CHAPTER 12
TV Fundamentals

12.1 The pixel:

We have seen before that audio broadcasting is based on the use of an audio signal as a signal which modulates a carrier. In the receiver, superheterodyne principle is used. In TV, the principle is basically the same, except that in TV we are dealing with two types of information, audio and video. Nevertheless, such information has to be converted into electrical signals which would modulate an AC carrier, much the same way as in audio broadcasting. Let us focus for the moment, on the video signal. The basic principle in video signal transmission is that the image to be broadcast - which is formed in its integrity - has to be dissected into a large number of picture elements (pixels) in the form of consecutive rows. Each row (line) is formed of a large number of pixels (e.g. 540 pixels/line). A frame which forms the integral image is composed of 525 lines (USA) or 625 lines (Europe).

Each of these pixels contains part of the information composing the entire picture/frame. There are 30 frames /second (USA) or 25 frames/second (Europe). A TV camera has two jobs; first to form an instantaneous image of the scene, and secondly, to send forth the information in the scene pixel by pixel. In other words, the image pieces are transmitted sequentially (or in series), pixel by pixel. The pixel stream forms the TV transmission. In the receiver, this stream is reassembled to form the image. Again, this is done pixel by pixel. The eye integrates the scene, and the continuity and integrity of the image is actually achieved in the brain. Thus, several systems lie at the heart of TV perception. One deals with an integrated scene at the transmitter, which transforms it into pixels, which are in turn transmitted as electrical bursts of various heights, depending on the illumination. This is called TV camera. The output of the camera modulates an RF carrier and composes an electrical train of pixel streams. The second system is the TV receiver, which transforms this pixel stream into an image by driving an electron beam across a CRT screen, forming the image, pixel by pixel, as photons are emitted from the screen. The amount of photons emitted is proportional to the intensity of the electron beam, which is - in turn - proportional to the illumination at the corresponding spot of the image in the TV camera.

Thus, the scene is reconstructed in accordance with the illumination distribution of the scene. The third system is the eye, which is but another camera. It recollects the photons emitted from the CRT onto the retina, where it transforms these photons into electric pulses, and transmits them in the optic nerve to the brain. In the brain, the sensation of vision is achieved, and the reconstruction of the integrated image is accomplished. The overall TV perception block diagram is conceptually shown in Fig. 12.1.

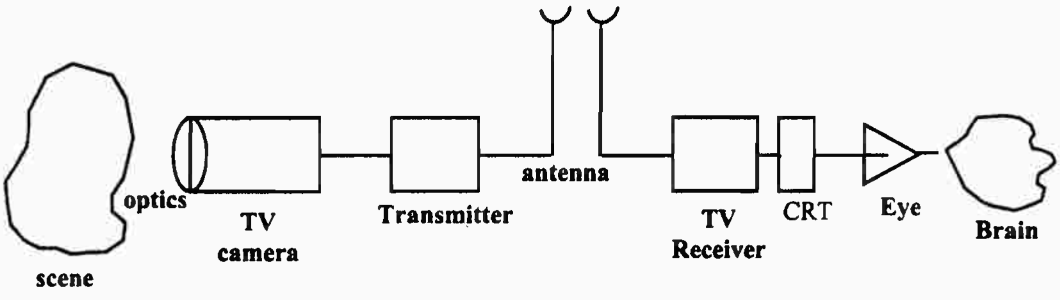


Fig. 12.1 A conceptual block diagram for an overall system for TV perception

12.2 Scanning and Synchronization:

The TV camera forms an image of the scene through appropriate optics into a screen. Each pixel of the image is then selected - one at a time - by a selection mechanism. This could be - for example - in the form of an electron beam, which reads out the information in the pixel, in proportion to the original illumination at the pixel site in the TV camera screen. It is this information which is modulated onto a carrier and is transmitted. In the receiver, the electrical signals are demodulated and passed onto a picture tube (CRT). An electron beam in this CRT is modulated by the demodulated pixel information. When this e-beam hits the screen at the CRT, it emits photons in proportion to the intensity of the e-beam, which is in turn proportional to the intensity of the illumination at the corresponding site at the TV camera. Thus, an image of the original scene is reproduced, as if the e-beam in the receiver is painting the image of the initial scene (Fig. 12.2). It must be noted, however, that the e-beam at the receiver's CRT must be synchronized with the e-beam at the TV camera, otherwise, a major distortion in the image would occur. This synchronism is ensured through transmitting a synchronizing pulse at the end of each horizontal line. It is called horizontal sync pulse. This sync pulse regulates the horizontal sweep oscillator which generates a sawtooth waveform in the receiver, and keeps it in synchronism with the horizontal sweep oscillator in the TV camera. This sweep oscillator is responsible for driving the beam across a line, and bringing it back to the beginning of the screen to trace a new line. In order to be able to shift from one horizontal line to another, a simultaneous shift in the vertical direction must be smoothly generated. This has to be done by yet another sweep oscillator, called vertical sweep oscillator. It generates another sawtooth waveform, which drives the e-beam vertically, and shifts it down the screen. Each of the smooth waveforms (horizontal and vertical) must consist of two parts, one is called "trace" (which sweeps the beam across) and the "retrace or flyback" (which brings the e-beam back quickly to a new beginning).

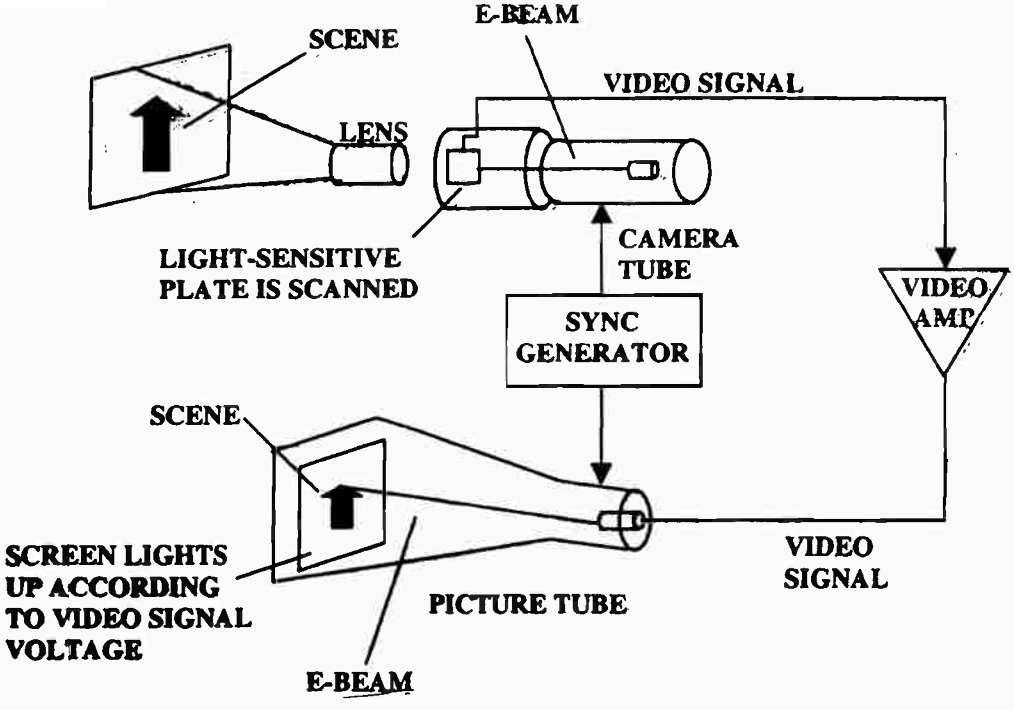


Fig. 12.2 A simplified TV system (camera and receiver)

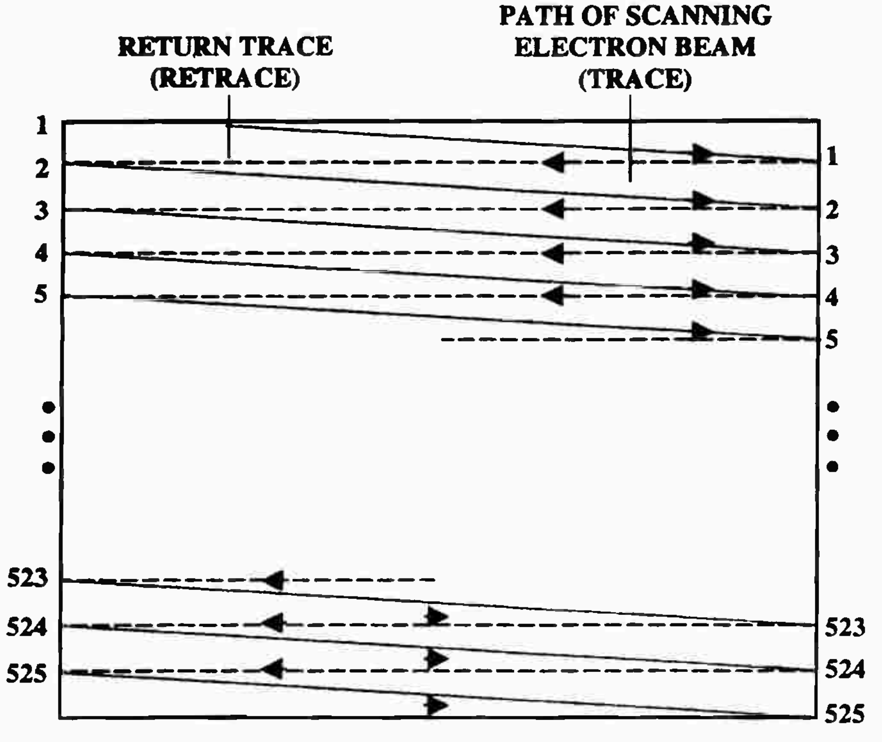


Fig. 12.3 Raster

Because both the horizontal and vertical oscillators are working at the same time, the lines traced by the e-beam are slightly slanted, due to the composite motion of the e-beam under the effects of horizontal and vertical electric or magnetic fields. The sweeping of the e-beam back and forth, and hence, the generation of horizontal lines across the screen is accompanied by a vertical down shift to cover the entire image. This is called scanning raster (Fig. 12.3).

This arrangement is similar to reading a page from left to right, and from top to bottom. It is desirable during the retrace to shut off the e-beam, so that the return line is not visibly drawn on the screen. This is done through blanking pulses. There is a blanking pulse at the end of each horizontal line, during which the e-beam is repositioned to the left, to start a new sweep. There is also a vertical blanking pulse to shut off the e-beam during the vertical retrace.

12.3 Interlacing:

The television must produce a fixed number of rasters or frames per second. This repetition rate involves a trade off. The frame rate has to be high, so that the eye would, ~~see a~~ continuous motion rather than individual pictures. However, the higher the frame rate - or the faster the e-beam - the more difficult it becomes to get sufficient brightness, as the electrons strike the screen. Also increasing the frame rate would require a greater bandwidth. It was, therefore, decided that a frame rate of 30 frames/second (USA) - or 25 frames/second (Europe) - was a good compromise. However, such a frame rate produces a flicker, which is quite disturbing to the eye. It is known that if still pictures follow each other at a rate of roughly 50-60 pictures per second, the eye perceives a continuity of motion in the pictures. This is the basis of motion picture industry, where the frame rate is 24 frames/second. But each frame is projected twice using a shutter. This brings the rate up to 48 pictures/second. This is based on a property of the eye called persistence of vision.

It means that if the eye is exposed to a stimulus, and then the stimulus is removed, the eye can keep the sensation of vision for 1/50 second after the removal of the stimulus. If the picture is projected twice (i.e., at a rate of 1/25 s), then the flicker disappears, and the film appears smoothly continuous. The same principle is used in TV. The frame consists of 525 lines (USA), or 625 lines (Europe). Each frame is divided into two fields; an odd field and an even field. Each field takes 1/60 s (USA), or 1/50 s (Europe); so that each frame takes 1/30 s (USA) and 1/25 s (Europe). Thus, the property of persistence of vision is satisfied, and the flicker is removed. The choice of field frequency 60 Hz (USA) - or 50 Hz (Europe) - coincides with the power frequency. This also reduces the hum effect, which would, otherwise, cause a disturbing interference from the power source on the image.

Starting at point A of Fig. 12.4 with line 1 of the odd field, all odd lines are scanned. At the point D, the odd field reaches the bottom of the screen. The e-beam is quickly retracted to point E at the top of the screen, to start the even field. The even field ends at point F, and the e-beam is quickly retracted to point A, to start a new odd field, and so on.

The odd and even fields blend in the brain, giving the effect of a continuous image. This is called interlacing or interweaving, and this type of scan is called interlaced scanning. Each field consists of 262.5 lines (USA) or 362.5 lines (Europe) from beginning to end.

A horizontal blanking pulse is added as the e-beam, reaches the right end of the screen (point B) (Fig. 12.5). This occurs at 0.84 H and lasts for 0.16 H, where H is the total time allocated for a horizontal line including retrace, H=63.5 μs (USA) or 64 μs (Europe) (Fig. 12.6). For the vertical retrace, it takes time equal to the equivalent of 21 H, to bring the e-beam back to start a new field.

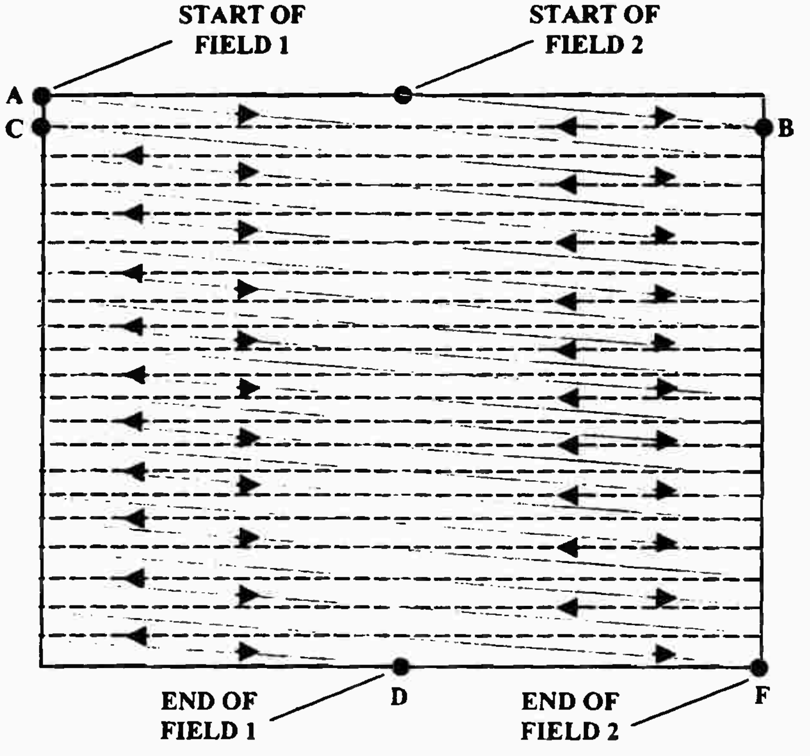


Fig. 12.4 Interlacing

This means that the vertical trace is 241.5 line (USA) or 291.5 (Europe). The vertical field period is V=1/60s (16667 μs) (USA) or 1/50s (20000 μs) (Europe). The blanking out of the TV camera must be synchronized with the blanking out in the TV receiver, by shutting off the e-beam during retrace for both horizontal and vertical sweeps. For this reason, both synchronizing pulses and blanking pulses must be part of the transmitted video signal, hence, called the composite video signal. The actual horizontal retrace takes about 7 μs of the total 10.16 μs blanking time

12.4 The composite Video Signal:

Fig. 12.5 shows the composite monochrome video signal. We note that the highest brightness is taken as 0 with maximum darkness taken as 100%. The horizontal blanking pulse is imposed at the end of each horizontal line. It shuts off the e-beam to prevent it from striking the screen of the TV camera or the TV receiver.

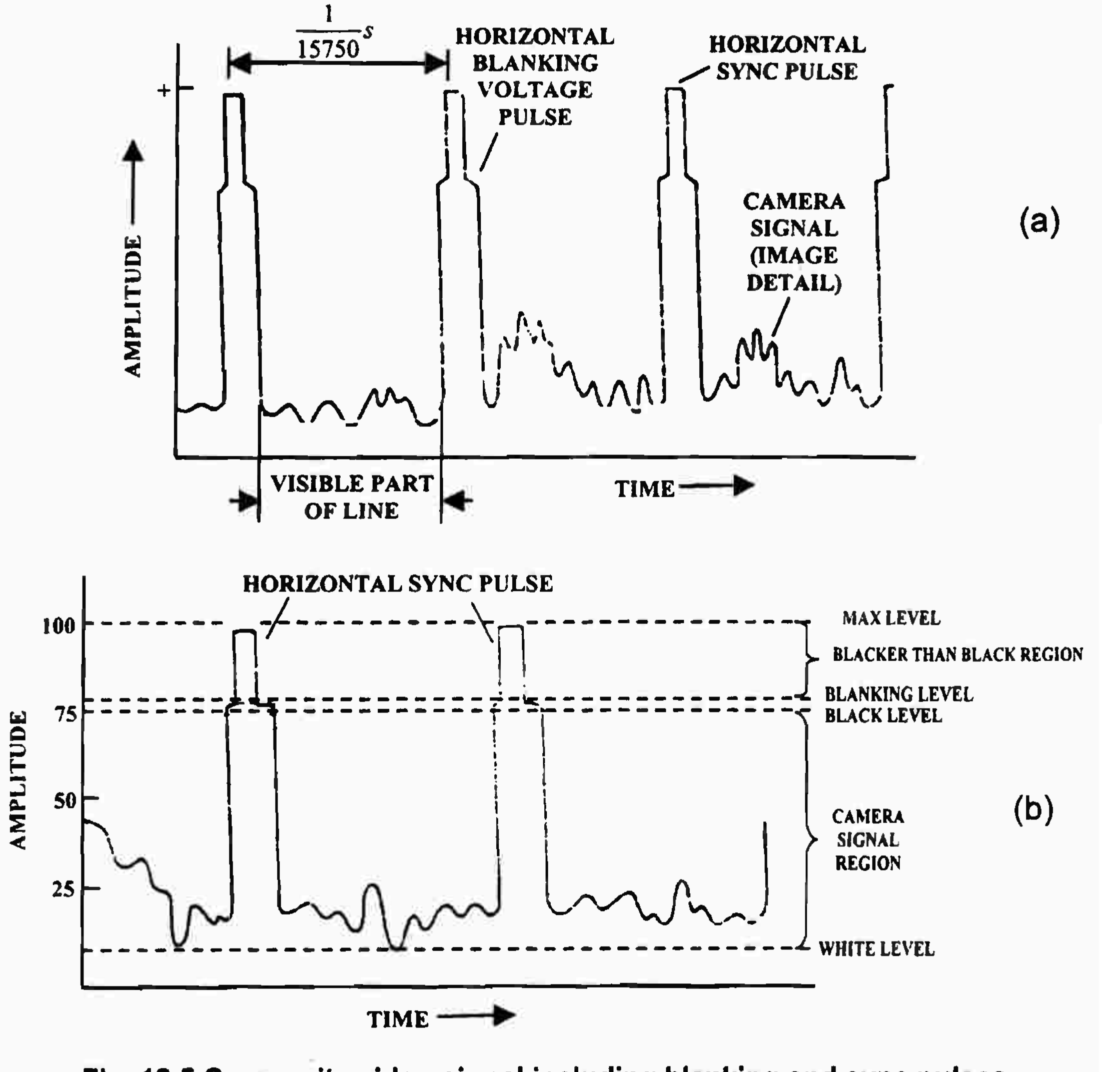
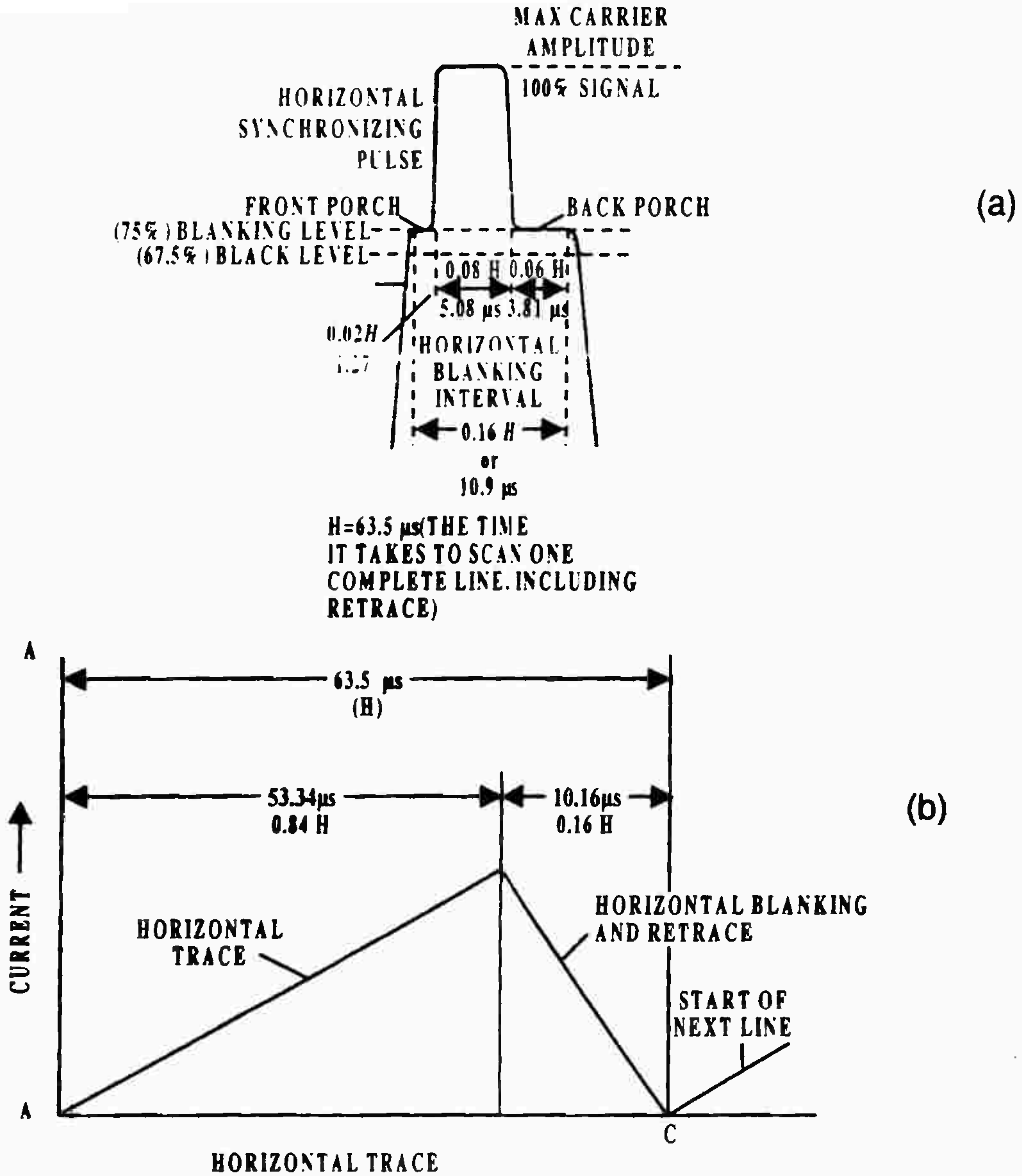


Fig. 12.5 Composite video signal including blanking and sync pulses
a) waveform b) signal levels



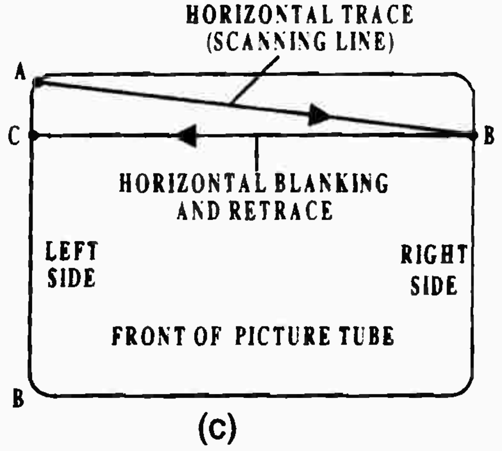


Fig. 12.6 Horizontal retrace
a) pedestal
b) sawtooth waveform
c) horizontal trace and retrace

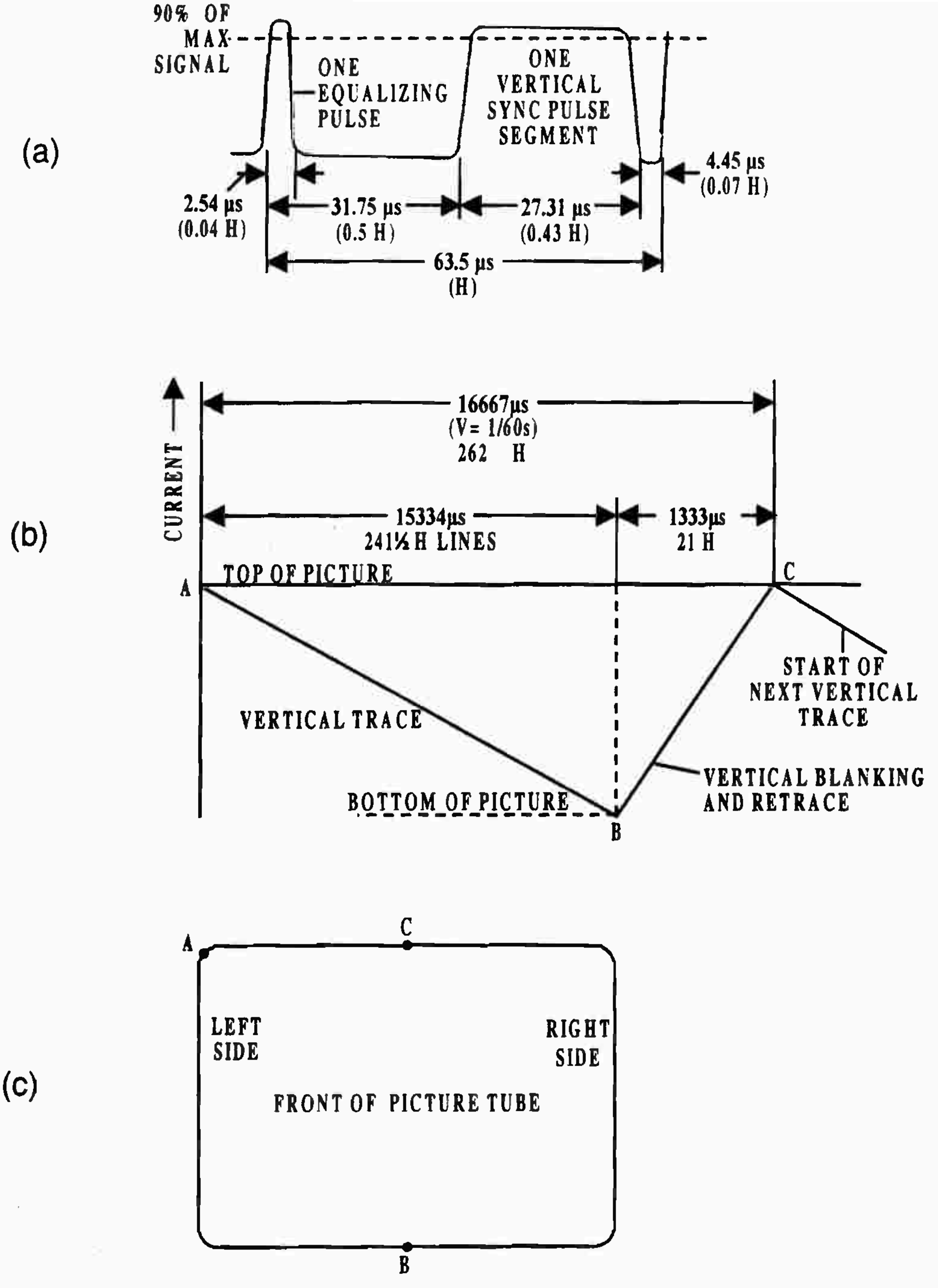


Fig. 12.7 Vertical retrace

a) equalizing pulse

b) sawtooth waveform

c) vertical trace and retrace

A horizontal sync pulse is added during the horizontal blanking pulse. The job of the horizontal sync pulse is to keep the horizontal oscillator - which drives current in the horizontal deflection yoke, causing the horizontal deflection of the e-beam - to fall in synchronism, by forcing it to deflect from the right side of the picture to the left side. The horizontal sync pulse ensures that the horizontal oscillator triggers in time, if it tends to tardy off. Once it triggers, the sync pulse loses influence over the oscillator, until the retrace is complete. The horizontal blanking pulse is over. once the retrace is complete, and a new line is traced, and so on (Fig. 12.6). At the end of the vertical field, it is necessary to bring the e-beam quickly to the top of the image. To blank out the e-beam during the vertical retrace, a vertical blanking pulse is inserted at the end of the field. This blanking pulse is much longer than the horizontal blanking pulse (Fig. 12.7). In fact, the length of this vertical blanking pulse is equivalent to 21 horizontal lines, or 1333 μs (USA), or 1344 μs (Europe). During this time, the horizontal oscillator cannot be left out without horizontal sync pulses. Therefore, even during the vertical retrace, horizontal sync pulses must be sent out. In this way, synchronism of the horizontal oscillator is not lost. Also, it is required to send vertical sync pulses during vertical blanking to make sure that the vertical oscillator will remain in synchronism. To serve this double purpose, namely, to keep the horizontal oscillator and the vertical oscillator synchronized at all times, the horizontal blanking pulse is serrated (or interrupted) into a series of vertical pulses. Fig. 12.8 shows the details of the serrated pulses of the vertical blanking pulse for each of the two fields. The first horizontal line of the odd field and the last horizontal line of the even field must be complete lines, while the last horizontal line of the odd field and the first horizontal line of the even field must be half lines (Fig. 12.9).

From Fig. 12.6, we note that blanking precedes the sync pulse by 0.02 H. This is called front porch. This ensures that at the start of the retrace, the screen is already blanked out. This produces a blank bar at the right hand edge of the screen. Also, we note that the retrace lasts for 0.08 H, while blanking continues for another 0.06 H. This is called back porch. This generates a black bar at the left hand side of the screen. These two bars are usually off limits to the seen picture on the screen. This form of arrangement of the sync pulse on top of the blanking pulse is called the pedestal.

To understand the vertical blanking pulses, consider first the simplified form (Fig. 12.8a). At the bottom of each field, this vertical sync pulse is inserted into the composite signal. This pulse controls the vertical sync oscillator. This pulse is serrated, however, to prevent the horizontal oscillator from slipping out during vertical blanking (Fig. 12.8b). The horizontal sync pulse and the vertical sync pulse can be easily separated. If we subject the serrated pulses to a differentiator waveshaping circuit, we obtain essentially a fresh horizontal sync pulse, without being affected by the wider portions of the serrations. The wider portions of the serrations, however, when inputted to an integrator will produce

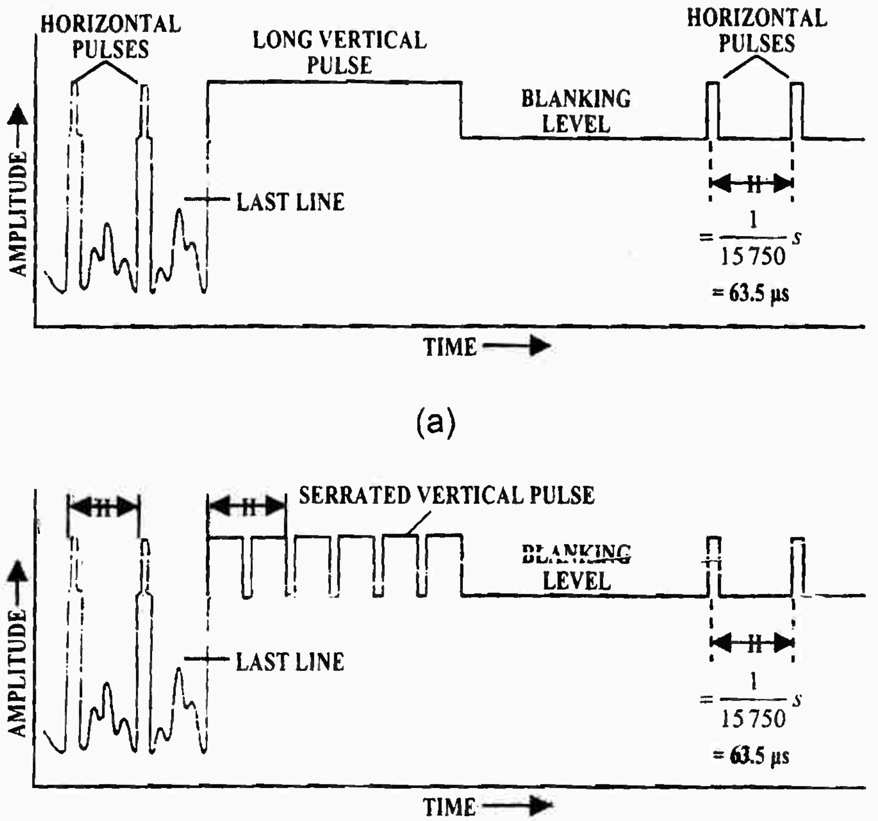


Fig. 12.8 Vertical sync pulse

a) basic form b) serrations

a pulse that may be used as a vertical sync pulse. The serrations will not change much in the integration process. But through serrations, both horizontal and vertical sync pulses may exist together, and may be distinctly separated.

During the vertical retrace, the horizontal oscillator is still working, and the e-beam is being swept back and forth. Thus, as the e-beam is retraced vertically, it does not go straight up but sideways. For a horizontal line of 63.5 μs (USA), the retrace time is equivalent to 21 H (21 invisible horizontal lines). This makes the effective frame (525 H – 42 H = 483 H), and the effective field 262.5 H – 21 H = 241.5 H (USA), or 291.5 H (Europe).

We note from Fig. 12.10, that the vertical sync pulse is inserted when a horizontal line in half completed for the odd field, and once at the end of a complete line for the even field. This condition is shown (Fig. 12.10). There is ½ H difference just before the start of the serrated vertical pulse. It is important to start the blanking before the retrace (as was done in the front porch in the horizontal retrace). This is done by adding 6 equaizing pulses, each at a period of ½ H and 6 equaizing pulses after the end of the 6 serrations. This ensures that the retrace occurs at a fixed time after blanking for both fields equally. The 21 lines are broken into 12 horizontal lines at the top of the raster, inserted after the retrace is over, and 4 H at the bottom of the raster and 5 H for the retrace.

A color burst signal is added to the back porch of all horizontal blanking pulses (Fig. 12.11). The burst consists of 8-11 cycles of 3.58 MHz which is the color subcarrier. This burst has the same phase as the transmitter 3.58 MHz subcarrier. The function of the burst is to ensure that the colors at the receiver picture tube match those at the transmitter. It also indicates to the receiver that a color signal is being transmitted. In the absence of a color program, a color killer circuit deactivates the receiver color circuits, to prevent confetti, which is colorful snow. The burst does not affect the horizontal sync pulse. It occurs during horizontal blanking and retrace, and does not affect the picture.

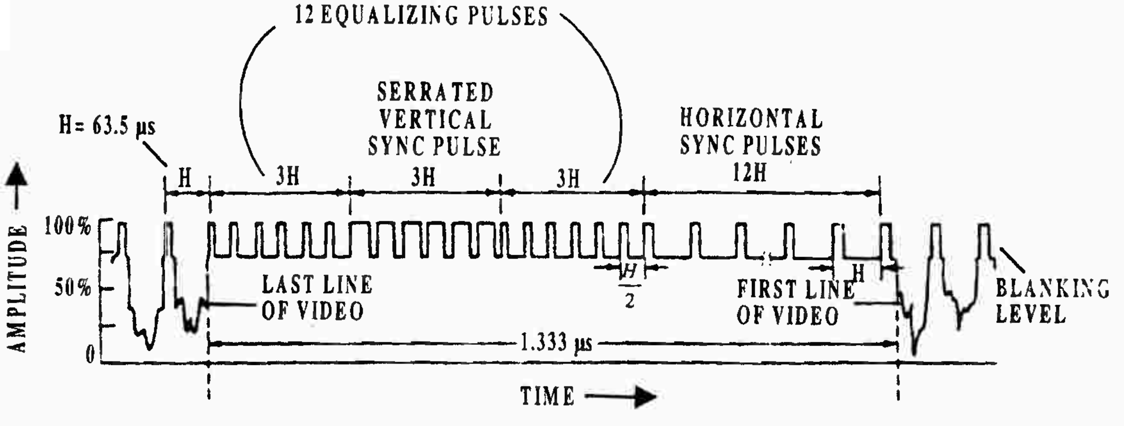
12.5 Bandwidth of the TV signal:

For audio signals, a bandwidth 20 Hz – 20 kHz covers all possible audio frequencies. To understand the requirements on the bandwidth in TV signals, we may consider the following extreme case. Consider an image in the form of a chess board in which illumination changes from 0 to 100% on moving from one pixel to the next pixel. This represents the most extreme case of change of contrast. In fact, this change of contrast is the information itself. An image of a flat desert or a clear sky has very little information. It is the texture or edges - or variety of features - that give intelligence to the image.

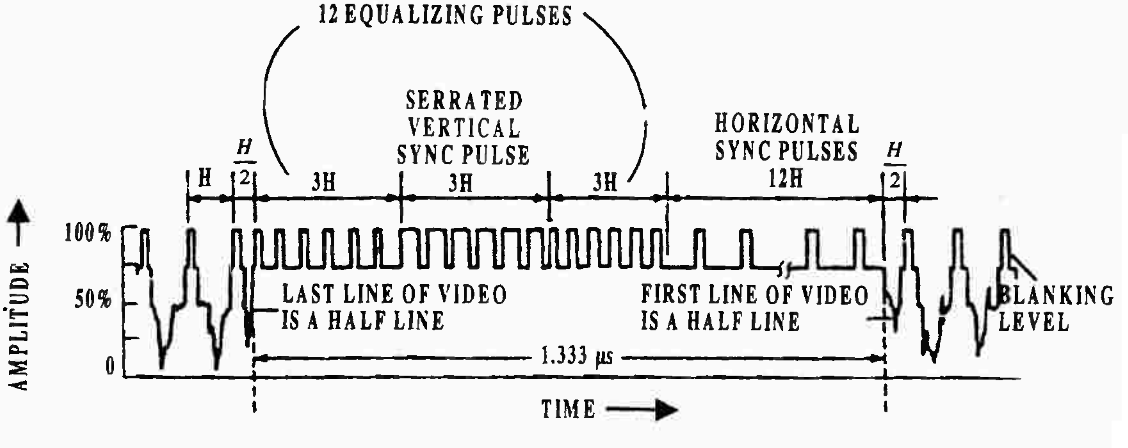
Since information is tied to changes in contrast, it is expected that the information content increases as there is abundant variations in illumination in the image. Since information is related to the bandwidth, we expect that we need an extensive bandwidth in the case of rapidly changing contrast. In the chess board example, we have the worst case of such rapid changes. They occur at the pixel level, i.e., from pixel to pixel, rather than from one region in the image to another.

Assume that we have a scanning line of 20 inch (50.8 cm) and that one picture element is 0.37 inch (0.094 cm) long. Thus, we have 540 horizontal pixels in one line. There are 15750 lines per second (USA). Therefore, for monochrome TV, there are 15750 x 540 = 8505000 elements to be transmitted per second. As we scan the chess board image (Fig. 12.12), the illumination passes from 0 to 100% on two consecutive horizontal pixels, thus, producing a waveform which has a period of 2 pixels. Hence, the frequency of the resulting periodic function - which may be approximated to a sinusoid or at best considered the fundamental component of the Fourier series of such a periodic function - is equal to 270 Hz per line. This leads to a fundamental frequency of

$$270 \times 15750 = \frac{1}{2} \times 8505000 = 4.25 \text{ MHz}$$



(a)



(b)

Fig. 12.9 Video and sync waveforms
a) at the beginning of an odd field
b) at the beginning of an even field

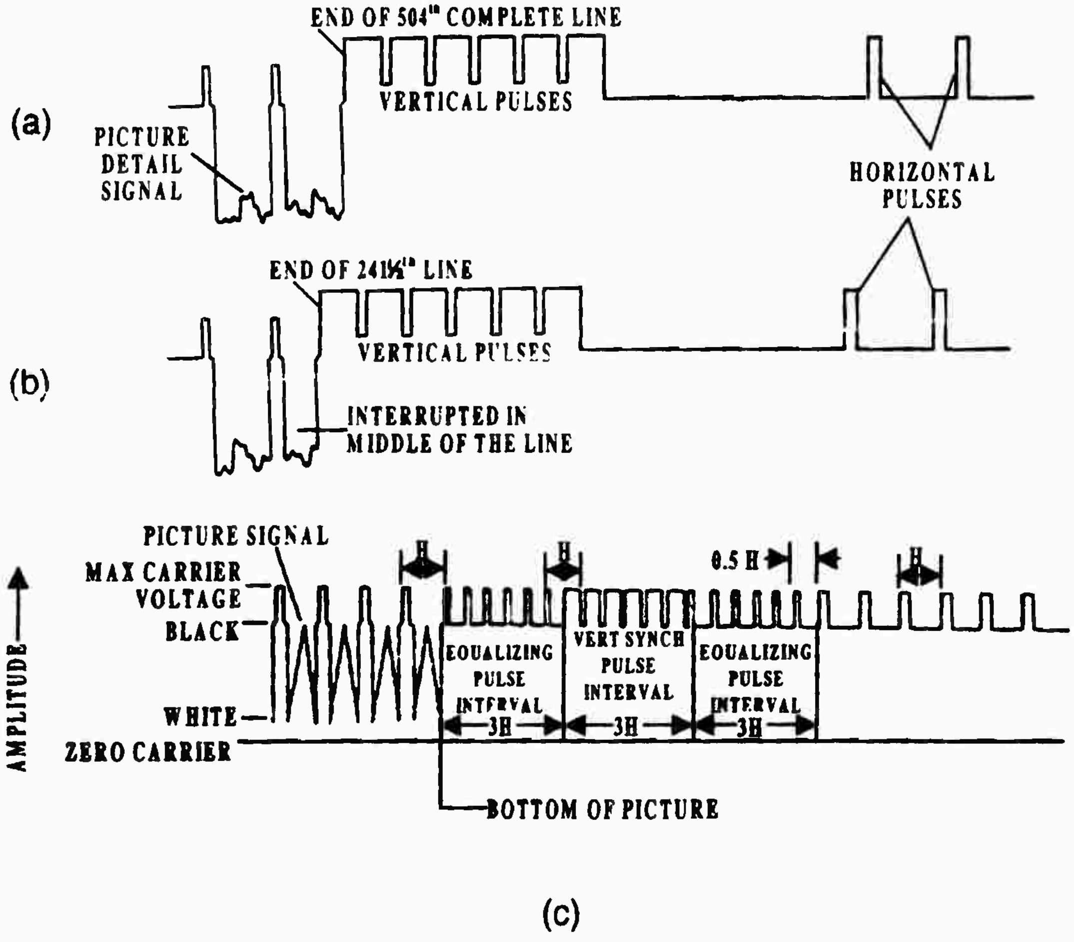


Fig. 12.10 The form of video signal

a) at the end of 504th line without equalizing pulses.
b) at the end of 241.5th line without equalizing pulses.
c) with equalizing pulses.

This is a rough calculation of the bandwidth. Its importance is that it alludes to an important theory in communication, called sampling theory. The sampling rate R_{samp} is the same as the pixel rate or dot rate. What we are stating here is that the minimum bandwidth BW_{min} is half the sampling rate

$$BW \leq \tfrac{1}{2} R_{samp} \qquad (12\text{-}1)a$$

$$BW_{min} = \tfrac{1}{2} R_{samp} \qquad (12\text{-}1)b$$

$$R_{samp} \geq 2\,BW \qquad (12\text{-}2)a$$

$$R_{samp} = 2\,BW_{min} \qquad (12.2)b$$

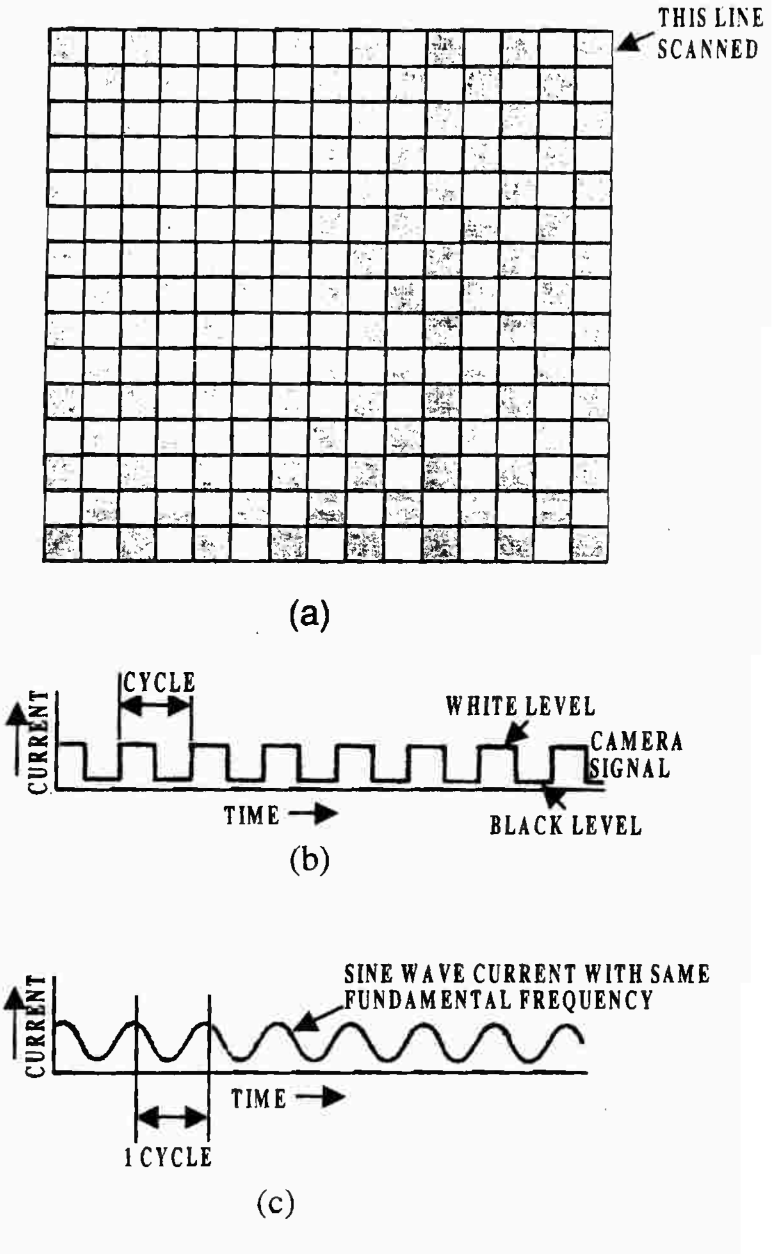


Fig. 12.12 Calculation of BW of a video signal

a) chess board image
b) illumination signal
c) fundamental frequency component of illumination signal

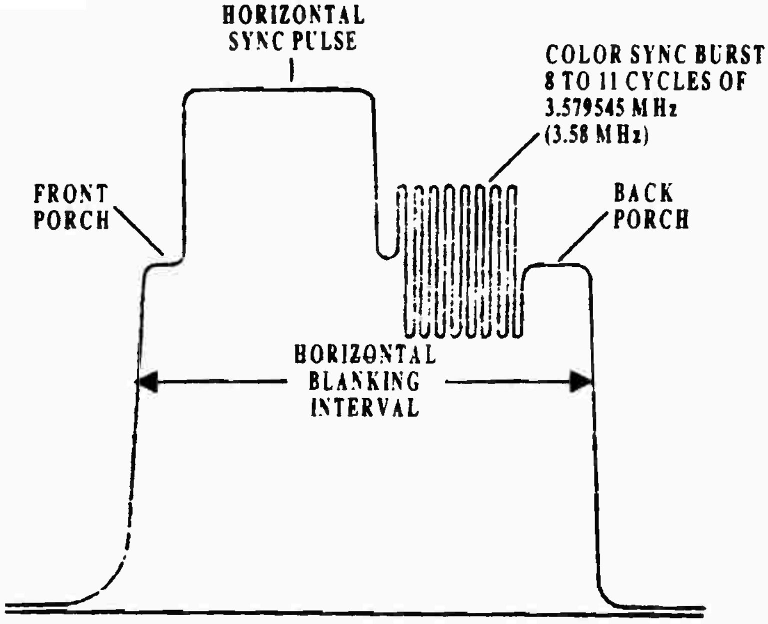


Fig. 12.11 Color burst signal

Thus, in the case of baseband TV signal, we have an extensive bandwidth up to 4.2 MHz (USA). In images other than the chess board example, we may need less bandwidth.

However, we must notice that the calculation of the bandwidth by this simple procedure should not suggest that the frequency spectrum of the TV signal is truly flat up to the BW limit.

Ex. 12.1:
Obtain the frequency spectrum of a TV signal using a simplified model.

Solution:

Both horizontal lines and vertical frames may be regarded as periodic functions. Brightness changes in the vertical direction can be represented by Fourier series:

$$e_v(t) = \sum_{m=o}^{\infty} E_m \cos(m\omega_v t + \theta_m), \qquad (12-3)$$

where ω_h is the angular field frequency.

The horizontal scanning may be represented by

$$e_h(t) = \sum_{n=o}^{\infty} E_n \cos(n\omega_h t + \theta_n), \qquad (12-4)$$

where ω_h is the angular horizontal line frequency. The total signal may be approximated by,

$$e(t) = \sum_{n=o}^{\infty} E_n \cos\left(n\,\omega_h t + \theta_n\right) \sum_{m=o}^{\infty} E_m \cos\left(m\,\omega_v t + \theta_m\right) \qquad (12-5)$$

This shows that the TV signal may be considered as consisting of components of field frequency ω_h and its multiples, and of horizontal frequency ω_h and its multiples, and of frequencies (sidebands) disposed symmetrically about multiples of line frequencies, spaced at field frequency and multiples thereof.

Thus,

$$e(t) = \sum_{n=o}^{\infty} \sum_{m=o}^{\infty} \frac{E_n\,E_m}{2} [\cos\left(n\,\omega_h t - m\,\omega_v t + \theta_n - \theta_m\right)$$

$$+ [\cos\left(n\,\omega_h t + n\,\omega_v t + \theta_n + \theta_m\right)] \qquad (12-6)$$

$$e(t) = \sum_{n=o}^{\infty} \sum_{m=-\infty}^{\infty} \frac{E_n\,E_m}{2} \cos\left(n\,\omega_h t + m\,\omega_v t + \theta_{mn}\right) \qquad (12-7)$$

It is clear from Fig. 12.13 that most of the energy is in the form of relatively narrow bands clustered around multiples of the line scanning frequency, with very little energy between. It is found that around 46% of the entire spectrum is essentially free from useful information, indicating that there is insufficient use of the spectrum. We shall see how we may make better use of the spectrum when we introduce color. We note that the upper frequency limit is the BW, which we have calculated to be 4.2 MHz.

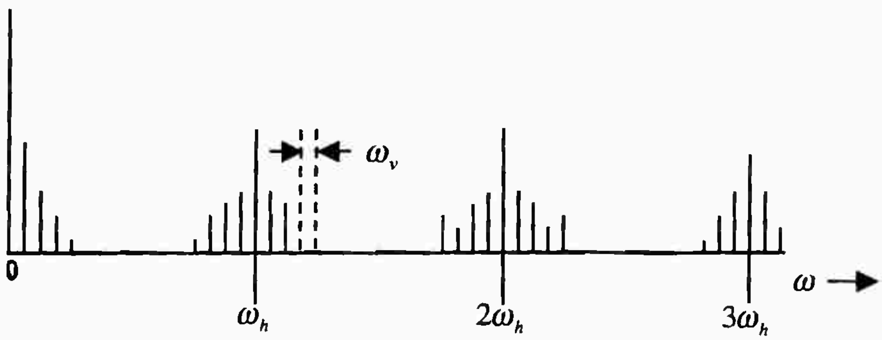


Fig. 12.13 Spectrum of a monochrome video signal

12.6 Negative Transmission:

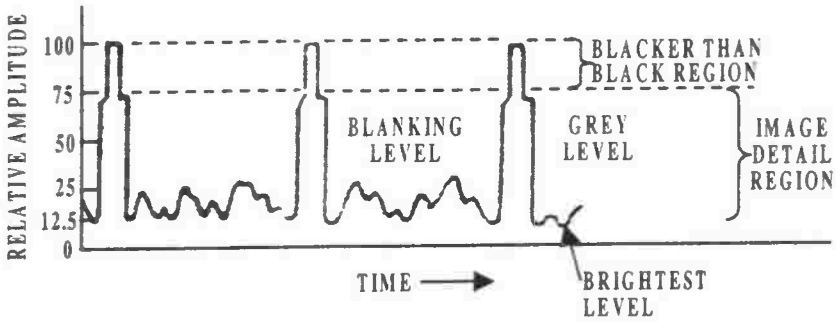
The composite video signal is composed of nearly 75% as information, and 25% as synchronizing signals (Fig. 12.6). This waveform is used as a modulating signal with the peak representing the black level. This is called negative picture phase, or negative picture transmission (Fig. 12.13). There are two advantages for negative picture transmission. First, noise pulses adding onto the carrier will drive the noise modulating amplitude toward the black level, and hence, becomes less conspicuous.

Secondly, there is a saving in power, since the dominant part of signal is the useful signal - which is inclined toward the bright side - is low level. The high power associated with peak level is the black level, which uses only about 25% of transmission time. However, in the receiver this negative picture must be inverted to be a positive picture phase (Fig. 12.15). The frequency spectrum of this composite signal is shown (Fig. 12.16). An audio carrier at 4.5 MHz is used with FM modulation and a 3.58 MHz subcarrier for color as we shall see. However, instead of having an extensive DSB bandwidth of 8.4 MHz, another form of AM modulation is used in which the USB of the picture and part of the LSB is taken. Specifically, the USB of the picture extends to 4.2 MHz, and the LSB to 1.25 MHz. This is called vestigial side-band (VSB) operation. The overall bandwidth is 6 MHz instead of 8.4 MHz. This saves the bandwidth, and is not as difficult to demodulate as SSB.

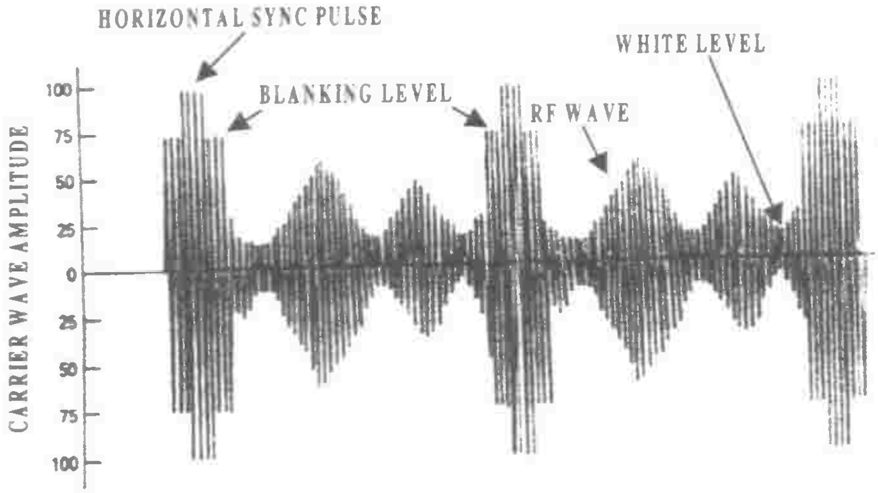
12.7 Picture Tube:

The composite video signal eventually is applied to the picture tube, which is a cathode ray tube (CRT) (Fig. 12.17). The electron gun of the CRT consists of a cathode heated by a filament. This cathode emits electrons toward a positively charged phosphor screen acting as an anode. A negatively charged grid in front of the cathode controls the number of electrons able to continue through to the anode. If this negative voltage (called bias) exceeds a limit (called cut off voltage), no electrons can go through.

However, in normal operation, the control grid controls, but not necessarily cuts off the e-beam. Superimposed on the dc bias, is the composite video signal, as extracted from the AM demodulator in the TV receiver. The video signal modulates the e-beam. Hence, the number of electrons impinging on the screen determines the number of photons emitted by the phosphor screen, hence, illumination at the spot the e-beam strikes the screen, which is in turn proportional to the original illumination level at the corresponding spot in the image of the scene in the TV camera. Hence, the image drawn by the e-beam on the screen is a replica of the original scene.



(a)



(b)

Fig. 12.14 Negative transmission
a) base band b) AM

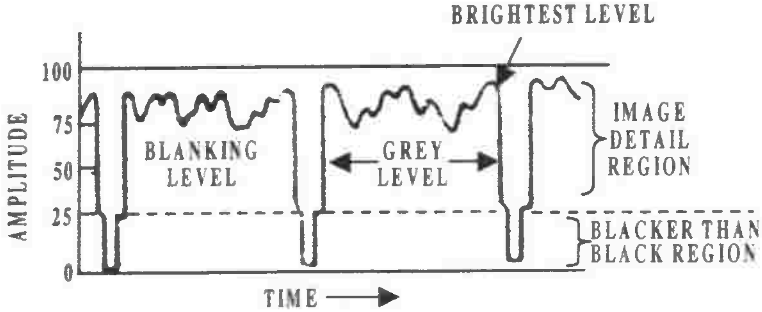


Fig. 12.15 Positive picture phase

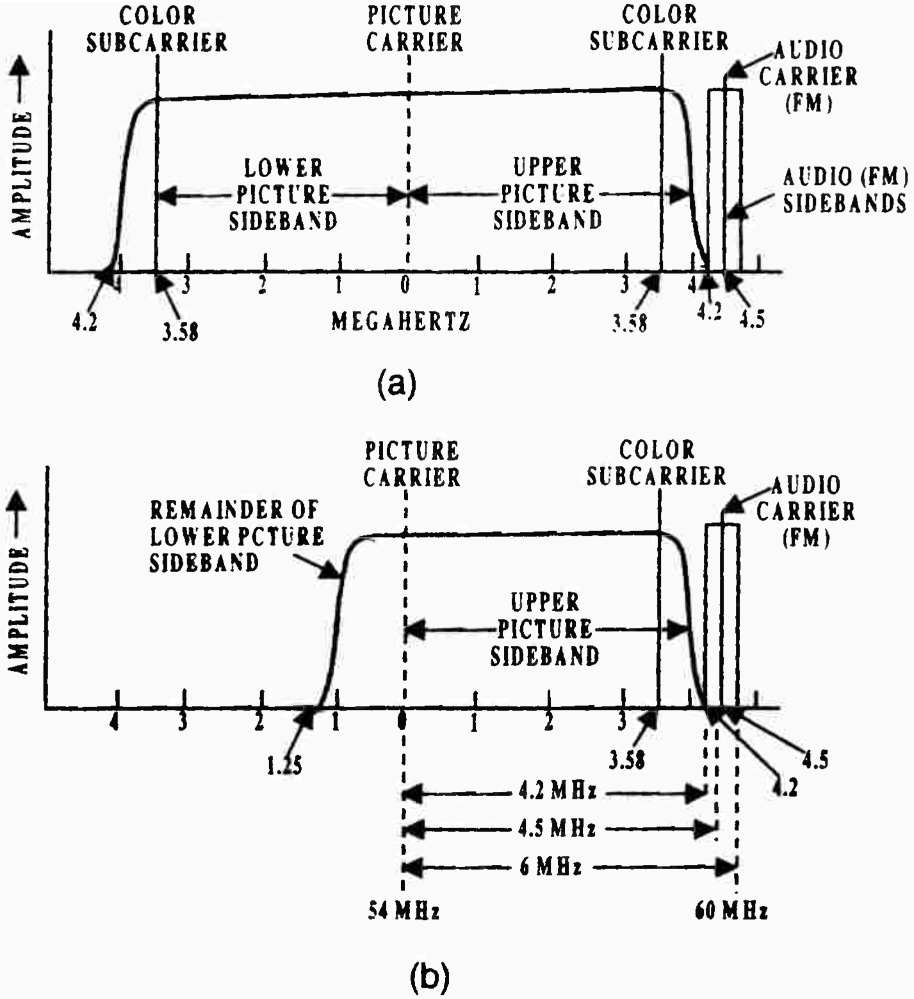


Fig. 12.16 Frequency spectrum of composite TV signal
a) DSB b) VSB

The blanking pulses drive the grids more negatively, and cut off the e-beam. The raster is obtained by either of two ways: electrostatic deflection, caused by electric fields across two sets of parallel plates (horizontal deflection plates and vertical deflection plates), or two sets of magnetic coils (yoke), causing horizontal magnetic deflection and vertical magnetic deflection. In TV magnetic deflection, coils are used, whereas in oscilloscopes, electrostatic deflection plates are used. In TV picture tubes, electromagnetic deflection with electrostatic focus is used. In Fig. 12.8, the control grid is labeled G_1, which is negatively charged. The screen grid G_2 is considered the first anode. It accelerates electrons in the e-beam, because of its positive voltage.

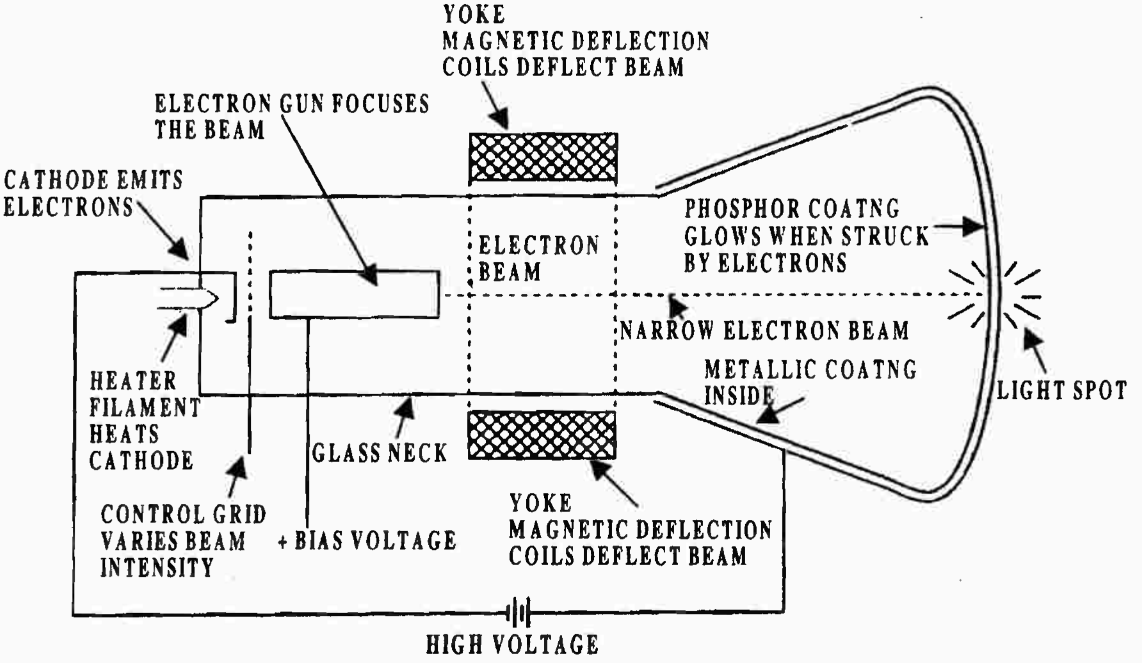


Fig. 12.17 CRT

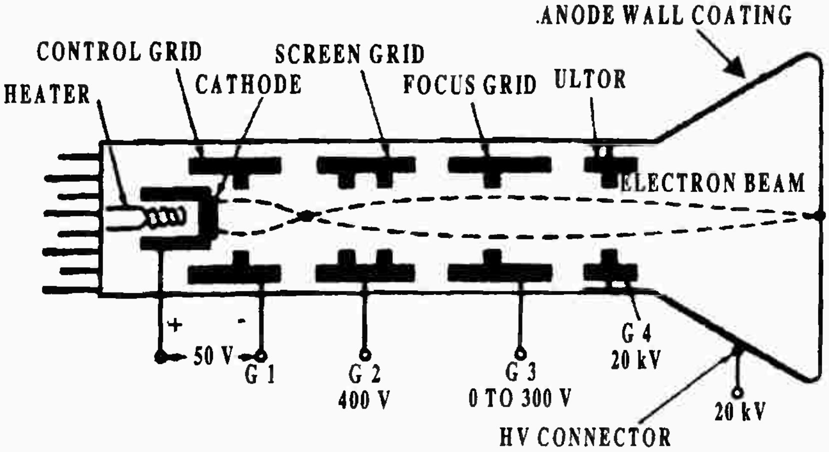


Fig. 12.18 Structure of electron gun with electronic focusing and magnetic deflection

The G_2 cylinder is followed by a focus cylinder G_3, which forms an electrostatic lens with G_2, to force electrons into paths that come to a point at the phosphor screen. Very little current is drawn by G_2, G_3 or G_4, because of the nature of the curved path of the electrons.

Problems:

1- Consider the case of transmission of a still image. The brightness level b is a functionl of x, y

a) Show that $b(x, y)$ may be represented by a 2-D Fourier series.

$$b(x, y) = \sum_{n=-\infty}^{\infty} \sum_{m=-\infty}^{\infty} B_{mn} \exp\left[j2\pi \left(\frac{m\,x}{\alpha} + \frac{n\,y}{\beta} \right) \right]$$

What are α and β ?

b) If the scanning beam moves with velocity components v_x , v_y , show that the video signal $e(t)$ is

$$e(t) = \sum_{n=-\infty}^{\infty} \sum_{m=-\infty}^{\infty} B_{mn} \exp\left[j2\pi \left(\frac{m\,v_x t}{\alpha} + \frac{n\,v_y t}{\beta} \right) \right]$$

What are $\frac{\alpha}{v_x}$ and $\frac{\beta}{v_y}$?

c) Show that

$$e(t) = \sum_{n=-\infty}^{\infty} \sum_{m=-\infty}^{\infty} B_{mn} \exp\left[j2\pi (15750m + 30n)t \right]$$

d) Sketch the spectrum. What do you conclude?

2- Calculate the effective number of lines available for the picture.

3- Describe in detail the vertical blanking pulse, noting that the actual retrace takes 5 lines.

4- Describe in detail the horizontal blanking pulse.

5- Describe in detail the equalizing pulses, and show why they are needed.

6- Suggest a method for separating horizontal and vertical sync pulses.

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