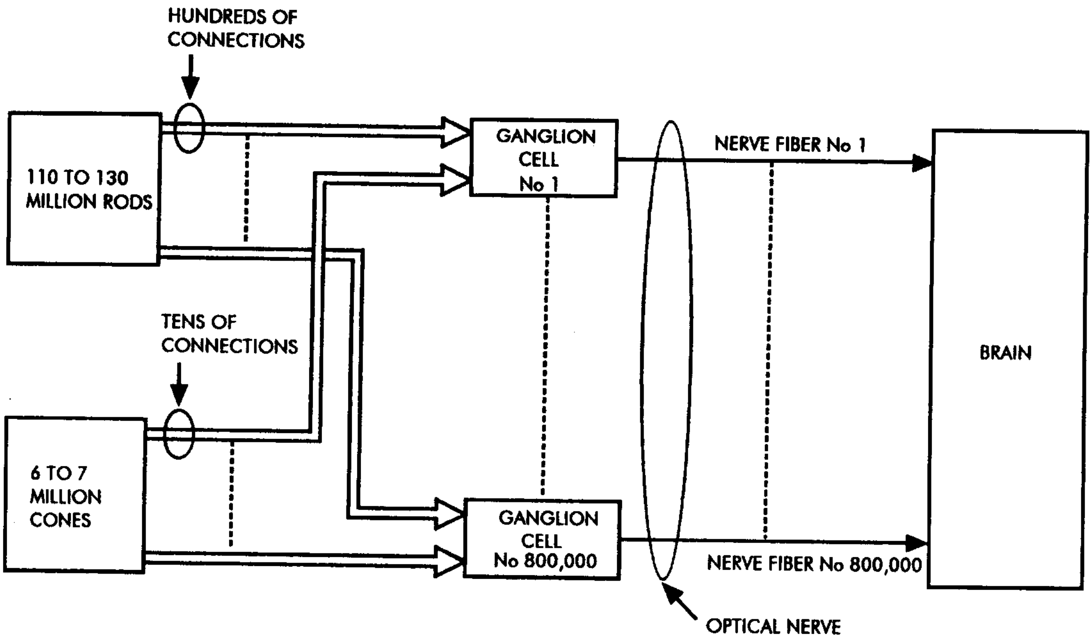

Figure 1.1 Simplified block diagram of eye-brain mechanism outside the fovea region.

- The highest visual acuity occurs in the center of the image.
- Night vision is colorless.

1.2.3 Visual acuity

Visual acuity is measured as the angle subtended by the smallest visible detail in an object. Figure 1.2 illustrates the concept of visual acuity.

Television system design takes as a reference a visual acuity of the eye of the order of 1 minute of arc. The extent to which a picture medium such as television can reproduce fine detail is expressed in terms of resolution. Television resolution is equal to the number of alternately white and black horizontal lines that can be resolved vertically over the full height of the screen. It is expressed in lines per picture height (LPH). It is determined by the rod-and-cone structure of the eye and depends upon the brightness level and contrast ratio. The 525-line and 625-line standards were developed taking into consideration the visual acuity of the eye (1 min), assumed viewing conditions in the average home (viewing distance six times the picture height), and transmission-spectrum-saving concerns. The relationship between the number of picture elements that can be resolved given a specified picture height and viewing distance is given by

$$N_v = \frac{1}{\alpha n}$$

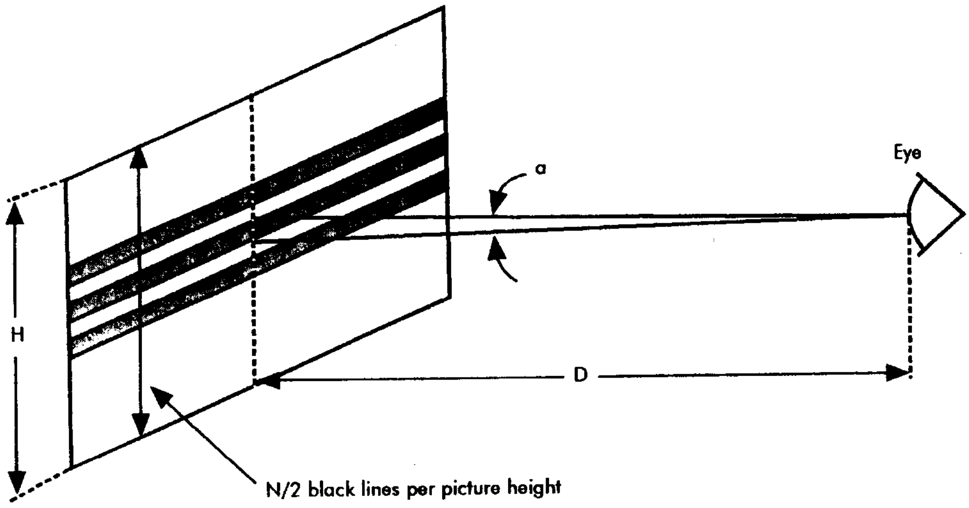

Figure 1.2 Visual acuity concept.

where N_v = Total number of elements to be resolved in the vertical direction
α = Minimum resolvable angle of the eye (in radians)
$n = D/H$ (viewing distance divided by picture height)

Given $\alpha = 1$ min of arc, or 2.91×10^{-4} radians, and $n = 6$, we have

$$N_v = \frac{1}{(6 \times 2.91\times10^{-4})} \approx 572 \text{ lines}$$

This ballpark figure is at the origin of the number of lines specified for the two conventional television systems, namely, the 525-line system used mainly in North America and Japan, and the 625-line system used elsewhere in the world. The actual resolution is smaller than 525 or 625 lines for reasons explained in Sec. 1.4. High-definition-television standards, with 1125 or 1250 lines per picture, require shorter viewing distances (e.g., $n = 3$) or larger screen sizes to enable the eye to resolve all picture details.

When color images are viewed, the visual acuity depends on the color. The acuity for blue and red is about 75% of that of a white image of the same brightness. The acuity for green is about 90% of that of a white image of the same brightness.

1.2.4 Persistence of vision

Persistence of vision is the ability of the viewer to retain or in some way to remember the impression of an image after it has been withdrawn from view. When light entering the eye is shut off, the impression of light persists for about 0.1 s. Ten still pictures per second is an adequate rate to convey the illusion of motion.

Motion pictures and television use higher rates than 10 still pictures per second in order to reduce the visibility of flicker. The critical flicker frequency is the minimum rate of interruption of the projected light that will not cause the motion picture to appear to flicker. The perceptibility of flicker varies widely with viewing conditions. Among the factors affecting the flicker threshold are luminance of the flickering area, the color of the area, the solid angle subtended by the area at the eye, the absolute size of the flickering area, the luminance of the surrounding area, the luminance variation with time and position within the flickering area, and the adaptation and training of the observer. In a constant viewing situation, that is, no change in the image or surrounding area, the luminance at which flicker just becomes perceptible varies logarithmically with luminance (the Ferry-Porter law). Empirical data indicate that increasing the flicker frequency by 12.6 cycles per second raises the flicker threshold level 10 times.

Motion pictures consist essentially of a sequence of 24 photographs (frames) of a single subject that are taken every second and projected in the same sequence to create an illusion of motion. Each successive image of a moving object is slightly different from the preceding one. When projected, each frame is presented twice, through the use of a mechanical shutter, resulting in a flicker rate of 48 cycles per second.

In television the picture elements are laid down on the screen one after the other through a process of scanning, but are perceived at the same time because of the persistence of vision. Scanning consists of breaking down the picture into a series of horizontal lines, for example, 525 or 625 in conventional television. In a process called interlaced scanning, each image is analyzed and synthesized in two sets of spaced lines. Each of the two sets comprises one half of the total number of lines (262.5 or 312.5) and fits successively within the spaces of the other. Each successive set of lines is called a *field.* Two consecutive (interlaced) fields constitute a frame. The field repetition frequency is nominally 60 Hz in the 525-line standard and 50 Hz in the 625-line standard. The frame repetition frequency is 30 and 25 Hz, respectively. In television the applicable flicker frequency is the field frequency. Two adjacent lines of two consecutive fields may not be identical, resulting in interline flicker. Interline flicker is tolerable because the eye is relatively insensitive to flicker when the variation of light is confined to a small part of the field of view.

Table 1.1 gives the flicker threshold for commonly encountered flicker frequencies. The low flicker threshold typical of motion pictures explains why

TABLE 1.1 Flicker Threshold for Commonly Encountered Flicker Frequencies

Picture source	Flicker frequency, Hz	Frames per second	Flicker threshold, cd/m^2
Movies	48	24	68.5
50-Hz television	50	25	99.4
60-Hz television	60 (nominal)	30 (nominal)	616.7

they are projected in darkened rooms. The flicker threshold of the 525/60 scanning standard is considerably higher than that of the 625/50 scanning standard, resulting in more comfortable viewing in brightly lit rooms.

1.2.5 Spectral visibility

The physical quantity that primarily determines the sensation of light is its wavelength. What is physically defined as wavelength is subjectively perceived as color. Ordinary white light contains a continuum of wavelengths throughout and beyond the range of visibility. Any visible radiation of uniform wavelength is perceived by the eye as a single (monochromatic) color. Under photopic viewing conditions, the brightest part of a spectrum, consisting of equal amounts of energy at all wavelengths, corresponds to a wavelength of about 560 nm. From this maximum, visibility falls off toward both ends of the spectrum. Under scotopic viewing conditions, the maximum perceived brightness shifts down to about 500 nm, resulting in a drastically reduced visibility in the red region. Figure 1.3 shows the relationship between scotopic and photopic vision.

1.3 The Scanning Standards

The scanning standards define the manner in which a television scene is explored for its luminance and chrominance values. They specify the number of lines per frame and the number of frames per second. Technical and economic considerations have led to certain compromises in the transmission of the essential information required by the eye. The first important consideration is the fact that any electronic system is capable of transmitting only one bit of information at a time. Consequently, the picture has to be broken down into

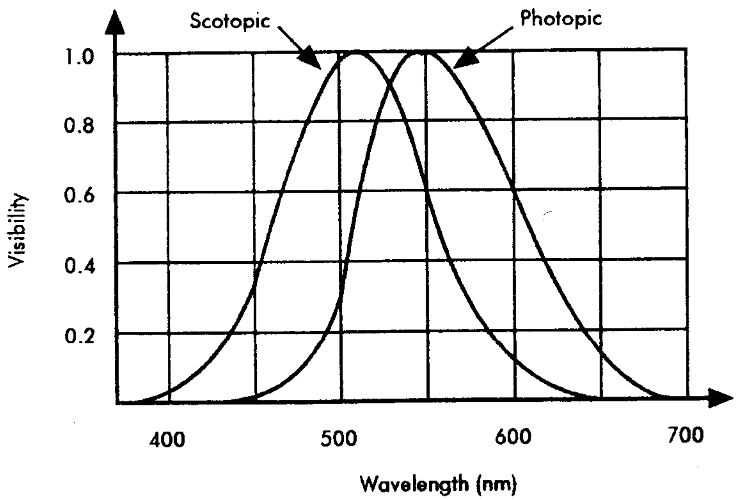

Figure 1.3 Visibility curves of the human retina.

small elements transmitted sequentially and then reconstructed at the receiver. In the end, all the elements of the reconstructed picture have to appear simultaneously to the eye.

1.3.1 The scanning process

The conventional television standards reflect the image pickup and display technology of the 1930s. This assumes that the camera uses a pickup tube where the image is focused onto a photoconductive layer. Electrical charges, proportional to the illuminated scene at each point, are developed and stored capacitively on this layer. An electron beam is used to convert the charge image into an electrical current. This beam is focused to a circular spot and deflected continuously over the image in two consecutive fields of horizontal lines. Each consecutive field contains half of the total number of scanning lines into which the picture is scanned. Two consecutive fields (field 1 and field 2) are displaced vertically such that their scanning lines are interlaced, and together they form a frame. The image is scanned from left to right, starting at the top and tracing successive lines until the bottom of the picture is reached. The beam then returns to the top and the process is repeated. The continuous deflection of the electron beam is achieved by subjecting it to two perpendicular (vertical and horizontal) magnetic fields that result from repetitive sawtooth-shaped currents flowing through a pair of (horizontal and vertical) deflection coils. The process is called *linear interlaced scanning*. The repetition rate of the horizontal component is related to the vertical component by the factor n, resulting in the formation of n lines during a complete vertical period. The retrace times involved (both horizontal and vertical) are a result of the physical limitations of early scanning systems. The retrace times are not utilized for the transmission of a video signal but for the transmission of auxiliary information such as horizontal and vertical scanning synchronization.

In the display device, a cathode-ray tube (CRT) re-creates the original picture. A focused electron beam, deflected horizontally and vertically in synchrony with the pickup tube electron beam, is projected onto a phosphor-coated viewing screen. The CRT beam current is, ideally, proportional to the beam current in the pickup tube, and the deflection currents through the deflection coils are in synchrony with those of the pickup tube. In reality, the CRT electron beam current versus control voltage transfer characteristic is not linear. To correct for this condition, the camera video amplifier introduces an opposite nonlinearity, called *gamma correction*, resulting in a linear relationship between original picture brightness and CRT-reproduced brightness. This subject will be discussed further in Chap. 2. Figure 1.4 shows a simplified block diagram of the monochrome television system from signal source to CRT display.

1.3.2 Lines per frame

This parameter was chosen to provide a value of vertical resolution appropriate to the acuity of normal vision at a distance of about six times the screen height.

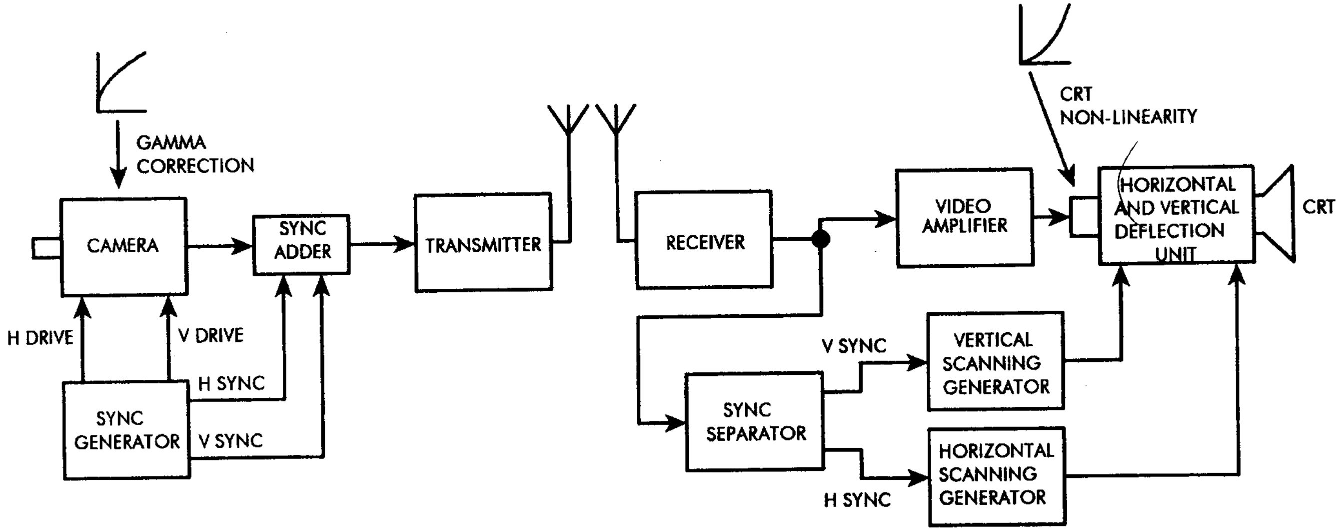

Figure 1.4 Simplified block diagram of monochrome television system from signal source to CRT display.

There is an odd number of lines per frame. The standardized values for conventional broadcast television presently are 525 and 625 lines per frame.

1.3.3 Pictures per second

The pictures per second standard is chosen to provide a sufficiently rapid succession of complete pictures (frames) to avoid flicker at levels of image brightness appropriate to viewing images in domestic surroundings. The frames are made up of two consecutive fields, each containing half of the total number of lines (262.5 or 312.5). The lines in two consecutive fields are interlaced, resulting in a frame made up of the total amount of lines (525 or 625). Historically, the values for the field repetition frequency were chosen to be equal to the power-line frequency, 60 Hz in the United States, Canada, and Mexico, and 50 Hz in other parts of the world. Under extreme conditions, a display in synchrony with the power-line frequency reduces the visibility of scanning distortions caused by stray magnetic fields and hum components, should they exist. This reduced visibility is obtained when the receiver and the transmitter operate from the same power source, which is not always the case. Consequently, the practice of synchronizing the field rate to the power line frequency has long been discontinued and, today, the vertical scanning frequency is only nominally equal to the power-line frequency, since it is obtained by counting down from a highly stable crystal-controlled high-frequency oscillator.

1.3.4 The conventional scanning standards

Two conventional television scanning standards coexist in the world today. These are the 525/50 standard and the 625/50 standard. These standards represent a cost versus performance choice based on the technology of the 1930s. Table 1.2 summarizes their characteristics.

1.4 The Resolution Concept

Historically, *resolution* was understood to mean "limiting resolution," or the point at which adjacent elements of an image cease to be distinguished. Various disciplines measure and specify resolution differently. Resolution can be specified as

- The number of units (i.e., lines or line pairs) per unit distance along the vertical and horizontal axis, such as lines per millimeter.
- The number of units (i.e., lines) for a full display, such as lines per picture height (LPH).

In television, the resolution is specified in terms of LPH. The various conventional television systems in use today were designed to achieve equal horizontal and vertical resolution, better known as *square pixels*.

TABLE 1.2 Significant Parameters of Conventional Scanning Standards

Parameter	525/60 Standard	625/50 Standard
Number of lines per frame	525	625
Number of lines per field	262.5	312.5
Number of frames per second	29.97	25
Number of fields per second (f_V), Hz	$2f_H/525 = 59.94$	$2f_H/625 = 50$
Horizontal scanning frequency (f_H), Hz	$3 \times 5 \times 5 \times 7(f_V/2) = 15{,}734.25$	$5 \times 5 \times 5 \times 5(f_V/2) = 15{,}625$
Field blanking duration (lines)	20	25
Frame blanking duration (lines)	40	50
Number of active lines per frame	485	575
Vertical resolution (N_V), LPH	$485 \times 0.7 \approx 339$	$575 \times 0.7 \approx 402$
Total line duration, μs	63.556	64
Horizontal blanking duration, μs	10.7 ± 0.1	12 ± 0.3
Active line duration, μs	52.856	52
Horizontal pixels for equal H/V resolution	$339 \times (4/3) \approx 452$	$402 \times (4/3) = 536$
Line-pair cycle duration (T), μs	$52.85/226 \approx 0.2338$	$52/268 = 0.194$
Bandwidth for equal H/V resolution, MHz	$1/T \approx 4.28$	$1/T = 5.15$
Horizontal resolution factor, lines/MHz	$339/4.28 \approx 79.2$	$402/5.15 = 78$
Horizontal resolution (N_H), LPH	333 (@4.2-MHz bandwidth)	390 (@5-MHz bandwidth)
H/V resolution ratio	0.98	0.97

1.4.1 Vertical resolution

The vertical resolution is independent of the system bandwidth and defines the capability of the system to resolve horizontal lines. It is expressed as the number of distinct horizontal lines, alternately black and white, that can be satisfactorily resolved on a television screen. Vertical resolution depends primarily on the number of scanning lines per picture and the combined effects of the camera pickup tube and the CRT scanning spot size and shape.

Ideally, the vertical resolution would be equal to the number of active lines per frame. This would happen if the scanning lines were centered on the picture details as shown in Fig. 1.5. The scanning lines cannot be assumed to occupy a fixed position relative to vertical detail at all times. Complete loss of vertical resolution will occur when the scanning spot straddles picture details as shown in Fig. 1.6. From subjective data, it has been found that raster lines in excess of the number of elements to be resolved are necessary, as shown in Fig. 1.7. This can be expressed by

$$N_V = kN_{AL}$$

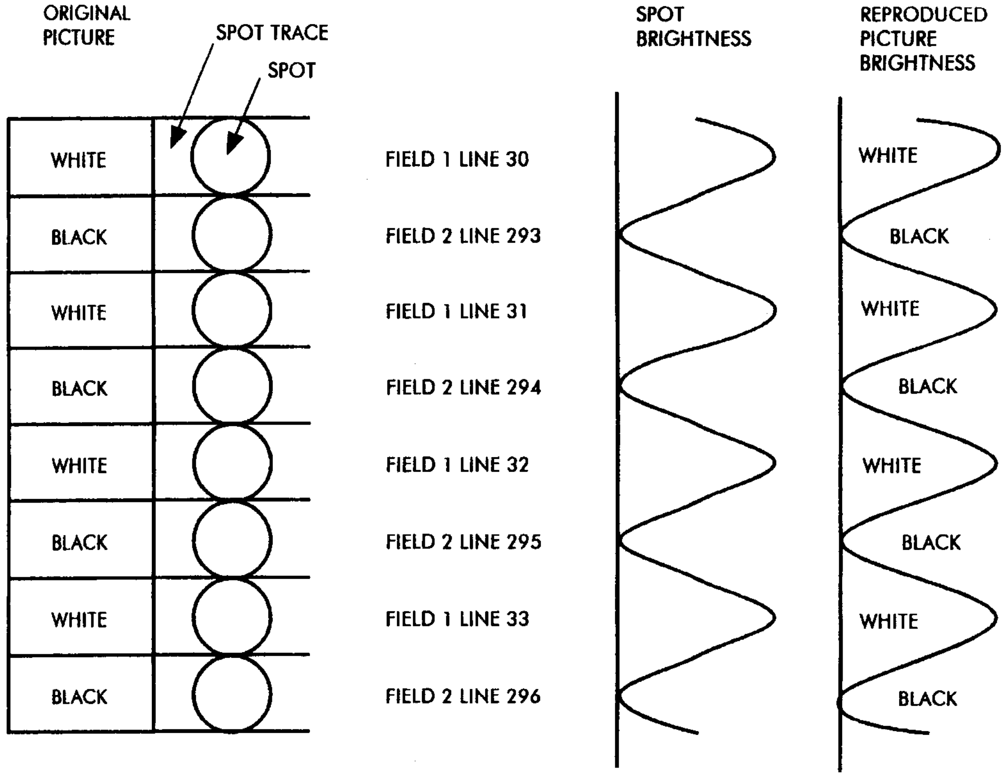

Figure 1.5 Vertical resolution equals number of active lines when the raster lines are centered on the picture details.

where N_V = Number of active vertical picture elements (pixels) to be resolved.
N_{AL} = The number of active lines (excluding lines formed while the beam is returning to the top of the picture).
k = Constant obtained from subjective measurements. This is called the *Kell factor* and is usually taken as 0.7.

In the 525/60 scanning standard there is a total of 525 lines per frame, of which 40 are blanked, leaving 485 active lines per frame. Given a Kell factor of 0.7, the effective vertical resolution of the 525/60 scanning standard is:

$$N_V = 0.7 \times 485 \approx 339 \text{ LPH or pixels}$$

In the 625/50 scanning standard there is a total of 625 lines per frame, of which 50 are blanked, leaving 575 active lines per frame. Given a Kell factor of 0.7, the effective vertical resolution is:

$$N_V = 0.7 \times 575 \approx 402 \text{ LPH}$$

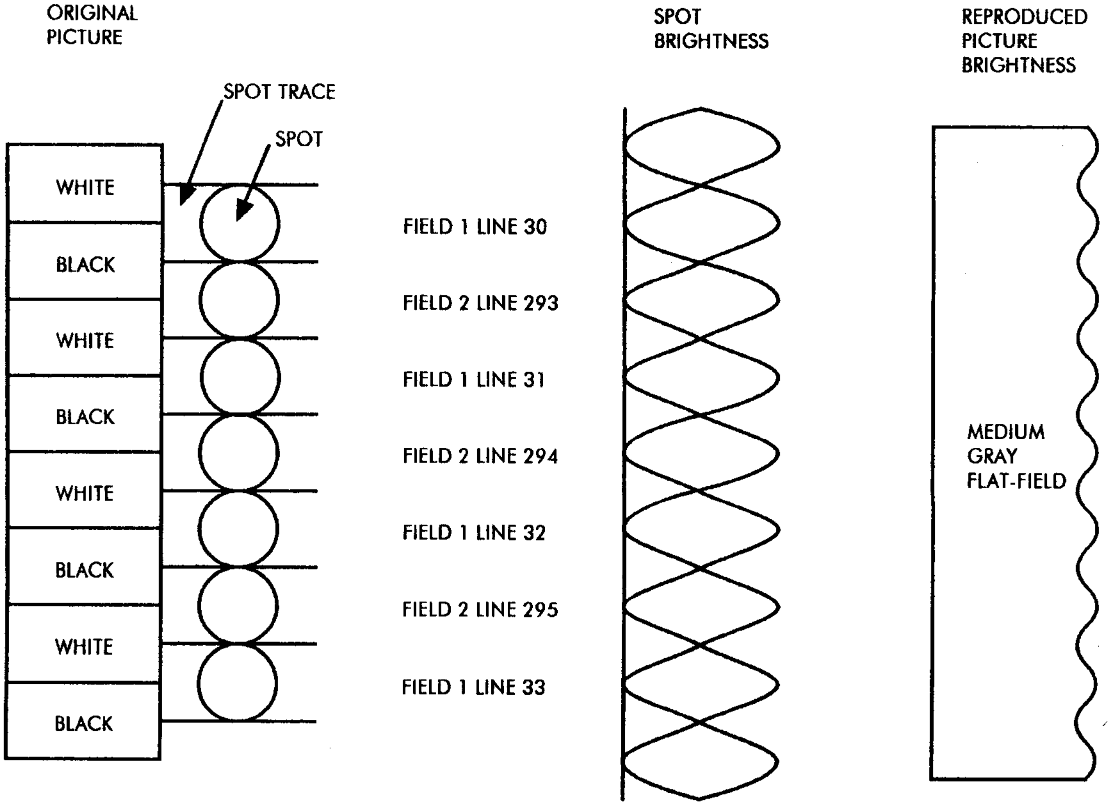

Figure 1.6 Loss of vertical resolution resulting from scanning spot straddling picture details.

1.4.2 Horizontal resolution

The horizontal resolution is directly related to the system bandwidth and defines the ability of the system to resolve vertical lines. It is expressed as the number of distinct vertical lines, alternately black and white, that can be satisfactorily resolved in three quarters of the width of a television screen. The horizontal resolution depends on the combined effects of the camera pick-up tube and CRT scanning spot dimensions as well as the high-frequency amplitude and phase response of the transmission medium. A system with a horizontal to vertical aspect ratio of 4/3, as in conventional television, needs to allow for $(4/3)N_V$ horizontal pixels to be resolved. In the 525/60 scanning standard, this results in $339 \times 4/3 \approx 452$ horizontal pixels.

Because of the finite size of the scanning spot, a beam exploring a pair of contiguous white-and-black pixels (line pair) results in a sine wave with a positive half-wave corresponding to the white pixel and a negative half-wave corresponding to the black pixel (see Fig. 1.8). A scanning beam exploring a

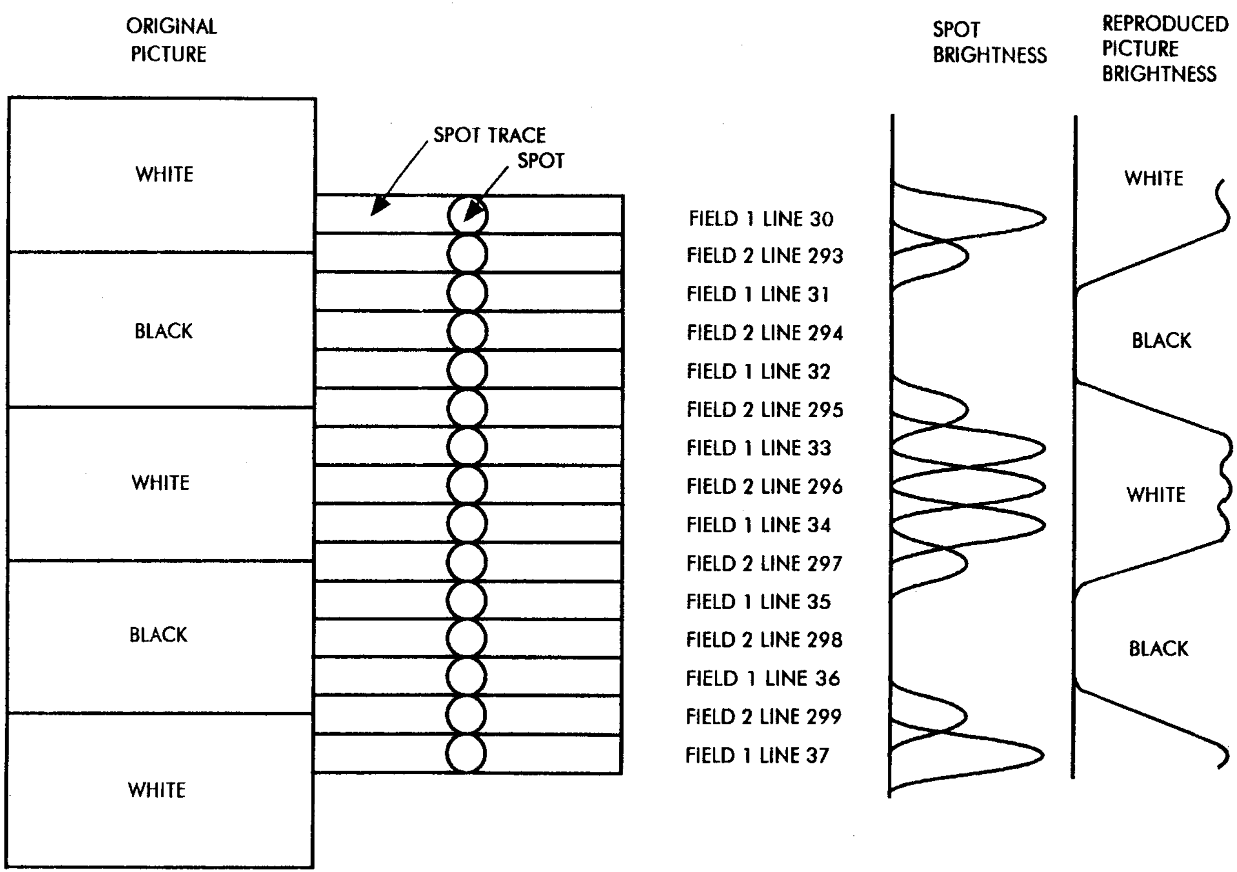

Figure 1.7 Effect of scanning spot shape and size on vertical resolution.

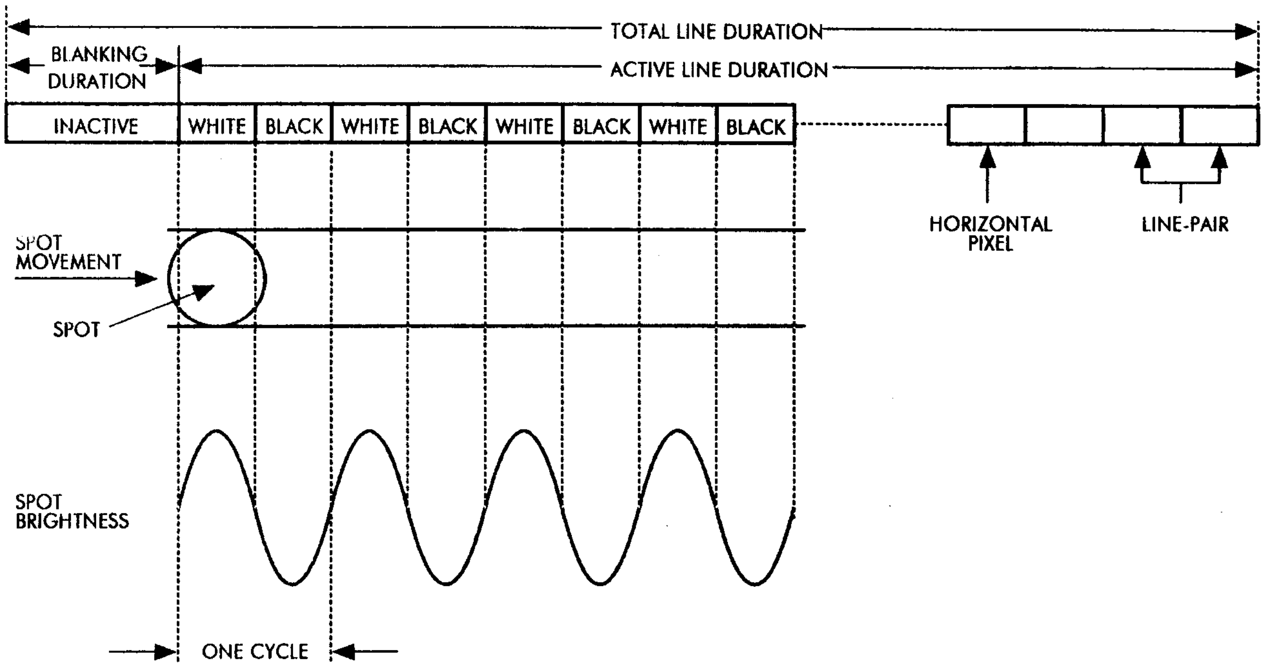

Figure 1.8 The horizontal resolution concept.

picture made up of 452 horizontal pixels results in an electrical signal with 226 complete cycles during the active horizontal scanning line.

In the 525/60 scanning standard the total horizontal scanning line duration is 63.5 μs and the horizontal blanking duration is 10.7 μs, resulting in an active line duration of 52.85 μs. The duration of a single cycle is

$$T = \frac{52.85\ \mu s}{226} \approx 0.2338\ \mu s$$

The fundamental frequency resulting from scanning 452 horizontal pixels is

$$F = \frac{1}{T} = \frac{1}{0.2338\ \mu s} \approx 4.28\ \text{MHz}$$

This is the bandwidth required for equal horizontal and vertical resolution. The horizontal resolution factor for a 4.28-MHz bandwidth is

$$\frac{339}{4.28}\ \text{MHz} = 79.2\ \text{lines/MHz}$$

In countries using the 525/60 scanning standard (CCIR M) the maximum transmitted baseband video frequency is 4.2 MHz, resulting in a transmitted horizontal resolution of

$$N_H = 4.2\ \text{MHz} \times 79.2\ \text{lines/MHz} \approx 333\ \text{lines}$$

The resulting horizontal versus vertical resolution ratio is therefore 333/339 ≈ 0.982. From an analog point of view, this represents a quasi-square pixel.

The minimum video bandwidth for equal horizontal and vertical resolution in the 625/50 scanning standard is 5.15 MHz, and the resulting horizontal resolution factor is 78 lines/MHz. Various countries have adopted different maximum transmitted baseband video frequency values, resulting in different transmitted horizontal resolutions as shown in Table 1.3.

Table 1.2 lists relevant figures of significant parameters for the 525/60 and 625/50 scanning standards.

TABLE 1.3 Horizontal Resolution Capability of Various 625/50 Transmission Standards

Standard	Bandwidth, MHz	N_H, LPH	N_H/N_V
CCIR N	4.2	327	0.81
CCIR B,G	5	390	0.97
CCIR I	5.5	429	1.067
CCIR K,L	6	468	1.16

1.5 The Composite Video Signal

The satisfactory reproduction of a picture requires the transmission of several types of information combined into a single waveform called the *composite video signal.* This signal is composed of

- Video information
- Synchronizing information

1.5.1 The video information

Video signals generated by a camera are suitably amplified to a standard level. The video signal conveys information concerning

- The blanking level
- The black reference level
- The average scene brightness level
- Picture details
- Color values (see Chap. 2)

The video signal is unipolar with one direct current (DC) level (nominally 0 V) representing black and a second level (nominally +700 mV) representing white. Any level between 0 and 700 mV represents a degree of gray.

1.5.2 The synchronizing information

The synchronizing information consists of

- Horizontal scanning synchronization
- Vertical scanning synchronization
- Chrominance decoder synchronization (see Chap. 2)

The horizontal and vertical synchronizing information is used to trigger the horizontal and vertical deflection circuits in the receiver. It consists of pulses having a specific amplitude, duration, and shape best suited to the task at hand. The synchronizing pulses are unipolar with a reference level of 0 V and a peak negative level of nominally −300 mV.

1.5.3 The makeup of the composite video signal

The video signal waveform, with a nominal peak-to-peak amplitude of 700 mV, and the synchronizing signal waveform, with a nominal peak-to-peak amplitude of 300 mV, are added together to form a composite video signal with a peak-to-peak amplitude of 1 V. The synchronizing pulses are placed in parts of the composite video signal that do not contain active picture information. These parts are blanked (forced to or below the black level) to render invisible the retrace of scanning beams on a correctly adjusted display.

1.5.4 Interface characteristics

The video equipment interconnections are made using an unbalanced coaxial cable. The source impedance, terminating impedance, and coaxial cable characteristic impedance is 75 ohms.

The peak-to-peak value of the luminance (monochrome) signal plus the synchronizing signal, measured from the peak of the synchronizing pulse (sync tip) to the peak white level, is 1 V. This standard video signal level applies to both conventional television scanning standards. Composite color signal levels are discussed in Chap. 2. Even though the peak-to-peak composite video signal levels are identical, operational practices have resulted in slightly different significant signal levels as shown in Table 1.4 and Figs. 1.9 and 1.10 as follows:

- Signal levels are expressed in millivolts in the 625/50 scanning standard. In the 525/60 standard, and specifically in North America, composite video signal levels are expressed in IRE units [Institute of Radio Engineers now known as Institute of Electrical and Electronics Engineers (IEEE)]. A standard composite video signal with a peak-to-peak amplitude of 1 V is said to have an amplitude of 140 IRE units of which 100 IRE units of luminance (monochrome signal) and 40 IRE of sync.
- The peak white level is 700 mV in the 625/50 scanning standard and 714.3 mV (100 IRE) in the 525/60 scanning standard.
- The blanking level is equal to the black level (0 V) in the 625/50 scanning standard. In the 525/60 standard, as used in North America, the black level is nominally 7.5% of the peak white level (53.5 mV or 7.5 IRE). In a monochrome signal there are no video signal components below the black (blanking) level.
- The synchronizing signal level is 300 mV in the 625/50 scanning standard and 285.7 mV (40 IRE) in the 525/60 scanning standard.

Analog distribution equipment usually has a headroom adequate to accept video signal levels of up to 2 $V_{p\text{-}p}$. Headroom limitations occur in analog videotape recorders, common-carrier links, and television transmitters. To avoid equipment overload, the camera controls are adjusted continuously by the operator to limit the signal-level excursions to the specified upper and lower limits. Specialized video oscilloscopes, called *waveform monitors,* are used for this pur-

TABLE 1.4 Monochrome Composite Video Signal Levels

Parameter	525/60 standard	625/50 standard
White level	100 IRE (714.3 mV)	700 mV
Black (setup) level	7.5 IRE (53.5 mV)	0 mV
Blanking level	0 IRE (0 mV)	0 mV
Sync level	−40 IRE (−285.7 mV)	−300 mV

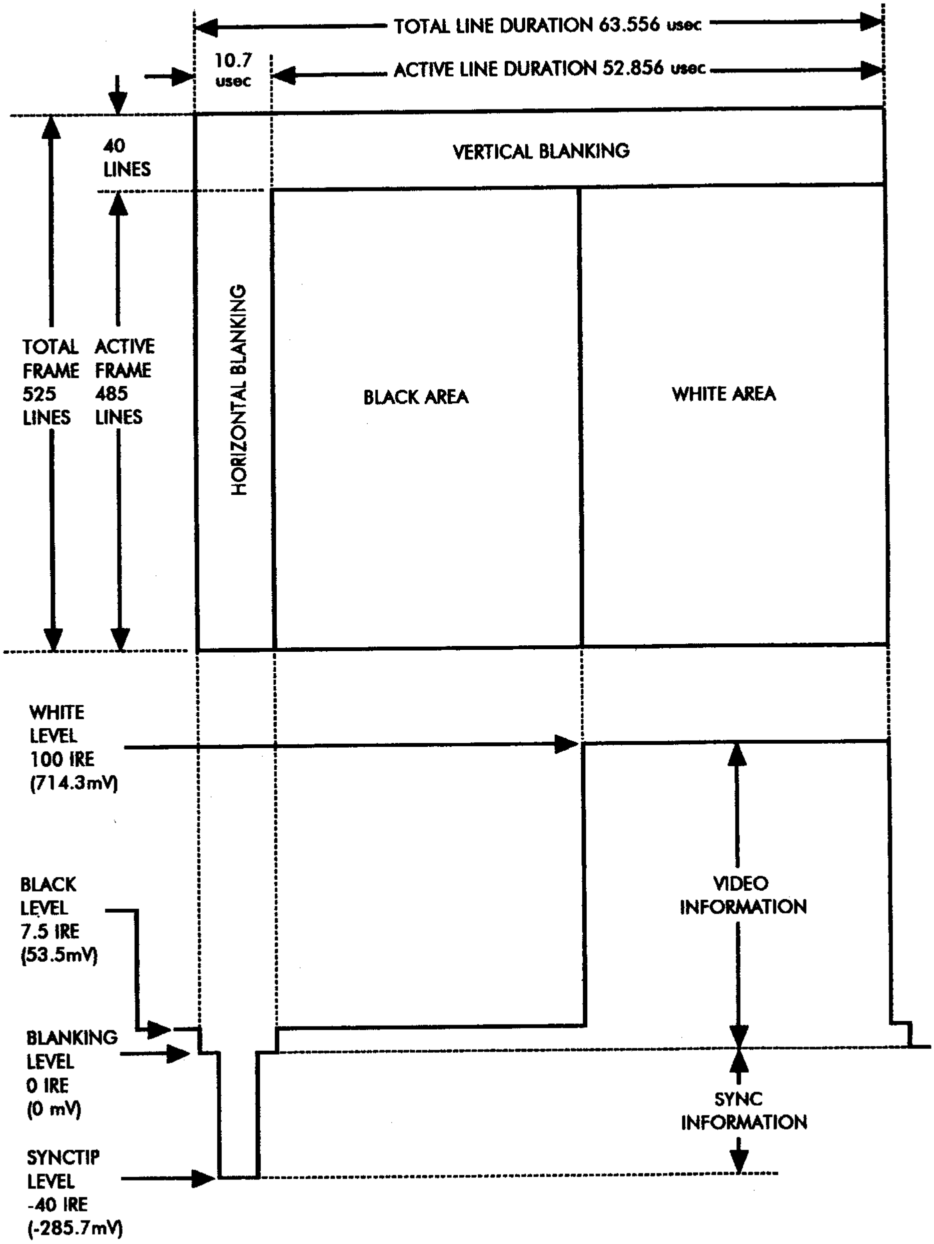

Figure 1.9 Significant amplitude and timing values of composite video signal relative to picture characteristics in 525/60 standard.

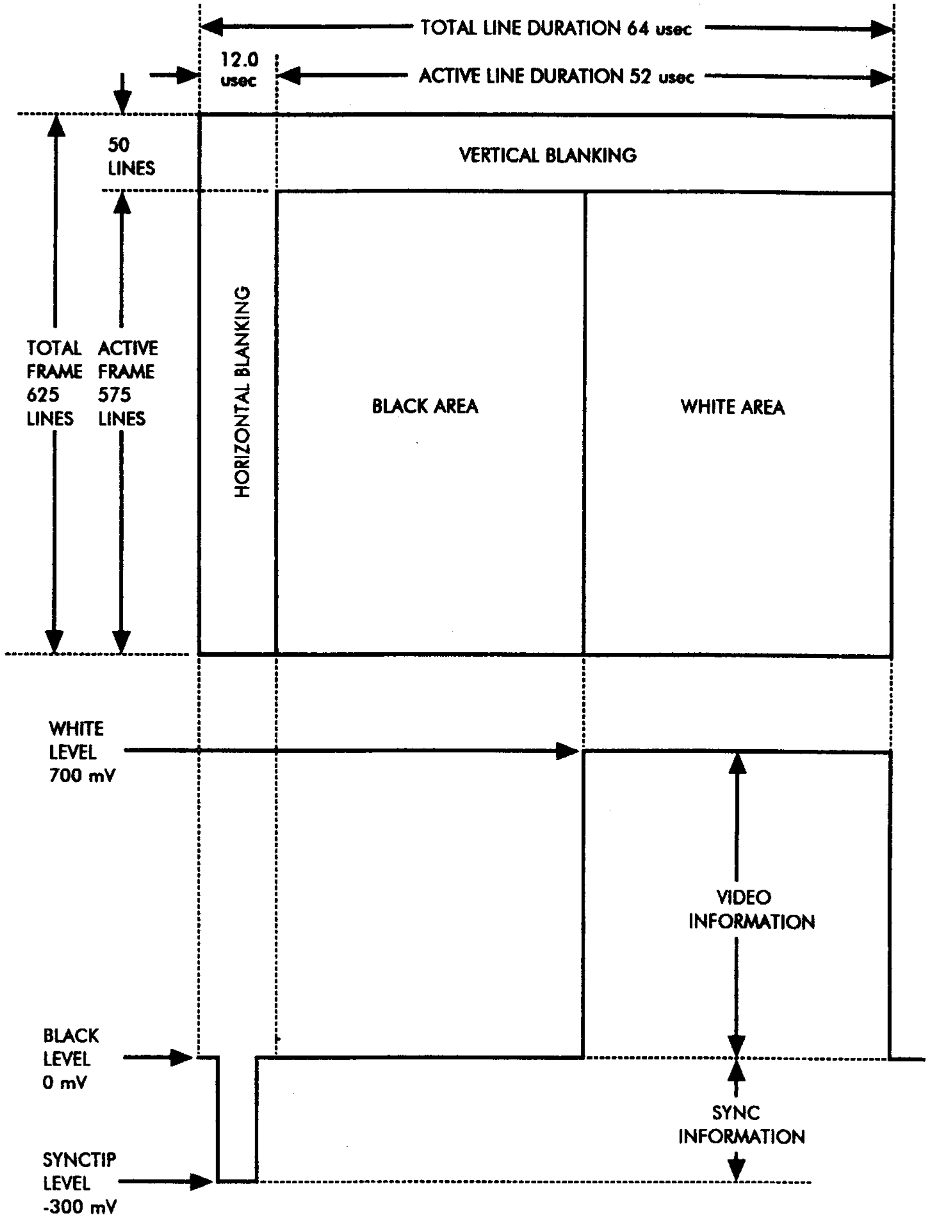

Figure 1.10 Significant amplitude and timing values of composite video signal relative to picture characteristics in 625/50 standard.

pose. Digital processing equipment, using analog input-output ports, requires special care because of the limited amount of overhead of the A/D converters.

1.5.5 Blanking intervals and structure

The horizontal and vertical blanking intervals are periods during which the scanning beam retrace occurs and in which synchronization information is located.

1.5.5.1 Horizontal blanking interval. Each horizontal line outside the vertical blanking interval is divided into an active line period and a horizontal blanking interval. The horizontal blanking interval contains a negative-going horizontal synchronizing pulse followed by the color synchronization burst (see Chap. 2). The remainder of the horizontal blanking interval is kept at the blanking level to delineate the synchronizing signal properly. The details of the horizontal blanking interval related to the two conventional scanning standards are described in Table 1.5 and Figs. 1.11 and 1.12.

1.5.5.2 Vertical blanking interval. Both conventional scanning standards feature an interlaced raster. Each television frame is divided into two fields. Each field contains half of the total number of scanning lines. The fields carry every other scanning line in succession and the following field carries the lines not scanned by the previous field. Each field is divided into an active picture area and a vertical blanking interval. The vertical blanking interval contains the vertical synchronizing information surrounded by blanking periods and auxiliary equalizing pulses. This technique permits the unambiguous recovery

TABLE 1.5 Details of Line-Synchronizing Signals (See Figs. 1.11 and 1.12)

Symbol	Parameter	525/60 standard	625/50 standard
H	Nominal line period, μs	63.556	64
A	Line blanking interval, μs	10.7 (derived)	12.05 ± 0.25
B	Horizontal reference point to horizontal blanking end, μs	9.2 +0.2/−0.1	10.5 (derived)
C	Horizontal blanking start to horizontal reference point (front porch), μs	1.5 ± 0.1	1.5 ± 0.3
D	Horizontal synchronizing pulse duration, μs	4.7 ± 0.1	4.7 ± 0.1
E	Horizontal synchronizing pulse end to blanking pulse end (back porch), μs	4.5 (derived)	5.8 (derived)
F	Horizontal blanking pulse risetime, ns	140 ± 20	300 ± 100
G	Horizontal synchronizing pulse risetime, ns	140 ± 20	200 ± 100

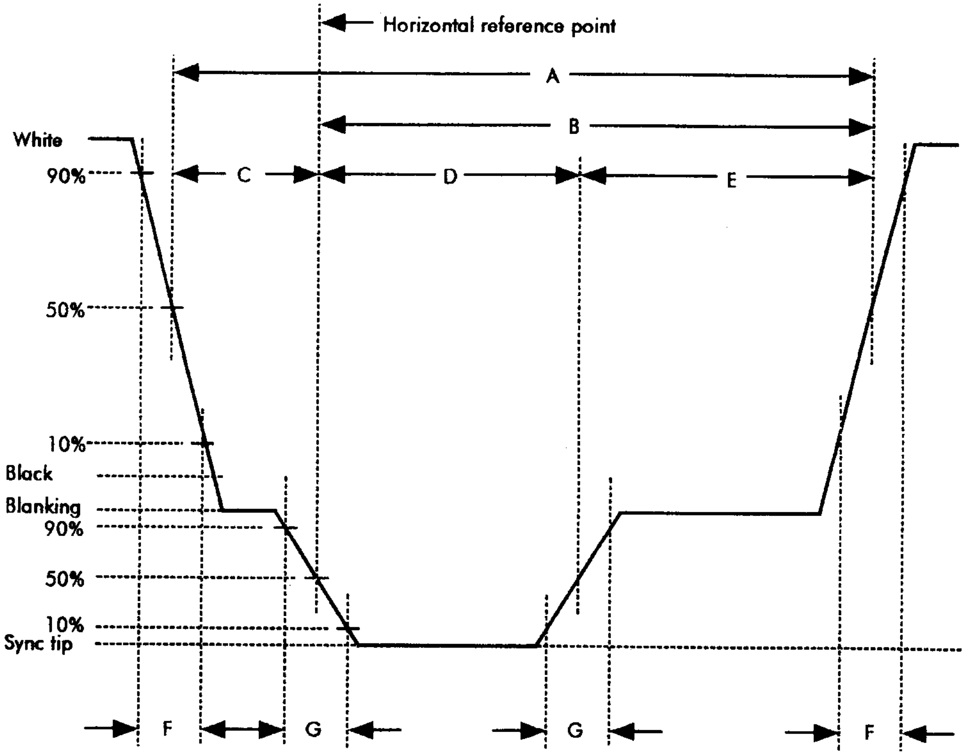

Figure 1.11 525/60 scanning standard details of horizontal blanking interval.

of the vertical synchronization information required to trigger the vertical scanning circuits of the receiver adequately. The vertical synchronizing signal is organized as follows:

- 525/60 scanning standard: A 9-line block divided into three 3-line-long segments. The first of the segments contains six preequalizing pulses. The second segment contains the vertical synchronizing pulse with six serrations. The third segment contains six postequalizing pulses.
- 625/50 scanning standard: A 7½-line block divided into three 2½-line-long segments. The first segment contains five preequalizing pulses. The second segment contains the vertical synchronizing pulse with five serrations. The third segment contains five postequalizing pulses.

The remainder of the vertical blanking interval not used for the vertical synchronizing block is available for special vertical interval signals. When such signals are carried on a particular line, they are confined to the active period between the horizontal blanking intervals. When such signals are not carried on a particular line, the line is maintained at blanking level. Color-synchronizing-burst considerations are covered in Chap. 2.

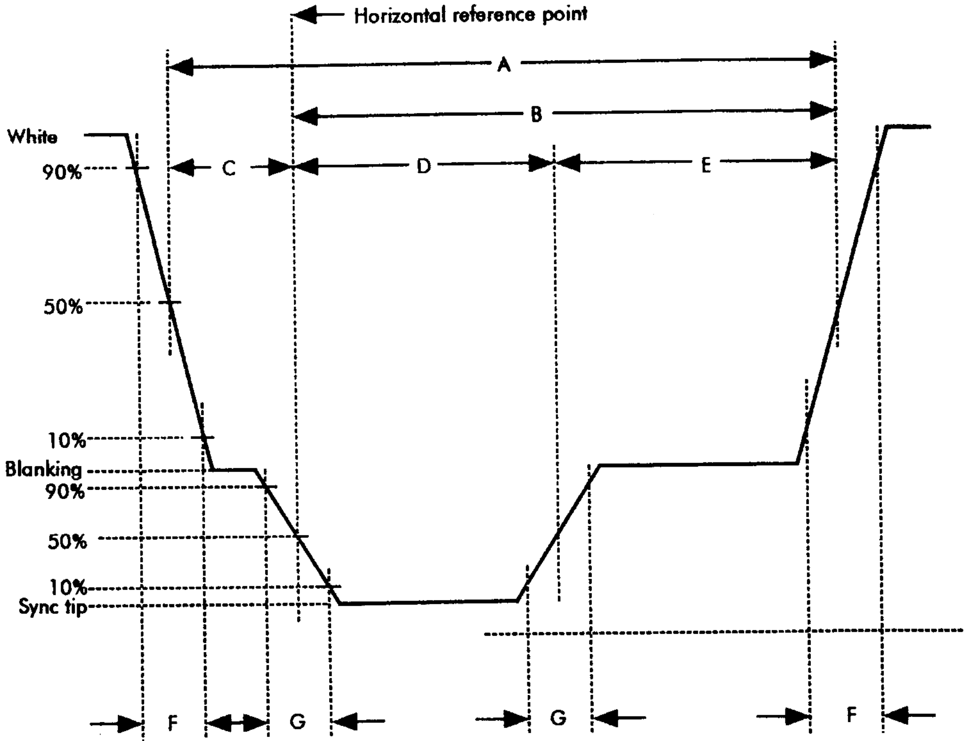

Figure 1.12 625/50 scanning standard details of horizontal blanking interval.

TABLE 1.6 Details of Field-Synchronizing Signals (See Figs. 1.13 and 1.14)

Parameter	525/60 standard	625/50 standard
Field period, ms	16.6833	20
Frame period, ms	33.3667	40
Vertical blanking start to front edge of first equalizing pulse, μs	1.5	Not specified
Vertical (field) blanking interval duration, lines	20 +1.5 μs	25
Preequalizing pulse sequence duration, lines	3	2.5
Preequalizing pulse width, μs	2.3 ± 0.1	2.35 ± 0.1
Vertical synchronizing pulse sequence duration, lines	3	2.5
Vertical serration pulse width, μs	4.7 ± 0.1	4.7 ± 0.2
Postequalization pulse duration, lines	3	2.5
Postequalizing pulse width, μs	2.3 ± 0.1	2.35 ± 0.1

The details of the vertical synchronizing waveforms related to the two conventional scanning standards are detailed in Table 1.6 and Figs. 1.13 and 1.14.

Details of the vertical blanking interval related to the two conventional scanning standards are shown in Figs. 1.15 and 1.16.

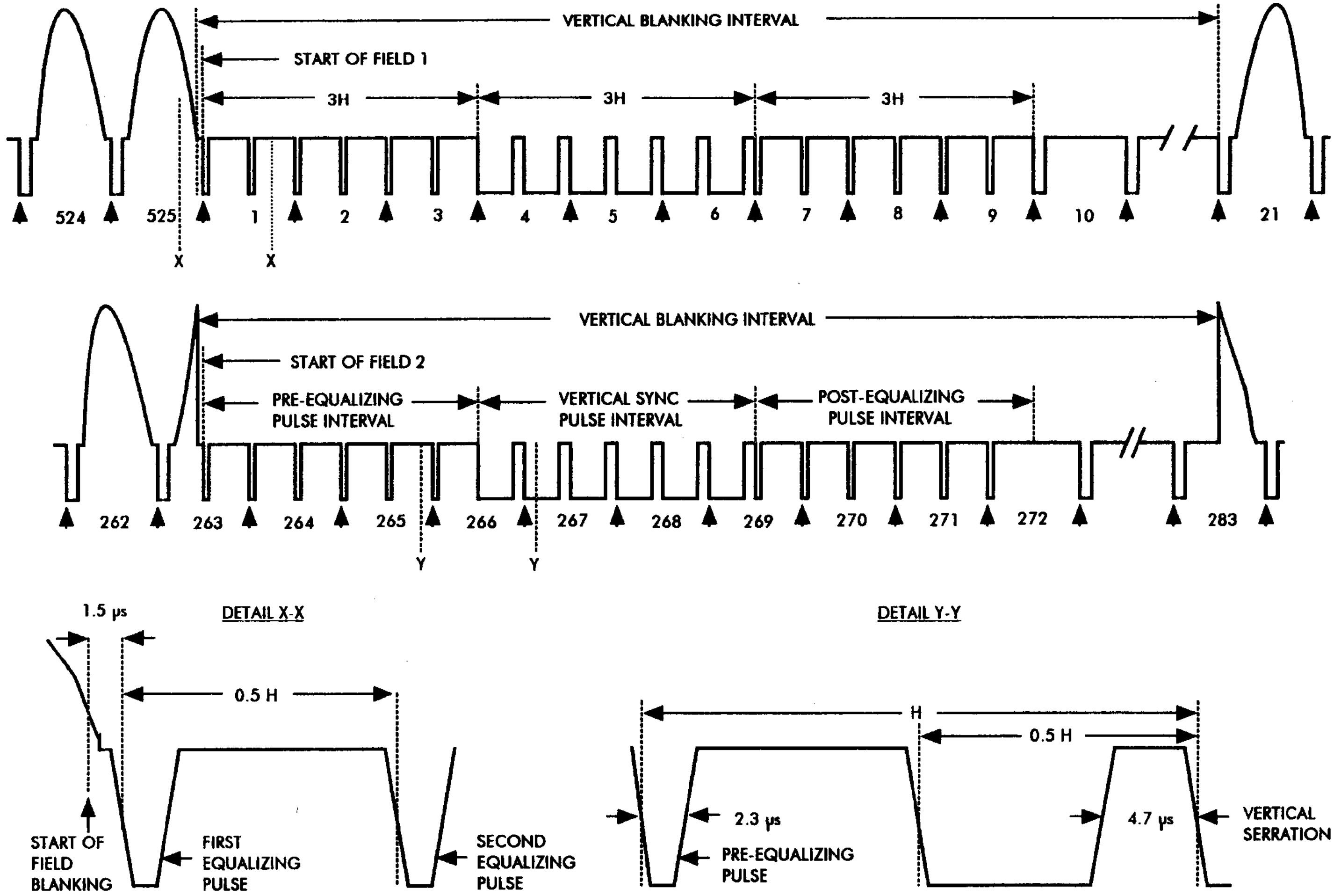

Figure 1.13 525/60 scanning standard details of vertical synchronizing waveforms.

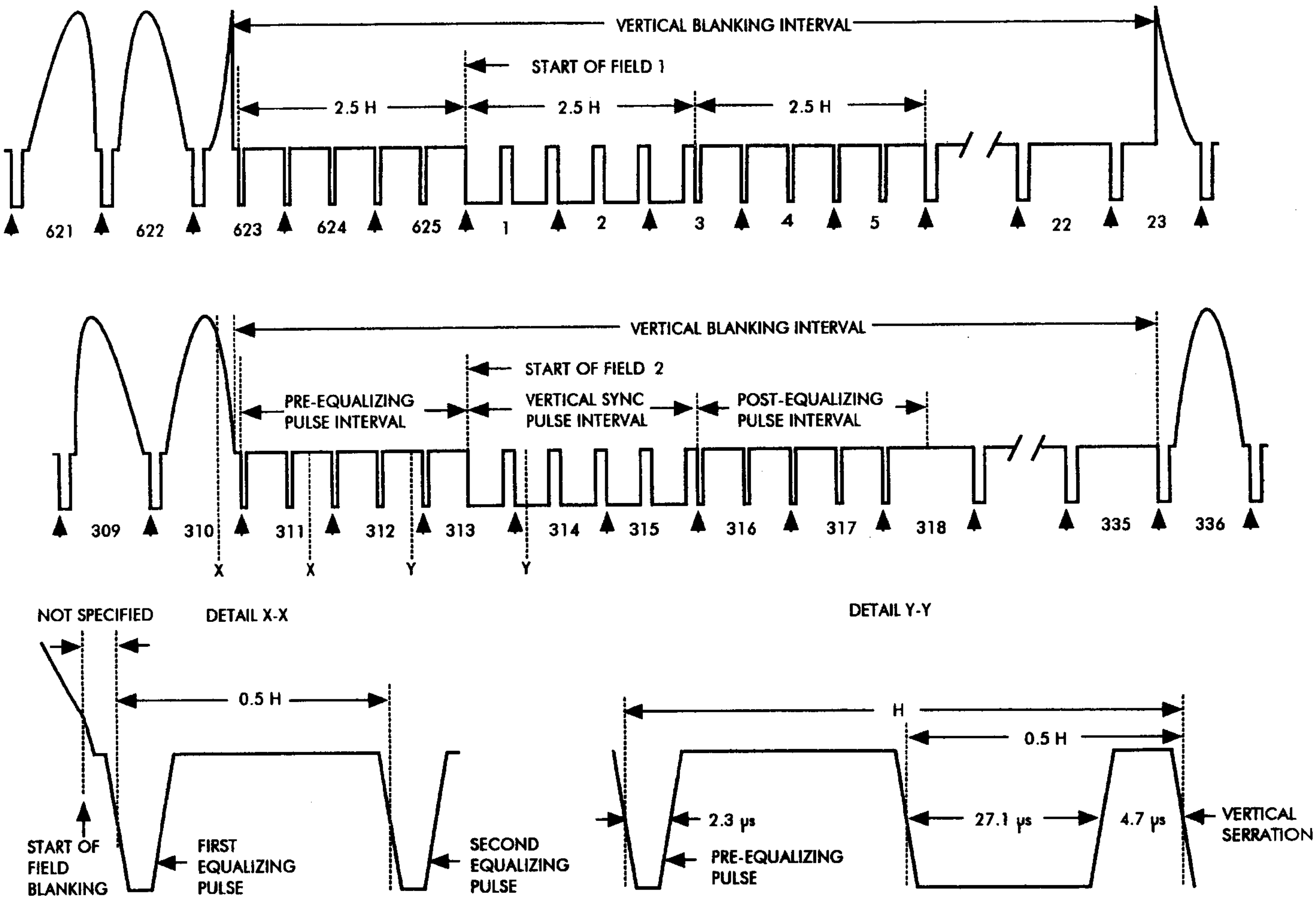

Figure 1.14 625/50 scanning standard details of vertical synchronizing waveforms.

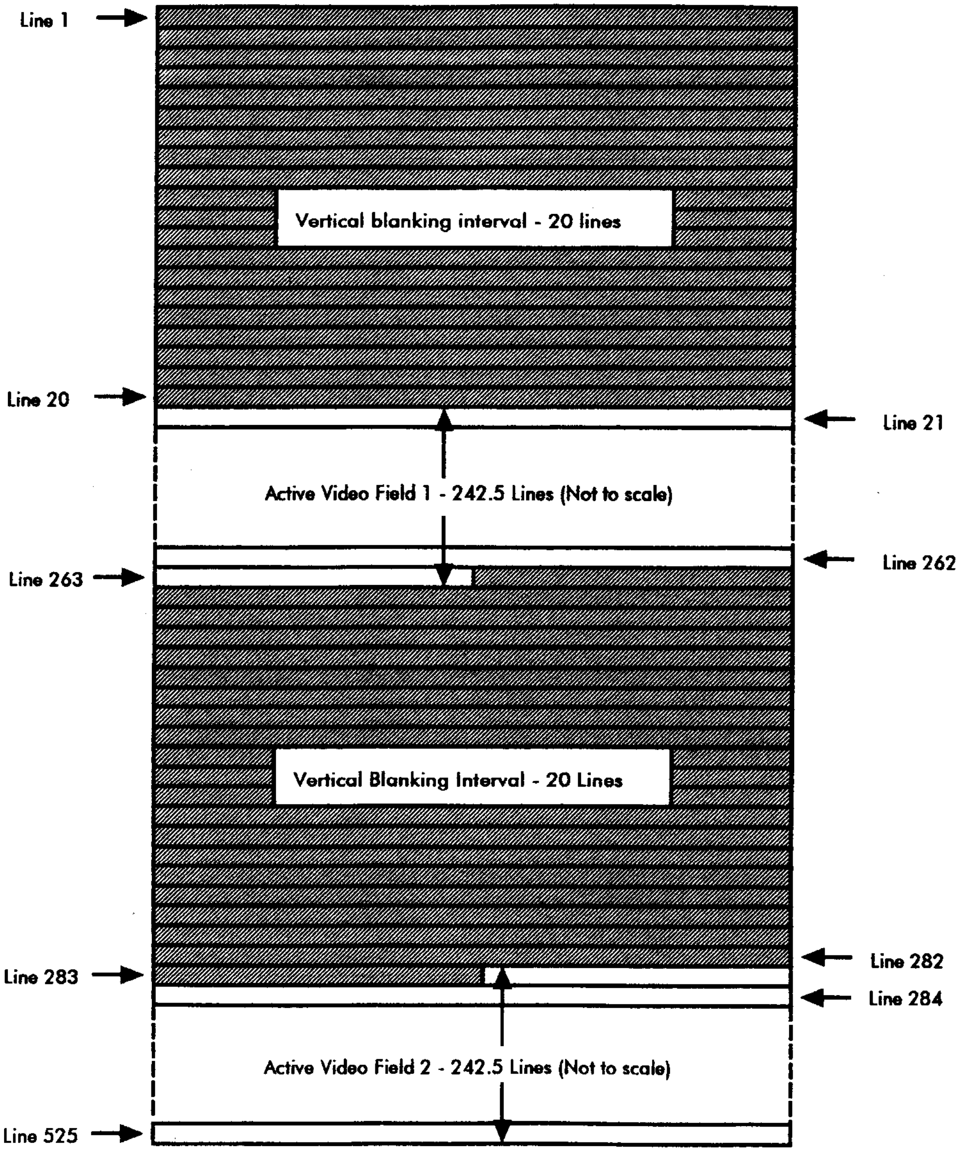

Figure 1.15 Vertical blanking interval details of 525/60 scanning standard.

1.6 The Spectrum of the Video Signal

The frequency components of a picture occupy a wide frequency band; however, the spectrum is not continuous. The spectrum components are spaced at intervals shown in Fig. 1.17, which represents the spectrum of a stationary picture for the 525/60 scanning standard. There is a strong component at the horizon-

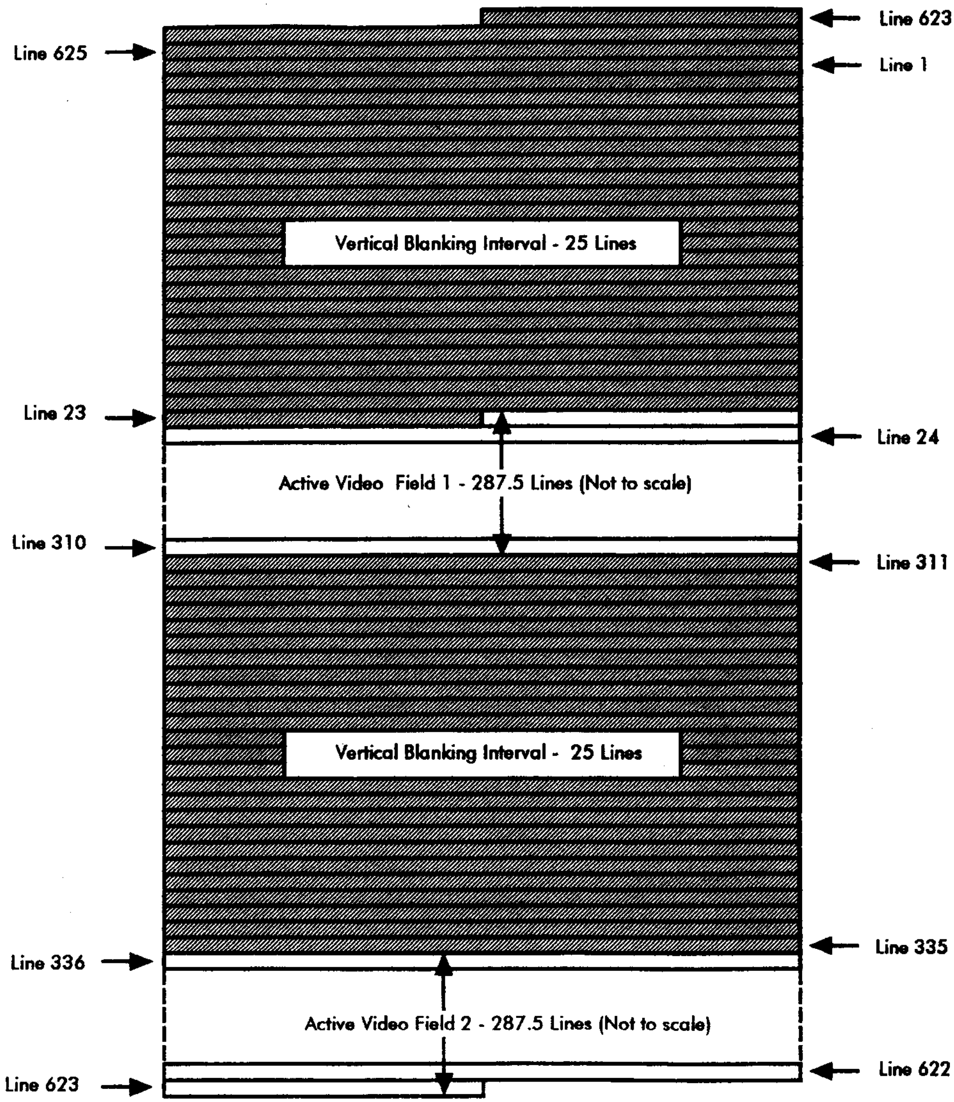

Figure 1.16 Vertical blanking interval details of 625/50 scanning standard.

tal scanning frequency f_H and components at multiples of this frequency. There is also a strong component at the vertical scanning (field repetition) frequency f_V and components at multiples of this frequency. The 625/50 scanning standard has a similar spectrum except that $f_H = 15{,}625$ Hz and $f_V = 50$ Hz. If there are details that change from frame to frame, there is, in addition, a component at the frame frequency (30 or 25 Hz). The components at the horizontal scanning frequency and its multiples have sidebands at the frame and field frequencies and multiples thereof. Finally, there is a strong zero-frequency

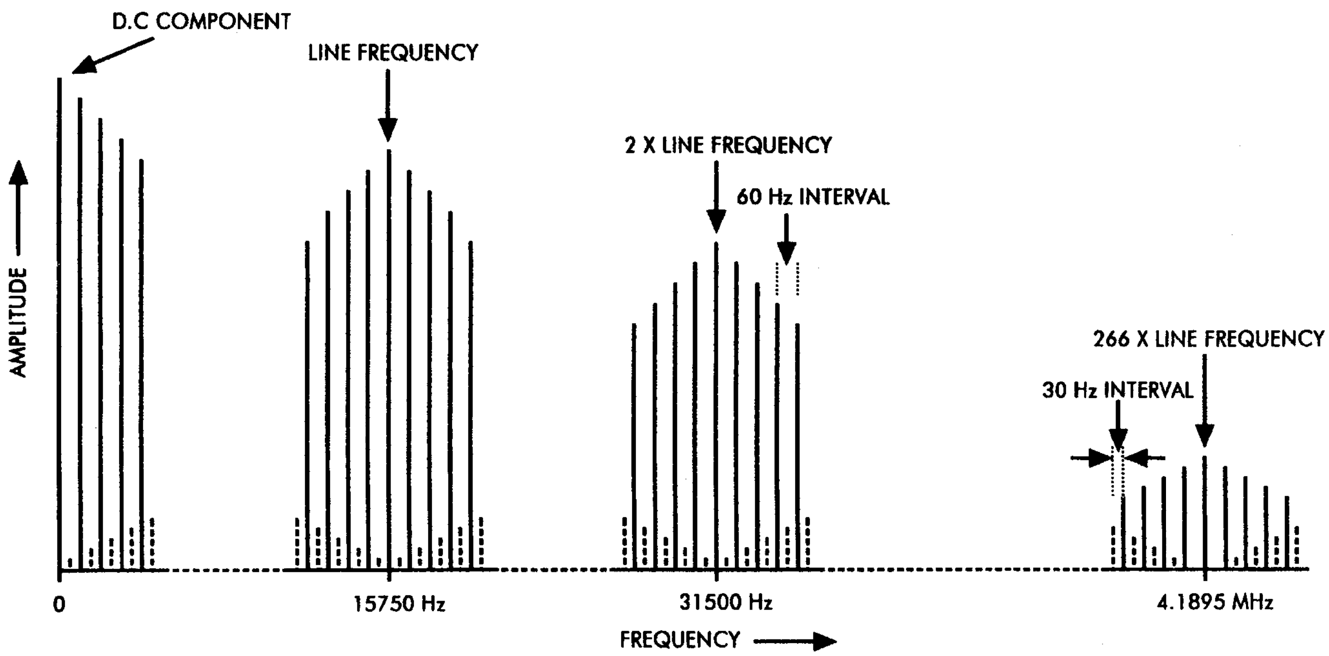

Figure 1.17 Simplified 525/60 monochrome video spectrum of a stationary scene.

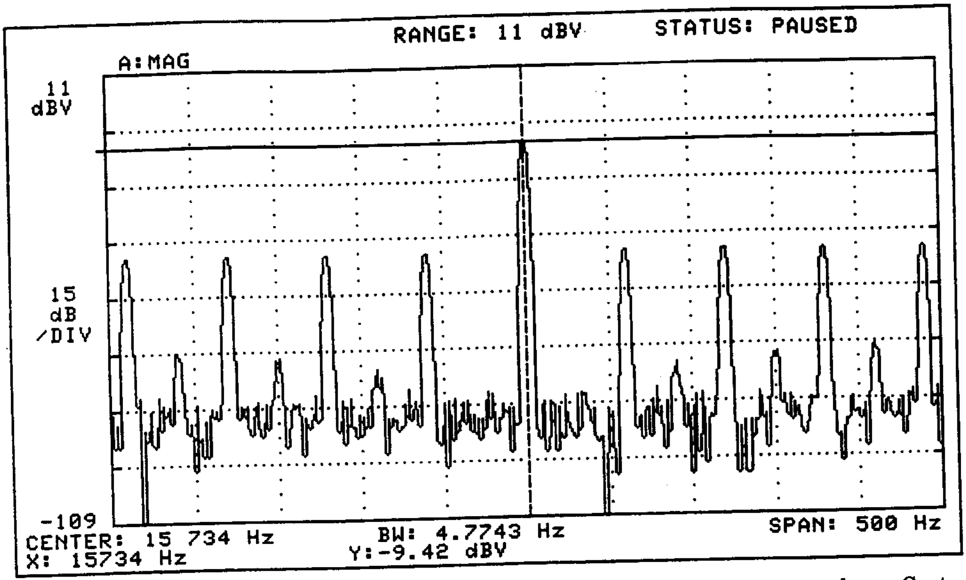

Figure 1.18 Details of 525/60 scanning system spectrum as seen on a spectrum analyzer. Center frequency, 15734 Hz; horizontal resolution, 50 Hz/division. Note sideband components at 59.94 Hz and 29.97 Hz intervals.

component representing the average picture brightness. If the picture contains movement, the spectrum becomes more complex because of the addition of further components. Theoretically, the spectrum extends to infinity but is bandlimited to the maximum video modulating frequency specified by the transmission standard in effect. Figure 1.18 shows a detailed spectrum analyzer display of spectral components around f_H = 15,734.25 Hz, the horizontal scanning frequency of the 525/60 NTSC color television system. Note the sideband components spaced at multiples of 59.94 Hz (the field repetition frequency) and 29.97 Hz (the frame repetition frequency).

1.7 Transmission Standards and Constraints

Transmission standards describe the characteristics of the signals radiated by television transmitters.

1.7.1 Video carrier modulation

Video transmitters are modulated in amplitude. All countries, with the exception of France, use negative modulation. In a negative-modulation system, increasing brightness in the transmitted picture produces a decrease in the modulation envelope amplitude. In a positive-modulation system, increasing the brightness in the transmitted picture produces an increase in the modulation envelope amplitude.

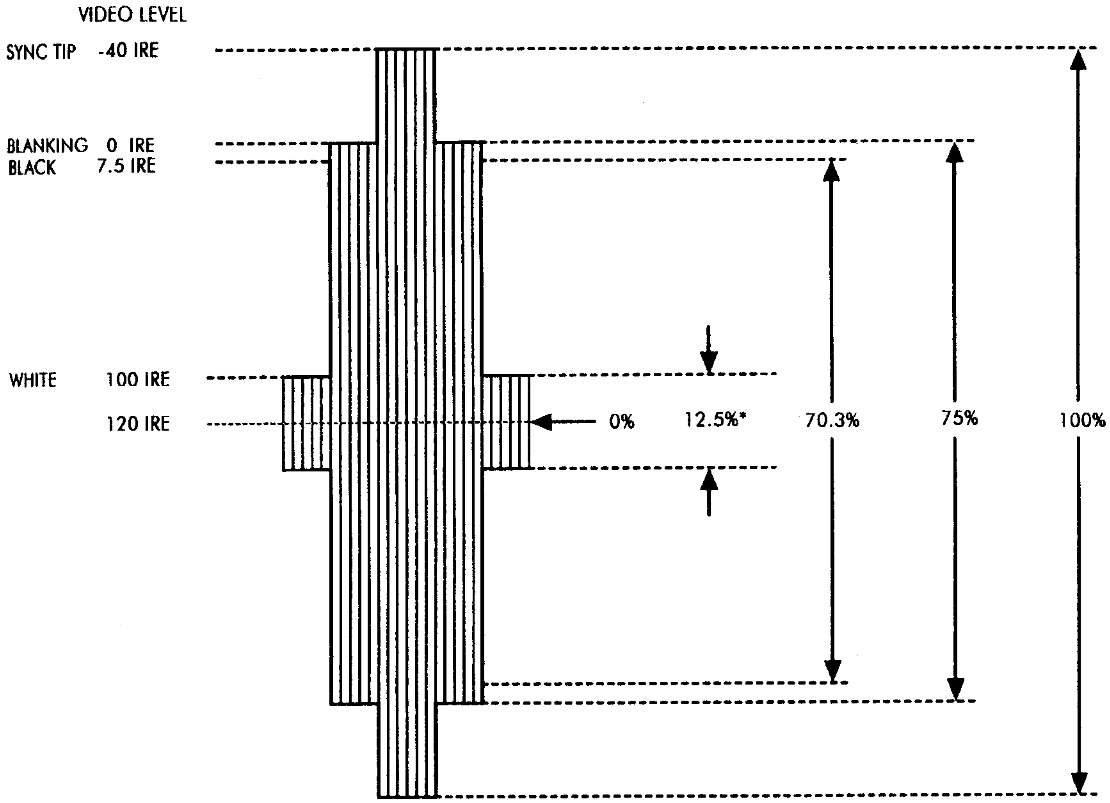

Figure 1.19 Significant video signal levels shown as a percentage of carrier amplitude in negative amplitude modulated systems.

The picture modulation envelope has three reference levels. These are

- Peak white level
- Blanking (black) level
- Sync level

When the black level differs from the blanking level, as in North America, a fourth reference level, the black level, is added. Figure 1.19 shows the reference levels for the negative amplitude modulation NTSC system as broadcast in North America. Other countries have slightly different standards.

1.7.2 Audio carrier modulation

All countries transmit the accompanying sound by modulating a separate carrier, situated at the high-frequency end of the television channel. All countries, with the exception of France (standard L), use frequency modulation of the audio carrier. The use of frequency modulation permits the use of the advantageous "intercarrier" audio reception method.

The peak-to-peak carrier deviation is ±25 kHz in North America (CCIR M) and ±50 kHz in most other standards (CCIR B, G, I, and K). These values are smaller than the value of ±75 kHz used in FM sound broadcasting. The relatively low energy associated with the high-frequency components of speech and music makes it appropriate to preemphasize the amplitude of the high frequencies prior to modulation at the transmitter and to deemphasize them correspondingly subsequent to demodulation at the receiver. In North America (CCIR M) the preemphasis time constant is 75 μs and in most other standards (CCIR B, G, I, and K) it is 50 μs.

1.7.3 Channel bandwidth and structure

Given a specific video baseband bandwidth, for example, 4.2 MHz in the 525/60 scanning standard, the conventional amplitude modulation of the video carrier results in upper and lower sidebands containing identical information. The resulting transmitted bandwidth is twice the baseband bandwidth. The 525/60 scanning standard would require an 8.4-MHz transmitted video bandwidth for the video information. The 625/50 scanning standard would require at least 10 MHz of transmitted bandwidth for the video information. To these figures has to be added the spectrum required by the audio carrier and its sidebands.

Spectrum conservation and frequency allocation concerns have led various countries to specify a reduced television transmission channel bandwidth. In 525/60 countries the specified transmission channel bandwidth is 6 MHz. In 625/50 countries the specified transmission channel bandwidth is 7 or 8 MHz. The method used to accommodate the required baseband video bandwidth in a reduced-bandwidth transmission channel is to transmit the upper sideband with full bandwidth and the lower sideband with reduced bandwidth. A portion of the lower sideband, corresponding to the higher video frequencies, is eliminated by a filter at the transmitter. The method is called *vestigial lower sideband transmission.* Various transmission standards have different vestigial sideband bandwidths.

Figure 1.20 shows in detail the channel structure corresponding to the CCIR M standard as used in North America. The channel bandwidth is 6 MHz. The video carrier is situated 1.25 MHz above the lower transmission channel edge. A full upper sideband of 4.2 MHz and a reduced (vestigial) lower sideband of 0.75 MHz are accommodated. In addition, a frequency-modulated audio carrier, with a center frequency 4.5 MHz above the video carrier, is also transmitted in the same channel.

Because of the vestigial lower sideband transmission, detected video signals whose frequencies are below 0.75 MHz have an amplitude twice that of signals whose frequencies lie between 0.75 and 4.2 MHz. The receiver compensates for this effect with a selectivity curve as shown in Fig. 1.21.

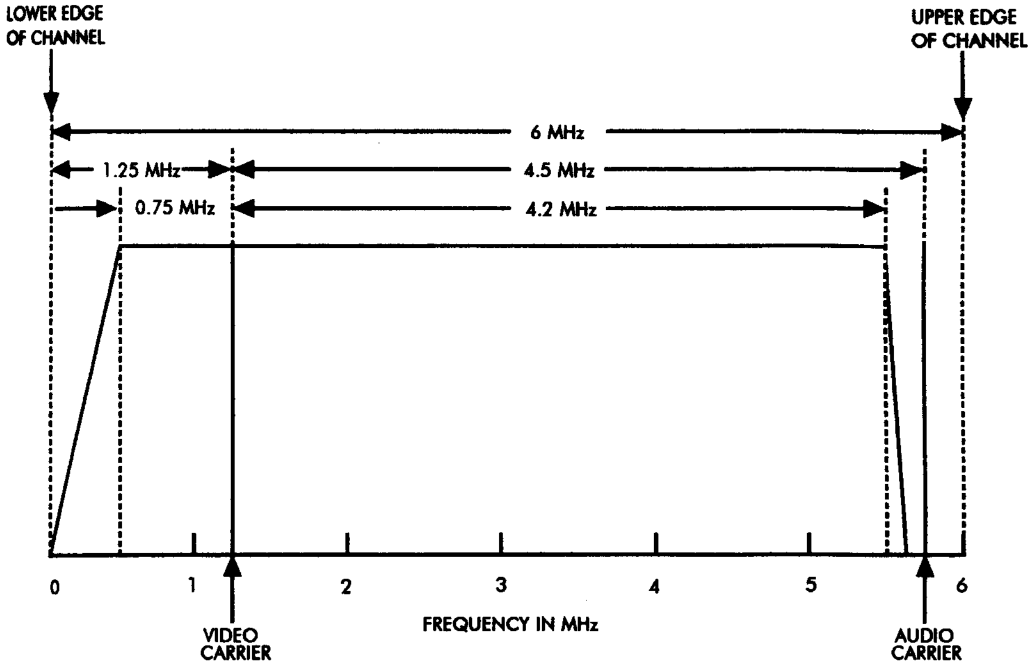

Figure 1.20 CCIR M Vestigial sideband characteristics and channel occupancy.

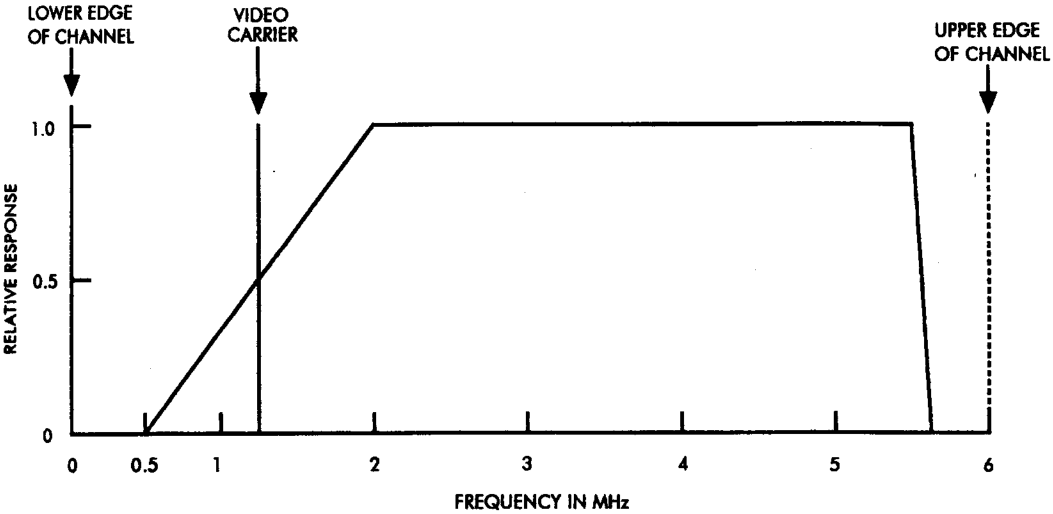

Figure 1.21 CCIR M Receiver selectivity characteristics to compensate for vestigial sideband effects.

Figure 1.22 shows the channel structure of several transmission standards. Note that the channel bandwidth, the vestigial lower sideband bandwidth, as well as the spacing between the video carrier and the audio carrier vary from system to system. Standards B, G, and K have a nominal vestigial sideband of 0.75 MHz whose significant spectral components are completely contained in the channel bandwidth. Systems I and L have a nominal vestigial sideband of 1.25 MHz and some significant spectral components extend below the lower channel limit. Various transmission standards for 625/50 signals have different spacings between the video and audio carriers. Standards B and G specify 5.5-MHz spacing, standard I specifies 6 MHz and standards K and L specify 6.5 MHz. Figure 1.22 also details the accommodation of the chrominance subcarrier and its sidebands in the transmitted channel.

1.7.4 Transmission constraints

The transmission of the video and audio information requires undistorted handling of the video and audio signals. Some of these concerns will be discussed in Chap. 2. One of the often misunderstood and neglected problems has to do with the modulation depth of the video transmitter. As shown in Fig. 1.19, the peak white signal level, 100 IRE in North America, results in a 12.5% modulation of the video carrier. The video carrier is completely cancelled at a video signal level of 120 IRE, resulting in a safety margin of 20 IRE. In color transmission, the peak positive signal levels could reach up to 131 IRE and create additional problems, which will be discussed in Chap. 2.

The overmodulation of the video transmitter has an obvious effect on the fidelity of the video signal. It also has a not-so-obvious and less-understood effect on the reception of the accompanying sound. This is because of the peculiar manner in which television receivers process and demodulate the audio and video carriers. Normally, since video and audio information is handled by two separate carriers, it would seem logical that two separate receivers be required to recover the original information. Television receivers, however, operate in a different manner, as shown in Fig. 1.23.

Because of the fact that the video carrier is amplitude-modulated and the audio carrier is frequency-modulated, it is possible to use the so-called intercarrier audio reception method. Here, the video and audio carriers are tuned, frequency-converted, and amplified by a single tuner. The standardized converted carriers are respectively 45.75 MHz (video) and 41.25 MHz (audio) in North America. The intermediate frequency amplifier has the adequate bandwidth and spectrum-shaping characteristic required to carry both converted carriers and their sidebands, as well as to correct for the vestigial sideband effects. Two detectors are used to recover the original information. The video detector recovers the original video information but also generates a 4.5-MHz spurious signal resulting from the interference between the audio and video carriers. This spurious signal, superimposed on the recovered video signal, is amplitude-modulated by the video signal and frequency-modulated by the audio signal. It is removed by a 4.5-MHz notch filter before further video processing.

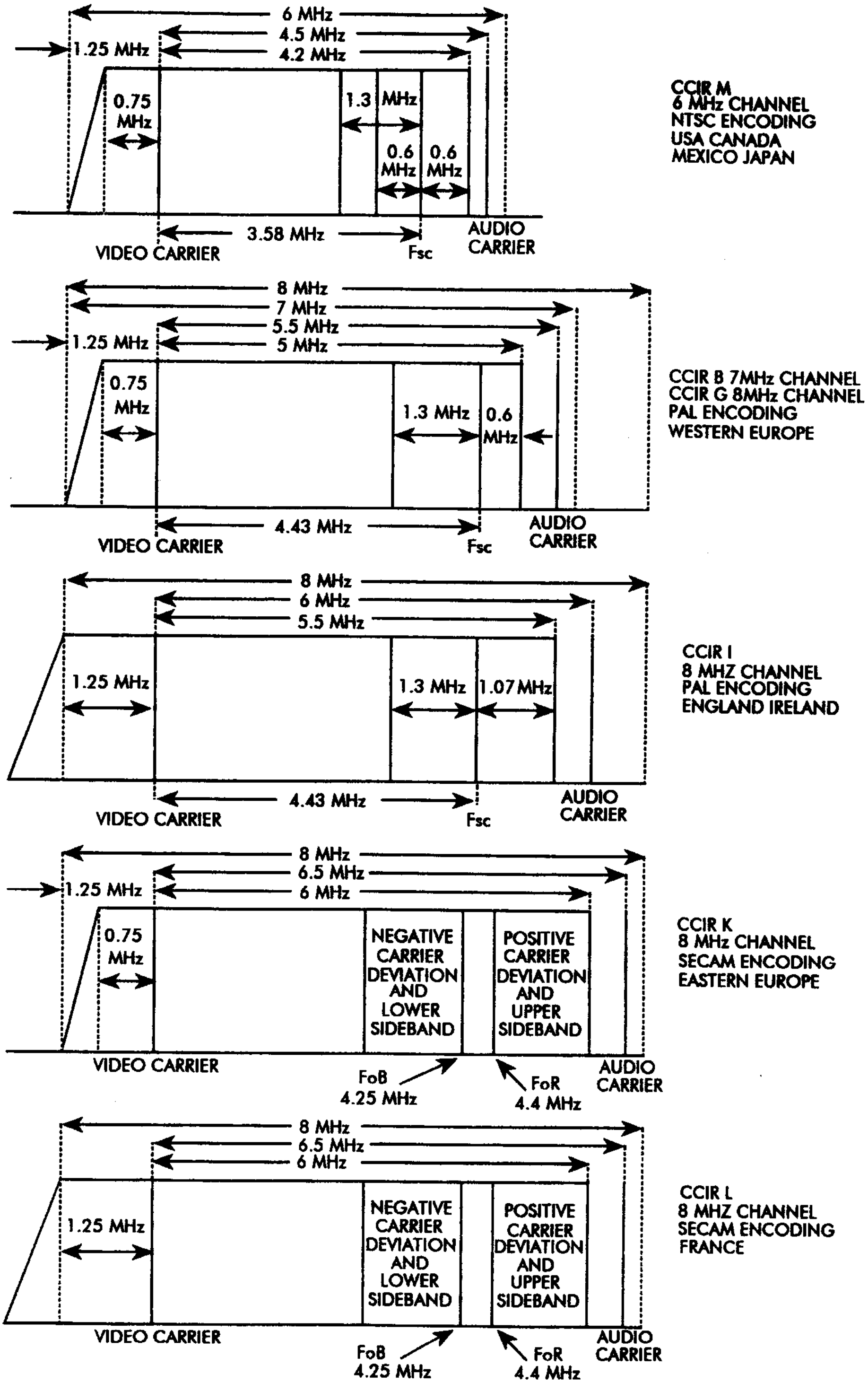

Figure 1.22 Transmission channel occupancy of several CCIR television systems.

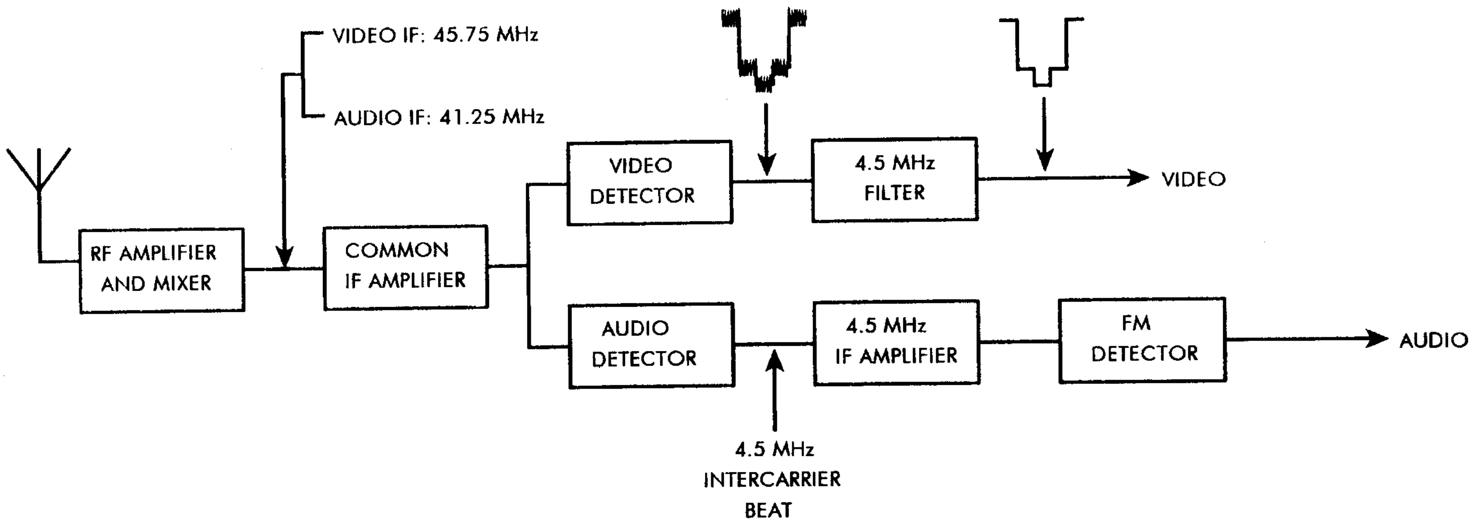

Figure 1.23 Simplified block diagram of CCIR M intercarrier receiver.

The audio detector recovers the same information as the video detector. The spurious 4.5-MHz signal is filtered by a bandpass filter to remove the video signal component and treated as a frequency-modulated carrier. It is amplified by an intermediate frequency amplifier with a center frequency of 4.5 MHz and signal amplitude variations are removed by a limiter. The resulting constant-amplitude FM signal feeds a standard FM detector to recover the original audio information. This reception method works very well with all systems employing frequency modulation of the audio carrier. Problems occur when the video transmitter is overmodulated, resulting in clipping of the video carrier. Under these extreme circumstances the derived 4.5-MHz audio carrier is periodically canceled at video horizontal and vertical scanning rates. This results in the so-called intercarrier buzz effect. This audio reception problem can be eliminated by carefully monitoring and adjusting the video signal levels feeding the transmitter to avoid transmitter overmodulation.