UNDERSTANDING COLOUR TELEVISION

by

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Reprinted by Technical Instructions Section from 'Electrical and Radio Trading', November 1962 to August 1963, by permission of the Editor

Reprint Article No. A.47

BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

ERT SERVICE BULLETIN

UNDERSTANDING colour television

With the start of colour TV tests on 625 lines we begin this week a series of articles explaining both the NTSC and SECAM systems which will be used in the tests. There is a possibility that colour will become a regular thing when a 625 service starts in 1964, and already far-seeing dealers and their engineers are preparing for C-Day. These articles by leading authorities on colour TV—G. B. Townsend, BSc, FInstP, MIEE, AKC, manager of the television equipment department, GEC (Electronics) Ltd., and his colleague, P. S. Carnt, BSc(Eng), ACGI, AMIEE—will help them in their task.

1: ANALYSIS OF LIGHT

by G. B. TOWNSEND

INTRODUCTION of a public colour television service draws inexorably nearer. The art of colour television is complex but none of the new principles involved is more difficult than the basic concepts of monochrome television.

In this series of articles we shall deal with the fundamentals of colour matching. the principles of the two main colour television systems—NTSC and SECAM—and the differences between receivers for these systems. Finally we shall discuss the techniques needed to install and repair colour receivers.

Fortunately for the television engineer, artists and scientists between them have developed a comprehensive understanding of colour, how the eye behaves when it is looking at colour, and how colours can be copied. The science of colour and colour measurement is called colorimetry. Newton's famous experiment of splitting up white light by passing it through a prism and thereby producing the spectrum of rainbow colours is familiar enough to most of us. Each wavelength of light corresponds to a slightly different colour, as in Fig. 1. A millicron is a thousandth of a millionth of a meter.

Heat, light, radio and X-rays are all basically similar types of radiation and differ only in their wavelength; we can think of light as a very high frequency radio signal at several hundred million megacycles—well beyond the upper limit of Band V!

Most sources of light, the sun, tungsten lamps, candles, etc., emit light with nearly all wavelengths present in roughly equal proportions. If an object reflects all these wavelengths equally well it looks white. If it absorbs all these wavelengths it looks black. Coloured objects reflect some wavelengths and absorb the others.

Now if we had to reproduce all these wavelengths individually with different amplitudes in order to simulate all the colours which occur in nature, our television colour display tube would be even more expensive than it is. However, artists have known for centuries that they need only a few primary colours on their palette, with mixtures of which they can match most of the natural colours.

Physicists have carried the process a stage further and have shown that if we choose very pure colours for the primaries, then it is possible to make do with just three for our palette without appreciably limiting the range of colours which we can reproduce. The particular choice of primaries is different for the two cases of mixing paints and mixing actual lights. For mixing lights the best choice of three primaries is a red light, a green light and a blue light.

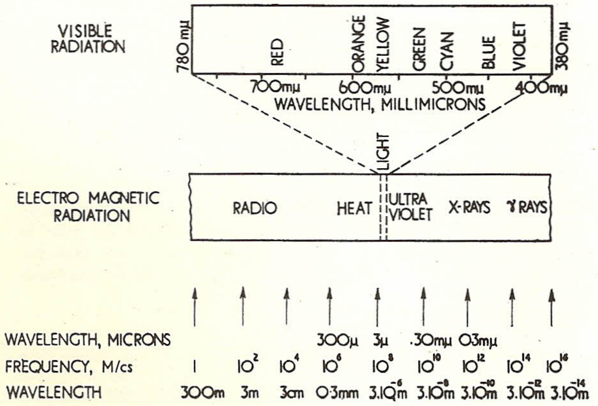


Fig. 1. The wavelength of the light determines which hue, or colour, is seen

This is the way colour is reproduced in television. The receiver does not attempt to reproduce the original distribution of light at all. The colour display tube produces only pure red, green and blue lights, but by altering the proportion of each light it succeeds in giving the observer an impression of the original colour.

It is useful to be able to remember the combinations of primary colours which produce the sensation of each of the other main colours, such as that yellow is reproduced by turning on equal amounts of red and green light.

Mixtures of all three primary lights in the correct proportion produce white and grey colours, while if one of the primaries predominates or is relatively weak then we see the pastel colours such as pink or pale yellow. Mixtures of blue and

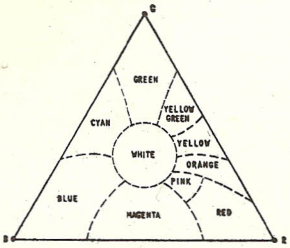


Fig. 2. The colour triangle. The colours named all merge gradually and smoothly into neighbouring hues. The colours are most pure and vivid along the outside edges of the triangle and become pale or desaturated towards the centre

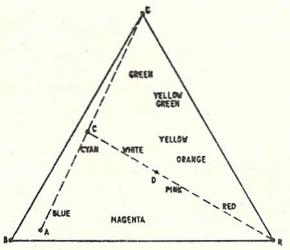


Fig. 3. If green and red voltages are low relative to the blue signal, then the receiver will reproduce a colour, indicated at A, similar to the blue primary. If the green signal is then increased, the reproduced colour moves to a point such as C, whereupon an increase in the red signal will change the colour through D

green give the impression of the blue-green colours such as turquoise: these colours are called *cyan* in the technical world of physicists and colorimetry.

Another unusual name in colorimetry is *magenta*, which is the collective word for the colours produced by mixtures of red and blue; that is, the purple colours. The purple colours do not appear in the spectrum, whereas mixtures of green with either red or blue will match, near enough, most of the colours of the rainbow.

Impression	Primary Colours in Matching Mixture		
	Red	Green	Blue
Blue	—	—	Predominates
Cyan	—	50%	50%
Green	—	Predominates	—
Yellow	50%	50%	—
Orange	75%	25%	—
Red	Predominates	—	—
Magenta	50%	—	50%
White	33%	33%	33%

The table shows how various colours can be imitated by mixing different proportions of just three primary coloured lights. Intermediate shades are produced by varying the proportions, whilst the pastel colours are reproduced by adding white light—or equal amounts of red, green and blue lights—to the main colour: such pastel shades are said to be *desaturated.*

RELATIVE VOLTAGES

Physicists, of course, have very precise ways of specifying what is meant by equal amounts of light, but for our purposes we can interpret the table as also referring to the relative signal voltages in the red, green and blue channels of the television system. Physicists also have a convenient way of representing colours graphically, and we can use a simplified form of their colour map to help us remember the relative proportions of the television signal voltages which are required to produce the effect of any particular colour on the display tube. The *colour triangle* shown in Fig. 2 illustrates the relationship between the colours. The dotted lines show the approximate boundaries between colours, but there is, of course, only a very slow transition between the colours, all of which merge imperceptibly into the adjacent hues.

If there is a large voltage in the blue channel and very little signal in either the red or green channel then we get a colour which might be represented, for example, by the point A in Fig. 3. Such a diagram does not tell us how bright the light is (how many watts) and strictly speaking we should call it a *chromaticity diagram* rather than a colour diagram. It is only showing the relative proportion of the primary lights.

If we now increase the green signal voltage the resulting colour moves along the straight line joining A to the green point G, up to a position such as C. The greater the proportion of green to blue the nearer C gets to G. To move C right up to G necessitates decreasing the blue and red signals to zero. Having increased the amount of green until the display tube is reproducing the colour shown by C in Fig. 3, suppose we now increase the red signal. The reproduced colour then moves from C along the straight line connecting C to the red point R. Precisely where it stops, say at D, along the line RC depends upon the relative strengths of the red signal to the other two signals.

Colours which produce white when they are mixed are said to be *complementary*. Yellow is the complementary colour to blue, while blue is the complementary colour to yellow. Thus corresponding to the three primary lights red, green and blue, are their respective complementaries, cyan, magenta and yellow. Reproducing colours by adding lights together is called an *additive* method of reproduction, and red, green and blue are called the additive primaries. Their complementaries, cyan, magenta and yellow, are sometimes called the *subtractive* primaries, since they are the best primaries to use for the subtractive processes, such as painting or colour photography, in which the colours are due to pigments or dyes subtracting certain wavelengths from the white light falling upon them. Most of us were probably taught to use mixtures of green, red and yellow paints at school and these simple names were adequate enough to describe the rather poor versions of the cyan, magenta and yellow paints which were available.

As we all know to our cost, our eyes are by no means infallible; this is particularly so when it comes to judging colour. Tungsten lamps look very yellow when viewed from outdoors on a blue winter's afternoon, but are a very satisfactory white indoors in the evening after our eyes have adapted to the artificial light.

In many ways our eyes behave as if they were sending separate signals to the brain corresponding to the amounts of red, green and blue needed to imitate the original scene. It is known that the eye sends electrical signals to the brain to tell it what it is seeing and that these signals are sent by a form of pulse code modulation. Colour-wise, the system behaves as if there are separate automatic gain controls on the red, green and blue information channels, and these gain controls are always operating to try to make the overall picture as white as possible.

BALANCE AND SIZE

The precise sensation of colour which we perceive depends upon the adaptation of our eyes to the overall colour balance, on the colours which we have just finished looking at, and on the colours which are adjacent to the area we are observing Two or three people in every thousand are colour blind and colour blindness takes several different forms. It is essentially a masculine complaint and very few women are colour blind. We can think of colour blindness as an open circuit in one or all of the three colour channels.

Some elementary areas of the eye are naturally colour blind in everyone, so that even when all the normal colour circuits fail, men are usually still able to distinguish black from grey from white by means of these other small areas which are merely sensitive to brightness. If only the green channel is inoperative, then men confuse reds and yellows, and so on. Quite a few men have a permanent difference in relative sensitivity between their three colour channels, and such people may prefer a rather different setting-up of the colour television picture.

The colour we see when we look at an object depends also upon the apparent size of that object, which is why women prefer to match cotton with the complete reel rather than a single thread. If the thread is fine enough we have difficulty in seeing any colour in it at all—that is to say, we are all colour

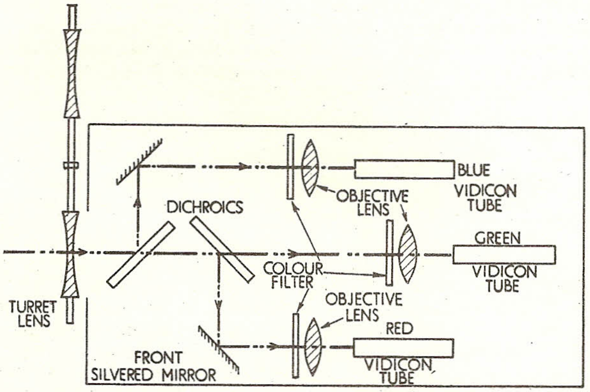


Fig. 4. Basic arrangement of EMI colour camera. The light from the studio scene is split into its red, green and blue components by semi-reflecting coloured mirrors called dichroics. Each primary colour goes to its own pick-up tube

blind when looking at small fine individual areas of colour. There is an intermediate stage in which the area is large enough for us to see some colour but not large enough for us to be quite sure as to precisely which colour it is. Reds are confused with yellows and blue-greens are confused with blue, but an orange colour can be distinguished from the cyan colours.

The colour receiver builds up an imitation of the original scene by producing a red picture, a green picture and a blue picture, superimposed one upon the other. The viewer's eye then gives him the impression that he is watching a fully coloured picture. The colour camera's job is to feed to the receiver the information which it needs. The camera is really three monochrome cameras in one box. One camera tube produces a complete television signal for the red picture, a second pick-up tube produces the picture for the green channel, while the third produces a signal for the blue picture. Each signal looks like a normal video voltage-waveform in a black and white system.

Fig. 4 shows in schematic form a representative colour camera. The light from the turret lens is split into three different paths by a system of colour mirrors. The red light is sent to one camera tube, the green to another, and so on. Each tube then produces its own television signal for that particular primary colour. Of course, lots of precautions have to be taken to ensure that the scan rasters on each target plate are identical in shape and size, etc., but the basic principle of the colour camera is simple enough.

The video signals from each pick-up tube have to be processed to overcome various imperfections and they are also pre-distorted to correct for some effects which arise in the receiver. The three signals are then usually represented by the symbols E'_R, E'_G and E'_B. The E is to show that they are voltages and the dash indicates that they have been corrected. It is perhaps less confusing to write them as R, G, B, providing we do not mistake the red signal voltage symbol with the symbol for resistance. The camera channel gains are adjusted so that when white is transmitted, $R=G=B$.

R, G, B are the voltages which are needed to drive the receiver's colour display tube, but it is inconvenient to transmit them as three separate television signals. We shall deal with the two principal methods of transmission in later articles. In the next article we shall discuss the various types of colour cathode ray tube.

ERT SERVICE BULLETIN

UNDERSTANDING
colour television
2: PICTURE TUBES

By G. B. TOWNSEND, BSc, FInstP, MIEE, AKC

THE colour camera analyses each part of the scene to be transmitted, and gives out three voltages, *R*, *G*, *B*, proportional to the amounts of red, green and blue light which the receiver must generate to simulate to the viewer the effect of the original colour. In certain closed-circuit colour television applications it is possible to convey each of these three television signals along separate cables to the monitor, where each signal produces a television raster in its own appropriate colour. If the three images are then superimposed, the viewer's eyes see an apparently fully-coloured picture.

For broadcasting, of course, it is necessary to combine the three *R*, *G* and *B* signals into a single transmitted signal suitable for black-and-white reception as well as colour. The broadcast colour receiver has to sort out the complex transmitted signal into its original three components *R*, *G* and *B*, before it can reconstruct an acceptable imitation of the scene before the camera. We shall deal with this process of *coding* the *R*, *G* and *B* signals before transmission, and the subsequent *decoding* at the broadcast receiver, in later articles in this series.

Colour display tubes for either closed-circuit monitors or broadcast receivers are basically the same and it is easier to understand the rather complex coding processes if the final use of the *R*, *G* and *B* signals at the cathode-ray tube is first clearly understood.

One obvious way in which to combine the three primary colour images is to use three separate projection systems. One projection tube has a red-glowing phosphor, one a green-glowing phosphor, and one a blue-glowing phosphor. The three lens systems are arranged to make the three projected images overlap on the viewing screen.

Elaborate precautions have to be taken to ensure that all three images are precisely the same size and shape, but this can be done and the system is used for large-screen colour viewing with audiences of a hundred or so people. The limitation on the size of the picture, and hence of the audience, is the brightness of the combined images. For domestic viewing in small rooms the projection apparatus is cumbersome and such systems have been developed so far only for professional use.

Three so-called "direct-viewed" cathode ray tubes can be used, and the three images viewed through an arrangement of half-silvered mirrors designed to combine the three images into one picture. Several arrangements are possible and two suitable combinations of semi-reflecting mirrors are shown in Fig. 1. The crossed mirror design of (b) takes up less space than that shown in (a), but a black line is seen across the centre of the picture. Such a display is called a Jumbo, or trinoscope. It takes up a fair amount of room and only one or two people can look into the mirrors at the same time since the tubes appear to be at the back of a rather deep box.

These projection and trinoscope arrangements are examples of a wide range of colour picture tube displays which can be broadly classified as three-gun displays. Such three-gun displays have certain advantages and disadvantages. In general the superposition of three images gives a relative increase in brightness and the spot size of each gun need be no smaller than for normal monochrome tubes. However, each image must have exactly the same shape, size and linearity as its associated images and this is not always easy to ensure. Further, the three images have to be registered precisely.

All cathode-ray tube electron-guns have a curved input-output characteristic, as shown in Fig. 2, and doubling the voltage drive to the modulator grid of a cathode ray tube produces about six times the brightness. This effect occurs in black-and-white television and has to be allowed for, either at the transmitter or in the receiver.

COLOUR CAST

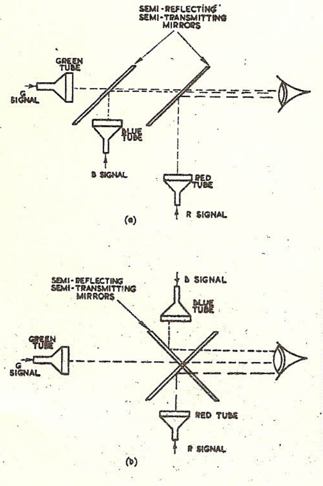
In a three-gun colour display there are three such curved characteristics, one for each colour; this raises a basic problem in producing a good black-and-white picture. As the red signal swings over the input-output characteristic of the red gun it is important that the blue signal swings over a similar part of the blue input-output curve, and the green signal over a similar part of its curve. That is to say, all three curves must be the same for each electron gun and the signals must start from similar bias points on each curve.

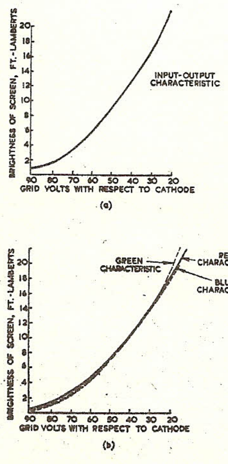
If these conditions are not satisfied then the balance between the brightness of the images is not maintained from dark grey to white. A black-and-white *grey scale*, such as the centre blocks of Test Card C, provides a stringent test for a three-gun colour display. The black-out voltage on each tube, and the curvature of each gun, have to be adjusted so that the red, green and blue light outputs stay in their correct proportions for every brightness level of grey.

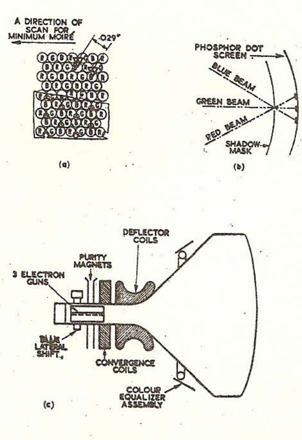
Errors in setting-up the tubes give a colour cast to the picture which may vary with brightness; for example, dark greys may look reddish whereas the picture highlights may look green. This kind of setting-up procedure is not needed for colour displays which use only a single electron gun.

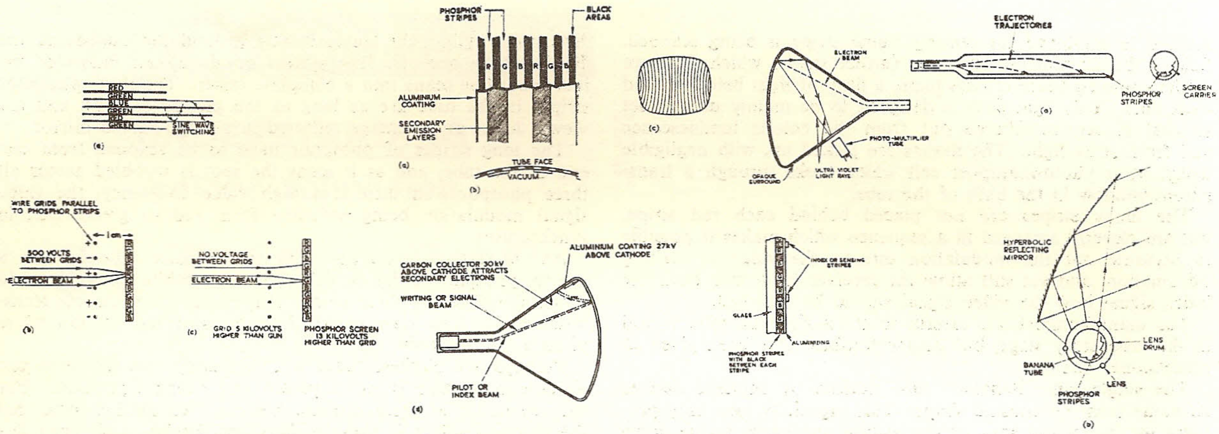
The most successful colour tube to date has been the American RCA shadow-mask tube, sometimes called an

In these three groups of drawings the first Fig. 1 (a) and (b) shows two forms of "Jumbo" display. The viewer looks into a pair of half-silvered mirrors and sees three images in primary colours superimposed. As an electron gun has a curved input-output characteristic—see centre, Fig. 2(a)—with three-gun displays the curves must be adjusted to be the same, otherwise as in (b) for example, dark greys could be red and highlights green. Extreme right, Fig. 3, the RCA shadow-mask tube: (a) section of mask and phosphor dots behind it, (b) principle of geometric separation of beams, (c) cross-section of tube and accessories









First of these four groups, Fig. 4 deals with the Lawrence tube: (a) phosphor stripes, viewed from front, (b) and (c) side views (from " Colour Television," Carnt and Townsend, 1961). Fig. 5 (centre), the Philco " Apple " tube: (a) back elevation of screen, (b) plan, (c) pin-cushion arrangement of Sensing stripes, and (d) cross-section (also from " Colour TV "). Fig. 6 Sylvania-Thorn " Zebra " tube—top, sectional view and, below, plan of phosphors and sensing stripes. Fig. 7 Mullard " Banana " tube—(a) basic construction, with electron paths and (b) arrangement of rotating drum of cylindrical lenses and a curved mirror

aperture-mask tube. This is the only type of colour tube in mass production and versions of it are made in other countries including Japan, Holland and Russia. The tube is usually a 21in. round glass tube with a 70 deg. deflection angle and a large neck diameter of two inches, although a recent Japanese type uses a 17in. rectangular screen and gives a very satisfactory picture, while 14-in. Japanese tubes will shortly be available.

Three separate electron guns are housed side by side in the wide tube neck. Each gun is modulated with one of the three primary signals. The guns fire their separate beams of electrons at the screen in the normal way, but the screen is composed of dots of red, green and blue glowing phosphors. When they are not bombarded with electrons all the dots look white under normal lighting, as a monochrome screen does.

The clever part of the design is the insertion of the shadow-mask itself, about an inch behind the phosphor screen, as in Fig. 3(b). The shadow-mask is a sheet of steel about .006in. thick and peppered with small holes. The function of the mask is to ensure that electrons from each gun fall only on phosphor dots of the colour appropriate to it. This is achieved, as illustrated in Fig. 3, by a simple geometrical arrangement, each group of three red, green and blue dots being aligned with one hole in the shadow-mask. In practice, the dots are so small—over a million dots on a 21in. screen—that each electron beam is always passing through two or three adjacent holes of the mask at the same time, and is lighting up its appropriate colour dot in two or three *triads* of phosphor dots.

From a normal viewing distance the eye is incapable of separating out the individual dots and the primary colours merge into one another to give the effect of mixing the three primaries together.

CONVERGENCE

To keep the three pictures in register it is necessary to keep the three separate scanning beams superimposed, or *converged.* Special yokes and magnets are provided for this purpose around the tube neck. The purity magnets provide a fine adjustment of the angle of approach of the beams to the mask, to ensure that the electrons do indeed hit the correct dots and that when the only signal is a red signal, then the tube screen shows only a pure red colour all over. On the latest tubes the colour equalizer assembly of magnets, which corrected purity around the outside edge of the screen, is not needed.

The shadow-mask tube gives excellent colour pictures, but it has been criticized because of all the adjustments which are needed to obtain a good grey scale, purity and convergence.

Colour picture tubes using only a single electron-gun have been developed, and although none is in mass-production, many engineers believe that the future of colour television lies with such display devices. Recently two novel British designs have been demonstrated, but before briefly describing these tubes we shall mention two earlier American tubes.

Single-gun tubes usually have a screen composed of stripes of colour phosphor and the single scanning spot passes over each colour in turn. The modulation on the gun has then to be switched to suit the primary colour being illuminated at that particular instant. Such tubes can be broadly divided into two further sub-divisions: *switching tubes,* in which the electron beam is switched from one phosphor to another as required, and *sensing tubes,* in which the spot crosses over the colour stripes with its normal scanning movement, but the modulation is altered to suit the colour which happens to be illuminated, there being a device in the tube which senses which primary is being lit and sends an appropriate pulse to make sure that the correct colour signal is applied to the tube.

Most single-gun tubes are designed so that on a monochrome signal the spot lights up each phosphor in turn without any special video switching pulses; the phosphors are deposited in such relative strengths that a white picture is naturally obtained under these conditions. Thus neither grey scale nor convergence problems arise with single-gun tubes.

Numerous variations of ~~this~~ the switching type of tube, named after Lawrence, an American scientist who suggested the principle, have been proposed. One basic idea is shown in Fig. 4. The single electron beam is switched from one colour to another by the set of grid wires. Usually, a sine wave beam switching waveform is used and the same waveform synchronizes a circuit which switches the grid of the tube to the appropriate video signal, *R, G* or *B.* One of the main disadvantages of this type of tube is the 25 watts or so of power needed for the beam switching grids.

As in all such tubes, there should ideally be at least one triad of three phosphor stripes to a picture element and the scanning spot should be several times smaller than for a monochrome tube.

BEAM INDEXING

Sensing tubes are sometimes called *beam indexing* tubes.

In the Philco "Apple" tube the stripes of red, green and blue phosphors are vertical (Fig. 5) and the black areas between stripes prevent the spot from lighting up two colours at once and thereby desaturating the colours. A second *sensing* beam of electrons scans with the normal *writing* beam, but the sensing beam does not disappear during the black parts of the picture. As the beams scan over the screen they emit secondary electrons from a special coating of further stripes which are placed behind the aluminizing.

These secondary emission stripes indicate that the spot is passing over the red phosphor stripe and that the red video signal should be switched on. The secondary electrons take time to reach the final anode collector surface and this time, which depends on the part of the raster being scanned, has to be allowed for; this is why the secondary emission stripes have the pincushion shape shown in Fig. 5(c).

The basic principle of the Sylvania-Thorn "Zebra" tube is shown in Fig. 6. The phosphor stripes are vertical and a novel method is employed for sensing which stripe is being scanned. Behind the aluminizing layer are further stripes which fluoresce as the scanning beam crosses them, a flash of light being emitted each time. This light flash is designed to be mainly ultra-violet so that it can be filtered out from the colour luminescence and from stray light. The flashes are picked up, with negligible delay, by a photo-multiplier cell which looks through a transparent window in the bulb of the tube.

The index stripes are not placed behind each red stripe, but are cleverly arranged in a sequence which makes it possible to separate out the modulation due to the video or writing information, and yet still allow the receiver to deduce from the index signal how the video signal should be switched.

The manufacturers are careful to stress that the tube is still in the laboratory stage, but demonstrations have been given to professional circles.

The single-gun "Banana" tube devised by Mullard derives its name from its unusual shape. This ingenious tube only provides the horizontal scan of the picture and keeps laying down each successive line scan in the same place. The field scan is carried out mechanically. A rotating drum bearing a series of horizontal cylindrical lenses rotates around the outside of the Banana tube and the lens system builds up an image of the individual line scans into a complete raster. The three phosphor stripes in the tube are as long as the picture is wide, and the viewer looks at the image reflected in a large curved mirror.

The long stripes of phosphor have to be scanned from one end of the tube, and as it scans the spot is wobbled across all three phosphors in turn at a high video frequency, the video signal modulation being switched from red to green, etc., in synchronism.

An interesting possibility with the Banana tube is that a fourth phosphor stripe which fluoresces white could be laid down alongside the three colour stripes; for monochrome transmission the line scan could then be switched to the white phosphor stripe only.

Perhaps one of these tubes will eventually oust the three gun shadow-mask tube from its present pre-eminent position. For the remainder of these articles, however, we shall assume that the colour receiver is using a three-gun display, and when discussing the display itself we shall describe the shadow-mask tube in more detail.

ERT SERVICE BULLETIN

UNDERSTANDING colour television

3: THE NTSC SIGNAL

By G. B. Townsend, BSc, FInstP, MIEE, AKC

THE television signals which are generated by each of the three television pick-up tubes in the colour camera need to be corrected for various sorts of defects before they are ready for transmission. Most of these corrections are concerned with effects which occur also in monochrome television, such as tilt and bend, spot size, etc. One of these corrections, however, has an important influence on the behaviour of the colour system and so we shall deal with it separately.

In closed-circuit colour television installations it is sometimes practical to run four cables from the camera control unit direct to the colour receiver. One cable carries the red television signal, *R*, one the green signal *G*, and one the blue signal *B*; the fourth cable carries the synchronising pulses. The standard level for the colour signals is 0.7V and they need to be amplified in the receiver before they can be applied to the appropriate electron gun of the colour display tube.

Since the input-output characteristic of display tubes is not straight but curved (see the second article in this series), the colour signals would present a distorted impression of the relative brightness levels in the original scene if these signals were not corrected somewhere in the system. This effect is illustrated in Fig. 1, where the signal waveform shown at (*b*) is similar to the relative brightness levels of the original scene, as at (*a*); the effect of the display tube, (*c*) is to increase contrast in the highlights of the picture and compress the tone separation in the shadows.

Somewhere in the system, therefore, the signals must be distorted to correct for this effect of the display tube. The process is termed *gamma correction*, after the Greek letter γ, since the effect is related to a similar phenomenon in photography which traditionally uses this Greek letter to denote the degree of contrast expansion. After gamma correction has been carried out, the signal waveform of Fig. 1(*b*) is changed to that shown in Fig. 2(*b*). The distortion of this signal is exactly equal and opposite to that which the display tube will cause, so that the final picture (*c*) is correct. In effect, the gamma correction circuits raise each signal voltage to the power $\frac{1}{\gamma}$, thus:

Original signal voltages	R	G	B
After gamma correction	$R^{\frac{1}{\gamma}}$	$G^{\frac{1}{\gamma}}$	$B^{\frac{1}{\gamma}}$

Gamma (γ) has a value of 2.2, so that the correction circuits can be considered as taking approximately the square root of each voltage.

$$\sqrt{R} \qquad \sqrt{G} \qquad \sqrt{B}$$

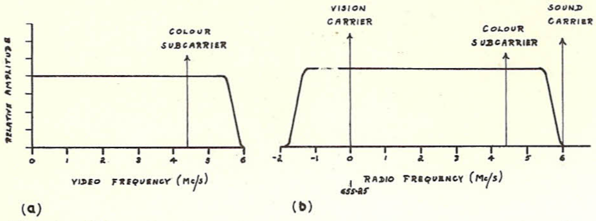


Fig. 3—Colour signals are first put on to a video-frequency subcarrier with asymmetric modulation and the result is added to the luminance signal (a) in modulating the RF carrier (b). These diagrams refer to the Band I transmissions

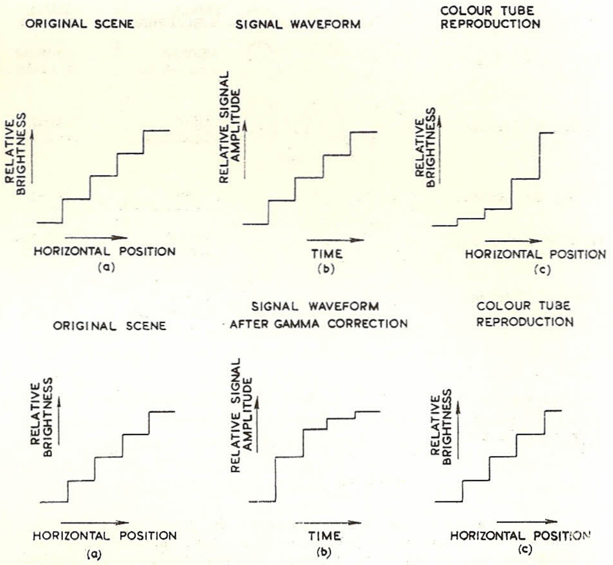


Fig. 1 (top)—If camera signals are linear (b) with respect to brightness (a), the curved characteristic of the colour CRT distorts the tone scale (c). Fig. 2 (below)—Gamma correction of signal (b) results in proper reproduction of tone values as at (c)

The colour display tube reproduces light with an intensity proportional to the modulating signal voltage raised to the power γ, thus

$$\left(R^{\frac{1}{\gamma}}\right)^{\gamma}=R, \quad \left(G^{\frac{1}{\gamma}}\right)^{\gamma}=G, \quad \left(B^{\frac{1}{\gamma}}\right)^{\gamma}=B.$$

To a first approximation this is equivalent to squaring the signal voltages:

$$(\sqrt{R})^2=R; \; (\sqrt{G})^2=G; \; (\sqrt{B})^2=B$$

Since it is rather a nuisance to keep writing $R^{\frac{1}{\gamma}}$, etc., it is conventional to indicate that gamma correction has been carried out by marking the voltage symbol with a prime R', so that

$$R'=R^{\frac{1}{\gamma}}, \qquad G'=G^{\frac{1}{\gamma}}, \qquad B'=B^{\frac{1}{\gamma}}$$

COMPATIBLE MONOCHROME SIGNAL

When it comes to broadcasting, as distinct from closed-circuit colour television, it is not practical to use three channels for carrying the three colour signals, R′, G′ and B′. It is also necessary to ensure that the transmitted colour signal will give an acceptable monochrome picture on black-and-white receivers—that is, the signal must be *compatible*.

The main part of the colour signal is therefore made to look as much like the normal monochrome signal as possible; it consists of a video waveform with synchronising pulses. The video waveform is representing the brightness of the scene, as in normal black-and-white television. Since brightness is a subjective effect and a lamp which looks bright at night can look very dim in sunshine, a more absolute measure of intensity is adopted, called *luminance*.

The three colours, red, green and blue, which the colour receiver is going to use to reproduce an impression of the original scene, all contribute towards the luminance of the picture. The blue light does not add much luminance while the green light adds quite a lot. To form a signal representing the luminance of the scene it is necessary to use all three R', G' and B' signals, but in appropriate proportions. This signal is called the compatible monochrome signal Y', and it is formed by adding fractions of all three signals together.

$$Y'=0.3R'+0.6G'+0.1B'$$

These signal voltages are added in just the same way as audio signals from several microphones can be mixed together. The signal mixing circuits are called *matrix* circuits in colour television. The resulting Y' signal looks like a normal black-and-white television

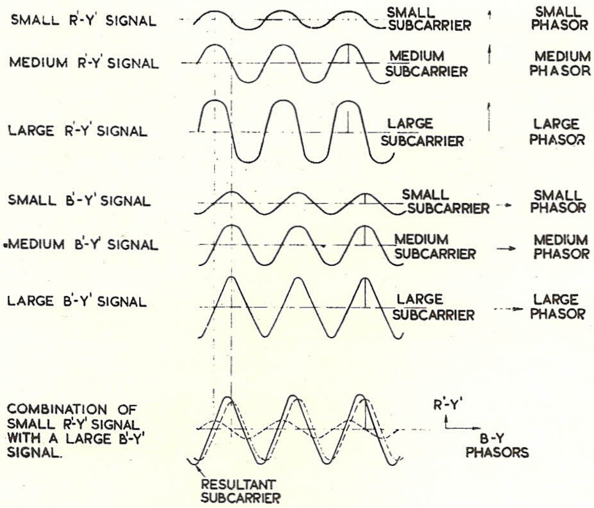


Fig. 4—A subcarrier amplitude modulated by R′-Y′ signal can be represented by an arrow, or phasor, as in the three lines at top. The B′-Y′ signal can be shown as a phasor at right angles. On adding together (bottom line), the resultant signal has the same amplitude as each component at the times they go through their maximum values

signal and is transmitted with synchronising pulses in the usual way. If there is no red in the picture, then $R'=0$ and the monochrome signal will become

$$Y'=0.6G'+0.1B'$$

and so on.

COLOUR-DIFFERENCE SIGNALS

The Y' signal produces a black-and-white signal on colour receivers as well as on monochrome receivers. Because the primary signals are gamma-corrected before Y' is formed, the Y' signal is not strictly proportional to the luminance of the coloured picture, but it is near enough so for our purpose. To reproduce a colour picture, the receiver needs to know the values of R', G' and B', and it cannot deduce these from the amplitude of Y' alone. It is necessary to send at least three signals which contain known proportions of R', G', and B', in order that the receiver can work out the original three voltages, R', G' and B', for itself.

As well as the luminance signal, Y', therefore, it is necessary to send two colouring ~~or chrominance~~ signals. These colouring signals could be R' and G', or G' and B', for example.

However, there are advantages in using two of the so-called colour-difference or chrominance signals.

$$R'-Y' \text{ and } B'-Y'$$

The red colour-difference signal is formed by subtracting the luminance voltage from the red primary voltage. The resulting $R'-Y'$ waveform still looks like a video signal and in many ways is very similar to the original red signal voltage. There is one major difference: if a grey colour is being transmitted then the red colour-difference signal vanishes. Similarly for the blue colour-difference signal. All the necessary information is then carried by the luminance signal, Y', alone. When grey or white is transmitted (see first article) the camera channel gains are adjusted so that $R'=G'=B'$ and for a mid-grey they may all have the value 0.4, say, if 1 represents peak white.

$$\begin{aligned} \text{Then }\ & Y'=0.3(0.4)+0.6(0.4)+0.1(0.4)=0.4 \\ \text{so that }\ & R'-Y'=0.4-0.4=0 \\ \text{and }\ & B'-Y'=0.4-0.4=0 \end{aligned}$$

I and Q SIGNALS

It is impracticable to send the two colour-difference signals with their full amplitude and bandwidth, and it is necessary to reduce both their magnitude and frequency range. The red colour-difference signal voltage is only slightly reduced, while the blue-colour difference voltage is halved. The precise amplitudes transmitted are

$$\frac{R'-Y'}{1.14} \text{ and } \frac{B'-Y'}{2.03}$$

This means that when the colour-difference signals are detected at the receiver, they have to be amplified by different amounts, relative to the Y' signal. The $R'-Y'$ needs to be amplified to 1.14 of its value, and the $B'-Y'$ signal has to be increased by a factor of 2.03.

It is also necessary to restrict the bandwidth of each colour-difference signal, since they are going to be transmitted in the same channel as the monochrome signal and this is not practical unless the two new colouring signals occupy only a fraction of the frequency band of the monochrome signal Y'.

Now there are two principal colour television systems which are currently being considered in Europe. The NTSC system, which takes its name from the initials of the American committee which developed it, the National Television System Committee, and was adopted in USA in December, 1953. Recently a French company, Compagnie Française de Télévision, a subsidiary of CSF, has developed an improved version of the NTSC system which it has called SECAM. SECAM is a made-up word which denotes the two principles on which the system is based, *sequential and memory*.

Everything said so far in these articles applies equally well to either of these two systems, but we have now reached the point at which the differences between the systems become important. The remainder of this article is concerned only with the American NTSC system.

The two colour-difference signals cannot be transmitted, in the NTSC system, with the same bandwidth unless this bandwidth is restricted to about $\frac{1}{9}$ of the Y' bandwidth. It is practical, however, to transmit one signal with as much as $\frac{1}{3}$ of the Y' bandwidth—if the other signal is reduced to $\frac{1}{9}$ of the Y' frequency band.

The question arises as to whether it is better to make the wideband signal the red $R'-Y'$ signal, or the Blue $B'-Y'$ signal. There is some advantage in forming the wideband signal so that it is representative of orange colours rather than red, and of making the narrow band signal correspond to magenta colours rather than blue. This technique makes the system go colour-blind for small-area changes of colour, in a similar manner to the way our own eyes have difficulty in discerning the exact shade of a small piece of cloth. In fact it is axiomatic in television that what the eye cannot see, the engineer need not grieve over. The new signals are formed by combining once again fractions of the existing signals:

$$\text{Wideband signal, } I' = 0.8\left(\frac{R'-Y'}{1.14}\right) - 0.5\left(\frac{B'-Y'}{2.03}\right),\ I' \text{ has } \tfrac{1}{3} \text{ of } Y'' \text{ bandwidth}$$

$$\text{Narrowband signal } Q'=0.5\left(\frac{R'-Y'}{1.14}\right)+0.8\left(\frac{B'-Y'}{2.03}\right),\ Q' \text{ has } \tfrac{1}{9} \text{ of } Y'' \text{ bandwidth}$$

However, there are difficulties in designing stable receivers to use these signals and since the majority of colour receivers treat the transmitted signal as if it contained only the two original colouring signals,

$$\frac{R'-Y'}{1.14} \text{ and } \frac{B'-Y'}{2.03}$$

with equal bandwidths, we shall do the same. We can think of these two signals as 0.9 $(R'-Y')$ and 0.5 $(B'-Y')$. The next section will

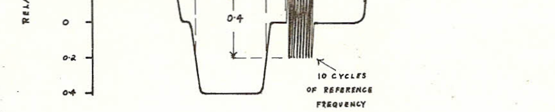


Fig. 5—Transmitted on the back porch of the line sync signal, the colour burst consists of 10 cycles of subcarrier frequency with phase of —(B′-Y′). Figures refer to 625-line signal

explain how one and the same transmission can be treated in two such different ways.

How are the two colouring signals $0.9\,(R' - Y')$ and $0.5\,(B' - Y')$ to be transmitted? They are both modulated on to a special colour carrier. The frequency of this subcarrier is chosen to be in the high-frequency part of the video band, at 2.7mc/s for 405 lines and 4.4mc/s for 625 lines, as in Fig. 3. If the colour-difference signals are both zero, then the colour subcarrier has zero amplitude and disappears. If the colour-difference signals are large, then the colour subcarrier amplitude is large.

The great difficulty is to modulate the subcarrier with both the colour-difference signals at once, without their getting hopelessly mixed up. The NTSC system uses a method called *quadrature modulation.* It is simple enough to amplitude modulate a subcarrier with the red colour-difference signal, as in Fig. 4, when we can represent the amplitude of the carrier by arrows of various lengths. Similarly, a second subcarrier can be amplitude modulated by the $B' - Y'$ signal, also in Fig. 4. If these two subcarriers have precisely the same frequency they can be combined together into one subcarrier as shown.

If the *phase* or *timing* of one subcarrier is kept consistently different from the other, in fact 90° different, then it is possible to separate out the two signals at the receiver by using phase detectors which detect either in the $R' - Y'$ phase or in the $B' - Y'$ phase.

COLOUR BURST

It is only possible for the receiver's phase detectors to operate if they receive a suitable synchronising or timing signal from the transmitter to enable them to decide the exact instant at which the $R' - Y'$ subcarrier is going through its maximum amplitude and the $B' - Y'$ signal is going through zero, and vice versa.

The *colour burst* synchronising signal is ten cycles of the subcarrier frequency transmitted on the back porch of every line synchronising pulse, as in Fig. 5. The phase of this signal is opposite to that of the $B' - Y'$ signal, i.e. 180° away from $B' - Y'$, or $-(B' - Y')$. The receiver uses the colour burst as a time reference by which it can judge the phase of the chrominance signal.

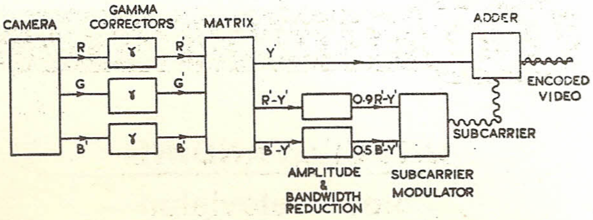


Fig. 6—The complete encoded colour signal is made up from the basic camera signals R, G and B as shown

The subcarrier chrominance signal appears on the screens of black-and-white receivers as a fine interference pattern, very much as any CW signal which is two megacycles or so away from the vision carrier would appear. Special frequency locking techniques are used at the studio to make this interference pattern less noticeable. These techniques do not affect the operation of receivers and we shall not consider them further. Similarly, we have omitted to mention the process by which the relative time delays of the three signals, Y', $(R' - Y')$ and $(B' - Y')$ are adjusted to be the same. We shall say more about this in the article on NTSC receivers.

SUMMARY

The formation of the NTSC colour signal is rather a complicated affair and Fig. 6 attempts to summarise the main points. The three basic signals, R, G, B have their amplitudes adjusted so that they are equal on peak white: this level is referred to as the normalised unity level of 1, and all other signals are measured relative to this level.

The three signals are then gamma corrected to R', G', B', to allow for the effect of the display tube characteristic. The next step is to matrix these signals to those required for transmission: Y', $R' - Y'$ and $B' - Y'$. Y' is used as the compatible monochrome signal, while the two colour-difference signals are restricted in amplitude and frequency, and then $0.9\,(R' - Y')$ and $0.5\,(B' - Y')$ are modulated on to the subcarrier.

The modulated subcarrier is added to the Y' video signal, sync pulses and colour bursts are added, and the *composite encoded colour signal* is then radiated in the normal fashion.

ERT SERVICE BULLETIN

UNDERSTANDING colour television

4: BASIC DESIGN OF NTSC RECEIVERS

By G. B. Townsend, BSc, FInstP, MIEE, AKC

IN earlier articles in this series we have described how the colour camera measures the amounts of red, green and blue light which the receiver display tube must produce in order to give the viewer an impression of the colour of the original scene. The camera and its associated circuits generate three video voltage waveforms, R', G', and B', which are suitable for applying simultaneously to the red, green and blue modulator grids of a three-gun colour tube, or for modulating sequentially a single-gun display.

It is not practical to use three separate RF channels to broadcast these three signals, so they are encoded into one composite signal. A compatible monochrome signal is formed which represents the luminance of the scene and is similar to the normal black-and-white television signal.

$$Y'=0.3R'+0.6G'+0.1B'.$$

Two colouring or chrominance signals are formed, $R'-Y'$ and $B'-Y'$, and these are restricted in bandwidth and amplitude before being modulated on to a subcarrier with a frequency of 4.4mc/s. The subcarrier with its two sets of modulation, representative of 0.9 $(R'-Y')$ and 0.5 $(B'-Y')$, is added to the Y' signal and all are broadcast together.

In practice, the colour-difference signals are changed once again into I′ and Q′ signals before being modulated onto the subcarrier, but as most colour receivers ignore this refinement, we shall do the same.

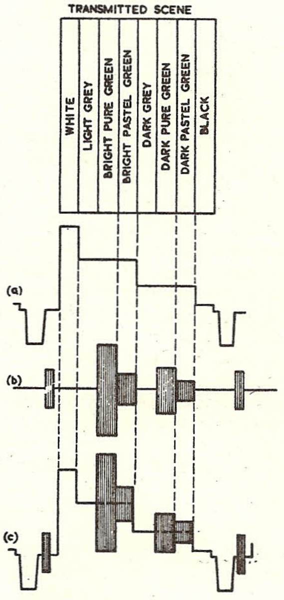
The colour signal is designed to produce an acceptable black-and-white picture on a normal monochrome receiver, that is to say, the signal is compatible. However, there are small differences between the reception of monochrome and colour transmissions which it is worth while considering before we discuss reception in colour.

The colour signal can be transmitted on the local monochrome channel frequency and be picked up by the normal monochrome aerial assuming, of course, that the broadcast is on the same line standards as the existing local programmes. The colour signal will be amplified by the tuner and IF circuits and detected at the vision detector as usual, where the video waveform will look much as normal on an oscilloscope, except that there will be a fuzz over the vision part of the signal, as in Fig. 1. This fuzz is the 4.4mc/s subcarrier; it disappears when the transmitted signal is grey and has its maximum amplitude where the waveform corresponds to bright and highly coloured parts of the picture. Notice the colour burst on the back porch. Fig. 1, of course, represents a fixed pattern; on a picture, the fuzz is distributed.

On the television picture the subcarrier appears as an interfering CW signal and produces a fine-structure brightness-modulation which looks like a series of black and white dots along each scanning line. Special frequency techniques at the transmitter make the dots form a pattern which helps to reduce their visibility. Since the subcarrier tends to disappear in dark or near-grey parts of the picture the subcarrier is only noticeable in those bright patches which correspond to highly coloured areas. It has the effect of brightening these areas slightly.

One result of the special frequency techniques mentioned above is that the exact frequency of the vision carrier may have to be changed slightly on colour transmission from its normal monochrome value; for 405 line NTSC the vision carrier was made about 40kc/s higher in frequency. For the British 625 line NTSC transmission, the vision carrier can be left unaltered, as the 6mc/s sound-vision carrier spacing is an exact multiple of the line scanning frequency. This does not affect the receiver performance, but it may change any echoes or ghosts on the picture from, for example, positive echoes to negative echoes.

It is necessary to keep a very strict frequency control on the subcarrier to help the receiver to decode the colour information, and one result is that the transmission has to be asynchronous; the field (or frame in British monochrome parlance) frequency is not locked to the



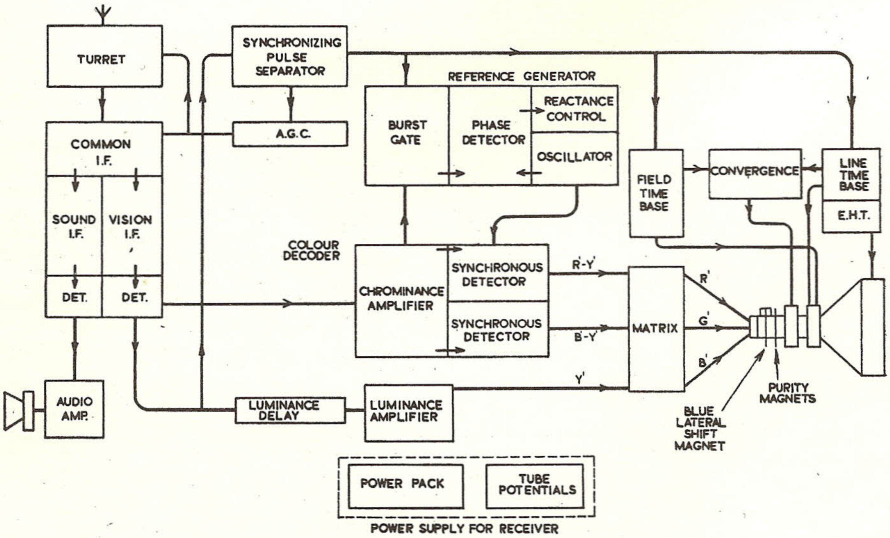


Fig. 1. Modulation waveforms for monochrome and colour: (a) monochrome video and colour luminance; (b) chrominance; (c) complete colour signal, luminance plus chrominance. **Fig. 2 (right).** Basic functions of an NTSC receiver using a shadowmask three-gun tube. (From "Colour Television," Carnt and Townsend: Iliffe Books, Ltd., 1961)

public utility 50c/s mains frequency. On some monochrome receivers this will give rise to hum effects.

Since the subcarrier is only 1.6mc/s away from the sound carrier there is much more chance of cross-modulation and breakthrough effects between the colour signal and the sound signal than between vision and sound. Subcarrier-on-sound breakthrough is very similar to picture-on-sound. Sound-on-subcarrier gives a beat pattern on the picture at 1.6mc/s. This effect can be quite serious with an FM sound carrier, as on 625 lines, with an intercarrier receiver.

BLOCK SCHEMATIC

The colour receiver has to accept the broadcast RF signal, amplify it, and separate out the composite vision signal from the sound signal. Next, it has to detect the composite video signal and then separate out the chrominance signal from the luminance signal. Both the luminance and chrominance signals have then to be amplified; the chrominance subcarrier has next to be detected in such a way that the two colour-difference signals can be recovered separately.

Finally, the *R′*, *G′* and *B′* voltages have to be reformed from the transmitted *Y′*, *R′* − *Y′* and *B′* − *Y′* signals. This chain of events will, perhaps, be easier to understand if we consider the block schematic of a colour receiver.

The basic functions of an NTSC colour receiver are shown in Fig. 2. We shall devote a further article to the shadowmask tube and shall treat it here as a display device into which we have only to feed three colour signals in order to obtain our colour picture. The timebases and synchronizing arrangements are similar to those in black-and-white receivers.

TUNER AND IF

These stages are similar to good monochrome practice, although care is taken to keep the amplitude response flat out to beyond the subcarrier frequency. The first major change from a normal receiver occurs at the vision detector. It is much easier to avoid certain types of colour distortion if the chrominance subcarrier is separated from the luminance signal while both signals are still at a low level. It is common, therefore, to have two vision detectors, one feeding the chrominance amplifier and one feeding the luminance amplifier.

LUMINANCE AMPLIFIER

The luminance amplifier is similar to the video amplifier of a monochrome receiver, although it is required to deliver a much larger signal (about 120V). There are two basic departures from monochrome practice. The first difference is that the luminance amplifier contains a rejector circuit tuned to the subcarrier frequency so that the overall luminance channel response is as shown in Fig. 3(a); this ensures that the subcarrier does not produce its interference pattern of dots in the colour picture—at least not in large areas, although dots still appear around the vertical edges of objects since the high-frequency sidebands are not rejected.

The second departure from monochrome practice is the insertion of a delay circuit in the luminance channel. This is necessary to ensure that the chrominance signals and the corresponding luminance signal arrive at the display tube at the same time. The chrominance circuits slow up the incoming signal more than the luminance amplifier does, and this has to be allowed for by inserting an artificial delay in the luminance channel to ensure that the colour signals are registered, horizontally, with the luminance signal on the final picture. The delay circuit usually consists of about a foot of special delay cable which has a time delay of approximately three-quarters of a microsecond.

CHROMINANCE AMPLIFIER

The chrominance amplifier can be considered as a video amplifier which rejects all the low frequency luminance information. The ideal response curve for a chrominance amplifier is shown in Fig. 4. The exact position of the low frequency cut-off varies from receiver to receiver, depending upon the type of decoding circuits used. Most of the first production receivers will probably cut-off at about 3 mc/s.

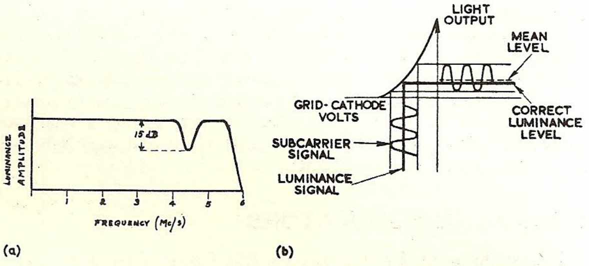


Fig. 3. A tuned circuit in the luminance amplifier attenuates the chrominance signal and its nearest sidebands so that the subcarrier interference does not appear on the colour picture (From "Colour Television")

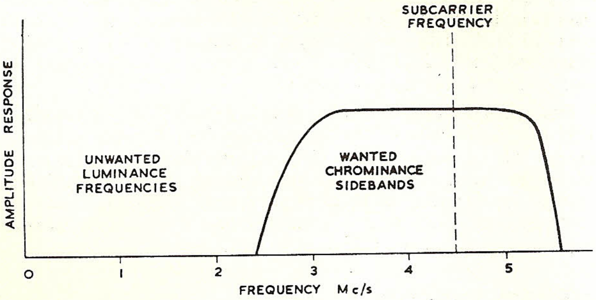


Fig. 4. Chrominance band-pass response (from "Colour Television"

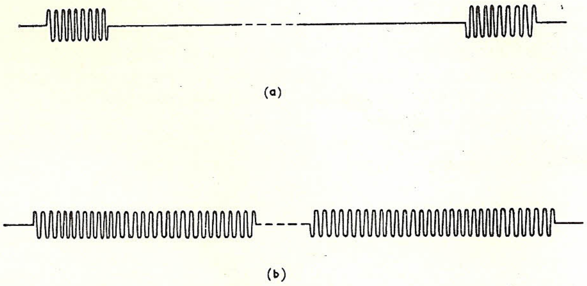


Fig. 5. The reference generator separates the colour burst from the synchronising signal and then fills in all the missing cycles between each burst

The chrominance amplifier amplifies the subcarrier and its sidebands up to a level suitable for the synchronous demodulators, which are going to detect the colour-difference signals; this level may be 1 volt or 100 volts according to whether low or high-level demodulators are used.

SATURATION CONTROL

A gain control in the chrominance amplifier alters the amplitude of the subcarrier and hence of the colour-difference signals which are fed to the matrix. This control is analogous to the contrast control but affects the amount of colour in the picture. If the gain of the chrominance amplifier is low, then the colours in the display will look washed-out or even non-existent. If the gain of the channel is too high, then the picture will be over-coloured and much too vivid.

It is possible to have an *automatic chrominance control* or ACC, similar to the AGC of vision and sound channels. The over-riding manual control which is normally available to the viewer is called the saturation control since it varies the purity of the colours in the reproduction.

Before the colour demodulators can detect the subcarrier, it is necessary to provide them with a phase reference so that they can distinguish between the two colour-difference signals. The phase reference, or timing signal, is produced in the reference generator, which uses the colour burst as a synchronising signal. There are several different kinds of reference generator but they all produce a continuous unmodulated sub-carrier signal, at 4.4mc/s, which is precisely locked in frequency and phase to the colour burst (Fig. 5).

The reference generator shown in Fig. 2 takes the chrominance signal and isolates the burst from the rest of the signal in the burst gate circuit. The burst is then compared with the continuous sine wave output of a local oscillator running at subcarrier frequency. Any difference in frequency or phase is corrected by a reactance valve circuit controlling the local oscillator. We shall discuss reference generators further in a later article.

COLOUR DEMODULATORS

The synchronous detectors use the CW reference signal to distinguish between the two sets of modulation which the chrominance subcarrier is carrying. A synchronous demodulator is a phase detector which can pick out the modulation occurring at one specific phase and reject the modulation which the subcarrier has at 90° to this phase. The exact phase at which the synchronous demodulator detects is determined by the phase of the reference signal which is supplied to it. This reference signal determines the precise time at which the colour demodulator measures the amplitude of the subcarrier (see Fig. 4 of the last article).

One synchronous demodulator picks out the $0.5\,(B'-Y')$ modulation and rejects the $R'-Y'$ modulation (Fig. 6) while a second demodulator chooses the $0.9\,(R'-Y')$ modulation and rejects the $B'-Y'$ modulation which is at right angles to it. It is possible to use the synchronous demodulators to pick out various suitable combinations of both the $R'-Y'$ and the $B'-Y'$ signals and we shall have more to say about this later.

MATRIX CIRCUIT

Now that the colour demodulators have detected the $0.9\,(R'-Y')$ and $0.5\,(B'-Y')$ signals, and the luminance amplifier has produced the Y' signal, it only remains to assemble the original R', G' and B' voltages. This is done in the matrix circuit by adding and subtracting the appropriate signals together. The gains of the colour-difference signals have to be adjusted, of course, so that the correct values of $B'-Y'$ and $R'-Y'$ are available to suit the particular level of Y' signal which is being used.

Then the red signal for the display tube is formed by adding the luminance signal to the red-colour difference signal:

$$R' = (R'-Y') + Y'$$

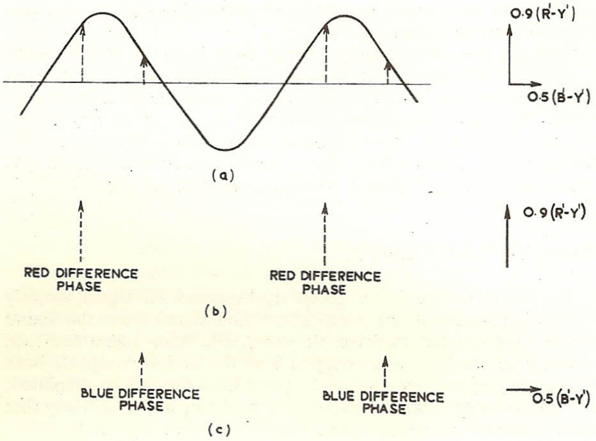
Similarly the blue signal is formed by adding the luminance signal to the blue difference signal:

$$B' = (B'-Y') + Y'$$

The third signal, green, can be formed in a number of ways. Fractions of the red and blue signal can be subtracted from the luminance signal:

$$Y' = 0.3R' + 0.6G' + 0.1B'$$

then $$G = 1.7(Y - 0.3R - 0.1B)$$



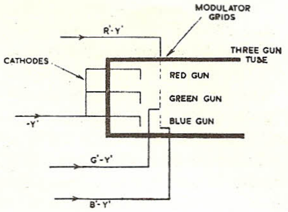


Fig. 6 (above). The two colour demodulators each separate out one of the chrominance signals and ignore the other (see also Fig. 4, Part 3). Fig. 7 (right). A very stable arrangement is to let the colour tube act as the final matrix circuit. On near grey colours only the luminance signal is effective and the grey scale does not depend on the balance between R′, G′ and B′ amplifiers

Another way is to first produce the green difference signal;

since $$0 = 0.3(R'-Y') + 0.6(G'-Y') + 0.1\,(B'-Y')$$

then $$(G'-Y') = -\frac{0.3}{0.6}\,(R'-Y') - \frac{0.1}{0.6}\,(B'-Y')$$

$$= -0.5\,(R'-Y') - 0.2\,(B'-Y') \text{ approximately}$$

The green signal is finally obtained by adding the luminance signal to the green colour-difference signal:

$$G' = (G'-Y') + Y'$$

In fact, most colour receivers make a point of producing all three colour-difference signals and then letting the colour display tube add the luminance signal to them. Fig. 7 shows a typical arrangement in which the negative luminance signal ($-Y'$) is fed to all three cathodes of the display tube while the three colour-difference signals are applied to the appropriate modulator grids. Such an arrangement has the advantage that for monochrome reception the colour circuits are not used at all, and it is a much more stable arrangement for colour reception as the grey scale is determined by the tube alone, for $(R'-Y')$, $(G'-Y')$ and $(B'-Y')$ are all zero for black, grey and white.

ERT SERVICE BULLETIN

UNDERSTANDING colour television

5: THE SECAM SYSTEM

By G. B. Townsend, BSc, FInstP, MIEE, AKC

THE NSTC system, the subject of the two previous articles in this series, is a magnificent achievement in many ways. The result of unprecedented co-operation between competing manufacturers, it is an example of large-scale administrative organisation *not* overwhelming the hundreds of engineers who were contributing to the development of the system. Above all it represents an advanced technical solution to the problem of adding colour to an existing monochrome TV network.

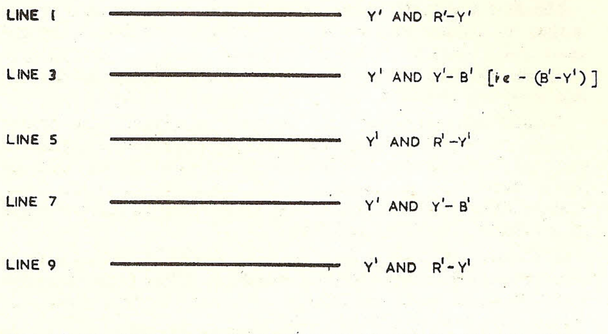
It has been described as the greatest intellectual achievement of American culture. This is perhaps an exaggeration but, certainly, everyone who has worked on the system is full of praise for the way conflicting requirements have been met and apparently impossible conditions overcome. What is more to the point, it can produce very good colour pictures.

The NTSC system was adopted by the American FCC in December, 1953. It is now 1963 and Europe, which has not yet finished developing its black-and-white networks, is beginning to think seriously about standardising on a colour system. The important question arises: Is it possible to improve on the NTSC system? Many engineers think it is. This article is concerned with the advantages which accrue from making one alteration to the American system, by changing the method of modulating the subcarrier.

FRENCH ORIGIN

The Secam system, which owes its origin to an eminent French engineer, Henri de France, is a development from the NTSC system and uses many of the basic principles of that system. The part of the NTSC system which most engineers have the greatest difficulty in understanding is the use of quadrature modulation and the emphasis on phase.

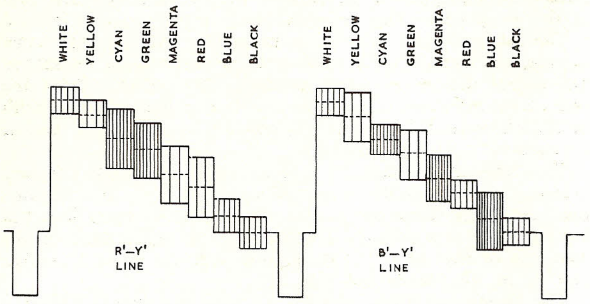
This process is perhaps not much of a disadvantage at the transmitter where test equipment and skilled personnel represent a very small part of the total operating cost. It is of considerably more importance at the receiving end of the system where cost is of prime importance and reference generators and synchronous demodulators are examined with little admiration for their intellectual elegance.



AND SO ON, CONSECUTIVELY THROUGHOUT SCANNING PROCESS FROM FIELD TO FIELD

Fig. 1. Only one colour-difference signal is transmitted on each scanning line in the Secam system

SECAM VIDEO WAVEFORM FOR COLOUR BAR SIGNAL



DOTTED LINES SHOW LUMINANCE LEVEL. VERTICAL BLOCKS INDICATE AMPLITUDE OF SUBCARRIER AND SPACING OF VERTICAL LINES INDICATES FREQUENCY OF SUBCARRIER

VIDEO PRE-EMPHASIS CURVE FOR COLOUR DIFFERENCE SIGNALS, BEFORE MODULATION ONTO SUBCARRIER

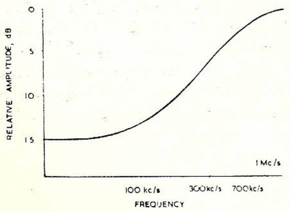


Fig. 2 (above). Composite Secam signal for colour bar pattern (frequency deviation indicated conventionally.) Amplitude variations are ironed out by limiters in the receiver, and give improved noise protection. Fig. 3. At the transmitter the higher frequencies in the colouring signals have their amplitude increased according to this curve. At the receiver, de-emphasis is applied

In any television system it is the receiver which is the dominant consideration, both from the point of view of national expenditure in manpower and money, and from the more prosaic standpoint of getting a reliable piece of equipment into everybody's home at a price which people can afford.

M. de France has made many contributions to the design of colour systems, and there have been several steps in the evolution of the present Secam system. The first break-through was the concept of not attempting to send both the chrominance signals at the same time on the same subcarrier. This removes the necessity for a phase sensitive system and overcomes the problem of cross talk between the two colouring signals.

The simplest form of modulation for the subcarrier, if it has only to carry one signal at a time, is amplitude modulation. Such a system has in fact been made to work, but it has several disadvantages compared with the new system. For instance, the chrominance signals may have either positive or negative values, and for cyan and orange one chrominance signal is positive while the other is negative. The only way to handle such negative values is to call a fixed level, such as 50 per cent. modulation of the subcarrier, the zero level of the chrominance signal, so that a lower level of subcarrier means a negative signal, whereas a higher level than 50 per cent. indicates a positive signal. However, then the grey scale of the receiver depends on maintaining the subcarrier and chrominance gains in perfect balance rather than on the absence of the subcarrier.

FURTHER ADVANCE

A further advance was made by changing to frequency modulation of the subcarrier. Grey then corresponds to zero deviation of the subcarrier and the subcarrier can tolerate large amounts of both amplitude and phase distortion without affecting the colour production.

A colour receiver for the Secam system does not need synchronous demodulators or a reference generator. But it does need a delay line so that at any instant the colour circuits can be provided with both the chrominance signal which is actually being transmitted at that moment, and the other chrominance signal which has been previously sent and has been delayed in the receiver for use a second time. This delay line is a purely passive component with no adjustments or controls.

The Secam system is being developed by the Compagnie Francaise de Television and is being investigated by companies and administrations all over Europe, from Russia to Italy. The name Secam comes from the two basic principles which are used—sequential and memory. The colouring signals are transmitted sequentially and the receiver uses a memory store, that is, the delay line. The name Secam is not a series of initials.

The Secam system uses the same colour primaries, the same camera, the same display tube, and the same basic luminance and colour difference signals as the NTSC system. Since the two colour-difference signals are not transmitted together, both of them can use the maximum bandwidth available and there is no need for I and Q signals.

The luminance signal Y' is transmitted on every line and provides a satisfactory compatible picture for monochrome receivers. The subcarrier is also transmitted on every line, but on one line it is modulated with the $R' - Y'$ signal while on the next line of that field it is modulated with the $B' - Y'$ signal, and so on, alternately (see Fig. 1).

The Secam subcarrier appears all over the picture but at a level which is lower than the amplitude of the NTSC subcarrier on bright saturated colours (see Fig. 2).

There is no longer any need for a precise frequency control on the unmodulated sub-carrier and it does not have to be an exact frequency multiple of the line scanning frequency.

In ordinary FM radio broadcasting the audio signal is pre-emphasised before being modulated on to the RF carrier and after demodulation at the receiver the sound signal is de-emphasised back to its normal state. The same process is used in the Secam system, where it confers the same advantage as in sound broadcasting, namely, an increase in signal-to-noise performance.

VIDEO PRE-EMPHASIS

In the Secam system it is the two colour-difference signals which are pre-emphasised. The amplitude of all the higher frequencies in each signal is increased by an amount depending on the particular frequency, according to the curve given in Fig. 3. At the receiver a very simple R-C circuit performs the inverse operation and restores the signal to normal.

For positive values of $B' - Y'$ the subcarrier deviation is positive, that is the subcarrier increases in frequency, and conversely for negative values of $B' - Y'$. However, for positive values of $R' - Y'$ the subcarrier is deviated in a negative direction, while negative values of the red-difference signal cause the subcarrier frequency to increase. These directions of deviation have been chosen after much experimentation with the system, because on the average kind of picture they confer certain small advantages. The modulation is arranged so that the deviation rarely exceeds 340kc/s.

It is not necessary in the Secam system to have a colour synchronising burst on each line to be able to measure phase along the line. In fact, it is not necessary to have any signal on the back porch of the line blanking, although earlier versions of the Secam system did use a switching signal in this position. However, if an undeviated subcarrier signal is transmitted during part of the line blanking period, it is possible for the receiver to clamp at 1 colour black level.

Since the subcarrier is modulated with $R' - Y'$ on one line and $B' - Y'$ on the next line, the line timebase can be used to give a switching signal to the colour circuits in the receiver so that they change over at the end of each line from receiving $R' - Y'$ to receiving $B' - Y'$. So long as the receiver timebase is synchronised then the colour circuits will be switched every line. The only problem is to make sure that the colour switching is done in the correct sequence. To ensure that the receiver is, indeed, switched to receive $R' - Y'$ when $R' - Y'$ is being transmitted, a special colour synchronising signal is sent out during the field blanking interval. If the receiver switching circuit is out of step with the transmitter sequence, then this field blanking signal makes the receiver circuit jump one switching operation so that it gets back into step.

COLOUR SYNC SIGNAL

The form of this colour synchronising signal is shown in Fig. 4. For five blanking lines a subcarrier signal is transmitted which corresponds on each line to a sawtooth colour-difference signal. The exact way in which the receiver uses this signal will be described in the next article on receivers for the Secam system.

In early versions of the Secam system the subcarrier amplitude was 16 per cent. of the peak white luminance signal. In the latest version it has been found possible to reduce the normal level of the subcarrier to only 10 per cent. of the peak luminance signal. This low level improves the compatibility of the colour signal when it is being received on a black and white receiver. So far as the colour receiver is concerned, the precise level of the frequency modulated subcarrier does not matter since the limiters in the receiver will keep the effective level of the subcarrier constant. Of course, for fringe reception there is the problem of noise if the subcarrier is at too low a level. To combat this, the subcarrier is increased at the transmitter whenever it is necessary to give any increased protection against noise or interference. Thus if a bright saturated colour is being transmitted the subcarrier amplitude is increased, since it has been found that noise appears first in these colours.

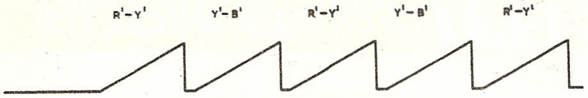


Fig. 4. The colour synchronizing signal is placed on five scanning lines on the back porch. The subcarrier signal corresponds to the chrominance waveform shown

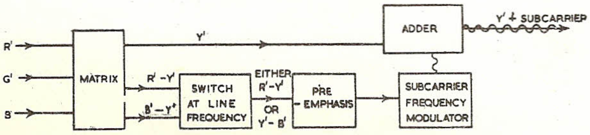


Fig. 5. Block schematic of the transmitter circuits. It is practical to introduce a lot more complication at the transmitter without in any way affecting the design of the colour circuits

There are several techniques of this kind which the transmitter can use to improve the performance of the system, although the receiver may be quite unaware of what is happening, the limiters removing any trace of the amplitude modulation. In fact, further modifications of this kind could be introduced after the public service has begun, since no modification to the receiver is called for.

Subcarrier phasing is one of these techniques. It is possible to readjust continually the phase of the subcarrier at the transmitter so as to reduce the visibility of the dot pattern formed on monochrome receivers, by breaking up any set patterns into which the dots may tend to fall. Since the colour receiver circuits are not sensitive to phase of the subcarrier, the colour picture is unaffected by such changes and the service man does not even need to know that such things are going on at the transmitter.

BASIC STEPS

Fig. 5 shows the basic steps in forming the Secam signal from the R' G' B' camera signals. An electronic switch selects whichever colour-difference signal is required for transmission on that particular scanning line, and the pre-emphasised signal is used to frequency modulate the subcarrier. The modulated subcarrier is then added, as in NTSC to the compatible luminance signal before the composite waveform, with sync. pulses, is sent to the main RF modulator at the transmitter.

The first and most important advantage of the Secam system is that the colour receiver becomes a more straightforward and more stable design. It has no reference generator and no synchronous demodulators, and it has no phase-sensitive circuits; this makes it an easier receiver to align and to service.

Because the subcarrier is frequency modulated the colour signal is very robust and will stand up to far more distortion than the NTSC signal will tolerate. It is easier to transmit the signal over long distances and to record it on video tape. Transmissions in hilly districts have shown it to be more immune to multipath distortions and echoes.

It is easier to transmit than the older NTSC signal since ~~there is no colour burst on the back porch~~, it is not phase sensitive and will stand quite an amount of amplitude compression of the subcarrier on very bright colours.

Secam transmissions on 405 and 625 lines have already been made in this country ~~and 625 line transmissions are being prepared.~~ The choice between the two systems may turn out to be a very important decision for the retail and servicing trade.

ERT SERVICE BULLETIN

UNDERSTANDING
colour television

6: RECEIVERS FOR THE SECAM SYSTEM

By G. B. Townsend, BSc, FInstP, MIEE, AKC

THE domestic receiver is the heart of any system of television, colour or monochrome. The total expenditure on receivers far outweighs the cost of providing the programmes, and certainly the average viewer is much more perturbed by a fault in his receiver than he is by a breakdown at the transmitter. In this article we shall discuss the influence of the new Secam colour television system on the domestic colour receiver. Previous articles in this series have dealt with both the American NTSC system and the French Secam system, but perhaps a brief recapitulation of the two will be helpful at this point.

Both use the same colour cameras and analyse the picture in the same way into its red, green and blue components. Fractions of each of the signal voltages corresponding to the primary signals are added together to produce a brightness or luminance signal Y'.

$$Y'=0.3R'+0.6G'+0.1B'$$

This luminance signal is transmitted as the normal black and white signal and produces a satisfactory picture on all monochrome receivers. The extra signals required by the colour receiver are transmitted as

$$R'-Y' \text{ and } B'-Y'$$

the so-called colour-difference signals.

In NTSC, these colour-difference signals are transmitted simultaneously by quadrature modulation of a colour subcarrier placed in the high frequency end of the video band of the luminance signal. In the Secam system the two colour-difference signals are transmitted sequentially, line by line, using frequency modulation of the subcarrier (see Fig. 1). In this way the use of reference frequency generators and synchronous demodulators in the receiver is avoided. The last article mentioned some of the advantages of the Secam system for transmission; let us see how other benefits arise in the receiver.

The main receiver functions are shown in Fig. 2. The colour receiver can use any colour display tube but, as the shadowmask tube is still the only type in production, we shall confine our discussion to receivers using three-gun simultaneous display.

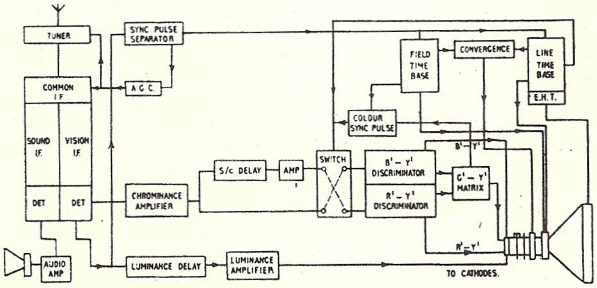


Fig. 2. Basic block diagram of a receiver for the Secam system, using a shadowmask tube

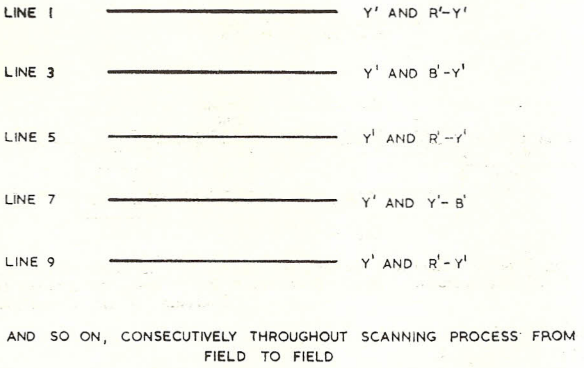


Fig. 1. Only one colour-difference signal is transmitted on each scanning line in the Secam system

Once the colour-difference signals have been recovered from the subcarrier, the colour receiver is similar for both systems.

The luminance channel gives out the brightness signal Y' which is fed to all three cathodes of the shadowmask tube. If there is no colour in the transmission then the colour-difference signals are zero and the luminance signal operates the colour tube as it would an ordinary monochrome tube. If the transmission is in colour, then the two transmitted colour-difference signals, $R'-Y'$ and $B'-Y'$, are applied to the red and blue modulator grids of the tube, respectively, while the third colour-difference signal, $G'-Y'$, is worked out by a simple matrix circuit:

$$0.6\,(G'-Y')=-0.3\,(R'-Y')\,-0.1\,(B'-Y')$$

and is then applied to the green modulator grid.

Since the luminance signal has to be put on the cathodes with negative polarity, the colour tube itself performs the final addition of the luminance signal to the colour-difference signals and produces the required red, green and blue drives to the respective guns:

$$(R'-Y')+Y'=R'$$

as in an NTSC receiver.

RF and IF stages are similar to those in NTSC receivers; there is no particular requirement on phase around the subcarrier frequency and any good quality monochrome receiver tuner and IF deck will be satisfactory.

After the second detector, the subcarrier is filtered from the luminance signal and the chrominance stages amplify the subcarrier. Since the subcarrier is frequency modulated there is no need for a chrominance gain control, automatic or otherwise.

COLOUR DEMODULATION

It is at the colour demodulators that the major differences between the two systems appear. The demodulators, of course, are simple FM discriminators as used in Band II radio receivers and are familiar to all service engineers. Since only one of the two colour-difference signals is being transmitted on any particular scanning line, the direct output from the chrominance amplifier is only fed to one of the two discriminators. However, the matrix circuit needs both colour signals at once in order to operate the colour tube, so the receiver uses the colour-difference signal which was transmitted on the preceding line to take the place of the signal which has not been sent on this particular line. This is why a delay line is needed in the receiver.

The delay line acts as a memory and enables the receiver to use each colour-difference signal twice, once immediately it is received and a second time, one scanning line later. Thus one discriminator gets the direct signal while the other discriminator is fed with the delayed signal from the previous line. At the end of each line the connections to the discriminators are reversed.

As an example, suppose that $R'-Y'$ is being transmitted on line 5 (see Fig. 1) then the connections in the receiver will be as shown in Fig. 3, with the transmitted colour-difference signal being fed to the $R'-Y'$ discriminator. The $B'-Y'$ discriminator has to make do with the colour-difference signal which was transmitted on the preceding line and which is now emerging from the delay line. At the end of this line scan the receiver gets a pulse from the line time-

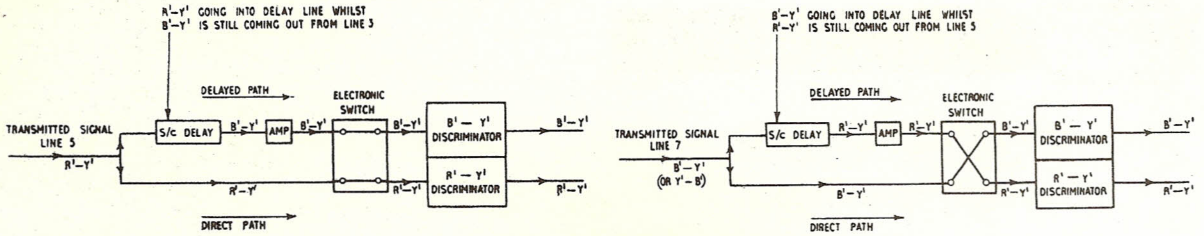


Fig. 3 (left). When R′-Y′ is being transmitted, the electronic switch connects the direct path to the R′-Y′ discriminator and the delayed path to the B′-Y′ discriminator. When B′-Y′ (or Y′-B′) is being transmitted (Fig. 4, right), the electronic switch connects the direct path to the B′-Y′ discriminator, and the delayed path to the R′-Y′ discriminator

base which reverses the connections to the discriminators, as shown in Fig. 4.

Thus during the following line scan, which is line 7 of the complete interlaced picture, the colour signal which is being transmitted—now $B'-Y'$—is fed to the $B'-Y'$ discriminator. At the same time the $R'-Y'$ signal from the line 5 transmission is appearing at the output of the delay line which is now connected to the $R'-Y'$ discriminator. In this way, the correct colour difference signal is always fed to each discriminator. The synchronization of the change-over has only to occur some time during the line blanking interval, and is much less critical than the synchronization of the line timebase itself.

Of course, the vertical colour definition is decreased by this technique, but the pattern by which colour-difference signals appear on each line reverses from picture to picture so that no information is completely omitted from the integrated scene which the viewer sees. Subjectively, the loss of colour resolution vertically is much less than the horizontal loss of resolution in the NTSC system, and few people can distinguish any defects due to this.

DELAY LINE

In principle it is possible to use several different kinds of delay line. It is too early to say which sort will eventually be chosen for mass production, although this decision may be an important one from the point of view of cost. One type of line being used at the moment is illustrated in Fig. 5. It is about the size of a large electrolytic condenser and externally looks very similar in appearance. It has an input terminal and an output terminal and no controls or adjustments whatsoever. In the unlikely event of the unit failing it can only be replaced and returned to the manufacturers—the service engineer is not required to align it, as he is with reference generators or synchronous demodulators.

Internally the delay line consists of a flat block of fuzed quartz. The subcarrier signal, at 4.4mc/s, is fed into the input transducer of barium titanate, which propagates it into the quartz block as a 4.4mc/s supersonic sound wave. This vibration travels down the length of the block and is reflected from the polished end back to the output transducer, which is again of barium titanate. The output transducer converts the sound wave back to an electrical signal once more. The relatively slow velocity of sound waves in the quartz material makes it practical to obtain the required delay of one scanning line interval, 64 microseconds, with a reasonable length of line.

Another type of delay line uses a glass rod for transmission of the sound wave, with a transducer at each end

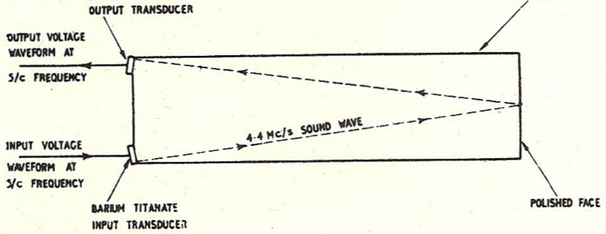


Fig. 5. The transducer converts the subcarrier electrical signal into a vibration in the quartz. This travels with the velocity of sound along the block and is reflected back from the far end

Of course, the output signal is smaller than the input signal and a stage of amplification has to be provided, but as the signal is frequency modulated its exact amplitude is not critical and it is not necessary to balance the direct and delayed signals. Also, although the delay line produces some spurious and unwanted signals, these are sufficiently low in amplitude to be rejected by the FM discriminators.

Although the switch which reverses the connections to the discriminators is operated by the line timebase and there is no colour synchronization as in NTSC, it is possible for the colour-difference switch to start up on a transmission in the wrong position, so that $R'-Y'$ is being fed to the $B'-Y'$ discriminator, and vice versa. If this happens the set will continue to produce the wrong colours indefinitely. It is possible to have a manual switch which reverses the connections once, to bring the electronic switch into the correct operating sequence again. However, to enable the receiver to perform this operation automatically, the Secam system includes a special signal which serves a dual purpose.

Earlier versions of the Secam signal included a burst of subcarrier on the back porch of the line blanking signal, rather like the colour burst of the NTSC signal, although in this case the colour burst contained no phase information and was only used to indicate that the next line would have $R'-Y'$ on the subcarrier. The presence of a colour burst on the back porch makes it necessary in the receiver to ensure that the peaks of the subcarrier do not show on the picture during the line retrace period, and makes it more difficult to clamp on to this porch; this latter point is a very real one for some designs of transmitter.

The synchronization signal used on the new system was described in the last article and consists of transmitting a sawtooth waveform for the two colour difference signals during the last five lines of the field blanking period.

If the discriminator switch is in the correct position this waveform gives a negative output in the $G'-Y'$ matrix. If the discriminator switch is in the wrong position, then the colour synchronising waveforms give a positive output which is measured by a diode; this diode then inserts an extra pulse into the series of pulses which the line timebase is sending to the discriminator switch. The extra pulse is sufficient to pull the switching sequence into step with the transmitted sequence.

DISCRIMINATOR CHECK

The field blanking colour synchronising signal can also be used by the service engineer to check the performance of the discriminators, since each of the saw-tooth waveforms is sweeping its appropriate discriminator across its frequency range and is continuously providing a check on the discriminator alignment. The system is thus providing the maintenance engineer with a free service.

As well as allowing straightforward and stable colour receivers to be mass produced, the Secam signal is a very robust signal which gives good protection—because of the FM capture effect—against interference, and which causes fewer difficulties in hilly reception areas. Distortion of the NTSC subcarrier during propagation and reception usually produces colour changes in large areas of the picture. With the Secam system these distortions are generally only noticeable on edges. Recent experiments by the Swiss broadcasting authorities, using both systems in the area around Berne, showed that the Secam signal gave appreciably better quality of colour reproduction than the NTSC in areas where the picture was marred by reflections or ghosts.

ERT SERVICE BULLETIN

UNDERSTANDING

colour television

7: SHADOW MASK COLOUR DISPLAY TUBE

By G. B. TOWNSEND, BSc, FInstP, MIEE, AKC

BOTH the contemporary colour television systems, Secam and NTSC, begin by analysing the colour in the original scene into its red, green and blue components. At the other end of the television system, in the viewer's home, the receivers for both systems terminate, effectively, with the application of red, green and blue signal voltages to the colour display tube.

Most types of colour display tube can be used with either system and, in particular, three-gun display tubes are very convenient for the simultaneous type of signal, in which the receiver at any instant is giving out all three primary colour signals at the same time.

In the second article in this series we discussed briefly several types of colour display tube. The shadow mask principle was first used by the Radio Corporation of America. When it was announced in the USA, the concept was greeted with considerable scepticism. In fact, one of America's most famous and learned television engineers swore on affidavit to the Federal Communications Commission that he thought such a tube was not practical: of course, he laughs about this now, but most engineers shared his view at that time.

However, RCA have spent tens of millions of dollars on colour tube research, have made many different kinds of tube work in the laboratory, and have been mass-producing the shadow mask tube for the best part of a decade. It is the only type of colour tube in large scale production, and is made in both Japan and America, while small quantities have been made in other countries such as USSR and Holland.

Most colour engineers feel that it may not be the final answer to the difficult problem of making a colour display tube, but there is little doubt that it will be the tube which is used in the United Kingdom to inaugurate our colour television service. Nor is there any doubt that the shadow mask tube can be set up to give a very fine colour picture.

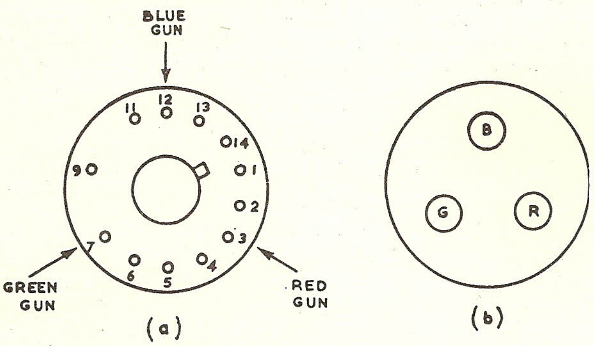


Fig. 2 (a) Base of RCA shadow mask tube. Pin connections are: 1 heater, 2 red modulator G1, 3 red screen G2, 4 red cathode, 5 green cathode, 6 green modulator G1, 7 green screen G2, 9 focus grid G3, 11 blue screen G2, 12 blue modulator G1, 13 blue cathode and 14 heater. Relative positions (b) of the three guns viewed from base. (From *Colour Television*, Carnt and Townsend, Iliffe Books, 1961)

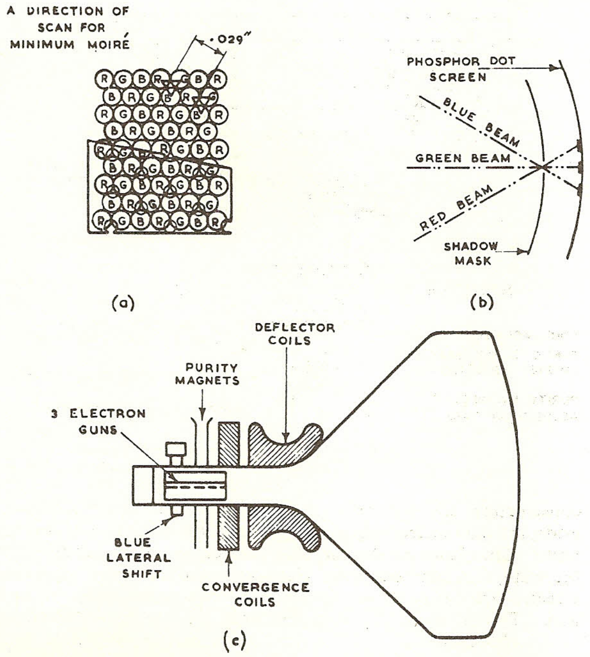


Fig. 1 (a) shows an enlarged view of the shadow mask with the phosphor dot screen behind it and (b) the principle of the geometrical separation of three electron beams; (c) is a cross-sectional view of the tube

The basic principles of the shadow mask tube have already been outlined. Three independent electron guns are placed alongside each other in the tube neck, and each sends its own focused beam of electrons towards the screen. The screen itself is a regular mosaic of tiny dots of phosphor. Three kinds of phosphor are used, one of which glows red when it is bombarded by electrons, another green, and the third blue. The three types of phosphor are arranged in a very orderly array as in Fig. 1.

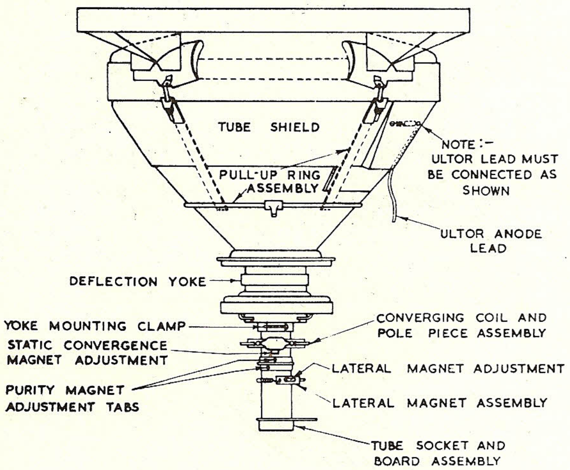
As one of the three electron guns is going to be modulated with the red signal, we require electrons from this gun—the so-called red gun—to light up only the red glowing phosphor dots and not the green or blue dots; to ensure this is the function of the 0.006in. thick steel mask. The mask is mounted rather less than an inch behind the phosphor dot screen, and for every trio of red, green and blue dots there is one hole in the mask, carefully aligned with the little group of phosphor dots and the three guns.

ABSORBS ELECTRONS

The shadow mask absorbs electrons which hit it, and the geometry is arranged (see Fig. 1) so that the red gun can only "see" red phosphor dots, the other dots being in the shadow of the mask while the red dots appear in line with the holes. From the blue gun position, however, the red and green dots are hidden by the mask and only the blue dots line up with the holes in the mask. The scale of the dots and holes is small, and the focused overlapping electron beams, in any one position, cover two or three holes in the shadow mask.

The majority of the electrons are absorbed by the metal mask, only about a quarter finally reaching the phosphor screen. The holes in the mask are graded from relatively large holes in the centre of the screen to smaller holes around the edge of the picture. It is possible to enlarge the centre holes as the tolerances here are not quite as critical as at the edge. The effect, of course, is to make the reproduced picture brighter in the centre than at the edges, but this effect is quite acceptable. As the mask absorbs so many electrons it gets hot, but it is so designed that as it expands it does not buckle and all the holes move outwards along the direction of electron beam travel without upsetting the alignment with the screen phosphor dots.

The three electron guns are each similar to the electron guns used in black-and-white cathode ray tubes. They are of tetrode



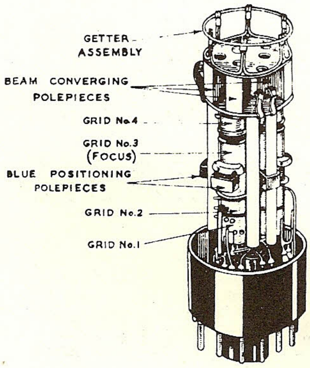


Fig. 3. External controls and coils on a shadow mask tube and Fig. 4, the electron gun assembly of an RCA tube. (From *Colour Television*, Carnt and Townsend, Iliffe Books, 1961)

construction with electrostatic focusing. All the three focus grids are connected together so that they are focused as one unit. The final anodes are all connected to the coating on the bulb, but the remaining electrodes, the cathodes, grids and screens, are brought out to the tube base separately for each gun. Typical operating voltages for a shadow mask tube are:

Heaters	6.3V 0.6A
Final anode voltage	24kV
Focus voltage	4.5kV
Screen grid to cathode voltage	500V
Modulator grid to cathode voltage	120V
Total beam current	1.5mA

The three guns are arranged symmetrically around the tube axis with the blue gun on top (see Fig. 2).

DEFLECTION COILS

The deflection coils are basically similar to those used on monochrome tubes, but are considerably larger. The neck of the shadow mask tube is 2in. in diameter and to obtain a uniform magnetic scanning field over the centre region of the tube neck, to cover all three electron beams identically, the deflection coils are larger than the neck and are held away from the tube neck by plastic spacers. The rear face of the deflection coils is usually shielded magnetically and electrostatically from the other controls around the tube neck.

Typical deflection coils for a shadow mask tube have these characteristics:

Field deflection coils: Inductance 120mH; resistance 55 ohms; sensitivity 0.5A peak to peak for a deflection angle of 55 degrees.

Line deflection coils: Inductance 12mH; resistance 7 ohms; sensitivity 1.7A peak to peak for a deflection angle of 70 degrees.

It is not practical to manufacture the shadow mask tube so precisely that the electrons from the three guns automatically come from the correct positions to suit the shadow mask and the phosphor dot screen. To take up the manufacturing tolerances a pair of external magnets are used on the tube neck to displace all three beams into the correct position inside the tube. These magnets are called the purity magnets. They are shown in position in Fig. 3.

They consist of two rings of magnetic material, each magnetised across a diameter so that they produce a transverse magnetic field across the tube neck. The two rings can be rotated together, or independently of each other, so that both the direction and the strength of the magnetic field can be varied. In this way the three beams can be moved across the tube neck until they are in the correct transverse position with respect to the tube axis. A slight movement of the deflection coils along the tube neck then ensures that as the beams are deflected they appear to come from the correct position *along* the length of the tube axis.

This procedure will ensure that the red electrons only hit red phosphor dots, and so on, and then the final raster looks even in colour: that is to say, on a uniform picture of one plain colour, the screen looks the same colour all over without patches of spurious hue. The tube is then said to be pure.

Once the tube is pure the red gun will produce a red picture quite independently of the blue picture and the green picture, and it does not follow that the three primary pictures will be in register. The process of making the three pictures overlap exactly is called converging the tube. It is essentially a matter of making the three focused beams coincide at the centre of the screen—called static convergence—and then of keeping the three spots coincident as they are scanned across the raster—called dynamic convergence.

BEAM CORRECTION

The three electron guns are all tilted slightly toward the axis of the tube so that the electrons are roughly aimed at the screen centre. To make sure that they hit precisely in the same spot it is necessary to correct each beam individually; this correction is made by applying an external magnetic field to the tube neck, where pole pieces inside the neck channel the magnetism around the particular beam (Fig. 3).

A convergence yoke assembly around the outside of the tube neck provides the required magnetic fields, one set for each gun. For static convergence it is possible to use either an adjustable permanent magnet or DC through a winding on the convergence yoke. Such an external field will move the

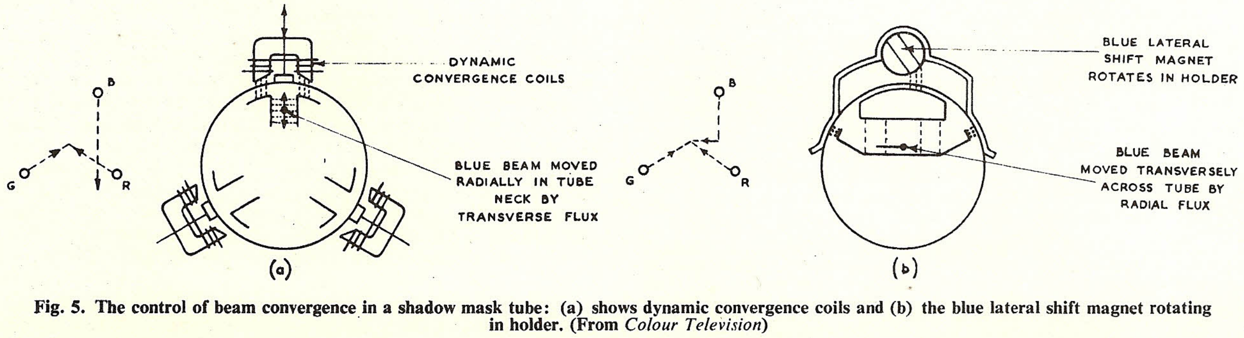
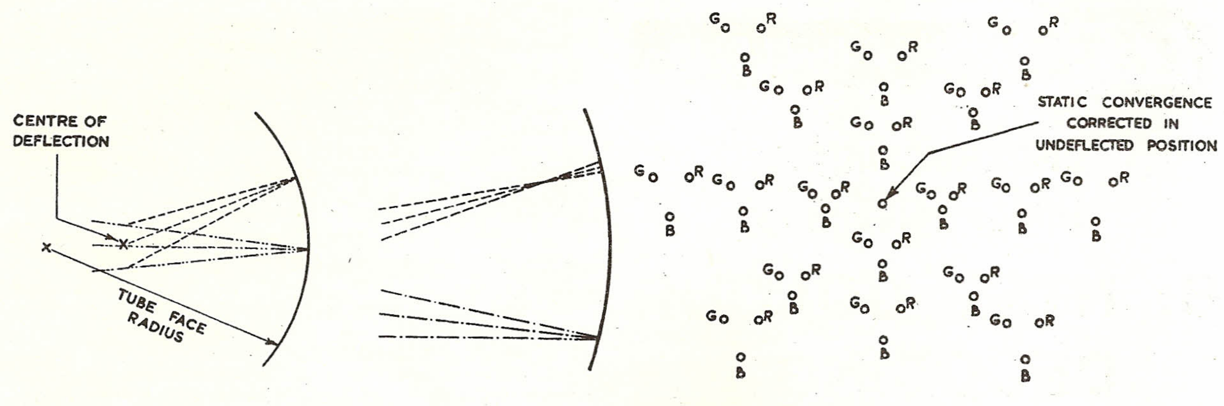


Fig. 5. The control of beam convergence in a shadow mask tube: (a) shows dynamic convergence coils and (b) the blue lateral shift magnet rotating in holder. (From *Colour Television*)



(a) (b)

Fig. 6. Convergence of a three gun tube. (a) Shows how the three beams diverge as they are deflected and (b) shows the separation of spots on the screen face as the three beams traverse the screen. (From *Colour Television*)

corresponding beam, viewed from the front of the tube, in a radial direction. Any two of the beams can thus be made to meet in the undeflected position, but the third beam may miss this position as it is moved along its radial path. To overcome this difficulty a further positioning control, the *blue lateral shift* magnet, is provided, which can move the blue beam sideways.

It is not sufficient to make the red, green and blue scanning spots register in the centre of the screen for it is found that, as the raster is scanned, the spots spread out again, as in Fig. 6. This is akin to deflection defocusing: if we think of the three electron beams as part of one large beam which produces a distorted spot out towards the edges of the raster, we have a mental picture of what is happening to our three actual beams.

In the same way as some precision monochrome tubes employ dynamic focusing, we have to apply varying magnetic fields to the convergence yoke to correct the position of each spot as the raster is scanned. The dynamic magnetic fields are produced by passing current waveforms, at both line and field repetition rate, through each of the three assemblies on the convergence yoke. By controlling the amplitude and shape of these waveforms, the three primary rasters can be converged over most of the picture area. The waveforms are obtained from the timebases and it is usual nowadays to derive them by passive circuits without valves.

In the second article in this series we mentioned the problem of making the three input-output characteristics match so that a monochrome signal reproduces the same grey colour at all luminance levels from black to white. In practice this is a matter of adjusting the screen voltages until the three input-output curves have the same shape, and then setting the three grid bias controls until the three curves overlap exactly.

The shadow mask tube has been criticised for all the numerous adjustments which have to be made to it. However, there are fewer adjustments to make on the latest tubes than on the early models, and the service engineer will soon find that it all becomes a matter of routine. The most difficult part of the procedure at which to become adept is setting the dynamic convergence adjustments. However, as in most things, practice makes perfect!

ERT SERVICE BULLETIN

UNDERSTANDING

colour television

8: NTSC COLOUR DECODING CIRCUITS

By G. B. Townsend, BSc, FInstP, MIEE, AKC

THE basic design of colour television receivers for the NTSC system was outlined in the fourth article in this series and a block schematic of a colour receiver is repeated here in Fig. 1. This block diagram is not quite the same as that given in the earlier article; it represents a receiver which keeps the colour information in the form of a luminance signal and colour-difference signals, right up to the cathode-ray tube itself. Such a technique avoids the difficulties of handling separate red, green and blue signals, and practically all contemporary receivers use this arrangement.

CHROMINANCE AMPLIFIERS

Chrominance amplifiers are essentially high-pass video amplifiers. They accept the sub-carrier frequency at 4.43mc/s, and its sidebands, but reject the low-frequency luminance signals which are also part of the composite video waveform. In accepting the colour sub-carrier the chrominance amplifiers also accept, necessarily, the high frequency part of the luminance signal.

These high frequency luminance components are, in the chrominance amplifier, an unwanted signal, but it is not practical to get rid of them; they produce some interference effects in the colour picture but this is part of the price of having a band-sharing system with three signals all packed into one video band. The unwanted luminance components are detected by the synchronous demodulators and produce spurious colour in the picture, called *cross-colour*. Cross-colour is usually only noticeable when there is a fine black and white repetitive pattern in the picture which corresponds, horizontally, to a frequency close to that of the sub-carrier. Black and white resolution test wedges show the effect so well that it can be used to judge the bandwidth of the chrominance amplifiers.

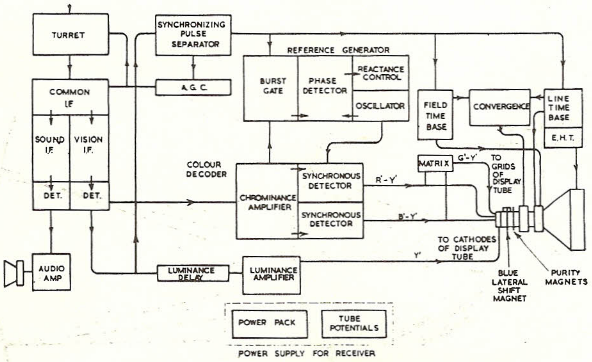


Fig. 1. Block schematic of an NTSC receiver in which the cathode ray tube itself performs the final matrixing to red, green and blue signals

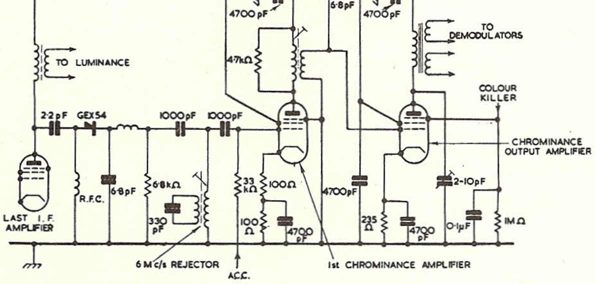


Fig. 2. Chrominance amplifier in the GEC colour receiver type TTIV (from *Colour Television*, Carnt and Townsend, Iliffe Books)

A fairly typical circuit for a chrominance amplifier is shown in Fig. 2. The last IF valve feeds two detectors, although only the one giving the video information to the chrominance channel is shown. The band-pass circuits are tuned to the sub-carrier frequency and are wide enough to accept its sidebands.

A typical response shape for a chrominance amplifier is shown in Fig. 3. The amplifier does not accept the low-frequency luminance components, nor does it accept the sound signal. A sound rejector circuit is necessary to prevent a 1.6mc/s beat between sub-carrier and sound.

The output from the first chrominance amplifier valve, which may be a variable-mu type, also feeds the burst gating circuit in the reference generator.

The receiver contrast control, operating on the gain of the IF stages, varies the amplitude of both the luminance and sub-carrier chrominance signals together, so that the reproduced picture does not vary in saturation. To change the amount of colour in the picture it is necessary to have a separate control over the chrominance signal amplitude. Such a *saturation control* may be a bias gain control on one of the chrominance amplifiers or it may be a potentiometer across the input to the amplifier altering the signal level.

It is practical to have an automatic chrominance gain control (ACC) to maintain the saturation in the picture constant as the receiver is switched from one channel to another or as differential fading takes place. The ACC control voltage can conveniently be obtained by measuring the colour burst amplitude, in the same way as the automatic contrast control voltage can be derived from measuring the sync pulse amplitude.

When the colour receiver is used on a monochrome transmission, it is usual to bias back the chrominance amplifier so that it does not pass any signals to the synchronous demodulators. In this way the high-frequency luminance-signal components cannot be wrongly interpreted as colour signals, and cross-colour is avoided; this is important on black and white pictures as quite small traces of colour are very obvious when all the rest of the picture is grey.

The circuit which provides such a bias to the chrominance amplifier is called a colour killer. In Fig. 2 the colour killer voltage is fed to the suppressor of the second amplifier valve. The colour killer circuit itself is normally part of the reference generator.

SYNCHRONOUS DEMODULATORS

The colour subcarrier has been modulated in the studio with the two colour-difference signals, and the receiver uses synchronous demodulators to detect these signals. A synchronous demodulator will detect one colour difference signal and ignore the other signal. This process is sometimes called decoding.

Since there are two colour-difference signals to be decoded, at least two synchronous demodulators are required. The colour subcarrier signal is fed to both synchronous demodulators; each demodulator is also fed with a continuous reference frequency from the reference generator. The reference frequency is locked precisely to the subcarrier frequency and its phase with respect to the phase of the colour burst signal can be accurately controlled. By selecting the phase of the reference signal fed to each synchronous detector, the detector can be made to demodulate either R′−Y′ or B′−Y′ signals.

It will be remembered that the NTSC subcarrier chrominance signal consists of the addition of two subcarriers of the same frequency but 90 degrees apart in phase, with each subcarrier amplitude-modulated by one of the chrominance signals. When they are added together, the two subcarriers form one signal which is both amplitude and phase-modulated. Thus in Fig. 4, the top diagram (a) can represent the R′—Y′ subcarrier, while (b) represents the B′—Y′ subcarrier. When both subcarriers are added, as in (c), it is still possible to measure the separate R′—Y′ and B′—Y′ amplitudes, provided the measurement is performed at the right time. The purpose of the reference signal is to tell the synchronous demodulator the right time at which to carry out the measurement.

It is not essential to measure the amplitude at times corresponding to (R′—Y′) and (B′—Y′): by choosing other times to carry out the measurements we can obtain signals which represent mixtures of so-much (R′—Y′) signal plus so-much (B′—Y′) signal. These combination signals are sometimes useful for special purposes. The I′ and Q′ signals mentioned in the fourth article are examples of such combination signals. If the amplitudes of (R′—Y′) and (B′—Y′) are measured directly, demodulation is said to be along the (R′—Y′) and (B′—Y′) axes.

There are many different types of synchronous demodulator, some of which are described in the next sections.

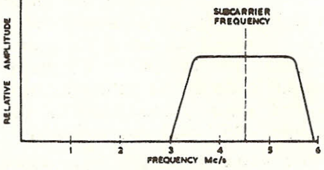
DEMODULATORS

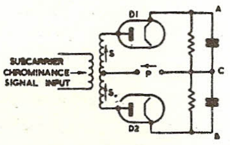
A simple form of synchronous demodulator is shown in Fig. 5. The incoming modulated chrominance signal is fed into the primary of the transformer, so that a chrominance signal of amplitude S is applied across each diode. At the same time, a reference sine wave signal P is applied between the two terminals, so that the diode D has to detect the difference between the two signals.

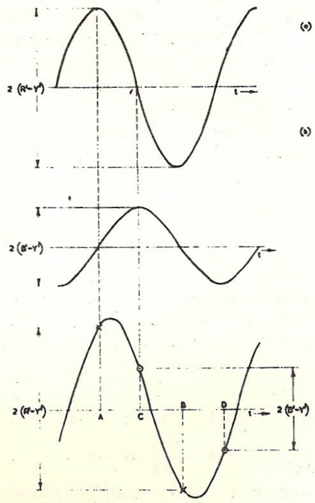
If the reference signal P is appreciably larger than S, then the diodes effectively ignore the component at right angles—as in Fig. 6. Thus P + S appears across AC, and P — S across CB, so that 2S can be measured across AB.

Another type of colour detector is very similar to a frequency changer. The basic circuit is shown in Fig. 7. The modulated chrominance signal is fed to one mixer grid, while the unmodulated reference is fed to the other mixer grid. A low pass filter in the mixer anode rejects the subcarrier frequency and leaves the chrominance modulation.

If the reference signal has the same phase as (R′ — Y′), then (R′ — Y′) modulation appears at the anode. It is rather like using a local oscillator to frequency change an incoming RF signal down to IF, but in this case the local oscillator has the same frequency as the incoming subcarrier signal, the IF frequency is zero (DC) and we are left with the modulation only. No output is obtained if the signal is at 90 degrees to the reference sine wave







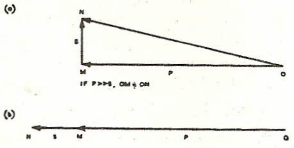
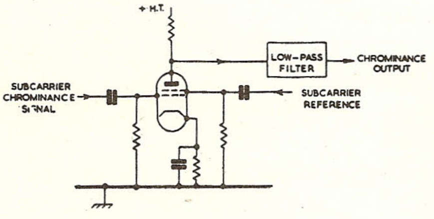


Fig. 3 (top left). Chrominance amplifier response for British TAC 625-line standard. Fig. 4 (left). Principle of synchronous demodulation—(a) shows the R′—Y′ component of subcarrier (b) the B′—Y′ component, and (c) composite subcarrier signal. Fig. 5 (top right). The basic circuit of double-diode synchronous demodulator (from *Colour Television*). Fig. 6. A vector diagram associated with the explanation of Fig. 5

A gated triode can be used to sample the incoming signal at the correct time each cycle of the subcarrier. Such a detector can be used with a high level of subcarrier signal amplitude so that enough colour-difference signal output is obtained to drive the display tube directly. Fig. 8 shows a schematic circuit. The large subcarrier signal is applied to the anode of the triode. The triode acts as a switch, which is switched on by the peaks of the alrge reference signal applied to the grid; for the rest of each cycle grid-current keeps the triode cut-off.

At the instants of conduction the anode voltage falls to a low value, about 25V, which is virtually independent of the signal on the anode. The triode thus clamps the incoming signal to +25V every time the triode conducts.

In this way the triode gives the incoming signal a low fre-



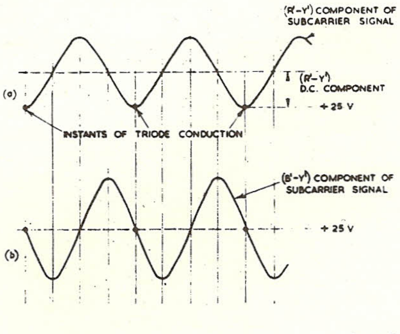
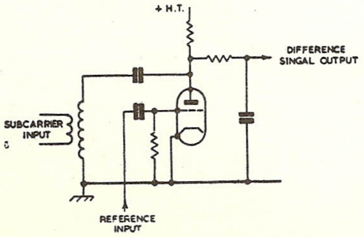
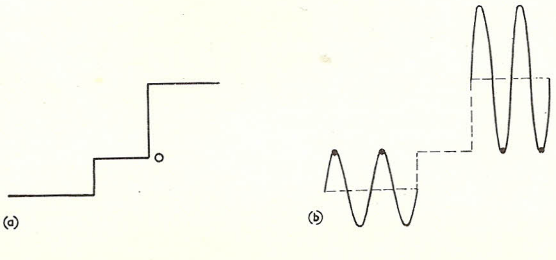


Fig. 7 (extreme left, top). Basic circuit of a mixer synchronous demodulator and, Fig. 8 (below) a high level, gated triode, colour demodulator circuit (from *Colour Television*). Fig. 9 (left, top). Triode anode voltage waveforms for positive (R′—Y′) and (B′—Y′) signals (from *Colour Television*).

Fig. 10 (a) an example of an (R′-Y′) video waveform
(b) The corresponding anode voltage waveform on a gated triode demodulator; the dotted line shows the filtered modulation signal





quency bias which depends on its modulation and the phase of the reference signal. Thus in Fig. 9, the triode would clamp on the negative peaks of an (R′ − Y′) signal, but at the mean, or zero level of a (B′ − Y′) signal. For the (R′ − Y′) signal, the RC filter on the anode output removes the subcarrier sine wave and leaves a positive DC value proportional to the original (R′ − Y′) signal, plus the +25V clamping potential.

For the (B′ − Y′) signal there would be no DC value apart from the clamping potential. Changing the phase of the reference signal so that the triode clamps on the peaks of the (B′−Y′) signal would give (B′−Y′) modulated output, but no (R′−Y′). For negative values of signal, of course, negative DC voltages are produced. If the chrominance signal varies, then the decoded output varies similarly as in Fig. 10.

It will be seen that, unlike the previous two demodulators, the gated triode detector has a detection axis which is the negative of the reference phase applied to the grid, i.e. is 180 degs. away in phase.

MATRIXING

The colour display tube needs R′− Y′, G′−Y′ and B′−Y′ signals on its three colour grids, but our two synchronous demodulators are only producing R′−Y′, and B′−Y′. The matrix circuit has to derive the third colour difference signal from the two detected signals.

$$\text{Since } Y' = 0.3\,R' + 0.6\,G' + 0.1\,B'$$

$$O = 0.3(R'-Y') + 0.6(G'-Y') + 0.1(B'-Y')$$

$$\text{so that } (G'-Y') = -\frac{0.3}{0.6}(R'-Y') - \frac{0.1}{0.6}(B'-Y')$$

Since (G′−Y′) is a combination of the two transmitted colour difference signals, it is possible to use a third synchronous demodulator detecting along the appropriate axis. However, it is more usual to add fractions of the negative values of (R′ −Y′) and (B′−Y′) together. The signals are combined in simple resistive adding circuits, and the change of sign is obtained with either a valve or a transformer.

A further slight complication is that as the red, green and blue phosphors have different efficiencies, the drives to the three guns have to be modified in the same ratio. The blue phosphor is the most efficient and needs the least drive, while the red phosphor is the least efficient. The ratios vary from one type of screen to another, but may be 0.6, 0.8 and 1.

X-Z SYNCHRONOUS DETECTION

A very effective decoding method, which is particularly stable in operation, has been introduced by RCA. The synchronous demodulators are conventional mixer types, and the novelty of the design is the balanced matrix circuit which they feed. Fig. 11. illustrates the principle.

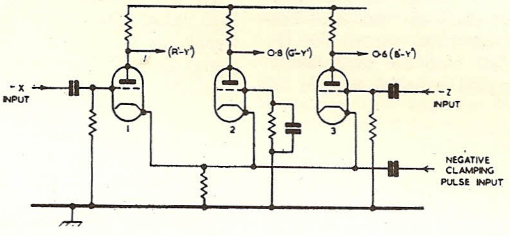
The three triode output stages feed the colour difference signals to the modulator grids of the display tube. The three cathodes of the output valves are connected together and as far as possible all three valves have similar operating conditions, except that the grid of the (G′−Y′) output valve is earthed, whereas the other two output valve grids are fed with detected chrominance signals.

If the right axes are chosen for the synchronous detectors, then this symmetrical arrangement will matrix the two detected signals to the required colour difference signals. The particular axes required are between the negative (R′−Y′) axis and the negative (B′−Y′) axis and RCA have called them the −X and −Z axes.

A large clamping pulse from the line timebase restores the DC component to the signals, which can be AC coupled from the mixer demodulators, and makes the three triodes draw grid current for their bias. As the triodes age, their grid current changes so as to keep a nearly constant standing anode-current in the output valves. The DC colour bias is therefore very stable.

Receivers for the Secam system need similar chrominance amplifiers to NTSC receivers, but no reference generators. The synchronous demodulators are replaced by FM discriminators which decode R′−Y′ and B′−Y′ signals; these signals are then matrixed to give G′−Y′.

Fig. 11 (below). X-Z matrix circuit



ERT SERVICE BULLETIN

UNDERSTANDING colour television

9: REFERENCE GENERATORS

By P. S. CARNT, BSc(Eng), MIEE

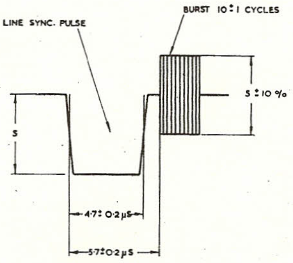
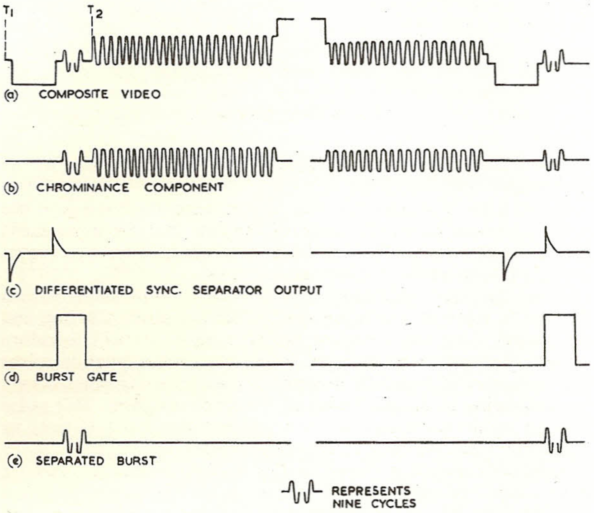


Fig. 1 Colour burst signal and, below, Fig. 2, burst gating waveforms (From *Colour Television*, Carnt and Townsend, 1961, Iliffe Books)



IN the NTSC system the colour difference signals are transmitted by amplitude modulation of two separate sub-carriers which have exactly the same frequency but a 90 degree phase difference. To demodulate these subcarriers, the colour receiver must have available a continuous sine wave which is locked in frequency and phase to the originating subcarrier at the transmitter. This continuous sine wave is called the reference signal, and the device in the colour receiver which generates it is called a reference generator.

To enable the receiver to generate the reference signal, the transmitter sends a colour burst signal during the post sync. blanking period—sometimes called the " back porch." The colour burst signal, shown in Fig. 1, is probably best understood by considering how the transmitter generates it.

A continuous sine wave of subcarrier frequency is taken, and samples of it are selected once every line. This can be done, for example, by feeding the subcarrier sine wave to a valve which is switched on at the appropriate instant (once every line) for an appropriate time (which determines the number of subcarrier cycles in each burst). It has become standard to transmit 10 cycles of subcarrier in each burst, so the burst lasts for 10/4.43 c/s or 2¼ micro seconds for the 625 line system.

Note that, because the bursts are samples of a continuous sine wave, it is possible to draw a continuous sine wave starting with any one burst which will be exactly coincident with all future bursts. No bursts are transmitted during the field sync. period, because the waveform level at the time that a burst would occur is at sync. rather than at black level, and therefore only half cycles of burst could be accommodated.

The exact frequency of the subcarrier (and therefore of the burst sample) is 4,429,687.5 c/s, and the transmitter will maintain this frequency to within ± 1 c/s. Furthermore, if the frequency does change within these limits, it will not change faster than 0.1 c/s per second.

The colour burst signal is transmitted with a fixed phase (actually the Y-B phase) which is independent of any picture content. During the active line, various subcarrier signals will be present which for large area colours will all have the same frequency (4,429,687.5 c/s) but whose phases will have different values depending on the particular hues of the colours. Now the whole process of accurate synchronous detection demands the use of a reference signal which has a fixed phase, so subcarrier signals during the active line cannot be used for reference generation.

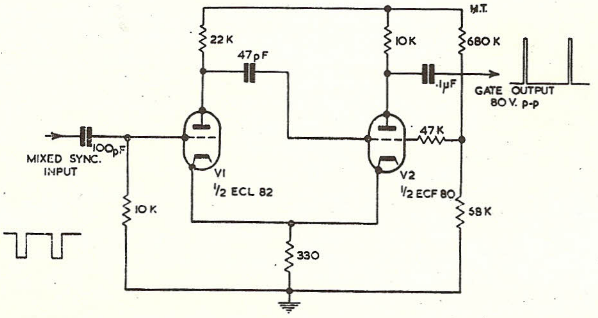


Fig. 3 Gate generator circuit

The colour receiver must therefore separate the burst signal from the other subcarrier signals and, in principle, this is done by feeding all the subcarrier signals to a valve which is switched on only during the burst period. This separation of the burst from the other subcarrier signals is usually referred to as " burst gating," and the switching waveform is variously called the burst gating waveform, or burst gate pulses, or burst separation pulses.

MORE CONVENIENT

The burst may be separated either from the composite video waveform or from the modulated subcarrier signal (often called the chrominance or chroma signal) but usually the latter is more convenient, particularly if automatic chrominance control (ACC) is desired. Fig. 2(a) shows one line of composite video and 2(b) the corresponding chrominance signal. The waveform shown at 2(d) is a suitable burst gate, which opens just before the burst and closes just after it.

Notice that, as far as separation of the burst from the other chrominance signals is concerned, a gate which opens not earlier than T_1 and closes not later than T_2 (i.e. a gate which is open for the whole of the line blanking period) would be satisfactory. Such a wide gate has certain undesirable features, however, which will be mentioned later, but nevertheless it has become a common practice in the USA to use a pulse from the line time base as a gating waveform.

While this is an economic solution, it may lead to hue errors which are a function of the setting of the line hold control. For example, if there is a large subcarrier signal at the beginning of the line, the timebase pulse may include some of this as well as the burst, so changing the effective phase of the burst. Of course the onset of this effect could be reduced by narrowing the width of the timebase pulse, but the danger then is that the burst may

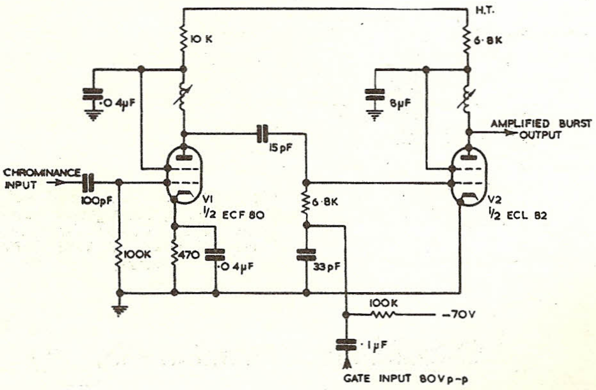


Fig. 4. Burst amplifier

not be included within it except for a very critical setting of the line hold.

A much more satisfactory way of separating the burst is to use a circuit which takes advantage of the fact that the burst starts almost immediately after the back edge of the line sync waveform (actually about 1 microsecond after).

Now the sync separator of the receiver will be fed with composite video in which the sync pulses are positive going, and the output from the anode of the sync separator will therefore consist of negative going sync, which after differentiation, gives the waveform of Fig. 2(c), in which a positive going pulse occurs corresponding to the back edge of the sync waveform. This pulse can be made to trigger a monostable "flip-flop" circuit, or "one-shot" circuit, as it is sometimes called.

A suitable circuit is shown in Fig. 3. Two triodes V1 and V2 have a common cathode load, and while V1 has its grid returned to earth, the V2 grid is returned to a positive voltage obtained from the HT line via a potentiometer network. Hence, V2 takes current which lifts the common cathode voltage positive, and therefore V1 is biased to cut off. Now negative going mixed sync from the sync separator anode is fed to the V1 grid via the differentiating circuit of 100pF and 10K, so the waveform at the V1 grid is that of Fig. 2(c).

Provided the positive going "pips" are large enough (greater than 2 or 3V) to overcome the bias on the V1 grid, V1 conducts and a negative going pulse appears at the V1 anode which cuts off V2. Since the V1 anode is capacity coupled to the V2 grid, V2 will remain in a non-conducting state only for a time determined by the time constant of the CR coupling. After this time, V2 will conduct again and render V1 non-conducting until the next positive "pip" is applied to V1. Hence the leading edge of the gate waveform will occur at the same time as the back edge of the sync (i.e. just before the burst) while the trailing edge of the gate will be determined by the circuit constants. These can be chosen so that the gate closes just after the end of the burst.

UNDESIRABLE EFFECTS

It has already been mentioned that a very wide gate is undesirable. Apart from the possibility that some of the picture subcarrier may be included, so changing the effective burst phase, there are two other undesirable effects.

First, any unnecessary burst gate time will let through more noise, so the reference generator would have to cope with a worse signal-to-noise ratio than it would for a correctly timed gate. Secondly, the edges of the sync. pulses and the edges of line blanking (for example, if the extreme left and right of the picture contain a white highlight) can produce a ring which may simulate a subcarrier signal. These ringing effects are usually referred to as sync. and video "widgets," respectively. Obviously it is desirable to arrange the burst gate to exclude these widgets.

A considerable level of burst signal (e.g. 150V p—p) is usually required by the reference generator, and it is therefore necessary to amplify the signal from the burst take-off point. This point is often one stage before the synchronous detectors where the burst amplitude may be about 0.5V p—p. (Incidentally, the point from which the burst is taken must be chosen carefully, otherwise the performance of the reference generator may be very seriously impaired. This will be explained later.)

The burst amplifier is a convenient place to apply the gating pulses from the gate generator, and Fig. 4 shows a suitable circuit. Two stages of amplification are shown, with the positive going gating pulses applied to the grid of the second stage. This stage also has a negative bias applied which prevents loading of the gate circuit, and also stops the output valve from taking excessive current if sync. signals are absent. The anode loads of both stages are simple tuned circuits tuned to the subcarrier frequency.

It can be seen that the burst amplifier is quite a conventional circuit, and it calls for only one comment, namely the bandwidth it should have up to the point where the gating waveform is applied. Now the burst waveform may be regarded as amplitude modulation of the subcarrier by a rectangular waveform of line frequency repetition rate. This modulation waveform has harmonics separated by the line frequency, so after modulation we get a carrier (the subcarrier) and (strictly speaking) an infinite number of sidebands separated from the carrier at line frequency intervals, and on both sides of it. Now if we pass this modulated waveform through a burst amplifier of a certain bandwidth, some of the sidebands will be lost, and the resulting waveform will be distorted. Therefore, when the relatively narrow gating pulse is applied, some of the burst information will be excluded.

It is possible to calculate how many sidebands must be accepted in order to recover a certain percentage of the total burst energy—thus, if we accept a total of 40 sidebands (a bandwidth of 40 times the line frequency, or about 600 kc/s) we recover 85 per cent. of the total energy. If we accept only 10 sidebands, we recover only about 33 per cent. of the total energy. The burst amplifier should therefore have a total bandwidth of about 600 kc/s in order to avoid serious distortion of the waveform—there is not much point in having greater bandwidths because it is a case of diminishing returns.

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UNDERSTANDING colour television

10: REFERENCE PHASE CONTROL

By P. S. CARNT, BSc(Eng), MIEE

We have, so far, considered how to separate and amplify the colour burst signal. Before discussing the methods which are available for generating a continuous reference signal from the burst, it would be as well to note the conditions which must be satisfied to obtain a satisfactory colour picture.

First of all, since a change in the phase of the reference will produce a hue change (in the same way that a change in the subcarrier phase will) we are interested in the phase errors which may be present in the reference signal. There are two kinds of phase error to consider: the static phase error and the dynamic phase error.

The static phase error is the value of the difference between the phase of the reference and the correct phase required by the synchronous detector. Thus, if a reference phase of 90 deg. is required by the synchronous detector, and if the reference generator supplies a signal of phase 80 deg., the static phase error is 10 deg. Subjective tests have shown that some people can detect the hue change corresponding to a static phase of error of only ½ deg., but, fortunately, people will accept the hue error corresponding to ± 5 deg. of phase error. However, as far as colour receivers are concerned, it is advisable to keep the phase error within about ± 2½ deg., since there may be hue errors introduced at the transmitting studio.

DYNAMIC PHASE ERROR

If noise is present in the colour signal, the signal from the reference generator will be modulated by it so producing a phase "wobble" known as the dynamic phase error. It is usual to consider the effects of random noise, since this is bound to be present and it is also the most difficult type to reject. As in the case of static phase error, the dynamic phase error which can be tolerated is best determined by subjective tests. It will be appreciated that dynamic phase errors show as fluctuations in hue, and the seriousness of this effect will, obviously, depend on the extent to which other features of the picture such as brightness changes and time base synchronisation are affected by the noise. With a good clean picture, a very small amount of dynamic phase error would be quite noticeable, but if the picture were very noisy hue fluctuations would be relatively unimportant.

It is, therefore, usual to specify the dynamic phase error for a given signal to noise ratio, and a realistic value is 5 deg. RMS phase error for a unity signal to noise ratio. (Here signal to noise ratio means peak to peak burst to RMS noise value.) It is implicitly assumed that the dynamic phase error will be inversely proportional to the S/N ratio—for a S/N ratio of 2, the dynamic phase error should not exceed 2½ deg. RMS for example—and this inverse law is justified in practice because reference generators automatically obey it.

Apart from the requirements for static and dynamic phase errors, the remaining important consideration is the time required for the output from the reference generator to become stable. When switching from one channel to another we, obviously, cannot wait for, say, five minutes for the colour to appear! Stabilisation times of up to about three seconds can be considered as acceptable, but 10 seconds or more is regarded as poor.

Since the presence of a colour burst is the only absolute indication that a colour signal is being transmitted, it is usual to use the reference generator for auxiliary supplies in the colour receiver. These include "colour killing"—the switching off of the chrominance channel unless a burst is present, thereby avoiding spurious colour effects during monochrome transmission—and automatic chrominance control (ACC) which is a convenient term for automatic gain control of the chrominance channel.

It has already been pointed out that the separated burst waveform can be expressed in terms of a carrier (the subcarrier) and sidebands separated from it at intervals of the line frequency. Therefore, if we pass the burst waveform through a filter which accepts the carrier and rejects all the sidebands, the output from the filter will be the required continuous sine wave reference frequency. It would seem that the closest spurious frequencies which have to be rejected are about 15kc/s away, but this assumes that the signal is "clean." With noise present, noise sidebands will appear and the greater the bandwidth of the filter the more noisy will be the reference output.

FILTER BANDWIDTH

However, we know that we can tolerate a 5 deg. RMS dynamic phase error for a unity signal to noise ratio, and this enables us to calculate the corresponding filter bandwidth which is required. It turns out that the equivalent noise bandwidth for this condition is 270 c/s, allowing for an excess burst gate width of 1.5 to 1. Now the equivalent noise bandwidth (usually called f_N) of a filter can be found by plotting the square of the voltage output for a given input against frequency, and finding the equivalent width of the rectangular pass band which encloses the same area with the frequency axis as the physical response, and having the same height as the physical response at the subcarrier frequency. For a simple tuned circuit, it can be shown that the equivalent noise bandwidth is $\pi/2$ times the 3 dB bandwidth. Thus, $f_N = \frac{\pi}{2}\frac{f_s}{Q}$

where f_s is the subcarrier frequency and Q is the Q factor of the tuned circuit.

Assuming that we use a simple tuned circuit, let us calculate the required Q.

$$\text{Thus, } Q = \frac{\pi f_s}{2 f_N} = \frac{\pi}{2} \times \frac{4.43 \times 10^6}{270} = 25{,}700$$

This high Q can be obtained by using a quartz crystal, and a complete circuit of one possible arrangement is shown in Fig. 1. The crystal is connected in a bridge circuit so that its mounting capacitance can be balanced out, and the signal from the crystal is then amplified and limited to give a constant

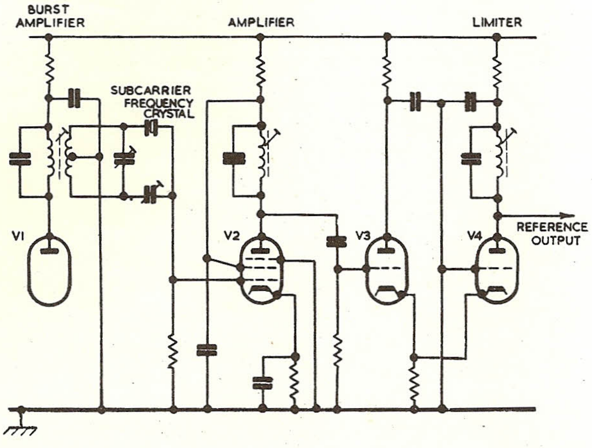


Fig. 1—Circuit of a passive type filter, incorporating a crystal, for control of a reference oscillator (from *Colour Television*, Carnt and Townsend, 1961, Iliffe Books)

amplitude of sine wave output, since there is an exponential decay between bursts. (This decay is, surprisingly, small—it is only 10 per cent. when the Q is about 9000.)

The circuit as described will have the required noise performance because the high Q crystal has the necessary narrow bandwidth, and the dynamic phase error will not exceed 5 deg. RMS for unity S/N ratio. But we have not yet considered the static phase error. If the crystal is not tuned exactly to the transmitter subcarrier frequency (which itself may be ± 1 c/s off tune) a phase shift will occur. This phase shift will have two components: one will be the phase shift between the voltage across the equivalent tuned circuit of the crystal and the current through it, and this will have a value of $2Q\Delta f/f_s$ radians where Δf is the tuning error from the subcarrier frequency f_s; the other component of phase shift arises because if the crystal frequency is not exactly equal to the subcarrier frequency, there will be an "out of step" effect which will accumulate during the period between bursts, and this has a value of $2\pi\ \Delta f/f_L$ radians, where f_L is the line frequency.

Using the above expressions for the phase shift, it turns out that if the static phase error is not to exceed 2½ deg., then for a Q of 25,700 the tuning error Δf must not exceed 3.7c/s. This represents a high order of stability for a crystal which is not enclosed in a temperature controlled oven, and for the sort of temperature changes likely to be encountered in a colour receiver, tuning errors of about 40c/s can be expected. Now a 40c/s error would give a phase shift of 27 deg., so the requirements of small dynamic and static phase errors cannot be simultaneously satisfied.

One solution to the problem is to compromise; allow a greater dynamic error than 5deg. RMS which would lead to a smaller Q value and therefore a smaller static phase error for a given tuning error. However, having arrived at the specification which is ideally required we should try to meet it. Note that if we have a Q value of 25,700 we achieve the required noise performance, and it is only the static phase error which is excessive. The obvious approach is therefore to correct the static phase error automatically, and Fig. 2 shows a general arrangement for doing this. The crystal filter is designed for the required noise performance, and its output is compared with the burst input in a phase detector. Any phase error produces an output voltage from the detector which in turn corrects the tuning of the crystal by means of a reactance valve. By having sufficient loop gain (the product of the phase detector sensitivity and the reactance valve sensitivity) the static phase error can be reduced as required. The low pass filter in the detector output is required to prevent noise modulation of the crystal tuning, and provided its pass band is small compared with the crystal bandwidth the noise performance will not be impaired. The 90 deg. phase shift is required because phase detectors give a zero output voltage (corresponding to the correct tuning point) when the signals being compared differ in phase by 90 deg.

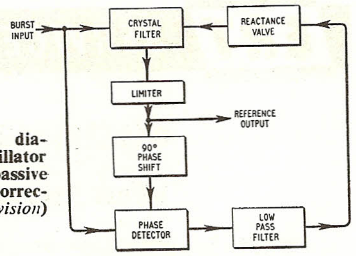


Fig. 2—Block schematic diagram of a reference oscillator control circuit employing a passive filter with automatic phase correction (from *Colour Television*)

While a crystal filter with feedback correction for static phase error satisfies the requirements of small dynamic and static phase errors, an accurately cut and high Q crystal is needed. Passive filter circuits have therefore not been widely used, at any rate up to the present time.

In the next article we shall consider another class of filter—the dynamic filter.

ERT SERVICE BULLETIN

UNDERSTANDING colour television

11: REFERENCE GENERATORS

(CONTINUED)

By P. S. CARNT, BSc(Eng), MIEE

IN the last article we considered the use of a passive filter which had a sufficiently narrow pass band to give the required noise bandwidth. We have now to consider a type of filter which is usually called a dynamic filter. The principle, in this case, is to beat the output of the reference oscillator against the colour-burst signal in a phase detector, and then pass the beat-note through a narrow low pass filter whose output controls the tuning of the oscillator.

The narrow band of the low pass filter gives the effect of a high Q filter, and because of the "frequency changing" effect of the oscillator twice the pass band is centred about the oscillator frequency—which, of course, is equal to the sub-carrier frequency. Note that twice the pass band of the low pass filter is relevant because the filter cannot distinguish between noise components which are above or below the sub-carrier frequency.

A typical arrangement for a dynamic filter is shown in Fig. 1, and this is an automatic phase control loop, or APC loop, employing a reactance valve and phase detector.

REACTANCE VALVE

The object of the reactance valve is to alter the tuning of the oscillator by means of a control voltage. The principle of the reactance valve is shown in Fig. 2. The values of the capacitor C and the resistor R are such that their series impedance is substantially capacitive. The current I, and therefore the grid-cathode voltage, lead V by nearly 90 degrees. Now the anode current is gm times the grid voltage, and therefore the anode current Ia leads V by 90 degrees. The valve therefore "looks like" a capacitor as far as the oscillator tuner ("tank") circuit is concerned, its value being approximately gmCR.

As the DC voltage on the grid is varied, so gm varies and hence the effective capacitance across the tank circuit is varied. For our purposes we are interested in the frequency change produced per volt applied to the reactance valve grid. This is called the sensitivity of the reactance valve, usually denoted by β, and typically has a value of 100c/s per volt for a crystal oscillator, and 2kc/s per volt for an LC oscillator. A grid voltage change of $+1$V reduces the frequency by βc/s, while a change of -1V increases the frequency by βc/s.

A typical phase detector circuit is shown in Fig. 3. One signal is fed in push-pull to two diodes, while the second signal is fed to the anode-cathode junction of the diodes. The output is taken between X and Y, that is, either from X while Y is earthed, or from Y while X is earthed through a resistor.

The phase detector's output is proportional to the cosine of the phase angle θ between the inputs, and also to the amplitude of the smaller signal. The voltage of the latter is called the sensitivity of the phase detector, and is denoted by μ.

When $\theta = 90$ degrees, the phase detector output is zero. This value of θ represents the equilibrium state, and we are usually interested in small departures from this value. In other words we are interested in the amount of phase error away from 90degrees. Such phase error is usually called ϕ.

There are conflicting requirements for satisfying the required "in-sync" performance and the required "pull-in" performance (of about one second) of an APC loop.. To understand how the oscillator is pulled in to the colour burst frequency, assume first that the reactance valve is disconnected. The phase detector output will be a sine wave having a frequency equal to the error between burst and oscillator frequencies. If the reactance valve is now connected, it will try to reduce the beat-note frequency during one half-cycle of the beat-note, and increase it during the other half-cycle of beat note. The phase detector output will therefore no longer be sinusoidal—one half-cycle will be "stretched out" corresponding to a low frequency, the other half-cycle will be "squashed up" correspondingly to a high frequency.

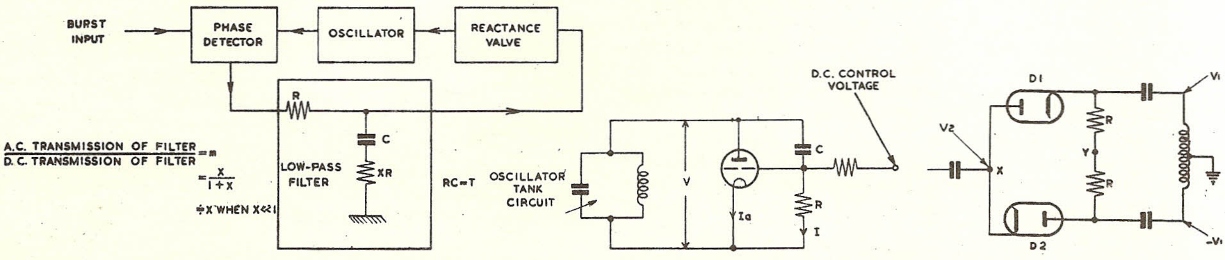
DC COMPONENT

Consequently these waveforms have a DC component and this is stored in the filter capacitor. The larger the DC component, the nearer the oscillator frequency becomes to the correct frequency, and as time progresses the DC component eventually becomes large enough to correct the error. The larger the frequency the smaller the difference between the opposite halves of the beat-note cycles and the smaller the DC component. Furthermore, the relationship is non-linear in an unfavourable manner. The larger error the smaller does the DC component become. It is possible to show that if th time to pull-in frequency lock is not to exceed one second, the error must not exceed 760c/s. This assumes optimum conditions which are not likely to be obtained in practice because of economic limitations.

For an LC oscillator and reactance valve combination, it is unlikely that a long-term frequency drift of less than about 3kc/s can be expected at 4.43mc/s. It therefore appears that an LC oscillator in a simple APC loop will not meet requirements.

Fortunately there are at least two solutions to the problem —one is an inherently stable oscillator, such as a crystal oscillator; the other is a two-mode APC loop in which the conflicting requirements of good noise performance and fast pull-in are separated.

The circuit of a typical crystal oscillator APC loop is shown in Fig. 4. The oscillator V1A uses the screen grid of a pentode as the "anode" and the control grid as the grid of a "triode," so that the output from the pentode anode is electron coupled to the oscillator. This modified Pierce oscillator has the advantage that variations in the anode load of the pentode (caused by adjustment of the hue control) do not affect the



Left to right: Fig. 1—Block diagram of an automatic phase control (APC) loop of the dynamic type. Fig. 2 (centre)—Basic features of a reactance valve circuit. Fig. 3—Basic phase detector circuit

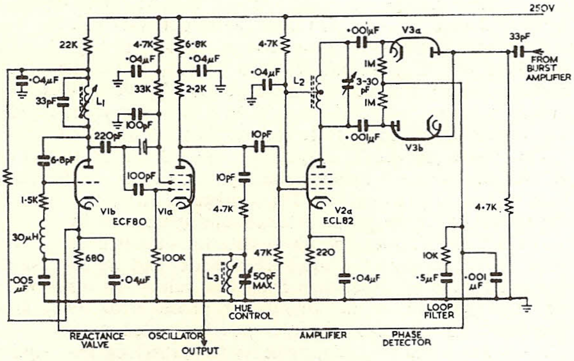


Fig. 4—Practical circuit of an APC loop incorporating a crystal oscillator

oscillator frequency. The hue control is a simple parallel tuned circuit whose inductance L3 may be used as a coarse adjustment of the hue. Since this tuned circuit is loosely coupled (via 10pF) to the pentode anode, as its tuning is varied so the phase of the output voltage will vary relative to the voltage on the anode.

The reactance valve (VIB) anode throws a reactive load across the crystal whose value is dependent on both the voltage fed to the grid of the reactance valve, and the value of the inductance L_1. For zero voltage on the grid of the reactance valve, L_1 should be adjusted so that the free running oscillator frequency is equal to the subcarrier frequency. This can be easily observed on a colour picture—all colours in the picture will alternate in hue at the beat frequency, correct tuning of L_1 being obtained of course at zero beat frequency.

The grid of the reactance valve is connected to the phase detector output via the loop filter. The 30μH inductance in the grid circuit reflects a negative resistance component into the reactance valve anode, and thereby reduces the resistive loading across the crystal as the reactance valve is driven more positive. This results in a more linear characteristic of oscillator frequency change versus DC voltage on the grid of the reactance valve. The circuit shown is suitable for a crystal designed for a capacitative load of 30pF and having an equivalent inductance of about 50mH. This gives an effective β value of about 100c/s per volt.

CENTRE-TAPPED

The anode load of the amplifier V2A, which feeds the phase detector, consists of a tuned circuit whose inductance is accurately centre-tapped. It will be appreciated that any unbalance in the phase detector will result in a spurious DC output which will cause a shift in the oscillator frequency. This unbalance can be caused either by an inaccurate centre tap of L_2, or by an inequality of the 1 megohm resistors. The latter should match in value to at least 1 per cent. The output impedance of the phase detector is approximately equal to half the total load, and is therefore about 1 megohm in this case. This forms the series R component of the loop filter.

It is important to remember that in APC loop circuits the output from the oscillator should not be allowed to contaminate the burst input. This is because the oscillator will try to lock to itself—that is, the reactance valve will shift the oscillator frequency in an attempt to establish a 90 degree phase difference across the phase detector. The effect of this is to produce an apparent unbalance of the phase detector. Undesirable feedback is reduced by screening the oscillator and burst amplifier sections from each other, and also by taking the burst input from a point at least one stage before the synchronous detectors (which, of course, are fed from the oscillator).

The circuit of a two-mode APC loop is shown in Fig. 5. This consists of an oscillator, reactance valve, loop filter and phase detector as in the crystal oscillator loop, but in addition we have an extra phase detector V4 and a filter by-pass cathode follower V2B.

Now the basic APC loop consisting of V1A, V1B, V2A and V3 is designed for the required in-sync noise performance, regardless of pull-in performance. The only real difference between this part of the circuit and the crystal APC loop is the fact that the oscillator is of the conventional LC type. Note, however, that precautions are taken to make the LC oscillator as stable as possible—relatively large capacitances are connected across the control and screen grids of V1A, and a negative temperature coefficient capacitor should form part of the 150pF screen capacitor. The oscillator coil of about 10μH may be adjusted by a brass slug rather than a dust core, since frequency control by the latter tends to be too coarse.

Note that while the extra phase detector V4 is fed directly from the push-pull driver stage, the ordinary loop detector V3 is fed from a phase shifted version of the drive, caused by the 4.7pF and 4.7K components. (Note that one of these capacitors is variable so that the balance can be accurately adjusted.) Ideally this phase shift should be 90 deg., but a smaller phase shift can be tolerated, and about 60 deg. is sufficient.

The extra or auxiliary detector V4, therefore, operates in the quadrature phase compared with the usual detector V3. While the usual beat-note waveform is determined by $\sin \phi$, the auxiliary detector output waveform is determined by $\cos \phi$. The $\cos \phi$ waveform has equal areas above and below the time axis, so that it has no DC component. Therefore, if the auxiliary detector output is passed through a low pass filter (100K and .25mF), the output is zero whenever a beat-note exists—that is, when the loop is not in sync. However, it is at maximum DC for the locked condition and the output can be made either positive or negative depending on the circuit configuration. Usually a negative output is required, and this is the case in Fig. 5.

DC QUADRICORRELATOR

Because the DC output of the auxiliary detector depends on the quadrature correlation between the signals, this arrangement is sometimes called a DC quadricorrelator.

The DC output from the auxiliary detector can be used to improve the pulling performance of the loop in the unlocked condition. Thus, when not in lock, the DC output from V4 is zero and the cathode follower V2B is operative. Notice that some of the output from the loop detector V3 is connected to the grid of V2B, while the cathode of V2B is connected (through the low impedance of 4mF) to the grid of the reactance valve. The effective transmission through the loop filter 1.5M, 4mF and 1.5K) is, therefore, increased when V2B is operative, and the loop rapidly pulls in to frequency and phase lock. As soon as the loop has locked, however, the auxiliary detector output becomes a negative DC value which biases off V2B. The extra transmission through the loop filter is, therefore, removed, and the good noise performance of the loop is restored.

There are several features of quadricorrelator circuits which should be mentioned. In the first place, although the pull-in range can apparently be increased indefinitely, it is in fact limited to half the line frequency (about 7.5kc/s). This is because the burst has sidebands separated from the subcarrier frequency at intervals of the line frequency, and the two adjacent sidebands have practically the same amplitude as the

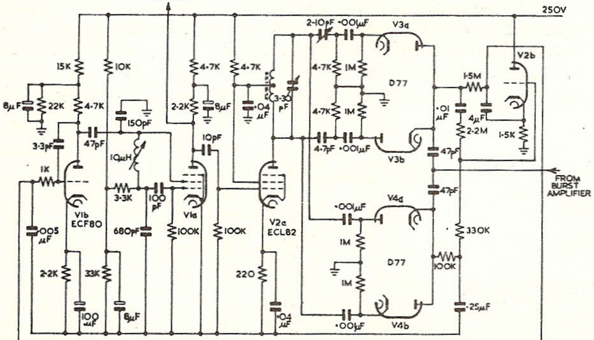
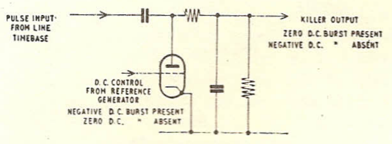
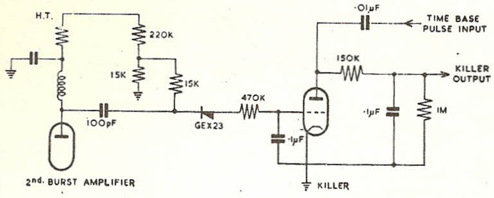


Fig. 5—The quadricorrelator APC loop circuit incorporates an auxiliary dector V4, the output of which depends on the quadrature correlation between the signals





Left to right: Fig. 6—Colour killer circuit (from *Colour Television*, Carnt and Townsend, 1961, Iliffe' Books Ltd.) and Fig. 7—An amplitude detector and killer circuit

subcarrier component. For oscillator errors greater than half line frequency an ambiguous beatnote can occur between the oscillator and the nearest sideband, and the oscillator may even lock to the sideband. This sideband frequency is not, of course, the correct frequency, and such a spurious lock is usually called side-lock. However, by having a potentially large pull-in range (though it cannot necessarily be used as such), pull-in time can be reduced, as can the undesirable effects of any unbalance.

Another important point to note is the extreme reliability of the DC output of the auxiliary detector under poor signal to noise conditions. This arises because the detector is synchronous—as distinct from the usual type of amplitude detector which merely gives an output determined by the peak value of any applied signal.

COLOUR KILLING

The auxiliary detector output of a quadricorrelator gives a very reliable indication of the state of synchronisation of the APC loop—if the output is zero, either the burst is absent (i.e. the transmission is monochrome), or the loop is not yet locked. On the other hand, if the auxiliary detector output is negative DC value, the loop has locked and a burst must be present. The auxiliary detector output is, therefore, very suitable for switching the chrominance channel off or on, depending on the absence or presence of the burst.

However, since a negative DC voltage is required to bias off a suitable stage in the chrominance amplifier and thereby provide colour killing, it will be realised that the auxiliary detector output is the "wrong way round" for killing purposes—it is zero for no burst and a negative DC for burst present, whereas for killing we require a negative DC for no burst and zero for burst present.

A suitable circuit for deriving the required bias arrangement from the auxiliary detector output is shown in Fig. 7. Here, a triode (½ECL82) is used as a grid-controlled rectifier which produces a negative DC voltage from positive-going pulses of about 100V p-p from the line timebase. When the burst is absent, the auxiliary detector output is zero, and the triode therefore behaves like a rectifying diode between its anode and cathode, and so provides a negative DC output. When the APC loop has locked, however, the negative DC from the auxiliary detector biases off the triode so that its anode-cathode space can no longer rectify, and the DC output is therefore zero. The killer output is connected to a suitable stage in the chrominance amplifier—naturally this stage must be after the burst take-off point, otherwise the reference generator would never receive a signal.

ANOTHER SOURCE

In the case of a single mode APC loop, there is no auxiliary detector and another source of killing voltage is required. One possibility is one of the diodes of the phase detector: for example, the anode of V3B (Fig. 4) has an increased negative DC value when a burst is present, due to simple amplitude detection of the burst. If this anode is DC coupled to the grid of the killer triode of Fig. 6, the required killer action will be obtained provided that some backing off of the DC at the V3B anode due to the applied oscillator signal is arranged. However, the use of one of the phase detector diodes as a killer source is not recommended because the balance of the phase detector will tend to be upset.

It is preferable to use a separate diode circuit, as shown in Fig. 7. Notice that a delay or backing off bias is applied to the detector from the potentiometer chain of 220K and 15K. This bias should be adjusted so that killer action does not occur until the burst signal at the anode of the second burst amplifier is relatively large, otherwise the killer could be activated by noise simulating a burst signal. Unlike the synchronous detector of a quadricorrelator, the simple amplitude detector of Fig. 7 will produce a DC voltage from noise voltages, so that a noisy monochrome signal may be interpreted as a colour signal.

The auxiliary detector output of a quadricorrelator may be used for automatically gain controlling the chrominance amplifier, provided that the burst signal fed to the detector is smaller than the oscillator signal. The DC output should be connected to a chrominance stage before the burst take-off point, and some DC delay should be provided (e.g. by lifting the junction of the megohm resistors of the auxiliary detector V4, Fig 5, by a suitable positive voltage) so that automatic chrominance control (ACC) does not occur until the signal level is sufficient for adequate saturation of the picture.

For single-mode APC loops, a circuit similar to the killer circuit of Fig. 7 is recommended for ACC. The anode of the diode detector is DC connected to the grid circuit of one of the chrominance stages (before the burst take-off point) instead of to the grid of the killer triode as in Fig. 7. ACC delay can be adjusted by the potentiometer network, as in the case of killer delay.

The ACC output, whether it be derived from a synchronous or an amplitude detector, should be shunted by a diode to prevent the line going positive relative to ground, otherwise the controlled valve in the chrominance amplifier may become overloaded.

ERT SERVICE BULLETIN

UNDERSTANDING
colour television

14: THE PAL SYSTEM

By G. B. Townsend, BSc, FInstP, MIEE, AKC

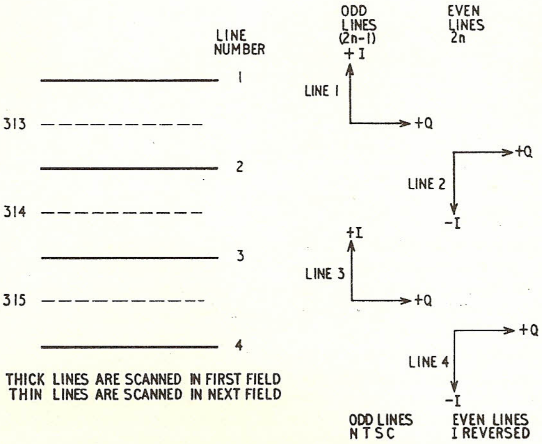


Fig. 1.—Left, in explaining the PAL system, the lines in each field scan are consecutively numbered. Both NTSC and PAL systems provide I and Q signals simultaneously on the subcarrier but, with PAL, the I signal is phase reversed on even lines as indicated in the vector drawings on the right

CONSIDERABLE controversy rages, in the United Kingdom and Europe as a whole, as to which colour television system should be adopted for broadcasting. The BBC wishes to press ahead with its plans for initiating a colour television service in its new second channel, but is anxious to ensure that the system chosen will also be the one eventually adopted in Western Europe as a whole.

The European Broadcasting Union, which represents the broadcasting authorities of Western Europe, met in London at the end of last year to witness some BBC colour television demonstrations. At that meeting it was decided to set up an *ad hoc* working group charged with deciding which colour system should be recommended for adoption. It was agreed that only those countries actively engaged in colour research should be represented in this group, and that these countries should only send as delegates engineers who were themselves actively engaged in the field.

PHASE ALTERNATION

The EBU Working Group on colour television consists, therefore, of delegates from the United Kingdom, Holland, Germany, France, Switzerland and Italy. Until recently the only systems being considered by the committee were the NTSC and Secam, as modified to suit the various forms of 625 line standards used by European countries.

In April of this year a committee of experts from the Group spent several days in Hanover investigating another system, one invented by Herr Walter Bruch, an eminent engineer in the Telefunken company. Bruch, who is a most inventive man, has in fact proposed a number of colour television systems, and these have often been referred to as the Bruch I, Bruch II, etc., systems.

Bruch's basic philosophy has been to combine the advantages of both NTSC and Secam into one system. The EBU committee concentrated its attention on one particular variant of Bruch's ideas, for which the name PAL has been adopted, the initials standing for Phase Alternation Line.

After three days of exhaustive investigation and argument in the Telefunken laboratories, at which the committee saw a large number of demonstrations and experiments, including the transmission of the PAL signal over a German PO radio link, and reception of both VHF and UHF transmissions from the local television stations, it was unanimously agreed that the system should be officially considered alongside the NTSC and Secam systems. So there are now three entries in the European colour television stakes. The NTSC and Secam systems have been explained recently in a series of articles in E R T. This article outlines the main points of the PAL system.

Herr Bruch argues that the NTSC system has certain advantages which ought to be maintained in any adopted system. He cites, as example, the fact that the NTSC subcarrier is suppressed so that no chrominance signal is transmitted during the grey parts of the picture. He also points out that the NTSC subcarrier frequency is very precisely defined so that co-channel transmissions can be operated in what is called "precision offset" with respect to the subcarrier frequencies. That is to say, since the two subcarriers have fixed frequencies, these frequencies can be chosen so that the beat between them is of low visibility. (There is some argument as to whether this is a worthwhile advantage.) Bruch further maintains that the subcarrier frequency of the NTSC system allows dot-interlacing to be used to reduce the visibility of the subcarrier signal on ordinary black-and-white receivers.

On the other hand, says Bruch, the line sequential transmission of the colour information which is used in the Secam system also has advantages—e.g., the FM modulation used means that the subcarrier is not subject to errors due to differential phase distortion. The IF amplifier response in the receiver is less critical.

In PAL, Bruch is proposing a transmission system very much like the NTSC with a receiver technique very much like Secam.

On every other scanning line of each field the transmitter sends out a normal NTSC signal. On the alternate scanning lines the NTSC subcarrier is modified slightly, so that one of the two pieces of colouring information which it is carrying is reversed in sign. This process goes on continuously from one field to the next. To get the full advantages of this line-by-line reversal of phase, the receiver requires a colour-recognition circuit, a delay line, an electronic switch—all Secam style—and a simplified NTSC reference generator.

It is possible to omit the delay line from the receiver and still get a fairly satisfactory picture, which, however, is then not so immune to some forms of distortion which can occur during transmission.

LINE NUMBERING

There are two ways of numbering the lines of an interlaced picture so that particular lines can be referred to in discussion. The more usual way is to number all the 625 lines of one picture in the space order that they appear on the combined picture. In this case all the odd number lines, 1, 3, 5, 7, etc. are scanned successively in time on one field, and then all the even lines, 2, 4, 6, 8, etc. are scanned in succession on the next field.

However, for some purposes it is more convenient to number the lines by the time sequence in which they are scanned, as in Fig. 1, so that on one field the lines are numbered 1, 2, 3, 4, 5, etc., while on the next field the scanning lines are lines number 313, 314, 315, 316, etc. This latter method of identifying the lines is particularly convenient for discussing line sequential types of television systems, including Secam and PAL. We shall use this time-sequence method of numbering the lines in the rest of this article.

All odd numbered lines in the PAL system are modulated exactly as in NTSC, with a suppressed quadrature-modulated subcarrier carrying both the two colour-difference signals. These colour-difference signals can be either $R-Y$ and $B-Y$ signals, or the rather more sophisticated I and Q signals which are derived from combinations of $R-Y$ and $B-Y$. As transmitted by the BBC, the PAL system uses the I and Q signals. Any odd number line can be called line $(2n-1)$, where n can be any whole number less than 314. For example, if $n=50$ then $(2n-1)=99$.

For all even numbered lines, such as 2n, the modulation of one colour-difference signal is reversed, as in Fig. 1. Another way of saying this is: on every other line the phase of the subcarrier for the I signal is shifted by 180deg. Phases are measured to the standard NTSC burst signal, which is transmitted at the beginning of every line with the phase of $-(B-Y)$ as usual. The subcarrier has a constant frequency with respect to line scanning frequency, as in NTSC, but the frequency is very slightly different from the NTSC subcarrier frequency. This change is made to improve the compatibility of the subcarrier dot pattern on monochrome receivers. Because of the line sequential structure of the colour information, the NTSC dot pattern—which is produced by choosing a subcarrier frequency which is in half-line offset—is not satisfactory for PAL transmissions. So the PAL subcarrier frequency is chosen to be in quarter-line offset plus 25 cycles, at 4.43361875mc/s. This choice of subcarrier frequency produces a dot structure in which two sets of dots appear to be crawling diagonally across the picture in opposite directions, along the arms of a cross.

CONTROL OF SWITCHING

Since the I signal is reversed in phase on every alternate scanning line, the receiver must be told which are the lines on which the I signal is in the correct phase. This is similar to the problem which arises in the Secam system where the receiver needs to know whether any particular line is carrying $R-Y$ or $B-Y$ information. The PAL system solves this difficulty in the same way as Secam, by sending a similar colour recognition signal during the field blanking interval. At the receiver this signal is used to ensure that an electronic switch is in the correct phase.

As the PAL signal is so similar to the NTSC signal it is probably practicable to convert one type of signal into the other and back again by simple electronic circuits with very little loss in picture quality. One or two ingenious methods of doing this have already been suggested.

The PAL receiver is very similar to an NTSC receiver, except that a few Secam circuits have been added. The essence of the true PAL receiver is the use of the Secam supersonic delay line to separate out the I and Q subcarrier signals before they are demodulated from the 4.4mc/s subcarrier.

As in any colour set, the incoming RF signal has to be amplified and the chrominance signals separated from the other modulations. The luminance signal is fed to the three cathodes of the three-gun colour display tube, and the colour decoding circuits have to provide the three colour difference signals, $R-Y$, $G-Y$ and $B-Y$, to the red, green and blue modulating grids. Fig. 2 shows how the colour signal is handled after it has been separated from the video signal.

The 4.4mc/s subcarrier is routed along three parallel paths. By sending the subcarrier through a delay line with a delay of one line interval (64μS), the receiver has available at the same instant both the subcarrier which is being transmitted on that line and the subcarrier signal from the preceding line. Since one of these signals will be carrying $+I$ while the other is modulated with $-I$, addition of the delayed and undelayed signals will cancel out the two I signals and leave twice the Q signal.

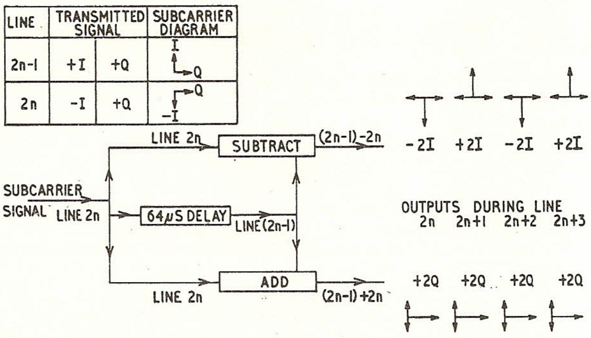


Fig. 2—Principle of decoding in the PAL De Luxe type receiver. By adding direct and delayed signals, the phase-reversing I signal is cancelled and removed from one output. The Q signal is removed from the other output by subtracting the direct signal from the delayed signal

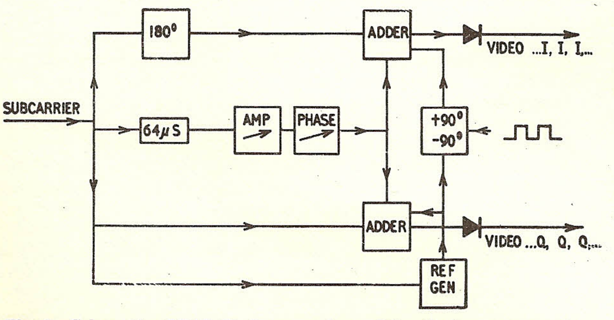


Fig. 3—Schematic of PAL De Luxe receiver. After the two components of the subcarrier signal have been separated, the reference signal is added and the resulting AM signals are demodulated

At the same time, subtraction of the two subcarriers will cancel out the two Q signals and leave twice the I signal.

There is a slight complication in so far as the signal which results from the subtraction process will alternately give . . . $+2I$, $-2I$, $+2I$, $-2I$, etc., as illustrated in Fig. 2. However, by means of a Secam type electronic reversing switch, the $-2I$ signals can be inverted to give a continuous stream of $+2I$, $+2I$, $+2I$, $+2I$ . . . signals.

The addition and subtraction of the delayed and undelayed signals has to be done precisely, and the normal Secam delay line is not accurate enough for the job, so a small lumped circuit variable delay has to be added in series for fine adjustment. Also, of course, the relative amplitudes of the delayed and direct signals have to be the same, so it is necessary to put an amplifier in the delayed signal path and to have a fine control over its gain.

The subtraction circuit of Fig. 2 can be replaced by a second adder circuit, as in Fig. 3, if a phase shift of 180deg. is inserted in that path. The phase shift effectively reverses the signal.

We now have two completely separate subcarrier signals, one carrying only I modulation and the other carrying only Q modulation. The gain factors of 2 can be allowed for in the overall amplification. These chrominance signals are amplitude modulated on to a suppressed subcarrier.

PHASE TOLERANT

A subcarrier has to be generated from the burst signal—as in NTSC—and added to the two signals. When this has been done the two signals can each be demodulated by ordinary diode detectors.

Unlike NTSC, the phase of the inserted subcarrier does not have to be correct to a couple of degrees or so. If the phase is wrong, the only effect is to reduce the output of both diode detectors together. This is equivalent to adjusting the saturation control on an NTSC receiver and, although the effect is more noticeable on some colours than others, a phase error of 30deg. can probably be tolerated even on saturated yellow colours.

The effect is different from that in an NTSC receiver; with PAL such a phase shift of the regenerated subcarrier with respect to the burst phase does not alter the reproduced hue.

The block diagram of the colour circuits of a PAL receiver can, then, be drawn as in Fig. 3, where the switching of the $-2I$ signals to $+2I$ is carried out by reversing the phase of the added subcarrier. The subcarrier can also be added in the same circuit stage that adds the direct signal to the delayed signal.

As mentioned earlier, the colour receiver manufacturer has the choice of making PAL receivers with or without the delay line. These two different types of receiver have been christened De Luxe PAL and Volks PAL.

The People's PAL receiver is essentially an NTSC receiver

THE PAL SYSTEM

CONTINUED FROM PREVIOUS PAGE

in which the output from the *I* synchronous demodulator goes through a phase reversing switch which changes the sign of the *I* signal on every other scanning line. In this way all the $-I$ signals are inverted to $+I$ signals. It is necessary to have a Secam-type switch-synchronising circuit to ensure that the reversing switch is inverting the signal on the correct lines (see Fig. 4).

Since this receiver has no delay line it is left to the eye of the viewer to add the two signals together. If there are no distortions in the incoming chrominance signal, and if the hue control is set correctly, then the colour produced by both the direct NTSC signal and the inverted signal will be the same. If they are not, then the observer's eye has to combine the two colours.

For example, a yellow might be rather greenish on one line and reddish on the next line, but over quite a range of errors the eye will combine these two colours to form a mixture of about the correct hue.

However, in general there will also be a change in brightness between the two lines as well as a difference in hue, and the eye is not so good at combining different luminances. Consequently, the viewer sees a crawling pattern of alternate light and dark lines in about the right colour. This venetian blind pattern has been nicknamed the Hanoverian Blind effect. The visibility of the pattern depends on the particular colour in that part of the picture, bright yellows being the most sensitive.

Bruch himself is not in favour of this type of receiver, but some engineers feel that manufacturers, in a bid to keep down costs, might make only this type. Finally, to sum up the main advantages of the PAL system:—

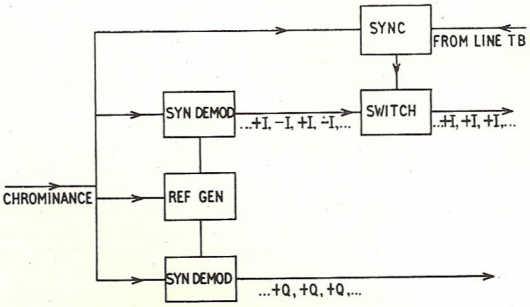


Fig. 4—Schematic of the PAL Volks receiver in which the I signal is restored by phase-reversing switch, following the synchronous demodulation of both the I and Q signals

The PAL signal is relatively immune to differential phase distortion and can be sent over long distance links with the same sort of immunity as Secam. At the same time, PAL can be transformed into NTSC quite readily, and vice versa. It has been suggested that it would be possible to use NTSC for broadcasting and PAL for carrying the programmes over the intercity networks.

The PAL receiver is rather more complicated than either of its rivals, but its reference generator does not need to have such a good performance as the NTSC. On the other hand, the line alternation of the signals makes the colour receiver remarkably immune to distortions of the upper sidebands of the colour signal; this makes both the design and the tuning of colour receivers easier, particularly for those Western European countries which use a 5mc/s luminance channel bandwidth.