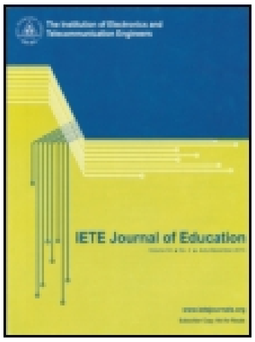

IETE Journal of Education

ISSN: (Print) 0974-7338 (Online) Journal homepage: http://www.tandfonline.com/loi/tije20

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To cite this article: H O Srivastava FIETE (1999) Television Signal and Broadcast Formats, IETE Journal of Education, 40:1-2, 23-37, DOI: 10.1080/09747338.1999.11415692

To link to this article: http://dx.doi.org/10.1080/09747338.1999.11415692

Published online: 26 Mar 2015.

IETE Journal of Education
Vol 40, Nos 1 & 2, January-June 1999, pp 23-37

Television Signal and Broadcast Formats

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Television: Almost every home has one. They are maligned, lauded, criticized and praised, but they are watched. This article describes the evolution of various standards, their characteristics, the video signal theory, scanning process, the colour television signal, transmission bandwidth and video signal measurement techniques. Finally, it discusses the ITU 601 standard.

TELEVISION is regarded by some as Man's greatest invention, possibly more life sustaining than fire and certainly more entertaining than the wheel. In its early days, it was regarded by many as the Anti-Christ; and it began with the transmission of the very first television picture in 1926 from one room to another by Helensburgh-born John Logie Baird. In 1927 he successfully sent a moving image along telephone wires from London to Glasgow, and the following year he achieved the first trans-atlantic television broadcast. Television started early-on in the history of radio, but didn't really take off until the 1950's. When colour became common in the early 60's, the stage was set for the explosive growth. Since then there has been no looking back. Today, Television is the world's most powerful form of communication. Every day it reaches out to millions of people to entertain and inform them with 'real life' images of the world around them.

Television pictures come from electronic signals like radio waves. The colour television camera begins the process of creating a picture on the television screen. This camera focuses images on television pickup devices, which convert light energy into electrical energy. The colour television camera has three pick-up devices-one for each of the primary colours-red, green and blue. Unlike movie pictures, which are 'whole screen images', television pictures are made up of horizontal lines. Each line is transmitted one at a time in a process called scanning. In India, each picture on the screen remains for 1/25th of a second and is made up of 625 lines. The number of scan lines varies in different countries, which use different broadcasting systems.

So, to get the moving picture, the colour television camera has to scan 625 lines in every image, 25 times every second. It takes the camera 64 millionths of a second to scan from side to side of one line in a single television picture. The television camera encodes the three separate colour signals into one signal, which is sent from the camera either to a video recorder or direct to the station's transmitter. The transmitter sends out a broadcast signal to be picked up by television antenna. The TV set then converts the electrical impulse of that signal to a colour image just like that picked up by the television camera.

The human eye retains an image for a fraction of a second after it views the image. This property (called persistence of vision) is essential to all visual display technologies. The basic idea is quite simple, single still frames are presented at a high enough rate so that persistence of vision integrates these still frames into motion. Motion pictures originally set the frame rate at 16 frames per second. This was rapidly found to be unacceptable and the frame rate was increased to 24 frames per second. In Europe, this was changed to 25 frames per second, as the European power line frequency is 50 Hz. When NTSC television standards were introduced, the frame rate was set at 30 Hz (1/2 the 60 Hz line frequency). Then, the rate was moved to 29.97 Hz to maintain 4.5 MHz between the visual and audio carriers.

In this article, the evolution of various standards, their characteristics, the video signal theory, scanning process, the colour television signal, transmission bandwidth and video signal measurement techniques shall be described.

EVOLUTION OF FIRST TV STANDARD

On January 27, 1941, the Federal Communications Commission announced a standard of electronic television for the United States. Initially, the Electronic Industries Association (EIA) standard was to have 441 scan lines. On the advice of Bell Laboratories the standard was updated to a 525 lines system on March 20, 1941. On July 1, 1941 the FCC allowed commercial broadcasting to begin using the new 525 line standard. Despite having seen a colour television system in the RCA labs, the commission decided that a colour system was not viable. It left the decision on a colour system open and to be decided at a future date. The black and white (B&W) system, known as the EIA system, had the specifications given in Fig 1.

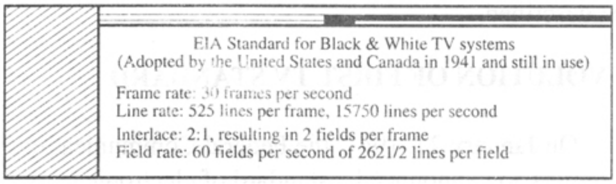
VIDEO SIGNAL THEORY

Video is line-by-line information of the image. The video signal consists of several smaller elements, each having a distinct function. Besides luminance, colour information such as chrominance and saturation are included in today's signal. Horizontal and vertical blanking pulses are also included. These pulses establish the framework for the signal and are vital to placing the video on the screen.

Scanning Process

The EIA B&W television system uses 525 horizontal scans in a frame. There are thirty frames scanned in each second. The scanning process starts at the upper left of the picture area known as line 1 (Fig 2). The beam then proceeds horizontally to the upper right edge at a steady, precise rate. It quickly returns to the left edge to a point two lines below the previous scan. It takes the scanning beam 52.5 microseconds to scan from left to right (Fig 3) and about eleven microseconds to return to the left again to begin scanning the next horizontal line (Fig 4). The return of the beam from right to left is called the HORIZONTAL RETRACE.

This horizontal scanning process proceeds in a downwards direction until 241 and 1/2 horizontal scans are completed. Then the beam moves upward to the top of the picture area but positioned at line 2. This upward movement to line 2 takes 1.3 milliseconds (Fig 5). While the beam moves up, it continues to move horizontally some twenty one times back and forth. Called


EIA Standard for Black & White TV systems
(Adopted by the United States and Canada in 1941 and still in use)

Frame rate: 30 frames per second
Line rate: 525 lines per frame, 15750 lines per second

Interlace: 2:1, resulting in 2 fields per frame
Field rate: 60 fields per second of 2621/2 lines per field

Fig 1 Specifications of EIA system

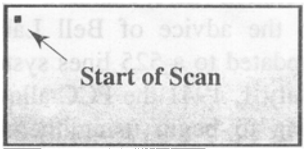


Fig 2 Start of scan

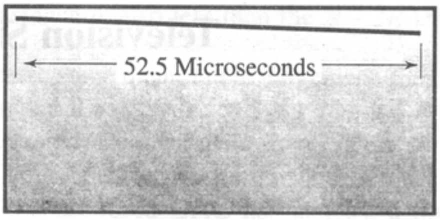


Fig 3 Scanning of line 1

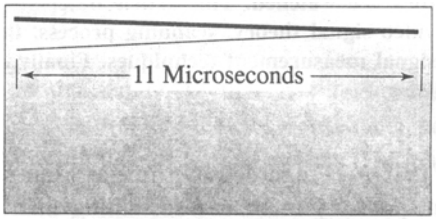


Fig 4 Horizontal retrace to line 3

VERTICAL RETRACING, the image it creates is named the Vertical Blanking Interval. One vertical downward scan and a vertical retrace containing 262 1/2 lines occurs in 1/60 second; it is called a FIELD.

The next field's scanning starts at the top middle of the picture and proceeds horizontally as before. This time however the picture tube scans between the lines scanned during the previous field. There is another vertical retrace containing twenty one horizontal lines, where upon scanning starts again at the top left and repeats the first scan pattern.

Interlaced Scanning

This method of scanning once down through the image and then again in the spaces between the first scanning lines is called Interlaced Scanning. An image created by two successive FIELDS is a television FRAME. The purpose of INTERLACE is to prevent the appearance of flicker in the viewed image. If the scanning was not interlaced, the entire 525 lines would illuminate the screen thirty times per second. The eye starts to blend flashing pictures when the pictures scan at a rate of about forty-five per second. This gives the viewer the impression of a continuously lighted image. If not interlaced, the resulting thirty per second scan rate would flicker and would be objectionable to the eye.

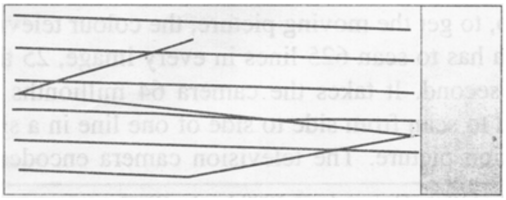
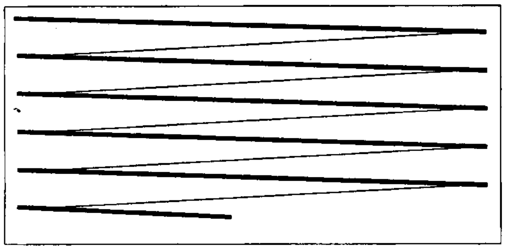


Fig 5 Vertical retrace in 1.3 milliseconds

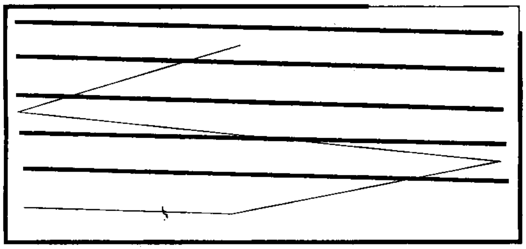
Blanking Signals

A HORIZONTAL-BLANKING signal is added to the camera video output to prevent the display of retrace lines and fogging of the picture (Fig 6). This is added at the end of each horizontal scan. The horizontal scan rate is of 525*29.97 or 15,734 Hz. Therefore, 63.6 μS are allocated per line. Typically about 10 μS of this is devoted to the blanking line on the horizontal scan. It lasts long enough to ensure that the entire retrace is completed and the active scan (the part that produces the picture) has started for the next line. Similarly to prevent the vertical retrace lines from showing up across the picture as a series of diagonal lines, a VERTICAL BLANKING signal is added at the end of each field (Fig 7). Because the scanning circuits for vertical scanning are considerably slower to retrace than the horizontal scan devices, a total time, equivalent to twenty-one complete horizontal line scans, is allowed for vertical retrace. Lines number 248 to 263 and 511 to 525 are typically blanked to provide time for the beam to return to the upper left hand corner for the next scan.



A horizontal blanking is signal provided which turns off the beam output during horizontal retrace. This prevents fogging.

Fig 6 Horizontal blanking



A vertical blanking signal is provided which turns off the beam output and prevents fogging during vertical retrace.

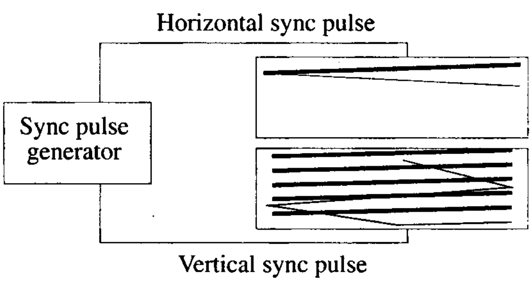
Fig 7 Vertical blanking

Synchronising Signals

When a video picture is displayed or transmitted, a synchronising signal is sent along with camera video signal. The SYNCHRONISING PULSES or, abbreviated, SYNC PULSES perform the function of controlling the TV monitors's scanning circuits so that it scans precisely what the camera is scanning. At the end of each line scan, just after the horizontal blanking signal has started, a HORIZONTAL SYNC pluse is included during the blanking interval. It is a "negatively going" pulse of short duration that reverses the beam until it arrives in the proper location to start the active scan. Similarly, at the end of each field, shortly after vertical blanking has started, a VERTICAL SYNC signal is included. It is a closely spaced series of six wide negatively going pulses that are sensed by the vertical scanning section in a TV receiver. They trigger the vertical scan circuits to retrace up and start the next field. The VERTICAL HOLD on the TV set is dependent on this vertical sync signal. A Sync Pulse Generator delivers both the Horizontal and Vertical Pulses (Fig 8)

All video equipment generate their own internal sync pulses. However, to connect multiple pieces of equipment, all the sync pulses must occur at the same time. Otherwise, if one were going to switch between the sources, the video would become scrambled. There are three ways in which multiple video sources are synced together:

- External sync: A sync generator strips the internal sync pulses from each video source and adds a united sync pulse.
- Genlock: A reference composite video source usually video black is used to synch up all the equipment. All the video equipment that have genlock capability will match their synchronisation pulses to the reference signal. Hence, switching can occur.
- Frame-sync: Frame synchronisation is used when the studio accepts an outside source (i.e. satellite, microwave, etc). The video signal with its internal synch is fed into the frame-sync where the signal is converted into digital bits and synchronised with the in-house sync generator or genlocked to video black. The final output is sent to the switcher.



A sync pulse generator provides horizonal and vertical pulses to regulate horizontal and vertical retrace

Fig 8 Sync pulse generator

NTSC-525 LINES OR 483 LINES?

Although NTSC is a 525-lines system, 42 lines are devoted to the vertical blanking area and are not part of the actual image. This means that only 483 vertical san lines make up the NTSC image.

Aspect Ratio

Aspect ratio is the ratio of width to height of the picture image. In television, as in pre-1952 cinema, the frame is 4 units wide and 3 units high. A screen 4 feet wide would be 3 feet high; a screen 16 inches wide would be 12 inches high; a screen 40 feet wide would be 30 feet high; and so on. This aspect ratio is thus 4:3, which may be reduced to 1.33:1 or simply 1.33. To date, 1.33 remains the standard in television (although HDTV may change this). The useful picture area after removing the blanking areas is shown in Fig 9. The aspect ratio is shown in Fig 10.

Since the mid-1950s, the cinemas has found a variety of methods to increase the screen's width:

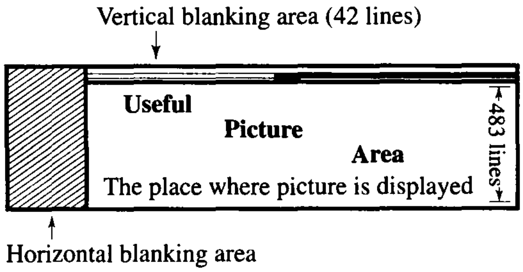


Fig 9 Useful picture area of a screen

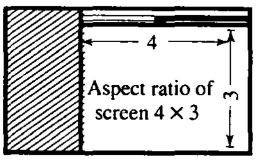


Fig 10 Aspect ratio of TV (4 × 3)

Fig 11 1.33 TV and pre-1952 cinema

Cinerama, CinemaScope, Todd-A-O, VistaVision, Panavision, and so on (Figs 11, 12 and 13).

In order to show these widescreen pictures on the normal TV, masking is used. Masked wide-screen is created during the projection of the film, not the actual filming. A regular 1.33 frame is used, but horizontal bands across the top and the bottom of the frame are "masked" (blackened) (Fig 14).

Safe Title Area

Due to image alignment differences on home receivers, 15% around the edge of the image is considered unsafe to place any important information. The remaining 85% of the image is considered safe title area (Fig. 15).

NTSC and B&W Transmission

NTSC was built around a transmission standard.

Fig 12 1.85 Masked widescreen

Fig 13 2.35 Anamorphic widescreen

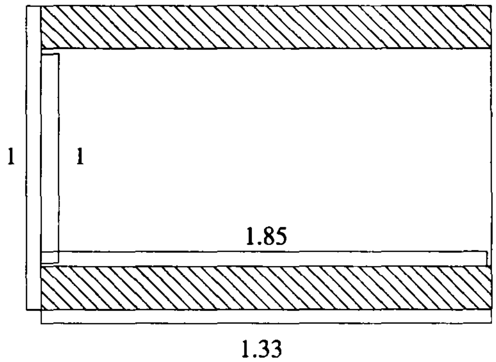


Fig 14 Masked screen for aspect ratio 1:1.85

The Federal Communications Commission (FCC) allocated 6 MHz bandwidth for each television channel. In order to transmit both audio and video inside the 6 MHz bandwidth, the B&W bandwidth was limited to 4.2 MHz (Fig 16).

The B&W bandwidth limits image sharpness or horizontal resolution. For each MHz of bandwidth, NTSC can place about 80 black dots on a white scan line. 4.2 MHz limits horizontal resolution to about 340 black dots per line (4.2 * 80 = 336). Thus, the broadcast television signal is limited in two ways. First, to a maximum 6 MHz bandwidth and secondly, to a horizontal resolution of about 340 lines (Fig 17).

Colour Television

The idea of colour television dates back to 1904. It was based on the principle of scanning three primary colours. As early as 1928, John Baird had demonstrated colour television, sending a bowl of strawberries to a full colour display. By 1949 both CBS and NBC had announced the development of colour television systems. With increased interest by the industry in colour television, the Federal Communications Commission on July 11, 1949 called for hearings to determine the feasibility of introducing colour service. Hearings began on September 26, 1949 and continued until May 26, 1950. Three competing methods of colour were proposed: the Field Sequential method by CBS; the Dot Sequential approach of RCA; and the Line Sequential proposed by Colour Television Incorporated.

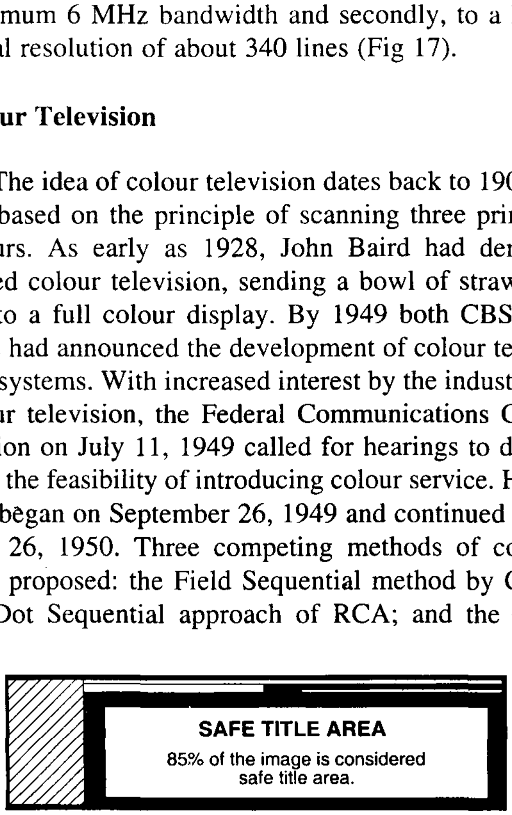


Fig 15 Safe title area

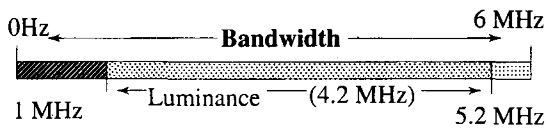
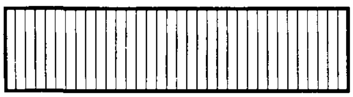


Fig 16 NTSC bandwidth



Horizontal resolution is maximum no. of black and white bars that can be resolved. Luminance Bandwidth determines horizontal resolution

Fig 17 Horizontal resolution

CBS's system followed the path John Baird attempted and was known as the whirling disc system. The system placed the Red, Green, and Blue colours on successive fields. But when applied to the EIA standard, with only 60 fields per second, each colour would appear only 20 times a second creating objectionable picture flicker. Eventually CBS increased the scanning rate to 180 fields per second and dropped the number of scanning lines from 525 to 405 lines. The cost of the CBS system was high. It required 43% more channel space (8.58MHz) and would render all existing B&W sets obsolete. NBC had taken a different approach and developed a colour television system that was compatible with existing B&W receivers. Complicating matters further was a third company, CTI, who had also developed a B&W compatible system.

The CBS system was chosen in October 1950 primarily because its development could be traced back as far as Baird. Even though the performance of the mechanical disk was questionable, the committee felt it was a mature system and it offered the best picture. The Korean War stopped CBS from manufacturing television sets. This gave NBC time to develop its system to exceed CBS's system. When NBC perfected their colour system they went back to the FCC. In the rematch with CBS, NBC's B&W compatible system was chosen on December 17, 1953. It took until 1954 for the National Television System Committee (NTSC) to set the standard for colour broadcast television. They settled on a system that was compatible with existing black and white TV sets. Colour was achieved by inserting the colour information inside the black and white signal. Japan adopted the NTSC system in 1960, but it wasn't until 1967 that the USSR and France Adopted the SECAM system (System Electronic Coleur Avec Memoire) that features less colour distortion than NTSC system along with 625 lines at 25 frames per second.

Image Quality: Colour and Black-and-White

There are a few basic colour characteristics that are described in the same way in both video and film. These are:

- hue
- saturation
- brightness

Hue designates a specific colour from within the visible spectrum of white light: e.g., red, green, and blue. The level of saturation defines a colour's purity—

how much or little grayness is mixed with the colour. Deep, rich, vibrant colours are said to be heavily saturated. They become less saturated as the colour fades. Saturation is also termed chroma or chrominance in video colour. Brightness of luminance in video indicates how bright or dark a colour is [1].

Despite these similarities, video and film take different approaches to creating colour images. Video constructs colours by adding them together. A single phosphor on the TV screen is coloured red, green, or blue. The electron gun (or guns) ignite three nearby phosphors and combine their individual colours, thus generating a broad variety of colours. Film, in contrast, is a subtractive colour process. As white light from a projector lamp passes through a piece of motion picture film, yellow, magenta (reddish), and cyan (bluish) colours are filtered out of the light.

Thus, both video and film rely upon three-colour systems to generate colour images. Different video systems and film stocks balance these three colours in different ways. Some are more sensitive to red, others to blue; some appear more naturalistic under sunlight, others under tungsten light (as in household light bulbs). No video system or film stock captures colour exactly as it exists in nature, but this is not necessarily a drawback. Rather, it presents a wide range of colour options to the camera operator. Colour may be manipulated through the choice of video system and film stock, as well as through lens filters and coloured gels on the lights.

In the 1980s, long after television had been a strictly colour medium, black-and-white video and film began to be reintroduced. Although black-and-white images are uncommon in narrative programs, they have been used to indicate dream sequences or events that occurred in the past. In these cases, black-and-white's contrast from colour has been used to communicate narrative information.

Colour Additive System

The colour additive system is based on the primary colours of red, blue and green (Figs 18 and 19). When combined, combinations of these primary colours create secondary colours of magenta, cyan and yellow. When all these colours are combined they create white. Thus, to create a colour television system, one must be able to scan, transmit and display the three primary colours [2].

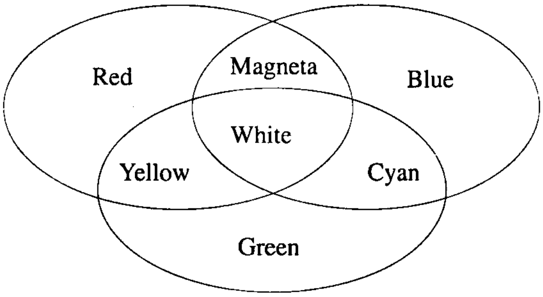


Fig 18 Colour production in TV

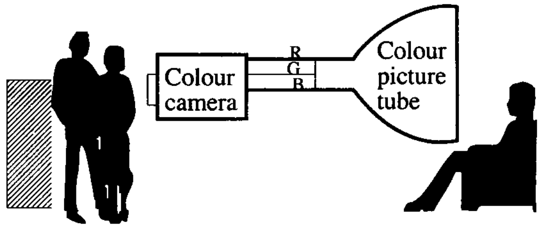


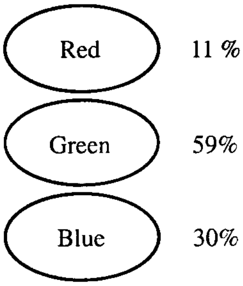
Fig 19 Colour picture system

NTSC Colour Standard

NBC devised a way of transmitting the three primary colours in one signal. They converted the B&W signal to a "base" signal representing 59% green, 30% blue and 11% red (Fig 20). "Y" denotes this "base" signal, known as the luminance channel. "Y" is interpreted as the B&W signal on B&W sets. Since the bandwidth of "Y" was kept the same, the television signal kept its horizontal resolution of about 340 lines.

Two colour difference signals known as I and Q were added to the NTSC signal at 3.58 MHz, in a way that did not interfere with the "Y" signal. Together Y, I and Q are the equivalent of red, green and blue. Colour television sets are designed to use Y, I and Q to reproduce colour. In adding I and Q, the scanning rate of the television signal was reduced from thirty frames per second to 29.87 frames per second. This change in time had no effect on existing B&W receivers.

The television bandwidth remains the same 6 MHz, as for B&W system. The sub-carrier for the colour is



Luminance Channel
Fig 20 Y the luminance

3.58 MHz off the carrier for the monochrome information. The sound carrier is 4.5 MHz off the carrier for the monochrome information. There is a gap of 1.25 MHz on the low end, and 0.25 MHz on the high end to avoid cross-talk with other channels (Fig 21). The NTSC suffers from the poor resolution limited by luminance bandwidth (Fig 22).

NTSC/525 Advantages

- Higher Frame Rate—Use of 29.97 frames per second reduces visible flicker.
- Atomic Colour Edits—With NTSC it is possible to edit at any 4 field boundary point without disturbing the colour signal.
- Less inherent picture noise—Almost all pieces of video equipment achieve better signal to noise characteristics in their NTSC/525 form than in their PAL/625.

NTSC/525 Disadvantages

- Lower Number of Scan Lines—Reduced clarity on large screen TV, line structure becomes more visible.
- Smaller Luminance Signal Bandwidth—Due to the placing of the colour sub-carrier at 3.58MHz, picture defects such as moire, cross-colour, and dot interference become more pronounced. This is because of the greater likelihood of interaction with the monochrome picture signal at the lower sub-carrier frequency.
- Susceptibility to Hue Fluctuation—Variations in the colour subcarrier phase cause shifts in the displayed colour, requiring that the TV receivers be equipped with a Hue adjustment to compensate.

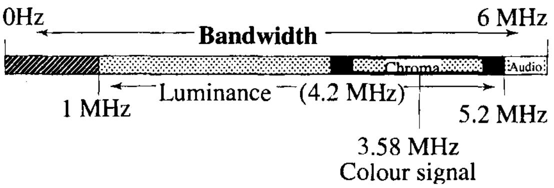


Fig 21 NTSC Colour Transmission Bandwidth

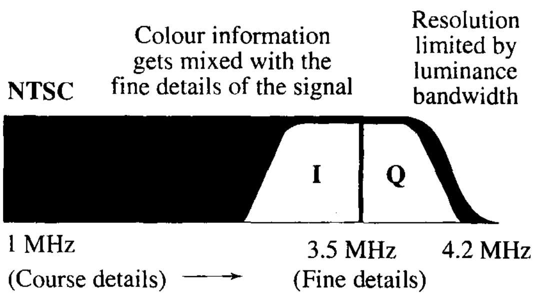


Fig 22 Fine and Coarse details in NTSC Signal

- Lower Gamma Ratio—The gamma value for NTSC/525 is set at 2.2 as opposed to the slightly higher 2.8 defined for PAL/625. This means that PAL/625 can produce pictures of greater contrast.
- Undesirable Automatic Features—Many NTSC TV receivers feature an Auto-Tint circuit to make hue fluctuations less visible to uncritical viewers. This circuit changes all colours approximating to flesh tone into a "standard" flesh tone, thus hiding the effects of hue fluctuation. This does mean however that a certain range of colour shades cannot be displayed correctly by these sets.

PAL (Phase Alternation by Line)

Introduced in 1966, Phase Alteration by Line was instituted by West Germany, England and Holland and improves upon colour distortions created by NTSC. PAL uses a 625 line system scanning at 50 Fields (25 Frames) per second. India uses PAL system. The PAL system places the colour Sub-Carrier at 4.43 MHz. It was derived from the NTSC system but by reversing the phase of the reference colour burst on alternate lines (Phase Alternating Line). PAL is able to correct for hue shifts caused by phase errors in the transmission path. The bandwidth of the 625/50 PAL system is 5 or 5.5 MHz for the luminance signal and 1.3 MHz for the colour difference signals modulating the V and U axes of the PAL sub-carrier.

PAL/625 Advantages

- Greater Number of Scan Lines—more picture detail.
- Wider Luminance Signal bandwidth—The placing of the colour Sub-Carrier at 4.43 MHz allows a larger bandwidth of monochrome information to be reproduced than with NTSC/525.
- Stable Hues—Due to reversal of sub-carrier phase on alternate lines, any phase error will be corrected by an equal and opposite error on the next line, correcting the original error. In early PAL implementations it was left to the low resolution of the human eye's colour abilities to provide the averaging effect; it is now done with a delay line.
- Higher Gamma Ratio—The gamma value for PAL/625 is set at 2.8 as opposed to the lower 2.2 figure of NTSC/525. This permits a higher level of contrasts than on NTSC/525 signals. This is particularly noticeable when using multi-standard equipment as the contrast and brightness settings need to be changed to give a similar look to signals of the two formats.

PAL/625 Disadvantages

- More Flicker—Due to the lower frame rate, flicker is more noticeable on PAL/625 transmissions.
- Lower Signal to Noise Ratio—The higher bandwidth requirements cause PAL/625 equipment to have slightly worse signal to noise performance than its equivalent NTSC/525 version.
- Loss of Colour Editing Accuracy—Due to the alternation of the phase of the colour signal, the phase and the colour signal only reach a common point once every 8 fields/4 frames. This means that edits can only be performed to an accuracy of +/- 4 frames (8 fields).
- Variable Colour Saturation—Since PAL achieves accurate colour through cancelling out phase differences between the two signals, the act of cancelling out errors can reduce the colour saturation while holding the hue stable. Fortunately, the human eye is far less sensitive to saturation variations than to hue variations.

SECAM

Instituted in 1967 by France, Sequential Couleur a Memorie has had an odd history. The French, sensing that they could develop their market for television sets resisted joining the rest of Europe by not adopting PAL and developing SECAM. It turns out that SECAM is so difficult to edit, its often standard converted to PAL for editing. As for the French market for manufacturing TV sets, Asian built tri-standard TV sets have taken a large part of their home market.

SECAM/625 Advantages

- Stable Hues and Constant Saturation—SECAM shares with PAL the ability to render images with the correct hue, and goes a step further in ensuring consistant saturation of colour as well.
- Higher Number of Scan Lines—SECAM shares with PAL/625, the higher number of scan lines than NTSC/525.

SECAM/625 Disadvantages

- Greater Flicker—(See PAL/625)
- Mixing of two synchronous SECAM colour signals is not possible—Most TV studios in SECAM countries originate in PAL and transcode prior to broadcasting. More advanced home systems such as SuperVHS, Hi-8, and LaserDisc work internally in PAL and transcode on replay in SECAM market models.
- Patterning Effects—The FM subcarrier causes patterning effects even on non-coloured objects.
- Lower monochrome Bandwidth—Due to one of the two colour sub-carriers being at 4.25MHz (in the French Version), a lower bandwidth of monochrome signal can be carried.
- Incompatibility between different versions of SECAM—SECAM has a wide range of variants, many of which are incompatible with each other. For example between French SECAM with the FM subcarrier, and MESECAM which uses an AM subcarrier.

CURRENT TELEVISION BROADCAST TRANSMISSION SYSTEMS

The main features of the three main formats viz. NTSC, PAL and SECAM are given in Table 1. The characteristics of various versions of these formats are given in Table 2 [3].

HOW TV WORKS

No matter how the signal is sent from one location to the other, be it radio waves, coaxial cable or fiber optics, the first thing to consider is the method used to convert images to electronic signals and back again. This process is the heart of television.

The first part of the process involves getting the image into an electronic form. The picture is broken up into small pieces by a scanning process, and sent one line at a time. In early cameras, various forms of special tubes were used for this process. The tubes had a special layer that was sensitive to light. As an electron beam scanned this layer, the image that was focused on the tube was converted to an electronic voltage, which corresponded to the brightness of the image. Modern cameras use solid state devices that do

TABLE 1 Main features of NTSC, PAL and SECAM formats

	lines	active lines	vertical resolution	aspect ratio	horizontal resolution	frame rate
NTSC	525	484	242	4/3	427	29.94
PAL	625	575	290	4/3	425	25
SECAM	625	575	290	4/3	465	25

TABLE 2 Characteristics of various formats

System	Lines	Transmission bandwidth	Channel bandwidth	Audio
Pal B	625	7 MHz	5 MHz	FM
Secam B	625	7 MHz	5 MHz	FM
Pal D	625	8 MHz	6 MHz	FM
Secam D	625	8 MHz	6 MHz	FM
Pal G	625	8 MHz	5 MHz	FM
Secam G	625	8 MHz	5 MHz	FM
Pal H	625	8 MHz	5 MHz	FM (Sideband Dif)
Pal I	625	8 MHz	5.5 MHz	FM
Secam K	625	8 MHz	6 MHz	FM
Secam K	625	8 MHz	6 MHz	FM (Sideband Dif)
Secam L	625	8 MHz	6 MHz	AM
NTSC M	525	6 MHz	4.2 MHz	FM
NTSC N	625	6 MHz	4.2 MHz	FM

essentially the same thing. Colour images are sent in the same way, except that there must be a signal for each of the primary colours used.

Regular television stations use a form of AM modulation known as vestigial sideband (VSB) to send the video via radio waves. Similar to AM, VSB filters out duplicate parts of the modulated signal in order to reduce the amount of channel space, or bandwidth necessary to send the signal. The signal is sent through terrestrial transmission systems using VHF or UHF antenna or satellite system. Traditional satellite TV uses microwave frequencies that require large dishes for best performance. These systems use frequency modulation (FM) for sending the video, which reduces interference between the various satellite transponders (satellite circuitry which relays the TV signal). The new DSS (Direct Satellite System) satellite TV units operate at a higher frequency than traditional units, which allows the dishes to be smaller. In addition, the video signals are converted to digital data, which is sent over the satellite link. At the receiver the digital signals are converted back to video which is sent on to the TV set. DSS signals are generally of higher quality than conventional satellite TV. An early television transmission and reception system used by RCA is shown in Fig 23[4].

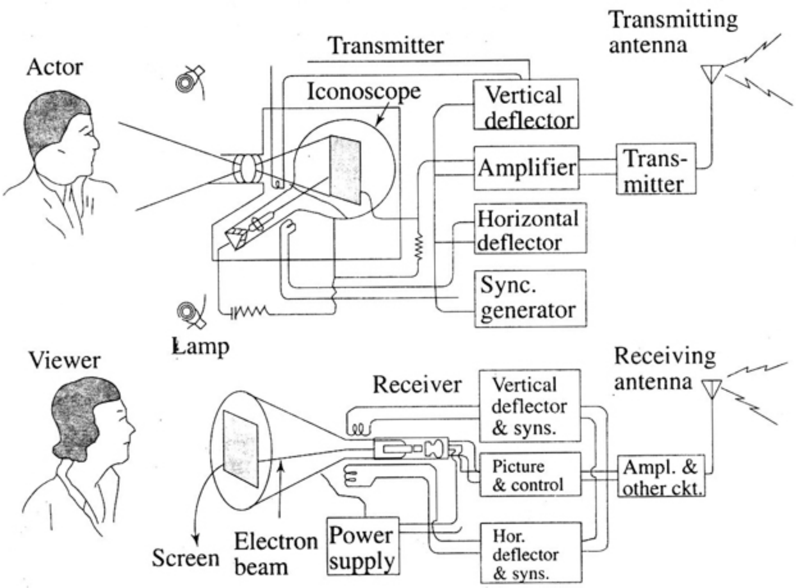


Fig 23 An early television transmission and reception system used by RCA

Ditial Video

Digital provides limitless copying without degradation, stability of operation, freedom from routine line-up and greater equipment reliability (Fig 24). Signal processes are realisable in a digital world that could not be contemplated if the signals were to have remained analogue. It was felt necessary to introduce A Digital Television standard that would make it possible to preserve the original quality whatever the processing complexity. Early experiments with digital technology were based on sampling the composite signal. However, it was realised that for the highest quality operation, component processing was necessary and the first digital standards were based on component signals. Interest in composite digital was revived when Ampex and Sony announced a composite digital recording format (D-2 format)[5].

ITU Rec. 601

Recommendation ITU-R BT.601, usually referred to as 4:2:2, is a sampling standard that was evolved by a joint SMPTE/EBU task force which, was set up with an aim to introduce the compatibility between 625/50 and 525/59.94. Main features of this standard are:

* for luminance (Y)-orthogonal sampling at 13.5 MHz
* for the two colour difference signal Cb and Cr (Scaled versions of the signals B-Y and R-Y) 6.75 MHz

The Task Force selected 13.5 MHz as a compromise because the sub-multiple 2.25 MHz is a factor common to both 525 and 625 line system. Some extended definition TV systems use a higher resolution format called 8:4:4 which has twice the bandwidth of 4:2:2.

The choice of sampling frequencies gives 720 samples/active line for luminance Y and 360 samples for colour differences and also includes space for representing analogue blanking within the active line. The equivalent analogue bandwidths are 5.75 MHz for luminance and 2.75 MHz for colour differences. Quantisation was initially based on 8 bits giving 256 equally spaced levels; luminance is encoded on 220 levels and each colour difference on 224 levels. Subsequently this standard was raised to 10 bits.

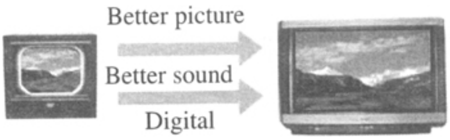


Fig 24 Better picture in Digital TV

The notation 4:4:4 indicates that each of signal components is sampled at 13.5 MHz. This corresponds to the signals produced by the individual image sensors, thus the 4:4:4 notation is often used for either YUV or RGB components.

The notation 4:1:1 indicates that the colour difference components have one-quarter the resolution of the luminance signal; this correlates well with luminance and colour resolution delivered by NTSC and PAL. 4:1:1 sampling is used in the consumer DV format and the 25 megabit per second (Mbps) versions of DVCPRO and DVCAM.

PARALLEL DIGITAL INTERFACE (CCIR) RECOMMENDATION 656 (RP 125))

A parallel interface for the data produced by Rec. 601 was standardised by CCIR and is included in Recommendation 656 (RP 125). In this interface, video signals are transmitted in a parallel arrangement using eleven twisted pairs and 25-pin 'D' connector [6]. This interface multiplexes the data words in the sequence Cb Y, Cr, Y, Cb, resulting in a data rate of 27 megaword. The timing sequences SAV (Start of Active Video) and EVA (End of Active Video) were added to each line. Ten-bit operation has proved beneficial in many circumstances and the latest revision of the interface standard provides for a 10-bit interface, even if only eight bits are used.

Digital-to-analogue conversion range is chosen to provide headroom above peak white and footroom below black. Quantising levels for black and white are selected so the 8-bit levels with two 'O's added will have the same values as the 10-bit levels. Values 000-003 and 3FF-3FC are reserved for synchronising purposes. Similar factors determine the quantising values for colour difference signals. The timing information is carried by EAV and SAV, and as such there is no need for conventional synchronising signals, and the horizontal intervals (the active line periods during the vertical interval) may be used to carry ancillary data. Under this form, the practical limit for carrying the signal is 100 meters without equalisation, which is adequate for post-production.

Parallel Composite Digital

The composite digital provides for digital processing and interfacing. This is also used for multi-generation recording. The composite video signal is sampled at four time the subcarrier frequency i.e. 14.3 MHz for NTSC and 17.7 MHz for PAL. Both interface specify ten bit precision, although D-2 and D-3 machines record only eight bits to tape. Quantising of the NTSC signal is defined with a modest amount of headroom above 100% bars, a small footroom below sync tip and the same excluded values as for component.

PAL composite digital has been defined to minimise quantising noise by using a maximum amount of the available digital range. Because of the specified sampling axis reference to subcarrier and the phase of the highest luminance level bars (such as yellow), the samples never exceed the digital dynamic range.

The composite digital active line is long enough to accommodate the analogue active line and the analogue blanking edges. Unlike the component interface, the composite interface transmits a digital representation of conventional sync and burst during the horizontal blanking interval. A digital representation of vertical sync and equalising pulses is also transmitted over the composite interface.

Serial Digital Video (SMPTE 259M and EBU Tech. 3267)

The need for long distance transmission of broadcast signals over a single coaxial cable lead to the recommendation of a standard for serial interface for Rec. 601 signals by EBU in 1980. The serial interface, which embodies component and composite signal including embedded digital audio, has been standardised as SMPTE 259 M and EBU Tech. 3267. The interface uses 8/9 block coding and resulted in a bit rate of 243 megabit/s. The interface uses channel coding that utilises scrambling and conversion to NRZI [7]

270 Mb/s Serial Digital Components Standards

This standard is based on 10 bit, but the system can transmit 8, 9 or 10 bit in a compatible way. This system uses a constant bit rate of 270 Mb/s. At the transmitter end, the digital video signals and auxiliary data are combined and then serialised in a single signal for transmission. At the receiver end, the signal is equalised, deserialised and then split between video and auxiliary data. Several AES/EBU digital audio stereo channels can be included in these auxiliary data transmitted during horizontal and vertical blanking [8].

The system is a single wire system, so the clock information is transmitted combined with the data. A self clocking system is used in order to get easy clock recovery. The principal used is to perform two operations on the serialized data: The first is a scrambling with a pseudo random sequence using a specified scrambling polynomial; the second is to make the data polarity free by the use of NRZI encoding.

The scrambling polynomial is: $G(x) = (x^9 + x^4 + 1)(x + 1)$

The data stream is recovered and descrambled in a similar complementary descrambler circuit.

Composite vs component

MPEG video signals are exclusively component YCbCr (CCIR Rec. 601). This permits programming to remain component over the entire signal path (from camera all the way to the TV monitor). The video signals encoded onto LaserDiscs are in fact a variant of the composite analog NTSC (or PAL for Europe) format, and as such, are subject to the host of traditional composite artifacts such as twitter and dot-crawl.

Extended Definition Television (EDTV)

The main features for EDTV are:

- Aspect Ratio
- Wider Luminance and Chrominance bandwidth
- No Y/C interface (Cross colour)
- Multichannel digital audio

For EDTV projects, obvious choice for the studio has been 4:2:2 Digital Component Serial.

High Definition Television (HDTV)

The basic concept behind high-definition television is actually not to increase the definition per unit area but rather to increase the percentage of the visual field contained by the image.

The majority of proposed analog and digital HDTV systems are working toward approximately a 100% increase in the number of horizontal and vertical pixels. (Proposals are roughly 1 MB per frame with roughly 1000 lines by 1000 horizontal points). This typically results in a factor of 2-3 improvement in the angle of the vertical and horizontal fields. The majority of

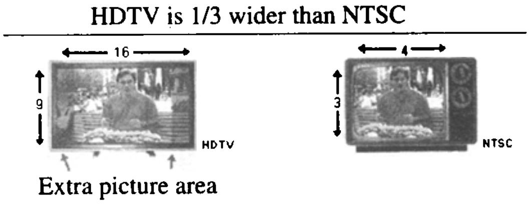


Fig 25 Aspect ratio comparison of HDTV and SDTV

HDTV proposals also change the aspect ratio to 16/9 from 4/3—making the image more "movie-like" (Fig 25). High Definition TV has the following format for Spatial and temporal resolution.

- lines/59.94 ~ 57.79 Megapels/sec.
- lines/60 ~ 59.62 Megapels/sec.

Digital Audio Standard

AES3-1985, EBU Tech. 3250-E, CCIR Rec. 647, SP/DIF, IEC 958, EIA CP340 and EIA DAT are major digital audio standards for serial interface transfer. These standards describe a unidirectional, self-clocking, two-channel standard based on a single serial data signal. The format contains audio samples up to 24 bit in length and non-audio data including channel status, user data, parity and sample validity. The differences between these standards lie in electrical levels, connectors, and the use of the channel status bits.

One serial frame of information is transferred each sample period, each consisting of 64 bits, and comprising two subframes, A and B, one per each audio channel, as shown in Fig 26. A group of 192 consecutive frames forms a block.

Preamble patterns are used to synchronise and identify subframes and blocks. There are tree types of preambles (Fig 27), named X, Y and Z or 1, 2 and 3 in AES specification and B, M and W in CP340 specification. The Z (1, B) preamble signifies the channel A subframe and also the beginning of a block. The X (2, M) preamble signifies the channel A subframe, any frame within the block other then the first. The Y (3, W) preamble signifies the channel B subframe anywhere within the block.

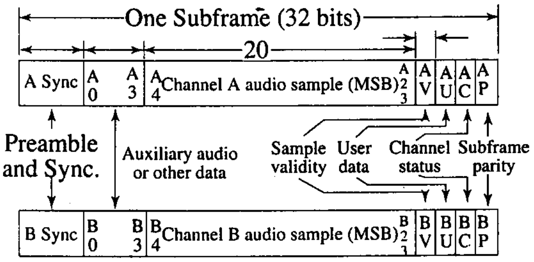


Fig 26 AES/EBUC/CP340 digital audio frame

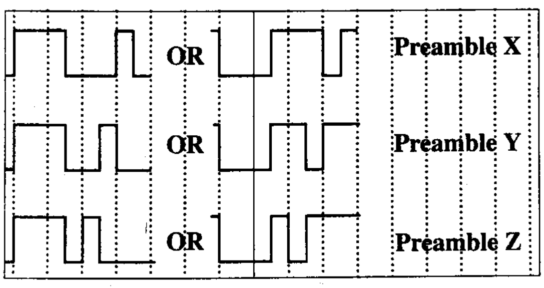


Fig 27 Preambles for AES3, EBU Tech. 3250-E, and CP340

The channel A audio samples are referred to as A0-A23 and the channel B audio sample are referred to as B0-B23. A23 is the MSB (Most Significant Bit) of the channel A audio sample and B23 is the MSB of the channel B audio sample for all serial interface modes. If 16 bit audio samples are used, A8 and B8 are the LSBs (Last Significant Bits). The auxiliary data bits may be used to extend to audio samples to 24 bits or may be used for other purposes.

The validity (V) bit indicates if the audio sample data bits are valid (error free) and is commonly used to mute automatically D/A converters if the data is invalid. The bit is defined as a logic zero (0) if the audio sample is valid, and a logic one (1) if the sample is defective. The default value is a logic zero. Each block provides 192 channel status bits (C). These form 24 bytes of channel status data.

The user bit (U) is free for user data of any type or format desired. The CD format implements subcode blocks of 1176 user bits, organised as 98 subcoding symbols, with twelve user bits per subcode symbol. The DAT format uses user bits for SYNC, Start-ID and Shortening-ID information AES 18-1992 specifies and optional usage of the user bits as well.

The parity bit (P) implements even-parity transmission error detection. Since the preambles have even parity as an explicit property the parity bit can be taken as applying to all the data in a subframe.

AES/EBU standards for digital audio

The "AES/EBU" (Audio Engineering Society/European Broadcast Union) digital audio standard is probably the most popular digital audio standard today. Most consumer and professional digital audio devices (CD players, DAT decks, etc) that feature digital audio I/O conform to AES/EBU standards.

AES/EBU is a bit-serial communications protocol for transmitting digital audio data through a single transmission line. It provides two channels of audio data (up to 24 bits per sample), a method for communication control and status information ("channel status bits"), and some error detection capabilities. Clocking information (i.e., sample rate) is derived from the AES/EBU bit stream, and is thus controlled by the transmitter. The standard mandates use of 32 kHz, 44.1 kHz, or 48 kHz sample rates, but some interfaces can be made to work at other sample rates.

AES/EBU provides both "professional" and "consumer" modes. The big difference is in the format of the channel status bit mentioned above. The professional mode bits include alphanumeric channel origin and destination data, time of day codes, sample number codes, word length, and other goodies. The consumer mode bits have much less information, but do include information on copy protection (naturally). Additionally, the standard provides for "user data", which is a bit stream containing user-defined (i.e., manufacturer-defined) data.

The physical connection media are commonly used with AES/EBU: balanced (differential), using two wires and shield in three-wire microphone cable with XLR connectors; unbalanced (single-ended), using audio coax cable with RCA jacks; and optical (via fiber optics). "S/P-DIF" (Sony/Phillips Digital Interface Format) typically refers to AES/EBU operated in consumer mode over unbalanced RCA cable [10, 11].

AES5-1998 AES recommended practice for professional digital audio

A sampling frequency of 48 kHz is recommended for the origination, processing, and interchange of audio programes employing pulse-code modulation. Recognition is also given to the use of 44.1-kHz sampling frequency related to certain consumer digital applications, the use of a 32-kHz sampling frequency for transmission-related applications, and the use of a 96-kHz sampling frequency for applications requiring a higher bandwidth or more relaxed anti-alias filtering.

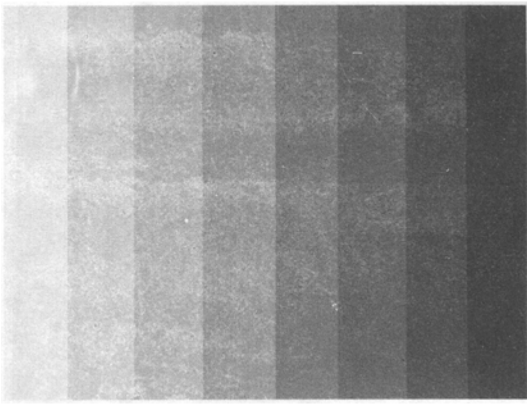
Colour Bars

Colour Bars are the standard video reference tool used in television. Colour Bars are used as a reference and contain correct luminance and chrominance (colour levels). Modern Colour bars contain the primary and secondary colours, produced by the colour additive system used in television. They also contain a reference white signal, a reference black signal, monitor set up bars and I and Q reference signals.

EIA Colour Bars

The first colour bar standardised in 1967 is known as full-field bars or RS-189 bars (Fig 28). These conform to the EIA (Electronic Industries Association) standards.

In 1976, these bars were changed by the EIA, and became the RS-189A standard. More commonly known as split-field bars, they added a reference white signal, a reference black signal, and I and Q reference signals Fig. 29).



EIA colour bars (RS - 189)

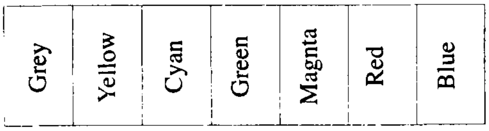
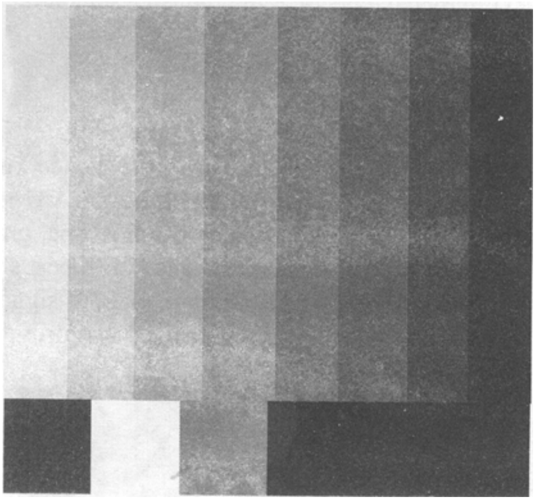


Fig 28 EIA RS-189 bars

SMPTE Colour Bars

The Society of Motion Picture and Television Engineers (SMPTE) felt the EIA split field bars were weak, especially in the area of monitor set up. In 1978, SMPTE adopted the third type of colour bars that addresses monitor set up. This was accomplished by



EIA Split-Field colour bars (RS-189-A)

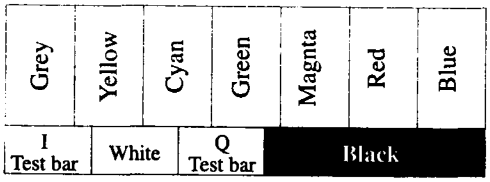
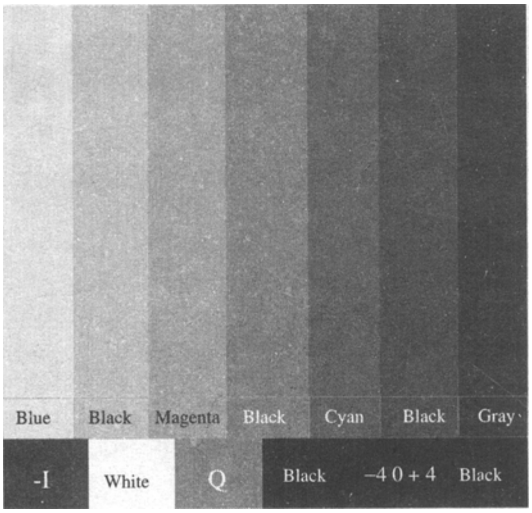
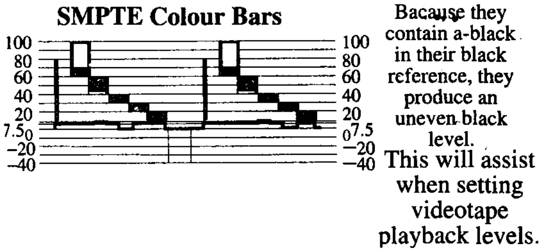


Fig 29 EIA RS-189A bars





adding a trio of black bars to the black reference signal (Fig. 30). The idea is to adjust the brightness on monitor until the bar on the left cannot be seen. If it can be seen, brightness is considered too high. If the right hand bar cannot be seen then the brightness is too dark. SMPTE bars have become the industry standard.

TV SIGNAL MEASUREMENT

The Waveform Monitor

Video signals are observed using a device known as a waveform monitor or WFM. Like the VU meter for audio, the WFM, which is an oscilloscope, graphically shows an electronic signal. The WFM best shows the luminance signal (the brightness or B/W signal) of the video image. On the screen of the waveform monitor there are two scales. The first is the vertical axis, which has a range from–40 IRE to 100 IRE. The horizontal axis displays microseconds which is used to measure the timing of electrical signal components. Video is inputted into the monitor and in the 2H mode, 2 scan lines are displayed. The portion between–40 and 0 IRE shows the sync signals. Between 0 and 100 IRE is the active video. In a colour video signal there are 8 components that can be spotted on the waveform monitor (Fig 31).

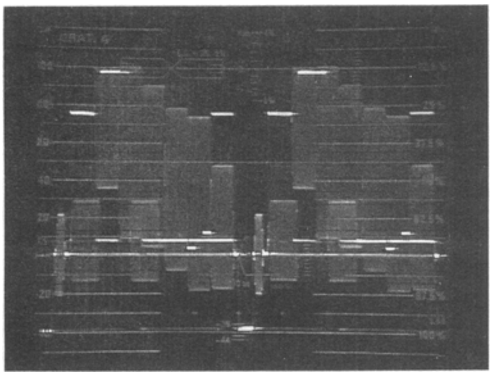


Fig 30 SMPTE colour bars

1. Reference Black Level: This occur at 7.5 IRE and is often called the setup or pedestal level. The darkest part of image should lie here.
2. Reference White Level: This occurs at 100 IRE (or 77 IRE) and the brightest part of image should lie here.
3. Front Porch: This is the distance within the HBI between the end of the active signal to the beginning of the sync pulse (0 IRE).
4. Horizontal Blanking Interval: The period of time from the start of the front porch to the back porch.
5. Back Porch: This is the distance within the horizontal blanking between the colour burst and active video signal.
6. Colour Burts: property of the colour video signal. It stretches from–20 IRE to 20 IRE.
7. Sync pulse: This must lie between–40 and 0 IRE.
8. Breezeway: The period of time between the sync pulse and colour burst.

On the waveform display there is a space that separates each line. Called horizontal blanking, this is where the scanning beam is turned off during horizontal retrace. Areas defined as the front porch and back porch identify the blanking width. The colour information for the video signal is contained in the colour burst signal located next to the back porch (Fig 32). The colour burst normally sits between–20 IRE to + 20 IRE units.

The Vectorscope

The waveform monitor is great in showing the brightness of an image, but it cannot show the colour portion of the signal accurately. The vectorscope dis-

Full video signal (including the colour burst)

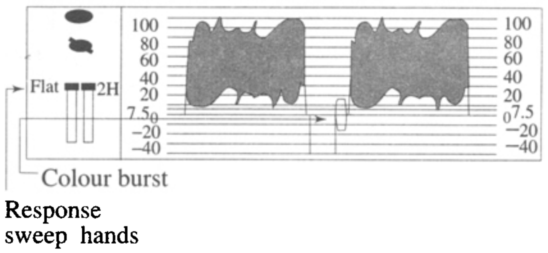


Fig 31 Full video signal

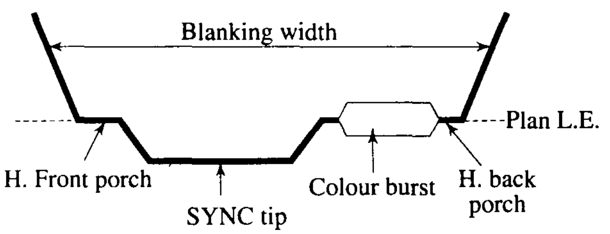


Fig 32 Horizontal blanking interval

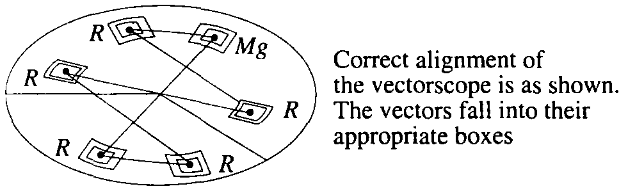


Fig 33 Correct alignment of colours in the vectorscope

plays a graphic representation of the colour in the video signal. The display is round with 6 boxes representing the six colours in the SMPTE colour bars signal. These colours are megenta, red, yellow, green, cyan and blue. When colour bars are fed to the vectorscope, the graphic representation resembles to hourglasses. The dot at the tip of the connected vectors should fall in the six boxes (Fig 33). If there is too much colour in the signal, the vectors will extend farther away from the box. If there is too little colour, the vectors will mòve closer to the center. If the hue is incorrect, then all the dots will move in unison clockwise or counter-clockwise, away from the boxes. By using the vectorscope and waveform monitor, the videomaker can insure that the video information is correctly recorded.

CONCLUSION

In this series, the evolution of various standards, their characteristics, the video signal theory, scanning process, the colour television signal, transmission bandwidth and video signal measurement techniques have been described. The working of Television system has also been described briefly. The digital video and audio standards have also been described. The details of digital compression technique shall be described in one of the later series.

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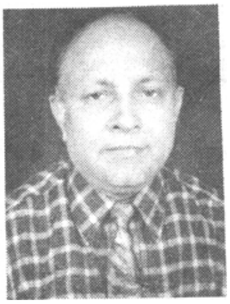

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