Television systems

11.1 INTRODUCTION

This chapter is concerned primarily with the fundamentals of domestic broadcast television systems which now includes direct broadcast satellite systems. There are, of course, many specialized closed-circuit television systems, but these are all based upon the same principles as the broadcast system and will not therefore be considered separately.

Television has progressed over a period of about 70 years from John Logie Baird’s mechanical scan system to the modern highly sophisticated colour systems that can transmit both entertainment programmes and teledata information. During this period the quality of sound and visual image reproduction has increased steadily and digital techniques, in particular, have made rapid inroads in what has been basically an analogue technology. The basic principles governing the transmission of visual information by electrical means have, however, remained unchanged. These principles rely upon a property of the human eye/brain combination known as ‘persistence of vision’. This means that under certain conditions, the brain is unable to differentiate between a moving image focused on the retina of the eye and a rapid sequence of still images. Television is specifically designed for the human eye/brain combination, and it is appropriate to begin by considering the subjective response of this combination to incident light energy.

11.2 MEASUREMENT OF LIGHT AND THE RESPONSE OF THE EYE

Light is a form of electromagnetic radiation and the power radiated from any source is measured objectively in watts. Light energy is visible only over a very restricted range of wavelengths, from $4 \times 10^{-9}$ m to $7 \times 10^{-9}$ m. The subjective sense of ‘intensity’ varies with the wavelength of incident light, where in this context intensity means the impression of an observer of whether a light source is bright or dim. The response of the eye varies between individuals but the variation in this response has been found to be small enough to allow a ‘standard observer response’ to be defined. This standard response is shown in Fig. 11.1.

A black body radiator radiates equal energy at all wavelengths. The luminous intensity of such a source is obtained by weighting the uniform spectral density of the source by the response of the standard observer. The resulting subjective unit is the candela and is defined as 1/60th of the luminous intensity per cm$^2$ of a black body radiator maintained at a
temperature of 2042 K. The lumen is the amount of light passing through unit area at unit distance from a point source of 1 candela, i.e. the total emission from a source of 1 candela is $4\pi$ lumens. The lumen is the unit of luminous flux and, unlike the power output from a light source, depends upon the response of the standard observer.

It is clear from Fig 11.1 that two light sources of equal power but different colour do not necessarily have the same luminous flux. Two light sources of different colour that appear equally bright to the standard observer do have the same value of luminous flux measured in lumens.

The significance of the last statement will become clear when colour theory is considered in Section 11.8. As far as monochrome television is concerned the response of the camera when viewing a coloured scene should closely resemble the response of the standard observer, i.e. the electrical output should be proportional to the brightness of the scene measured in lumens. Such an output signal is termed the luminance signal.

11.3 THE MONOCHROME TELEVISION WAVEFORM

In Europe broadcast television pictures are transmitted using the 625 line standard (it should be noted however that vigorous efforts are being made to define a universal European high-definition standard). The 625 line signal waveform will be considered as the means of explaining the transmission of a three-dimensional vision signal (i.e. one that is a function of time and both horizontal and vertical position) over a one-dimensional channel (i.e. a channel in which voltage is a function of time). The three-dimensional visual image to be transmitted is focused onto a photosensitive (in the electrical sense) surface by an optical lens system. The photosensitive surface may be considered as a large number of separate photoelectric transducers. Each of these transducers produces an electrical output proportional to the intensity of the image that falls upon it. The original image is thus decomposed into a large number of picture elements known as pixels (or pels). The electrical output corresponding to each pixel is one-dimensional since it is a function only of time. The three-dimensional signal, which is the combined output of
all pixels, is actually transmitted as a rapid sequence of one-dimensional outputs. The original optical image is then reconstructed by displaying each pixel in its correct spatial position.

This image is produced, in a domestic television receiver, by modulating the beam current of a cathode ray tube (CRT). The screen of such a tube is covered with a photo-emissive layer and will have the same number of pixels as the photosensitive plate in the image capture system. The image is reproduced by effectively connecting each pixel in the image capture system to the corresponding pixel in the CRT in turn. This is achieved by scanning the photo-emissive screen in the CRT with an electronic beam synchronized to the scanning beam in the image capture system. Sequential scanning of the image capture system and CRT are shown diagrammatically in Fig. 11.2. The electron beam is deflected in both vertical and horizontal directions. The scan begins at point A in Fig. 11.2 and proceeds to point B. During flyback, which occurs very rapidly, no information is transmitted. The next line is scanned from C to D and the process is repeated until point F is reached. At this point flyback occurs to point A and the scanning of the complete picture is repeated.

The above explanation is based on the assumption that both image capture and display systems are based on vacuum tubes with scanning electron beams. In many personal computer systems, for example, the CRT has been replaced by a liquid crystal display in which the individual pixels are addressed by a switching waveform generated from a digital circuit and such displays are also employed in miniature TV receivers. It is also commonplace for image capture devices to be based on solid-state technology (see Section 11.18) and in such cases the scanning electron beam is replaced by a similar switching waveform. The scanning electron beams are thus replaced by synchronized switching waveforms, but the scanning process illustrated in Fig. 11.2 is still relevant to the production of television images.

It can be seen from Fig. 11.2 that each picture scan takes a finite time. If this time is longer than the duration of persistence of vision the eye will perceive flicker on the picture. If the scan time is very short the number of pixels/second and hence the signal bandwidth will be large. The optimum scan rate is therefore one that is just fast enough to avoid flicker. The picture frequency at which flicker occurs is related to the luminance of the picture being viewed. For television systems, flicker is avoided when the picture rate is as low as 25 complete scans/second. This is made possible by use of interlaced scanning, which is shown in Fig. 11.3.
Fig. 11.3 Interlaced scanning.

The scan now occurs in two fields, the odd field starts at A and the line is scanned until point B. Flyback then occurs from B to C and so on. It will be seen from Fig. 11.3 that the last line is scanned from D to E, i.e. field flyback occurs from E to F. (In fact this flyback takes the equivalent of several line scan periods so will not be a straight line as shown in Fig. 11.3.) The even field starts half-way across the picture at F and the scan of the first line finishes at G, flyback occurring from G to H. The last line of the even field is scanned from I to J, flyback then occurs to point A, which is the start of the next odd field.

Interlaced scanning avoids flicker because although each complete picture is scanned 25 times/second, a localized area of the picture is scanned by both odd and even fields. Thus each such area is apparently scanned 50 times/second. This deception relies on the fact that the variation in brightness in a vertical direction usually occurs gradually. If there is a significant difference in the brightness between one line and the next, some localized flicker will be observed. It should be noted that two field frequencies are in common use i.e. 50 fields/second or 60 fields/second depending on the local power supply frequency.

It has been pointed out that it is necessary to synchronize the scans in the image capture system and the display device. To achieve this, a line-synchronizing pulse is transmitted at the end of each line and a field-synchronizing pulse is transmitted at the end of each field. The synchronizing pulses trigger the flyback circuits in the television receiver. The transmitted video signal thus has distinct components, i.e. the picture signal that represents the variation in brightness of each line and the synchronizing pulses that are transmitted below black level. The composite waveform is shown in Fig. 11.4.

The 625 line transmissions in the UK use negative amplitude modulation of the vision carrier, i.e. an increase in picture brightness produces a decrease in signal level. A portion of the envelope of the modulated signal is shown in Fig. 11.5. The advantage of negative modulation is considered to be that the black spots produced on the screen by some forms of ignition interference are less objectionable than the white spots that would be produced in the same circumstances if positive modulation were used. The ratio \( WB/BS \) shown in Fig. 11.5 is known as the picture/sync ratio and has a value of 7/3. This is a compromise figure that produces a reasonable picture quality and adequate
synchronization in poor SNR conditions. Figure 11.5 shows that a portion of each line before, and just after, each line synchronizing pulse is at black level. This allows the line flyback to be suppressed and hence no visual output is produced during this interval. A similar provision is made at the end of each field, but in this case the duration of black level extends for 25 line periods. This means that in one complete picture (two fields) there are 50 lines which are suppressed. These lines are actually used for various forms of data transmission which is considered in Section 11.8.

11.4 BANDWIDTH OF A TELEVISION WAVEFORM

The bandwidth of a television waveform is directly related to the number of pixels transmitted per second. In each 625 line picture 25 lines are blanked off at the end of each field and the number of lines seen by a viewer is thus \((L - L_b)\) where \(L = 625\) and \(L_b = 50\). The vertical resolution of the picture is equal to the number of lines seen. Assuming equal horizontal and vertical resolution the number of pixels per line is \(A (L - L_b)\) where \(A(=4/3)\) is the picture aspect ratio (width/height). Since each line is blanked out for a period of \(H_b\), the
The number of pixels transmitted per second is

\[ P_s = \frac{A(L - L_b)}{H - H_b} \]

For a 625 line system the line period \( H = 64 \mu s \) and \( H_b = 12.05 \mu s \) giving a value of \( P_s = 14.76 \times 10^6 \) pixels/second. The maximum signal bandwidth occurs when adjacent pixels alternate between black level and peak white. The video signal is then represented by a square wave as shown in Fig. 11.6. It can be seen from this figure that it is possible to transmit adjacent black and peak white levels by a sine wave with a period equal to the period of two pixels. The bandwidth required is then \( 1/T \) which, in the 625 line system, is 7.38 MHz. It is clear from Fig. 11.6 that if the transmission bandwidth is restricted to this figure then the sharp edges of the square wave will be lost. This is virtually undetectable in practice because of the finite size of the scanning beam, which does not allow detail of this resolution to be displayed in any case. Statistically speaking, very few pictures require the degree of resolution allowed by a bandwidth of 7.38 MHz. Use is made of this fact to reduce the signal bandwidth even further. The actual bandwidth allowed for 625 line transmissions is \( K \times 7.38 \) MHz. The constant \( K \) is known as the Kell factor. The value of \( K \) depends upon several elements, e.g. the width of each line on the CRT and the low-pass filtering effect of the eye (which itself depends upon how close the viewer is to the CRT). The value of \( K \) used in Great Britain is 0.73, which gives an acceptable subjective picture quality and results in a video bandwidth of 5.5 MHz.

### 11.5 CHOICE OF NUMBER OF LINES

There have been various standards in operation throughout the world, but this has now been essentially reduced to two, 525 lines in North America, Greenland and Japan and 625 lines elsewhere. All the systems that have been used have one feature in common, the use of an odd number of lines. The reason for this can be explained by reference to Fig. 11.3. If each picture has \( 2n + 1 \) lines, then each field will have \( n + \frac{1}{2} \) lines. If it is assumed that the distance between adjacent lines of the same field is \( d \) the odd field scan finishes halfway across the last line. This means that field flyback (if assumed instantaneous) would cause the even field to start halfway across the first line and would therefore be a distance of \( d/2 \) above the first line of the previous field. Interlacing is thus achieved automatically with the same field deflection on both odd and even fields.

![Image](image_url)  

**Fig. 11.6** Television picture bandwidth.
11.6 SYNCHRONIZING PULSES

Pulses are required to trigger both line and field timebase generators in the receiver. In early receiver designs the transmitted synchronizing pulses were used directly and this imposed a number of requirements on these pulses. The detail of the line synchronizing pulse is shown in Fig. 11.7. The line flyback is triggered by the leading edge of the synchronizing pulse. To avoid a ragged picture the triggering must be fairly precise. This means that the rise time of

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**Fig. 11.7** Details of synchronizing pulses.
the pulse should be as short as possible and trigger level should not be affected by the level of the luminance signal just before the synchronizing pulse. In the 625 line system a rise time of 0.2 \( \mu s \) is specified and it may be seen, by reference to Fig. 11.7(b), that this requires a signal bandwidth exceeding \( f = 2.5 \) MHz. This is well within the allotted bandwidth of 5.5 MHz.

It will be seen from Fig. 11.7(a) that the video signal is reduced to black level for a short interval before and after the line sync pulse; these intervals are known as the front and back porch, respectively. The function of the front porch is illustrated in Fig. 11.7(c). The luminance signal can have any value between peak white and black level at the end of each line. In the absence of the front porch the time taken for the video signal to drop to the triggering level would vary with the amplitude of the luminance signal just before the leading edge of the synchronizing pulse. The timing of the flyback would then vary from line to line giving a ragged picture. The front porch ensures that each line is reduced to black level before the leading edge of the synchronizing pulse. The flyback then occurs at the same instant at the end of each line.

The back porch has two functions – it ensures that the beam is blanked off during line flyback and also provides a convenient reference for restoring the zero frequency component to the signal which has been passed through ac coupled amplifiers.

The field synchronizing pulses occur at the end of each field and their purpose is to trigger the vertical deflection system. It is important that precise triggering is affected to ensure correct interlace of the odd and even fields. The field synchronizing pulses must obviously be distinguishable from the line synchronizing pulses. The picture sync ratio is fixed as 7/3, and hence to distinguish the two types of pulses the field synchronizing pulses are made much wider than the line synchronizing pulses. These pulses have, in fact, a duration of approximately 2.5 line periods.

Modern receivers do not use the transmitted synchronizing pulses directly but use a form of line synchronization known as flywheel synchronization. Instead of using individual sync pulses to trigger each line scan the frequency and phase of locally generated line synchronizing pulses are compared with those present on the incoming video waveform in a phase detector. Any phase error is averaged and fed back to a voltage-controlled oscillator which pulls the two streams of synchronizing pulses into phase coincidence. This averaging effect minimizes the effect of noise and interference on the incoming sync pulses and produces superior picture quality. It is therefore no longer strictly necessary to provide line synchronization pulses during field flyback for modern TV receivers.

Figure 11.8 shows the detail of the field and equalizing pulses transmitted in the UK. The equalizing pulses also relate to early TV designs in which line and field pulses were separated using an integrator. (Integrators produced a higher output for wide field pulses than for narrow line pulses). The equalizing pulses were inserted to ensure that the residual output of the integrator was the same on odd and even fields, thereby ensuring accurate interlacing. In modern receivers line and field pulses are separated in a single IC which also accommodates flywheel synchronization. In such devices simple counter circuits produce the field synchronizing pulses at the correct instants.
11.7 THE TELEVISION RECEIVER

The domestic television receiver is required to receive signals over a wide bandwidth and is based on the superheterodyne principle. The television receiver is considerably more complicated than a broadcast radio receiver because the former is required to reproduce a video signal, synchronized scanning waveforms for the CRT, and a sound signal. The block diagram of a typical monochrome receiver is given in Fig. 11.9.

Fig. 11.9 Superheterodyne television receiver.
The British 625 line system transmits the video signal using amplitude modulation of the vision carrier and frequency modulation of a sound carrier 6 MHz above the vision carrier. (The original FM sound carrier is now accompanied by an additional carrier 6.552 MHz above the video carrier which is used for digital transmission of stereophonic sound. The coding scheme used is known as NICAM, which is covered in detail in Section 3.6.) The local oscillator in the receiver operates at 39.5 MHz above the vision carrier, the difference frequency being used as the vision IF. The relative positions of sound and vision carriers will of course be reversed in the IF signal. The spectrum of the IF signal and the frequency response of the IF amplifier are shown in Fig. 11.10.

The asymmetric response of the IF amplifier around the frequency of 39.5 MHz is required to compensate for the vestigial sideband transmission of the vision signal. The detection of VSB signals is discussed fully in Section 2.12. The IF amplifier response is 30 dB down at the FM sound carrier frequency. This is required because both sound and vision carriers are applied

![Diagram](image)

**Fig. 11.10** Signal spectra: (a) transmitted signal spectrum; (b) spectrum of 625 IF signal; (c) IF amplifier response.
to the vision detector, which then produces sum and difference frequencies between these two carriers. The difference frequency of 6 MHz is used as the sound IF and this is known as the 'intercarrier sound' principle. This component will be modulated in both amplitude and frequency. The 30 dB drop in the IF amplifier response at the sound carrier frequency ensures that the amplitude of the sound carrier is much less than the vision carrier. The resulting depth of amplitude modulation of the 6 MHz component is then consequently small and easily removed by limiting. (Note that in receivers designed to accommodate NICAM the digital sound carrier is extracted from the mixer output by a filter with a centre frequency of 32.95 MHz.)

Clearly the intercarrier sound principle requires both sound and vision carriers to be present at all times. This requirement is met by ensuring (see Fig. 11.5) that the vision carrier has a minimum amplitude of not less than 18% of its peak value. The demodulated vision signal is the drive signal for the cathode ray display tube. This is a thermionic device, in which the intensity of the electron beam emitted from the cathode is a function of the cathode-to-grid voltage. The electron beam is electronically focused onto a screen coated with a photo-emissive phosphor, which produces the displayed image. The light output of a CRT is not a linear function of the cathode-to-grid voltage, but is equal to this voltage raised to power \( \gamma \). This means that the output voltage \( E_Y \) produced by a television camera would not produce an acceptable image on a CRT. The non-linearity of the display device is equalized by pre-distorting the image capture system output voltage. The transmitted gamma corrected signal is \( E_Y^{1/\gamma} \) and has an important but unwanted effect on colour images, as will be considered in Section 11.13.

In addition to gamma correction, the vision signal must be further modified before it is applied to the cathode and grid terminals of the CRT. The dc component of the vision signal, which represents the average brightness of a picture, is removed when the vision signal is transmitted via ac-coupled amplifiers. The dc component also affects the synchronization of line and field timebase circuits, as illustrated in Fig. 11.11 and must be restored to the vision signal. A full discussion of the operation of dc restoration circuits is given by Patchett. After dc restoration the complete vision signal, including synchronizing pulses (which are actually below black level), is applied to the control grid of CRT.

The synchronizing pulses are separated from the picture information and are then used to trigger the line and field scan circuits. The scanning process in television tubes is produced using magnetic rather than electrostatic deflection, the electron beam being deflected at right angles to the magnetic field direction. There are several advantages associated with magnetic deflection systems, the main one being that the deflecting force is proportional to the electron beam velocity and thus increases as the anode accelerating voltage increases. Electrostatic systems, which are commonly used for oscilloscope applications, produce a force that is independent of beam velocity. This means that a high accelerating potential, required to give a bright image, would be accompanied by a small deflection because individual electrons would be influenced by the deflecting force for a shorter interval. The current in the deflection coils has a sawtooth waveform, and during flyback the
current changes very rapidly. This produces a considerable induced voltage, which is stepped up by a transformer action and used to form the anode accelerating voltage. A typical accelerating voltage for a colour tube is 15 kV.

Colour television transmission uses the same standards as monochrome transmissions. There are, however, several specific requirements, which must be met to produce acceptable colour images, and in order to understand these requirements it is first necessary to consider the properties of coloured light.

11.8 COLORIMETRY

The colours produced by the display tube in a colour television receiver depend upon the principle of additive colour mixing. This is based on the postulation that a large range of the subjective sensation of colour may be produced by adding certain primary colours in different proportions. This principle is quite different from the principle of the subtractive colour mixing used by artists to create different colours by mixing pigments. A wide range of primary colours can be chosen for the additive colour process, but the primary colours used in television transmission are red, green and blue.
Examples of some colours produced by these primaries are:

\[
\begin{align*}
\text{red} + \text{green} &= \text{yellow} \\
\text{red} + \text{blue} &= \text{magenta} \\
\text{blue} + \text{green} &= \text{cyan} \\
\text{red} + \text{blue} + \text{green} &= \text{white}
\end{align*}
\]

Coloured light is usually described in terms of hue (the actual colour), saturation (the dilution of the colour with white light) and luminance (the brightness). The response of the eye is additive, i.e. the luminance of a colour produced by adding three primary colours is the sum of the luminance of the individual primary colours. This algebraic relationship is referred to as Grassman’s Law.

White light can be defined in several ways; one convenient definition is equal energy white, in which the energy at all wavelengths has equal brightness because, as is apparent from Fig. 11.1, the sensation of brightness varies with wavelength. Using the response of the standard observer, equal energy white can be expressed in terms of the three primaries, \(R, G, B\) as

\[
1 \text{ lumen } W = 0.3 \text{ lumen } R + 0.59 \text{ lumen } G + 0.11 \text{ lumen } B \quad (11.2)
\]

In colour television trichromatic units (\(T\) units) are used to simplify Eqn (11.2). White light is then said to be composed of equal quantities of red, green and blue light when the latter are expressed in \(T\) units:

\[
1 \text{ lumen } W = 1T(R) + 1T(G) + 1T(B) \quad (11.3)
\]

where \(1T\) unit of red = 0.3 lumen, \(1T\) unit of green = 0.59 lumen, \(1T\) unit of blue = 0.11 lumen.

In order for Eqn (11.3) to balance, evidently 1 lumen of white = 3 \(T\) units. Equation (11.3) can be adapted to represent any colour in terms of \(R, G\) and \(B\):

\[
1T(C) = xT(R) + yT(G) + zT(B) \quad (11.4)
\]

The coefficients \(x, y, \text{ and } z\) in Eqn (11.4) are the trichromatic coefficients of the colour \(C\) and it is evident that since this equation obeys Grassman’s Law then \(x + y + z = 1\). This means that the colour \(C\) is actually defined in terms of two trichromatic coefficients. If \(x\) and \(y\) are known then \(z\) can be obtained from \(z = 1 - (x + y)\). Colour is often represented graphically in the form of a colour triangle as shown in Fig. 11.12, in which white is defined by the point \(x = 0.33\) and \(y = 0.33\) (hence \(z = 0.33\)). The point \(x = 0, y = 0\), on the other hand, represents saturated blue as in this case \(z = 1\). The colour triangle therefore represents both the hue (the actual colour) and the saturation (dilution with white light), for example the point \(x = y = 0.25\) represents 50\% desaturated blue as \(z = 0.5\) is the dominant component. The hue and saturation of any colour which can be produced using \(RGB\) primaries lies within the colour triangle of Fig. 11.12, but the range of colours produced in a colour television display system will ultimately depend upon the phosphors used in the CRT.

Red emitting phosphors are based on a rare earth material yttrium/oxy sul-
phide/europium, green emitting phosphors are based on zinc sulphide mixed
with copper and aluminium, blue emitting phosphors are based on zinc
sulphide mixed with silver.
In reality no three primaries exist that can produce the full visible range, and to overcome this problem a universal colour triangle based on hypothetical super-saturated primaries has been defined. All visible colours can then be defined in terms of these hypothetical primaries. This colour triangle is shown in Fig. 11.13.

The primaries used in display tubes in the UK lie within the visible spectrum which can be produced using the hypothetical primaries. The theoretical range of colours that can be produced by a colour television display tube then lies within the dotted triangle shown in Fig. 11.13. It should be noted that although the colour receiver can produce only a limited range of colour, this range is considerably greater than that of high-quality colour film. Equal energy white has the coordinates $x = 0.33$, $y = 0.33$, but the white used for television is slightly different and has the coordinates $x = 0.313$ and...
\[ y = 0.329, \text{ which is known as illuminant } D. \text{ This in no way affects the validity of Eqn (11.2).} \]

11.9 REQUIREMENTS OF A COLOUR TELEVISION SYSTEM

It may be concluded, from Eqn (11.4), that in order to transmit colour pictures it is necessary to split the light from the scene being viewed into its red, green and blue components, which are then recombined in the receiver. The bandwidth of the three signal components will be comparable to the figure of 5.5 MHz derived for monochrome signals in Section 11.4. Apart from the excessive bandwidth that such a transmission would require, it would not be compatible with monochrome receivers, i.e. the monochrome receiver would not be able to produce an acceptable black and white image. The requirement of compatibility is an important one and has dominated the development of terrestrial colour television system. However, compatibility is much less of an issue in satellite broadcast systems and this has led to the development of superior colour systems.

This chapter deals primarily with the PAL system which is used in Western Europe (except France and Greece), Australasia and some South American Countries. PAL is based upon the American National Television Standards Committee (NTSC) system, but there are several important differences that will be highlighted at the appropriate point in the text. There are also some minor differences in the PAL standard used in various countries, for example in Australia the sound carrier is 5.5 MHz above the vision carrier. In addition to PAL a brief description of the SECAM system which is used in France, Greece, Cyprus and Eastern Europe is given in Section 11.16, and a brief description of the MAC system, used for some satellite direct broadcast transmissions, is given in Section 11.17.

11.10 THE PAL COLOUR TELEVISION SYSTEM

The basic concept used in all three terrestrial systems mentioned in the previous section is that the colour signal is split into two distinct components. The luminance signal carries the brightness information and is identical to the monochrome signal described earlier. The chrominance signal transmits the colour information (i.e. hue and saturation). Splitting the transmitted information into these categories provides the necessary compatibility because the luminance signal produces an acceptable image in monochrome receivers.

In a monochrome television system, the camera response closely approximates the response of the standard observer. In a colour receiver the red, green and blue signals should approximate to the energy in the primary colours. This is because the eye actually sees the colour image and performs its own relative attenuation on this image, hence when displaying white light red, green and blue signals should be equal in magnitude. The luminance signal can be derived in two ways. One method is to use a standard mono-
chrome camera tube; the other method is to combine the outputs of three separate camera tubes, each tube producing an output corresponding to a different primary colour. When viewing white light the outputs of these three cameras $E_R$, $E_G$, and $E_B$ are adjusted to be equal. The camera output voltages are therefore interpreted directly in trichromatic units. The luminance signal is derived by combining these outputs according to Eqn (11.2).

$$E_Y = xE_R + yE_G + zE_B$$ (11.5)

where $x = 0.3, y = 0.59$ and $z = 0.11$.

The colour receiver requires a separate knowledge of the $E_R$, $E_G$, and $E_B$ signals. Ideally the chrominance signal should not transmit any brightness information, as this is already transmitted in the luminance signal. If the effects of gamma correction are ignored it may be shown that this condition is satisfied when the chrominance signal is transmitted in the form of colour-difference signals. The colour-difference signals are:

$$(E_R - E_Y)(E_G - E_Y)(E_B - E_Y)$$

where $E_Y$ is the luminance signal defined by Eqn (11.5)

i.e.

$$(E_R - E_Y) = (1 - x)E_R - yE_G - zE_B$$
$$(E_G - E_Y) = (1 - y)E_G - xE_R - zE_B$$
$$(E_B - E_Y) = (1 - z)E_B - yE_R - xE_G$$ (11.6)

When transmitting a black and white picture $E_R = E_G = E_B$ and since $x + y + z = 1$, then

$$(E_R - E_Y) = (1 - x - y - z)E_B = 0$$

This result is true for the other colour-difference signals also, indicating that these signals do not contain any brightness information. The original $E_R$, $E_G$, and $E_B$ can, of course, be reproduced at the receiver simply by adding the luminance signal to the colour-difference signals in turn.

The chrominance signal is in fact completely defined by any two of the colour-difference signals. This can be shown as follows, from Eqn (11.5):

$$E_G - \frac{1}{y}E_Y - \frac{x}{y}E_R - \frac{z}{y}E_B$$

Therefore

$$(E_G - E_Y) = \frac{1 - y}{y}E_Y - \frac{x}{y}E_R - \frac{z}{y}E_B$$

but $(1 - y) = x + z$. Hence

$$(E_G - E_Y) = -\frac{x}{y}(E_R - E_Y) - \frac{y}{z}(E_B - E_Y)$$ (11.7)

The green colour-difference signal can thus be derived from the other two colour-difference signals and need not be transmitted. In fact any one of the colour-difference signals could be reproduced from the other two. The values
of \((E_R - E_Y)(E_G - E_Y)\) and \((E_B - E_Y)\) may be calculated for a range of transmitted colours and such calculations reveal that the mean square value of the green colour difference is significantly less than the mean square values of the other colour difference signals. The SNR performance will therefore be greatest when the \((E_R - E_Y)\) and \((E_B - E_Y)\) signals are transmitted.

In addition to providing compatibility, the colour television signal must be confined to the same bandwidth as a monochrome signal, otherwise adjacent channel interference would be a serious problem. The question then has to be answered as to how it is possible to fit the chrominance signal into a bandwidth which is already fully occupied by the luminance signal. Fourier analysis of the luminance signal shows that it does not completely occupy the bandwidth allocated to it. The scanning process may be regarded as a sampling operation, and the spectrum produced will be composed of the sum and the difference frequencies centred on harmonics of the sampling frequency (in this case the line frequency). Using the sampling analogy, and noting that the sampling frequency is much larger than the maximum frequency of the signal being sampled, it is clear that there will be periodic gaps in the spectrum of the sampled signal. This is the case with the luminance signal, which has a spectrum of the form shown in Fig. 11.14.

The chrominance signals will have a similar spectrum; the actual amplitude of the components will of course be different. If it assumed that the red and blue colour-difference signals can be combined, it is apparent from Fig. 11.14 that the chrominance spectrum can be slotted into the gaps in the luminance spectrum. To achieve this it necessary to shift the spectrum of the combined chrominance by modulating a sub-carrier of frequency equal to \(\frac{1}{2}n f_L\), where \(n\) is an odd integer.

The effect of such a modulated sub-carrier on a monochrome receiver is shown in Fig. 11.15. This component will produce an unwanted modulation of the CRT in the receiver. As the chrominance sub-carrier is an odd multiple of the half-line frequency the unwanted modulation on any line should cancel

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**Fig. 11.14** Amplitude spectrum of a luminance signal.

**Fig. 11.15** Effect of chrominance signal on a monochrome receiver.
when that line is scanned a second time. In fact this cancellation is not complete. There are several reasons for this, one of the more important being that the light output from a CRT is not linearly related to the grid–cathode voltage (i.e. the decrease in brightness of negative half-cycles of modulation is not equal to the increase in brightness on positive half-cycles of modulation). The result is that a very fine dot pattern is produced on the CRT of a monochrome receiver. This is only visible if the picture is viewed closely and it is usually ignored.

11.11 TRANSMISSION OF THE CHROMINANCE SIGNALS

In the previous section it was assumed that the red and blue colour-difference signals were combined to form a single chrominance signal, the spectrum of which could be fitted into the gaps in the luminance spectrum. The technique used to combine the colour-difference signals uses quadrature amplitude modulation of the chrominance sub-carrier and is similar to the QAM described in Section 3.20. The resulting QAM in this case is given by Eq (11.8)

\[ h_c(t) = h_r(t) \cos (2\pi f_{sub}t) + h_b(t) \sin (2\pi f_{sub}t) \]  \hspace{1cm} (11.8)

where \( h_r(t) \) and \( h_b(t) \) represent the red and blue colour-difference signals, respectively. The composite signal may be conveniently slotted into the gaps in the luminance spectrum. Each of the two colour-difference signals is obtained from the chrominance signal at the receiver by coherent detection, which requires the local generation of \( \cos (2\pi f_{sub}t) \) and \( \sin (2\pi f_{sub}t) \). The outputs of the coherent detectors are:

\[ h_r(t) \cos (2\pi f_{sub}t) = \frac{1}{2} h_r(t) [1 + \cos (4\pi f_{sub}t)] + \frac{1}{2} h_b(t) \sin (4\pi f_{sub}t) \]  \hspace{1cm} (11.9)

and

\[ h_b(t) \sin (2\pi f_{sub}t) = \frac{1}{2} h_r(t) [1 - \cos (4\pi f_{sub}t)] + \frac{1}{2} h_b(t) \sin (4\pi f_{sub}t) \]  \hspace{1cm} (11.10)

It is clear from these equations that \( h_r(t) \) and \( h_b(t) \) may be readily obtained by filtering.

Coherent detectors require the locally generated components to be in phase with the suppressed chrominance sub-carriers. The maximum phase error that can be tolerated is in fact \( \pm 5^\circ \). The local oscillator thus requires synchronization which is accomplished by transmitting 10 cycles of sub-carrier tone on the back porch of each line synchronizing pulse. The tone is used to synchronize the local oscillators. The detection process is illustrated in Fig. 11.16.

The QAM process is effectively the addition of two double sideband suppressed carriers in phase quadrature. The phasor diagram for the QAM signal may be derived from the phasor diagram of two DSB-AM carriers in phase quadrature as in Fig. 11.17. When the carriers are suppressed the resultant is a single modulated component that varies both in amplitude and phase. It may be shown that the phase of this component represents the transmitted colour (i.e. the hue) and the amplitude of the component
Fig. 11.16 Recovery of colour-difference signals.

Fig. 11.17 Phasor representation of chrominance sub-carrier.

represents the saturation. The amplitude of the resultant phasor $C$ is proportional to $\sqrt{[(E_R - E_V)^2 + (E_B - E_Y)^2]}$ and the phase $\phi$ is proportional to $\tan^{-1}[(E_R - E_V)/(E_B - E_Y)]$. It is convenient to represent various hue and saturation combinations in tabular form. In this context the percentage saturation of any colour is defined in terms of the RGB primaries as

$$S = \frac{\text{maximum amplitude} - \text{minimum amplitude}}{\text{maximum amplitude}} \times 100 \quad (11.11)$$

The hue and saturation for three representative colours are given in Table 11.1 together with the resulting amplitude and phase of the chrominance.

### Table 11.1 PAL chrominance sub-carrier amplitude and phase

<table>
<thead>
<tr>
<th>Colour (Hue)</th>
<th>Saturation (%)</th>
<th>$E_R$</th>
<th>$E_G$</th>
<th>$E_B$</th>
<th>$E_V$</th>
<th>$E_R - E_V$</th>
<th>$E_B - E_Y$</th>
<th>$C$</th>
<th>$\phi$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>100</td>
<td>1.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.30</td>
<td>0.70</td>
<td>0.30</td>
<td>0.76</td>
<td>113.19</td>
</tr>
<tr>
<td>Red</td>
<td>50</td>
<td>1.00</td>
<td>0.50</td>
<td>0.50</td>
<td>0.65</td>
<td>0.35</td>
<td>0.15</td>
<td>0.38</td>
<td>113.19</td>
</tr>
<tr>
<td>Red</td>
<td>25</td>
<td>1.00</td>
<td>0.75</td>
<td>0.75</td>
<td>0.83</td>
<td>0.18</td>
<td>0.08</td>
<td>0.19</td>
<td>113.19</td>
</tr>
<tr>
<td>Yellow</td>
<td>100</td>
<td>1.00</td>
<td>1.00</td>
<td>0.00</td>
<td>0.89</td>
<td>0.11</td>
<td>0.89</td>
<td>0.89</td>
<td>172.95</td>
</tr>
<tr>
<td>Yellow</td>
<td>50</td>
<td>1.00</td>
<td>1.00</td>
<td>0.50</td>
<td>0.95</td>
<td>0.06</td>
<td>0.45</td>
<td>0.45</td>
<td>172.95</td>
</tr>
<tr>
<td>Yellow</td>
<td>25</td>
<td>1.00</td>
<td>1.00</td>
<td>0.75</td>
<td>0.98</td>
<td>0.03</td>
<td>0.22</td>
<td>0.22</td>
<td>172.95</td>
</tr>
<tr>
<td>Magenta</td>
<td>100</td>
<td>1.00</td>
<td>0.00</td>
<td>1.00</td>
<td>0.41</td>
<td>0.59</td>
<td>0.59</td>
<td>0.83</td>
<td>45.00</td>
</tr>
<tr>
<td>Magenta</td>
<td>50</td>
<td>1.00</td>
<td>0.50</td>
<td>1.00</td>
<td>0.71</td>
<td>0.30</td>
<td>0.30</td>
<td>0.42</td>
<td>45.00</td>
</tr>
<tr>
<td>Magenta</td>
<td>25</td>
<td>1.00</td>
<td>0.75</td>
<td>1.00</td>
<td>0.83</td>
<td>0.15</td>
<td>0.15</td>
<td>0.21</td>
<td>45.00</td>
</tr>
</tbody>
</table>
sub-carrier. The last two columns in the table indicate that the phase of the sub-carrier represents the colour transmitted (i.e. the hue) and the amplitude of the sub-carrier represents the saturation. This being so, it is clear that any phase error in the chrominance sub-carrier which may occur during the transmission will thus produce an incorrect hue at the receiver. The PAL system is specifically designed to compensate for this type of phase error and is a development of the NTSC system, which is described in Section 11.14. The sub-carrier frequency used in the British system is 4.433618 MHz, which is equal to \((283.5 + 0.25) \times \text{line frequency} + 25 \text{ Hz}\). This differs from the odd multiple of the half-line frequency specified earlier (which is the value used in the NTSC system). The reason for the difference is related to the effect of the PAL compensation for sub-carrier phase error. If a sub-carrier frequency of \(\frac{1}{2} f_L\) is used with PAL an objectionable dot pattern is found to ‘crawl’ across the display. This is avoided by modifying the sub-carrier frequency as indicated.

11.12 THE TRANSMITTED PAL SIGNAL

The bandwidth of the luminance (i.e. monochrome) signal is fixed at approximately 5.5 MHz. In order to fit the modulated sub-carrier into this bandwidth it is necessary to restrict the sidebands to a bandwidth of 1 MHz. The resolution of the chrominance signal is therefore considerably less than the luminance signal. This is not usually detectable by the eye which is insensitive to high-definition colour. The combined luminance and modulated chrominance signal as shown in Fig. 11.18 is then used to modulate the main vision carrier.

This combined signal is less than ideal for several reasons, for instance in the monochrome receiver there is no provision for removing the chrominance sub-carrier and this signal will consequently be applied to the CRT along with the luminance signal. In the colour receiver it is not possible to separate the luminance and chrominance signals completely which gives rise to a form of distortion known as cross-colour distortion. Before discussing these effects in detail it is necessary to consider the significance of gamma correction in the case of colour television.

![Fig. 11.18 PAL combined luminance and chrominance signals.](image-url)
11.13 GAMMA CORRECTION

Most commonly used image capture systems produce an output voltage proportional to the light input and are said to have a gamma value $\gamma = 1$. However, it has already been indicated in Section 11.7 that the light output of a CRT = (grid to cathode voltage)$\gamma$, where $\gamma$ has a numerical value of 2.2. To compensate for the non-linearities of the CRT the transmitted luminance signal should be $E_{Y}^{1/\gamma}$, i.e.

$$E_{Y}^{1/\gamma} = (0.3E_k + 0.59E_{\alpha} + 0.11E_{b})^{1/\gamma} \tag{11.12}$$

In a colour system each of the separate colour signals is individually gamma corrected, the resulting luminance signal being

$$E_{Y}^{1/\gamma} = (0.3E_k)^{1/\gamma} + (0.59E_{\gamma})^{1/\gamma} + (0.11E_{b})^{1/\gamma} \tag{11.13}$$

The actual light output produced at the CRT is obtained by raising Equs (11.12) and (11.13) to the power $\gamma$. Equation (11.12) produces the correct luminance value for all values of $E_k$, $E_{\alpha}$, $E_{b}$ but Eqn (11.13) produces the correct luminance value only when $E_k = E_{\alpha} = E_{b}$. This occurs only on black and white scenes. For coloured scenes the light output produced by Eqn (11.13) is less than the light output produced by Eqn (11.12). This means that intensely coloured parts of a picture will be reproduced on a monochrome receiver with a lower luminance than the correct value. This error is reduced, to some extent, by the presence of the chrominance sub-carrier which will have a large amplitude on saturated colours, and no attempt is made to remove this component in monochrome receivers. This is regarded as an acceptable compromise from the compatibility point of view.

The situation in a colour receiver is quite different. The individual gamma-corrected colour signals are obtained and applied simultaneously to the CRT. The light output obtained by raising these individual signals to the power $\gamma$ is therefore correct, i.e.

$$(E_{Y}^{1/\gamma})^{\gamma} = E_k$$

The consequence of this is that if the light output is correct in the colour receiver then part of the luminance information in the gamma-corrected colour signals must be contained in the chrominance signal, which is not used in the monochrome receiver. Therefore the gamma-corrected signals do not provide the required monochrome compatibility.

The signal which is used to modulate the vision carrier is $E_r$ + chrominance sub-carrier (which is equivalent to a sinusoidal component of varying amplitude and phase). In monochrome transmissions the maximum depth of modulation of the vision carrier occurs on peak white. In colour transmissions maximum modulation occurs on bright yellow, the total video signal amplitude being 1.78 times the peak white value. The next peak occurs at bright cyan, the total amplitude being 1.46 times the peak white value. It is clear from Fig. 11.5 that overmodulation of up to 78% of the vision carrier could result. This overmodulation is reduced to a practically acceptable value of 33% which only occurs rarely. Considering the transmission of bright yellow and taking $\gamma = 2.2$ the values of the luminance and chrominance
components are:

\[ E'_Y = 0.92 \quad (E_{R'}^{1/\gamma} - E'_Y) = 0.08 \quad (E_{B'}^{1/\gamma} - E'_Y) = -0.67 \]

For bright cyan the figures are:

\[ E'_Y = 0.78 \quad (E_{R'}^{1/\gamma} - E'_Y) = -0.53 \quad (E_{B'}^{1/\gamma} - E'_Y) = 0.22 \]

Multiplying factors \( m \) and \( n \) are chosen for the gamma-corrected colour-difference signals to restrict total amplitude of the vision carrier to 1.33, i.e.

\[ E'_Y + \{ n^2 (E_{R'}^{1/\gamma} - E'_Y)^2 + m^2 (E_{B'}^{1/\gamma} - E'_Y)^2 \}^{1/2} = 1.33 \quad (11.14) \]

The numerical equations for bright yellow and cyan are

\[ 0.92 + \{ (0.08n^2) + (0.6/m)^2 \}^{1/2} = 1.33 \]
\[ 0.78 + \{ (0.53n^2) + (0.22m)^2 \}^{1/2} = 1.33 \]

Solving these equations gives \( m = 0.877 \) and \( n = 0.493 \). The \( \gamma \)-corrected colour-difference signals transmitted in the PAL system are called \( U \) and \( V \) signals and are given by

\[ U = 0.493 (E_{R'}^{1/\gamma} - E'_Y) \]
\[ V = 0.877 (E_{B'}^{1/\gamma} - E'_Y) \quad (11.15) \]

The original components \( E_{R'}^{1/\gamma}, E_{G'}^{1/\gamma} \) and \( E_{B'}^{1/\gamma} \) may then be reproduced in the receiver for applying separately to the CRT.

It is common practice to use a colour bar test signal known as the CVBS (chroma, video, blanking and sync) in setting up television receivers and such a signal clearly demonstrates the concept of the allowable overmodulation

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Fig. 11.19 Standard colour bar CVBS reference signal.
outlined above. This standard signal has a nominal value of 1 V peak-to-peak and is the reference signal at the video input and output sockets of cameras, video recorders, monitors and so on. The reference signal is shown in Fig. 11.19. It may be seen from this figure that peak white has a value of 0.7 V, bright yellow has a maximum value of 0.934 V (1.334 × peak white) and bright cyan has a maximum value of 0.933 V (1.332 × peak white).

11.14 THE NTSC CHROMINANCE SIGNAL

The NTSC chrominance signal differs significantly from the PAL equivalent. The NTSC system transmits I and Q signals instead of colour-difference signals. The I and Q signals and their relationship to colour difference signals are shown in Fig. 11.20. The rationale for the use of I and Q signals is based on the observation that the human eye is most sensitive to colour detail in orange and cyan hues and is least sensitive to colour detail in green and magenta hues. This means that the Q signal may be transmitted in a relatively narrow bandwidth, double sideband transmission being employed. The I signal is transmitted in a much larger bandwidth with vestigial sideband transmission.

The I and Q signals may be fully separated at the receiver over the bandwidth of the Q signal, using normal coherent detection with quadrature carriers, as two sidebands are present for both signals. Compensation is necessary for the I signal for the frequencies present in one sideband only, as is usual for vestigial sideband detection.

Restricting the bandwidth of the Q signal in this way means that the highest possible chrominance sub-carrier frequency may be used which produces the finest possible dot pattern on monochrome receivers. In colour receivers the high chrominance sub-carrier frequency means that spurious colour effects

![Diagram of NTSC chrominance signals](image-url)

Fig. 11.20 NTSC chrominance signals.
due to adjacent luminance components (which are not fully removed by the sub-carrier detection circuits) are minimized because the luminance energy decreases at the higher video frequencies. This is also true for PAL and is illustrated in Fig. 11.18.

The \( I \) and \( Q \) signals are derived from the red and blue colour-difference signals according to the relationship specified in Eqn (11.16). These colour-difference signals, and subsequently the colour signals themselves, may be derived from the \( I \) and \( Q \) signals at the receiver.

\[
I = 0.74(E_R - E_V) + 0.27(E_B - E_V) \\
Q = 0.48(E_R - E_V) + 0.41(E_B - E_V)
\] (11.16)

11.15 THE PAL RECEIVER

The PAL system is a development of the NTSC system, in which special provision is made to correct any phase errors that may occur in the chrominance sub-carrier. Such phase errors are mainly due to incorrect synchronization of the local oscillator and sub-carrier generator in the television receiver or to differential phase distortion in the transmission system. It is clear from Table 11.1 that the phase of the chrominance sub-carrier is related to the hue of the image and any phase error will produce incorrect colours. The PAL system compensates for this by reversing the phase of the \( V \) signal on alternate lines (PAL in fact means 'Phase Alternation, line by line'). In the receiver the correct phase of the \( V \) signal on alternate lines is restored by averaging the phase error over a period of two lines.

A sub-carrier that has a phase error of \( \theta \) is illustrated in Fig. 11.21. When the \( V \) signal is inverted on alternate lines by the receiver the phase error is also inverted (i.e. a positive phase shift of \( \theta \) on the received signal becomes a negative phase shift of \( \theta \) after the phase of the \( V \) signal is inverted). If the chrominance information on two adjacent lines is the same the average phase error over this period is zero. In practice the chrominance signal on adjacent lines will not be identical and complete cancellation of phase error will not result.

![Fig. 11.21 Alternate line inversion of the V signal.](image-url)
The averaging is carried out in most modern receivers by adding and subtracting the chrominance signal from its value on the previous line. This requires a delay of 64 μs, which is easily produced using a charge coupled delay line similar to the analogue shift registers shown in Fig. 11.28. A block diagram of the phase error averaging procedure is shown in Fig. 11.22. The matrix unit combines the $U$ and $V$ signals in the required ratios to produce the three gamma-corrected colour-difference signals. These signals are added to the luminance signal to produce the gamma-corrected primary colour waveforms which are fed to the tri-colour display device.

It is clear from the discussion of the PAL system that many compromises are made at various stages of production, transmission and detection of the composite video signal. Non-ideal circuit components invariably add further distortion to the eventual colour image produced. Most of the compromises which occur within the PAL system have been dictated by the requirement of compatibility with monochrome receivers. Ironically the monochrome receiver is now something of a rarity but the limitations due to the requirements of this compatibility remain. In satellite television systems monochrome compatibility was not an issue and much higher quality colour images are possible as a result. Before discussing satellite systems a brief consideration of a third widely used terrestrial system known as SECAM will be given. As with NTSC and PAL this system has also been constrained by the requirements of monochrome compatibility.

11.16 THE SECAM SYSTEM

The Séquentiel Couleur à Mémoire (SECAM) system differs from PAL and NTSC, which both transmit two colour-difference signals simultaneously, by transmitting two colour-difference signals sequentially. The red and blue colour-difference signals are transmitted separately on alternate lines using frequency modulation of the chrominance sub-carrier. There is no local chrominance sub-carrier required in this system, and hence phase distortion is not a problem. However both colour-difference signals are required at the receiver at the same time. SECAM meets this requirement by delaying each colour-difference signal by 1 line interval and using the delayed signal on the next line. Hence each transmitted colour-difference signal is used on two adjacent lines. This obviously halves the colour definition, but this is virtually
undetected since the luminance signal transmits the full definition. A block diagram of the SECAM action is given in Fig. 11.23.

The inherent simplicity of the SECAM system suggested by the block diagram of Fig. 11.23 is not in fact realized in practice. The frequency modulated chrominance sub-carrier produces a visible dot pattern on both monochrome and colour receivers which varies with the frequency deviation. Several signal-processing techniques are used to reduce this effect, which consequently increases the complexity of the receiver. Discussion of these techniques is beyond the scope of this text, and the reader is referred to Sims² for further information.

11.17 SATELLITE TELEVISION

Satellite communications are covered in detail in Chapter 14. In this section consideration will be confined to the specific issues associated with the transmission of television signals. Direct broadcasting from satellites, in geo-synchronous orbit, to individual homes became established during 1989 with the advent of the Astra 1A satellite. In order to be geo-synchronous, satellites are required to orbit at an altitude of approximately 35 800 km above the equator with a speed of 11 000 km/h, the orbital path is known as the Clarke Belt, after the man who first suggested using satellites for communications (see Section 14.1). Since the geo-synchronous orbital path is fixed it is necessary to regulate the number of satellites permitted and individual satellites are allocated a slot in the orbital path by the World Administrative Radio Conference (WARC). The main satellites visible from Europe are shown in Fig. 11.24.

Satellites are equipped with a number of transponders, receiving programmes and signalling information from an earth station on one frequency and transmitting the programmes back to earth on a different frequency, the frequencies used for the up and down links are in the range 10.95 GHz to 14.5 GHz.

Direct broadcast satellites are usually equipped with up to 10 transponders each of which has a transmitter power of about 100 W. Satellite TV transmissions therefore use frequency modulation to capitalize on the higher
immunity of such transmissions to noise and interference (see Section 4.9). Satellite channels are typically 27 MHz wide and often use the same transmission standards as terrestrial systems in the countries for which they are intended (i.e. PAL, NTSC etc.). These standards are far from ideal as they were designed specifically for amplitude modulation of the vision carrier. However, they do preserve compatibility which reduces the cost of receiving equipment. However, some satellites use an entirely different form of transmission known as multiplexed analogue components system or MAC.

11.17.1 The MAC standard

The terrestrial systems covered earlier in this chapter all exhibit significant compromises which are necessary to maintain compatibility with monochrome transmissions. For example in the PAL system it is not possible to completely separate the chrominance and luminance signals and this produces a form of distortion, in areas of the picture with fine definition, known as cross-colour. This appears in the form of spurious blue/yellow and red/green herringbone patterns. The MAC system is one of several new coding schemes that have been developed for broadcast systems which do not sacrifice quality for the sake of monochrome compatibility and is currently used on the Marcopolo satellite, positioned at 31°W relative to the Greenwich meridian.

The main attribute of the MAC signal is that the chrominance and luminance information are separated completely during transmission so that much higher quality images may be reproduced at the receiver. In addition MAC systems give good quality reception at a signal-to-noise ratio of 11 dB, compared to a figure of about 40 dB for amplitude modulated systems.
Current MAC transmissions are based on a 625 line standard and therefore are required to maintain the 64 $\mu$s line period. In the MAC system this interval is divided into four distinct slots (data, clamp, chrominance and luminance) and time compression techniques are used to accommodate both luminance and chrominance components. The line format for the MAC TV signal in Fig. 11.25.

In this figure the 64 $\mu$s line period is divided up into 1296 clock intervals of which 206 intervals are used for data transmission, 15 intervals are used for clamping purposes, 349 intervals are used for the analogue chrominance signal and 697 intervals are used for the analogue luminance signal. The remaining clock intervals are distributed between the necessary ramp-up and ramp-down periods between the four slots. The luminance signal is compressed in the ratio 3.2 and the chrominance signal in the ratio 3:1, a technique for achieving the required time compression is described in Section 11.18 under solid-state image capture devices. The time-compressed luminance and chrominance signals are used to frequency modulate the carrier. The uncompressed luminance signal in MAC has effectively the same bandwidth as in the PAL system. The uncompressed MAC chrominance signal has a bandwidth of 2.8 MHz compared with the 1 MHz figure for PAL.

The MAC digital data signal uses the same carrier frequency as the vision signal but the transmission mode is by PSK. The digit rate is therefore 20.25 Mb/s which fits within the allocated channel bandwidth of 27 MHz. The 206 bit data slot contains one run-in bit, a 6 bit word for line sync, 198 bits of data and one spare bit. The data bits are used to provide several high-quality voice channels, with multi-lingual options and many pages of teletext. The effective data rate is therefore 198 bits for each line period which is 3.09 Mb/s.

The satellite transmission reaches the receiver dish at microwave frequencies (12 GHz for example) and it is necessary to down-convert this frequency to a value suitable for transmission over a coaxial cable to the MAC decoder. The initial amplification and down-conversion to a first IF (usually between 950 MHz and 1.7 GHz) takes place at the point of reception (i.e. at the dish) in
a unit known as the low-noise block (LNB). The LNB has a noise figure between 1 dB and 1.6 dB with an overall gain of in the region of 60 dB. The output of the LNB is fed by coaxial cable to a satellite tuner which performs a second down-conversion to an IF of about 480 MHz. The coaxial feeder is also used to supply power to the LNB (typically 200 mA at 15 V). The signal at 480 MHz is then fed to a frequency demodulator and the original luminance and chrominance signals are produced in a MAC decoder. In order to achieve the full potential of MAC transmissions the final output of the decoder can be made available as RGB signals and the majority of modern TV receivers on sale in Europe can accept such signals via a EURO-AV (SCART) socket, which means that such a receiver can accommodate both satellite and terrestrial transmissions.

The satellite decoder system actually performs many ancillary functions. For example many broadcasts are scrambled and encrypted to prevent unauthorized reception. Authorized decoders often contain a ‘smart card’ which may be purchased from the programme company and will facilitate descrambling and decryption enabling normal reception for a fixed period. A typical satellite receiving system is shown in Fig. 11.26. The MAC system is able to accommodate various enhancements, in particular an increase in definition provided by the 1750 line high definition TV standard with an aspect ratio of 16:9. Using digital techniques this can provide compatibility with the 625 line standard with an aspect ratio of 4:3.

11.18 IMAGE CAPTURE AND DISPLAY SYSTEMS

Image capture systems are the electronic components of the television camera which transform incident light energy into electric signals. The television camera also consists of complex optical systems which are outside the scope of this chapter and will not therefore be covered. There are essentially two
forms of image capture systems in widespread use. One is based on a photoconductive vacuum tube, known as the vidicon, and the other form is based on charged-coupled solid-state electronic devices.

11.18.1 The vidicon tube

The construction of the basic vidicon tube is shown in Fig. 11.27. Incident light is focused on to a target disc of continuous photoconductive semiconductor material. The resistance of this material is inversely proportional to the intensity of incident illumination. The photo conductive target is scanned by a low-velocity electron beam, emitted from the cathode, which results in the rear surface of the target being stabilized at approximately cathode potential. The vidicon has electrostatic focusing supplemented by a magnetic focusing coil which is coaxial with the tube. The effect of these two focusing arrangements is to cause individual electrons in the scanning beam to move in a spiral path which coincides with the paths of other electrons at regular distances from the cathode. The focusing arrangements are adjusted so that one of these points of convergence coincides with the target and this produces a scanning spot size diameter in the region of 20 micron.

The front surface, or signal plate, is held at a potential of about 20 V, which produces a current flow through the resistance $R_d$. When there is no illumination this current is of the order of 20 nA and is known as the dark current. When an image is focused onto the target disc the conductivity of the disc rises in proportion to the intensity of illumination. This allows an electric charge to build up on the rear surface of the target disc and, between scans, the target disc gradually acquires a positive voltage relative to the cathode. The scanning beam deposits sufficient electrons to neutralize this charge and, in so doing, generates a varying current in $R_L$ (typically 200 nA). Since charge is conducted to the rear surface of the target disc over the whole of the interval between scans the vidicon is very sensitive.

However, the vidicon suffers from the two problems of dark current and long persistence (or lag). The dark current tends to produce shading and noise on the low intensity parts of reproduced images. Image persistence arises from the fact that the scanning electron beam does not fully discharge the target plate and this problem is particularly noticeable when levels of

![Fig. 11.27 The vidicon tube.](image-url)
illumination are low. A number of techniques are available to reduce these problems, one of which is the excitation of the face plate by low-level red light generated within the camera assembly.

The vidicon tube described is essentially a monochrome device and will produce a luminance signal. For colour transmission it is necessary to generate the individual RGB signals. This is achieved by using a matrixed face plate in which the front glass surface is covered with thin vertical stripes of RGB colour filter. The vidicon target is similarly divided into vertical strips each one precisely aligned with the corresponding colour filter. All strips on the target corresponding to a primary colour are connected together and brought out to a separate load resistor. Hence by this means it is possible to derive the individual RGB signals from a single tube. These signals are fed to a matrix unit which can produce the gamma-corrected luminance and chrominance signals.

There are several variations on this theme, for example some amateur equipment uses green, cyan and clear filter strips. The target strips behind the green filter produce a G signal, the strips behind the cyan filter produce a B + G signal and the strips behind the clear filter produce a R + B + G signal. It is therefore possible to generate the individual RGB signals by means of a simple matrix unit.

11.18.2 Solid-state image capture devices

Solid-state devices for image capture first appeared in amateur and professional equipment around about 1985. In such devices the photosensitive surface is not continuous but arranged as many thousands of separate silicon photodiodes arranged in horizontal rows equivalent to the lines in a television picture. Each photodiode is therefore equivalent to one pixel and during the 20 ms field period builds up a charge proportional to the light falling on it. Each photodiode is connected to the input of one cell of an analogue shift register, known as a charge-coupled (or bucket brigade) device, by a MOSFET which is normally OFF. Analogue voltages may be shifted through these devices in the form of the charge on a capacitor. The shift registers are arranged so that adjacent parallel inputs are connected to adjacent photodiodes in a vertical direction as shown in Fig. 11.28.

At the end of each field a transfer pulse is applied to the gate of each of the MOSFETs which causes the charge on each photodiode to be transferred to the appropriate input of the vertical analogue shift register (the number of vertical shift registers is equal to the number of pixels on each television line). Therefore at the end of each field the charge on each pixel is transferred to a cell of one of the vertical analogue shift registers. The complete images is thus stored in the shift registers. The last cell in each vertical analogue shift register is connected to the parallel input of a horizontal analogue shift register. Shift pulses are applied to each vertical shift register simultaneously causing the contents of each cell in the vertical registers to be shifted to the next cell above. The charge in the topmost cell of each vertical register is shifted into one of the cells of the horizontal register.

At this point the cells of the horizontal shift register contain the charge
values of the pixels of one complete horizontal line. The complete contents of
the horizontal register are shifted out serially in an interval corresponding to
the line scan interval and, after appropriate filtering, form the analogue video
waveform corresponding to one line. When this shift operation is complete
the next shift pulse is applied to the vertical registers, thereby loading the
horizontal register with the charge values of the pixels of the next complete
horizontal line, and so on. The horizontal shift pulse waveform has a
frequency of approximately 14.76 MHz, which corresponds to the number of
pixels per second given by Eqn (11.1).

It may be noted here that the horizontal shift register may be simply
employed to perform time compression of the luminance signal as is required
in the MAC transmission system described in Section 11.17. A time compression
of 3/2 would be achieved by clocking out the contents of horizontal shift
register (one line) at $1.5 \times 14.76$ MHz.

Clearly there is no scanning waveform or deflection system required with
this type of device and the clock and drive pulses are produced in a
timing/divider integrated circuit driven by a precision crystal oscillator. The
shift pulses required for the analogue shift registers are more complex than
the simple diagram of Fig. 11.28 would suggest. In practice a four-phase
switching waveform is required. Techniques for generating colour signals
from charge-coupled devices are based on similar principles to those of the
vidicon tube.
11.18.3 Display devices

Display devices in colour television systems are largely based on cathode ray tubes, but intense research is ongoing to perfect a large screen solid-state equivalent. This section will be confined to current practice and the basic construction of the colour display tube is as shown in Fig. 11.29.

The colour display tube is required to produce three separate images in the primary colours. The formation of a single colour image is then dependent on the averaging effect of the eye. The electron gun in the colour display tube contains three separate cathodes in line abreast formation. Each cathode produces an electron beam and the three beams are deflected magnetically to form the usual scanning action, but each beam is arranged to strike only the screen phosphor corresponding to its colour. These phosphors are arranged in vertical strips on the screen of the tube each strip producing either red, green or blue light when excited by the electron beam. To ensure that the output from each cathode strikes only its own colour phosphor a mask is placed about 12 mm in front of the screen. This mask is composed of elongated slots which allow the passage of electrons in the scanning beams. The slots are positioned so that electrons passing through strike only the appropriate phosphor and a colour picture is therefore produced.

The mask is clearly a major source of inefficiency in the tube as only about 20% of the incident beams actually reach the phosphor. This means that the mask itself absorbs considerable energy and, in so doing, heats up. Special arrangements are made so that expansion of the mask does not result in inaccuracy when the electron beams strike the screen. Special mounts are incorporated within the tube so that the mask expands in an axial direction.

A variant on the display tube described above is known as the Trinitron. The main difference is that the shadow mask is composed of slots which run the complete height of the tube (rather than the elongated variety shown in

![Fig. 11.29 Precision in-line display tube: (a) plan view of tube layout; (b) front view of mask.](image-url)
Fig. 11.29). There are also some differences in the electron gun assembly and focusing arrangements which allow a smaller spot size than is possible with the arrangement of Fig. 11.29. However, the operating principles of the in-line display tube and the trinitron are broadly similar.

11.19 TELETEXT TRANSMISSION

There are essentially two forms of data transmission for television receivers in the UK known as teletext and viewdata. Teletext is transmitted directly by the broadcast companies and viewdata is transmitted over the switched public telephone network (and therefore requires a modem). Teletext has been developed by individual broadcast companies to a common standard and it is possible to display many hundreds of pages of information on each network. It was noted in Section 11.4 that 25 lines on each field are blanked out to allow for the field flyback to return the scan to the top of the picture. Some of these lines (2.5 per field) are used to transmit field synchronization and equalization pulses and receiver circuits are adjusted so that the remaining blank lines do not appear on the screen. These remaining lines are therefore available for the transmission of data pulses that may occur above the black level. The teletext specification allows for 16 lines on each field to be used for data transmission logic 0 being equivalent to black level and logic 1 being equivalent to 66% of peak white level. These data signals are undetected on a standard receiver but can be separated from the normal video signal in specially equipped receivers.

Each page of teletext information contains up to 24 rows of text with 40 characters per row. Each character is represented by a 7 bit international code with an odd parity check (7 information bits + 1 parity bit ⇒ 8 bit byte). The odd parity has an additional receiver synchronization function when all 7 bits of the standard code have the same value. Unlike the asynchronous data transmission, described in Chapter 4, teletext transmission is synchronous and is therefore more efficient because start and stop bits are not required. Synchronizing information is required, however, and this is transmitted during the first five bytes of each row. This means that each row contains a total of 45 eight bit bytes.

The format of each line is shown in Fig. 11.30. The bits in each byte are identified by sampling the data at the centre of each bit interval, the sampler
being driven by a locally generated clock. This means that each row contains 360 bits, these bits being transmitted during one line scan interval using NRZ pulses. The bit rate used is $444 \times$ line frequency or 6.9375 Mb/s which means that 360 bits occupy 51.89 $\mu$s which allows 12.1 $\mu$s for line blanking purposes. The television receiver has a local clock running at this frequency which is synchronized with the incoming data stream by the first two bytes of each line. These bytes contain alternate 1s and 0s at the clock frequency and produce what is known as **clock run in**.

Once the local clock is synchronized it is necessary to detect the beginning of each individual 8 bit byte in order that correct decoding can take place. This is achieved by transmitting a special framing code 11 100100 as byte 3. The data stream is used as a serial input to an 8 bit shift register. When the register contains the framing code a flag is set indicating that the next bit will be the first bit of byte 4, i.e. byte synchronization is achieved. Rows 4 and 5 contain a row address (see later), the first character byte is byte 6 and the first step in decoding a character is to check the parity. A circuit that will produce an 8 bit parity check is shown in Fig. 5.9 and is composed of seven exclusive-OR gates. If a parity check fails (i.e. if the output of this circuit is a binary 0) the character is not decoded, but is replaced by the code for a blank.

Each page of text is composed of 24 rows, hence it is necessary for the decoder to be able to select individual pages and once a page has been selected, to assemble the rows of the page in the correct order. The rows within each page are recognized by a row address code that is transmitted in bytes 4 and 5 of each row. Since there are 24 rows in each page, a minimum of 5 bits is required to specify the number of row addresses. It is necessary at this point to consider the effect of occasional errors. An error in a character byte can be tolerated simply by omitting the character when this occurs. However, an error in the bytes containing the row address is much more serious, as this can cause a row to be wrongly placed within a page. To reduce the probability of such errors occurring, the page and row address are error-protected using a Hamming code. Hamming codes and error detection and correction are discussed in detail in Chapter 5. The code used for row addressing has a Hamming distance of 4, which means that it can correct a single error and can detect a double error.

To provide a Hamming distance of 4 each address bit is accompanied by a parity check bit, hence a total of 10 bits (address + parity) is required. Eight of these bits are transmitted in byte 5 of each row and the other two in byte 4. The remainder of byte 4 is used for a Hamming-coded magazine address which forms part of the page identification. Both row and magazine address codes are transmitted least significant bit first. The format is shown in Fig. 11.31.

![Fig. 11.31 Format of magazine and row address bits.](image)
The function of the row address is to direct the following 40 bytes of text data to the appropriate locations in the page memory. Before this is done the required page must be selected. The top row of each page is called the header row and has the row address 00000. This row contains only 32 text characters instead of the usual 40. The first 8 bytes of text data in the header row carry a page number code, a time code and a control code. These eight bytes are Hamming coded in the same way as bytes 4 and 5 of the other lines. The text in the header row, with the exception of the page number display, is the same for each page.

The page address code (tens and units) is transmitted as two 4 bit binary coded decimal (BCD) numbers with the appropriate Hamming error coding. BCD is used because this can be compared directly with the page selection number entered by the viewer from the decimal keyboard of his/her remote control unit. The page address code occupies bytes 6 (units) and 7 (tens) of the header row. The next four bytes are used for transmitting the minutes (units and tens) and hours (units and tens) of the time code, the Hamming coded BCD format being used for these bytes also. The next two bytes are used to transmit control information.

11.19.1 Page selection

The page is selected by keying in the required three digit number on the viewer’s key-pad. Each page is identified by a combination of the page code in the header row and the magazine address code that is transmitted as part of byte 4 of every row. The magazine row contains three digits that are Hamming coded and can thus have any value between 0 and 7. This code is used as the ‘hundreds’ of the page number identification. The page code is selected from the header row and the magazine code is selected from each transmitted row of text. When a complete match occurs, the following data is written into the page memory. The row address codes are used at this stage to select the appropriate locations within the page memory. When another header row is detected (row address 00000) the page address code are again compared. If there is no match the following data is ignored. In this way only the data from the requested page is transferred to memory. A block diagram of the page selection hardware is shown in Fig. 11.32. If an uncorrected error

![Fig. 11.32 Page selection schematic.](image)
occurs in either the page or row address codes the following data is ignored until the requested page header is repeated.

Normally all header rows are displayed until the requested page header is received. This avoids a blank screen that could occur for up to 30 seconds in an average-sized magazine. In this case the only part of the header that changes on the display is the page number and the time. Full pages are transmitted at the rate of approximately four per second, which means that 25 seconds are required to cycle through 100 pages. This can be inefficient when several blank rows within a page exist. To increase the efficiency of transmission, the page memory is completely filled with the code for ‘space’ when a new page code is keyed in. Blank lines within a page can then be omitted, i.e. gaps can occur in the row address. Filling the page memory with blanks prevents the row of a previous page from being displayed when the requested page has rows omitted. This technique increases the speed of transmission by up to 25%.

If there are several pages dealing with a common subject, they are sent out in sequence using the same page number. Each new page is transmitted after a delay of about 1 minute, which is sufficient time for the viewer to read the displayed text. The whole sequence of ‘self-changing’ pages is then repeated continuously.

11.19.2 The page memory

In order to produce the illusion of a fixed image the data representing each page must be scanned 50 times per second. Hence there is a requirement for a complete page memory that can then be scanned sequentially at the required rate. Since each page has 24 rows of 40 characters and each character has a 7

![Page memory diagram](image)

**Fig. 11.33** Page memory based on a $1K \times 8$ bit RAM.
bit code the minimum storage requirement is 6720 bits per page. This may be readily achieved by use of a 1024 × 8 bit random access memory (RAM) as shown in Fig. 11.33.

11.19.3 Character display

The character set in a teletext display is produced using a 6 × 10 dot matrix. The format allows both upper and lower case letters and special purpose symbols to be displayed. The vertical dot resolution is made equal to the line spacing, which means that ten scanned lines are required for one row of text. A typical example is shown in Fig. 11.34.

Each character is in fact represented by a 5 × 9 dot matrix, column 6 being reserved for character separation and line 10 being used for row separation. The character patterns are stored permanently in a teletext read only memory (TROM). The scan proceeds on a line-by-line basis. During each line scan any character will have a corresponding 5 dot code. Hence the TROM must store a series of 5 bit numbers corresponding to the data code. The TROM is addressed by a combination of the character code (7 bits) and the line number (4 bits are required for one to ten lines), the appropriate 5 dot code is then stored at each 11 bit address.

As each line is scanned, the character codes in the particular row of text being displayed are placed upon the address lines of the TROM in sequence together with the 4 digit line scan code. This produces the correct sequence of 5 dot codes on the data lines of the TROM. Smoother characters than the one illustrated can be generated by producing slightly different dot codes on alternate scans. This is known as character rounding.3

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![Teletext character display](image)

Fig. 11.34 Teletext character display.
11.19.4 Graphics

The teletext display is not restricted to text but can also operate in a graphics mode. This mode is used for the display of simple diagrams and extra large characters. The display in the graphics mode is also divided into a dot matrix, but in this case a $2 \times 6$ rather than a $6 \times 10$ matrix is used. The graphics mode is indicated by a control code and when in this mode each 7 bit character is interpreted directly as a graphics symbol. The graphics dot matrix and the corresponding bit number is shown in Fig. 11.35. The total number of graphics symbols which can be defined is $2^6 = 64$ symbols.

There are many other features of teletext, such as mixing of text and graphics, colour of display, super position of teletext on normal programme pictures, etc. that it is not possible to cover in this volume; the interested reader is referred to Money.  

11.20 VIEWDATA

This is a generic term for systems which retrieve and display computer-based information and interactive services using the public switched telephone network and a television receiver or monitor. The main difference between teletext and viewdata is that two way communication is provided between the user and database, which requires a modem to connect the television receiver with the telephone network. This makes possible such services as electronic shopping, home banking etc. The other significant difference is that viewdata services (such as Prestel, which is offered by British Telecom) operate on a menu-driven principle in which the operator selects an item in a series of branches from intermediate menus. The display format of viewdata systems uses the same standard as teletext and thus a specially adapted receiver can be used for both services. A typical set-up is shown in Fig. 11.36.

Fig. 11.36 Basic viewdata system.
In the viewdata system only one page is transmitted in response to the page number keyed in by the user. The arrangement of the British national viewdata network is shown in Fig. 11.37. Each of the local centres contains a computer with about $5 \times 10^6$ pages of information. Most of the information accessed by the average user will be stored at the local centre, hence the pattern of telephone usage will be on a local call basis. The regional centre is the next stage in the hierarchy. If the requested information is not stored at the local centre it will be automatically transferred from the regional centre over a high-speed data link. The regional centres are connected by high-speed links to a national centre. By this means any user is able to access local information from any one of the regional or local centres. The capabilities of the system in terms of the amount of information are vast, and can, of course, be extended to an international centre at a future date.

A second difference between teletext and viewdata is that the viewdata system uses a cursor instead of page and row address. The position of the cursor is, in effect, controlled by the contents of two counters. One counter represents the position of a character within a row, the other represents the position of a row within a page. The viewdata system uses a similar 7 bit code to teletext for character transmission plus a parity check bit. The viewdata transmission uses an even parity in contrast to teletext which uses odd parity. There are thus $2^7 = 128$ possible characters that can be transmitted, several of which are used for cursor control. For example the code 0001100 (form feed) causes the cursor to return to the top left-hand corner of the screen (i.e. character and row counters are set to zero) and the page memory is filled with blanks. As symbols are received the cursor is moved along the top line (i.e. the character counter is reset and the row counter is incremented by 1). The location address in the page memory RAM is formed from a combination of character and row counter. The cursor can be placed at any point on the screen by using cursor controls, this avoids transmitting blank rows and blanks within a row. For instance the code 0001101 (carriage return) causes the cursor to return to the beginning of the current line (resets character counter to zero) and the code row counter.

11.20.1 Line signals

Data is transmitted to the subscriber using frequency shift keying with asynchronous transmission as described in Section 3.8. The data rate used is 1200 baud with binary 1 being transmitted as a 1300 Hz tone and binary 0 as a
2100 Hz tone. This means that a modem is required in the television receiver to interface the FSK signals. This modem also allows transmission of the page-selection code in the reverse direction, again using FSK. The transmission speed in the reverse direction is 75 baud, a 390 Hz tone being used for binary 1 and 450 Hz for binary 0. The viewdata modem is also required to drive the line and field scan circuits of the CRT in the receiver. This means that the viewdata service, unlike the teletext service, does not require the provision of broadcast line and field synchronization. It is thus available outwith normal broadcast periods.

11.21 CONCLUSION

This chapter has outlined the fundamental engineering principles of broadcast television systems and has shown that, in general, the development of transmission standards has been largely influenced by requirements of compatibility. The advent of satellite television has broken this link and the prospect now exists for the development of the full potential of colour television using digital signal processing techniques, which has recently become possible at video frequencies. The next obvious development is the introduction of a high-definition television standard and associated solid-state, ultra thin, large screen display devices. The advantages of a single global standard are clear but whether such a standard will emerge it is not yet possible to predict.

REFERENCES


PROBLEMS

11.1 The transmission standards for television in the USA are as follows:

- number of lines/picture = 525
- number of fields/picture = 2
- number of picture/second = 30
- field blanking = 14 lines
- line blanking = 14 μs
- displayed aspect ratio = 1.33:1

Differentiate between the transmitted and displayed aspect ratio and calculate a value for the former figure. What is the theoretical bandwidth of the transmitted video waveform?

Answer: 1.545:1, 6.37 MHz.
11.2 If the standards of the previous question were modified to accommodate 3 fields/picture what is the theoretical bandwidth of the transmitted waveform? Increasing the number of fields/picture produces a corresponding reduction in signal bandwidth. Comment on this statement and suggest why, in practice, there is a limit to the number of fields/picture.

Answer: 4.25 MHz.

11.3 The UHF television allocation allowance for channel 50 is 702 MHz to 710 MHz. A television receiver with an IF of 39.5 MHz is tuned to this channel. Calculate the frequency of the local oscillator in this receiver.

Using the channel allocation table (Table 11.2) determine which channel forms the image frequencies for channel 50.

Answer: 743.25 MHz, channel 60.

11.4 Three primary light sources RGB are designed to produce an output light power that is linearly proportional to a control voltage. When these three sources are used to match equal energy white light of intensity 1 lumen, the required voltages are \( R = 6.9 \text{ V}, G = 3.8 \text{ V}, B = 8.6 \text{ V} \). The same light sources are used to match an unknown colour, the corresponding voltage being \( R = 5.6 \text{ V}, G = 2.2 \text{ V}, B = 1.5 \text{ V} \). Find the trichromatic coefficients of the unknown colour and its luminance. What are the chromaticity coefficients of this colour on the colour triangle?

Answer: 0.81 \( T \), 0.58 \( T \), 0.17 \( T \), 0.6 lumen, 0.52, 0.37.

Table 11.2 UHF channels and frequencies (British Isles)

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<th>Sound (MHz)</th>
<th>Bandwidth (MHz)</th>
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<th>Vision (MHz)</th>
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11.5 The output voltages from a three-tube colour camera when viewing equal energy white light are adjusted such that $R = G = B = 1.0 \, \text{V}$. When the camera is directed towards an object of uniform colour the output voltages are $R = 0.56 \, \text{V}, G = 0.21 \, \text{V}$ and $B = 0.75 \, \text{V}$. Calculate the amplitude of the resulting luminance signal when:
(a) gamma correction is applied after the formation of the luminance signal;
(b) gamma correction is applied to each colour separately.

What is the percentage difference in the luminance produced when these two signals are applied to a monochrome CRT? Assume the overall gamma is 2.2.

Answer: 0.639 V, 0.617 V; 7.42%.

11.6 When the output voltages of the camera of the previous question are $R = 0.5 \, \text{V}, G = 0.9 \, \text{V}$ and $B = 0.8 \, \text{V}$, find the percentage saturation for this colour.

What would the values of the output voltages for a fully saturated colour of the same hue?

Answer: 44%, 0 V, 0.3 V.

11.7 The row addressing data in a teletext transmission is coded to have a Hamming distance of 4. If the probability of a single digit error is $1 \times 10^{-4}$, find the probability that an undetected error will occur in the coded address information. State all assumptions made.

Answer: $4.33 \times 10^{-4}$. 