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F. C. McLean

Colour television

Already a noted success in the United States, colour television is likely to become widespread within a decade. Some European nations have yet to decide which system they will adopt

After nearly ten years in the doldrums, colour television in the United States has in the past three years increased dramatically in popularity: at present some 25 per cent of all TV receivers sold in the United States are for colour and the proportion is still rising. Until recently only one of the major networks carried any appreciable amount of colour, but now all carry it for virtually the whole of their evening hours. After long years of doubt American colour television is today undeniably successful.

The United States colour television system is known as the NTSC (National Television Standards Committee). In Europe the situation is much more complicated: three separate systems are under study. The first is the American NTSC. The second, known as PAL (Phase Alternating Line), was developed in Germany but closely resembles the NTSC and is widely favoured. The third, SECAM (Sequential Colour with Memory), system differs further and is favoured by France and some other countries. I shall discuss the respective merits of the three systems later in this article.

In the United Kingdom a decision on the start of a colour service was finally taken last month. It will take nearly two years between the decision and the provision of the service. The Television Advisory Committee, a body appointed by the British Government, has recommended an "early start", that colour should be on 625 lines only and that the PAL system should be adopted.

Colour television is in many ways very similar to colour printing. In colour printing three separate pictures of selected colours are superimposed, one after the other, to give the required pictures. In colour television pictures in three colours are superimposed simultaneously. But, whereas colour printing uses reflected light and the colours chosen are three selected 'primaries' of red, yellow and blue, colour television works with direct light and the three colours required are red, green and blue. Accordingly, what has to be done in colour television is to find a means of analysing a picture into its red, green and blue components, transmitting these efficiently and economically and then recombining them in the viewer's home.

The ways in which this can be done are limited by some important restrictions. The first of these is concerned with availability of channels. Radio frequency channels for television broadcasting are very scarce and it is essential that the minimum demands should be made of them. Secondly, colour television will initially be viewed by only a very few people in any area changing over to colour, and it is necessary to ensure that the colour transmissions can also be received by people equipped only with black-and-white receivers. Conversely, initial colour transmissions will form only a portion of the whole transmissions and the systems must be such that black-and-white pictures can be sent and be adequately received on colour receivers. The combined requirement that colour should be received on a black-and-white receiver and that black-and-white pictures should be sent over the same chain is called 'compatibility' and is absolutely essential. Thirdly, the method chosen for the transmission of the pictures must be economic at the studio and transmitter and, in particular, at the receiver. Economics carries with it the requirement of reliability, and the more components there are in a piece of equipment the less reliable it is.

As a result, the essential basis of all the possible systems is to send a signal identical with that used in a normal black-and-white transmission and to add to this the minimum of information sufficent to enable the receiver to regenerate the three colour signals. The black-and-white transmission is determined by the 'luminance' signal and the colour content of the picture by

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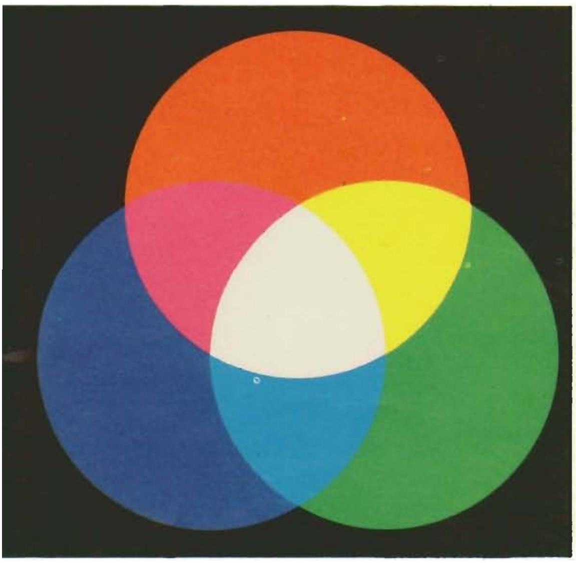
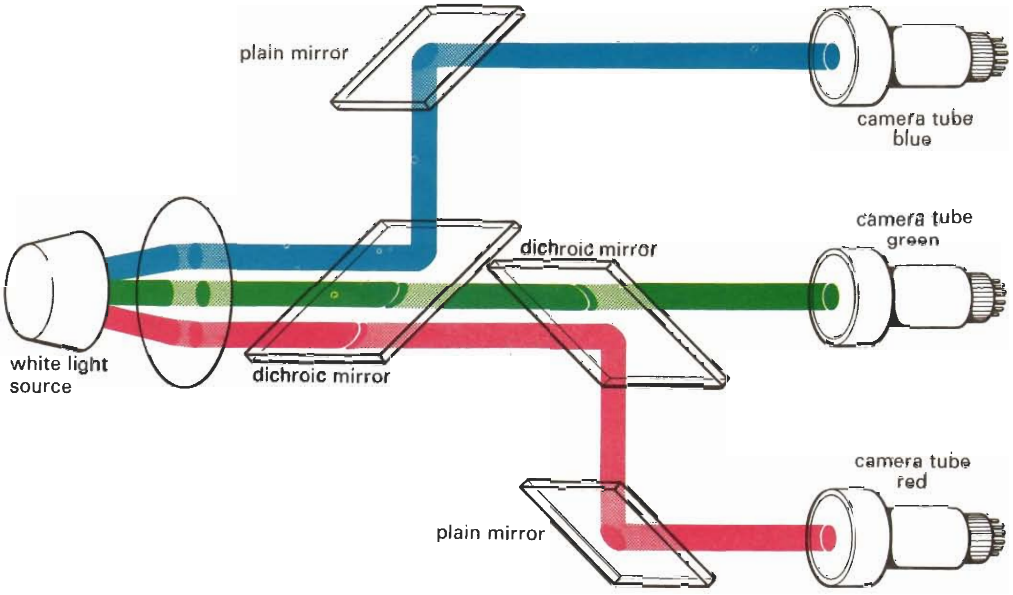
Francis Charles McLean is Director of Engineering of the British Broadcasting Corporation. He is also Chairman of the Telecommunication Industry Standards Committee of the B.S.I. and during World War 2 was Chief Engineer in the Psychological Warfare Division of SHAEF.



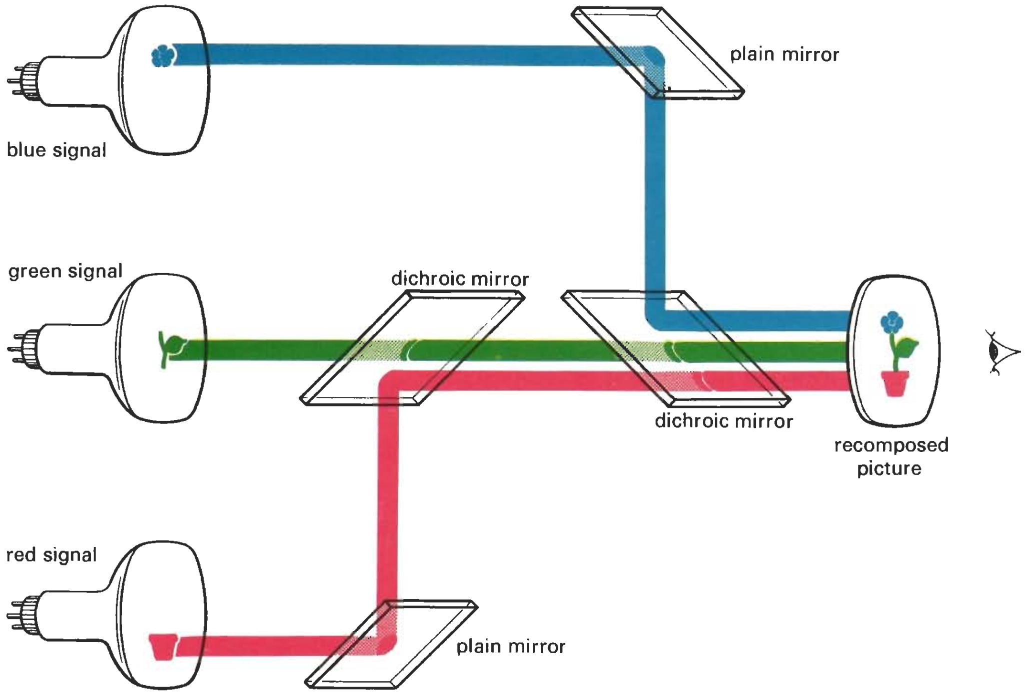
ADDITIVE COLOUR MIXING—the reverse of colour printing—is used in colour television to produce the whole spectrum from three primaries: red, green and blue



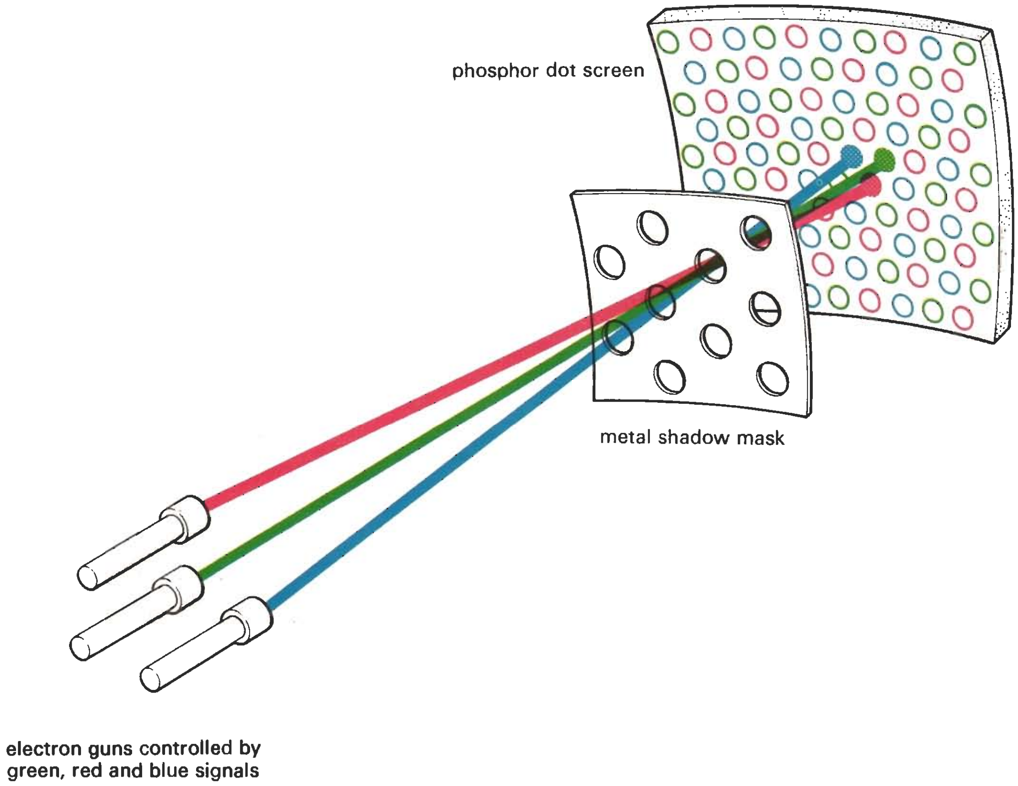
DICHROIC MIRROR SYSTEM is used to analyse the white light from the image into three colours ready for transmission. Each mirror consists of a glass base on which are deposited from 7 to 20 thin layers of a transparent material which alter the mirror's ability to transmit and reflect certain colours. The mirror system is normally built into the television camera

the 'chrominance' signal. The problem is therefore: to analyse the picture to be sent into the red, green and blue components and obtain the corresponding signals; to code these signals in a suitable form with separate luminance and chrominance signals; to transmit the coded signals; to receive the coded signals and decode them into separate red, green and blue signals; to display the picture corresponding to the individual red, green and blue; and to do all this in such a way that there is no interference to normal black-and-white reception. The basic process of forming a television picture by a line-by-line scanning process is, of course, the same in colour as in black-and-white transmissions.

White light is a mixture of all the colours of the spectrum but if appropriate shades of red, green and blue are combined in suitable proportions the result looks like white light, while combinations of any two produce the other colours shown on page 49. Almost any colour can be produced by mixing appropriate amounts of the three primaries. The human eye cannot distinguish between light consisting of radiation in any given narrow band of visible wavelengths and light that consists of mixed radiation in widely separated bands. For example, yellow light with a wavelength of about 6000 Ångstrom units (1Å is 10^{-8} cm) is indistinguishable from an appropriate mixture of red near 7000Å and green around 5300Å. This is a great help. The luminance signal conveying the information for a black-and-white picture is electrically equivalent to the sum of the signals representing the red, green and blue. If the chrominance signal is made to contain two signals electrically equivalent to the red and green then, by separating these out in the receiver, the red and green are obtained individually and, by subtracting the sum of these two from the white signal, the blue is obtained. This is the essence of all proposed methods of achieving colour television; although there are variations in the actual content of the chrominance signal, and in the way in



COLOUR RECEIVER can incorporate a dichroic system of the kind used to analyse white light. The red, green and blue images are then combined on the screen and the resulting image is seen in full colour. Disadvantage of the system is that superimposition is accurate only when the image is viewed square-on, which makes it impracticable for domestic viewing



SHADOW MASK TUBE, now in production in the United States, contains three electron guns, each controlled by one of the primary colour signals. They fire through a shadow mask containing 300,000 holes and aim at 300,000 sets of three dots on the tube face, each set containing one dot which glows red, when energized by an electron, one which glows green and one blue. Electrons from the guns fall only on their respective colour phosphors

THREE STAGES of colour television transmission are shown below. Picture immediately below was made only from the luminance—the black and white signal. Centre picture is composed only of the chrominance signal. Final, full colour picture is the result of combining both signals

which it is transmitted, basically all are similar. We therefore have to analyse the white light to obtain the signal in the three colours and then build up the luminance and chrominance signals to the form required by the chosen system.

Analysis of the white light is done with dichroic mirrors. These consist of a glass base on which are deposited from 7 to 20 very thin layers of transparent material. Each layer has a thickness of only a fraction of a wavelength of visible light and, according to its individual design and deposition, transmits certain colours and reflects others. By the use of a number of layers fairly steep changes of reflectivity as a function of wavelength can be obtained. In the upper diagram on page 49 the white light source is shown as a mixture of red, green and blue. When this meets the first dichroic mirror the red light is reflected and the green and blue pass straight through without reflection or appreciable absorption. The green/blue then strikes the second dichroic mirror which has a coating which reflects the blue light and lets the green light pass through.

At each of the three outputs of the dichroic mirror system is placed a television camera tube employing normal methods of scanning the scene. By a combination of electrical and optical adjustments the pictures produced in the three camera tubes are made identical in size, providing three otherwise identical pictures giving the red, green and blue content of the scene. The three colour signals pass through the chain to the receiver in which the three colour pictures are accurately superimposed. Thus the original picture is reconstructed.

THE COLOUR TELEVISION PROCESS is started by building into a television camera a colour analyser, using either dichroic mirrors or some other device derived from this principle, and providing three separate camera tubes. From the latter the three colour outputs, adjusted to give pictures of identical dimensions, are added together to give the overall black-and-white brightness: this is the luminance or 'Y' signal. The luminance signal is used to modulate a carrier exactly as is done in black-and-white television, thus ensuring the compatibility of the system. A proportion of the red, green and blue outputs is used to derive the two signals required to give the red and green, or whatever other combination has been chosen, in the chrominance signal.

An analysis of the energy distribution of a television signal shows that all the information is contained in fairly narrow bandwidths centred on multiples of the line frequency. There is comparatively little information between these discrete frequencies, and comparatively wide frequency spaces centred on multiples of half the line frequencies contain little information. Points of minimum energy occur all along the scale. The chrominance information is therefore packed into the spaces between the information in the luminance signal so as to cause a minimum of mutual interference; an adequate chrominance signal can therefore be sent within the bandwidth occupied by the luminance channel.

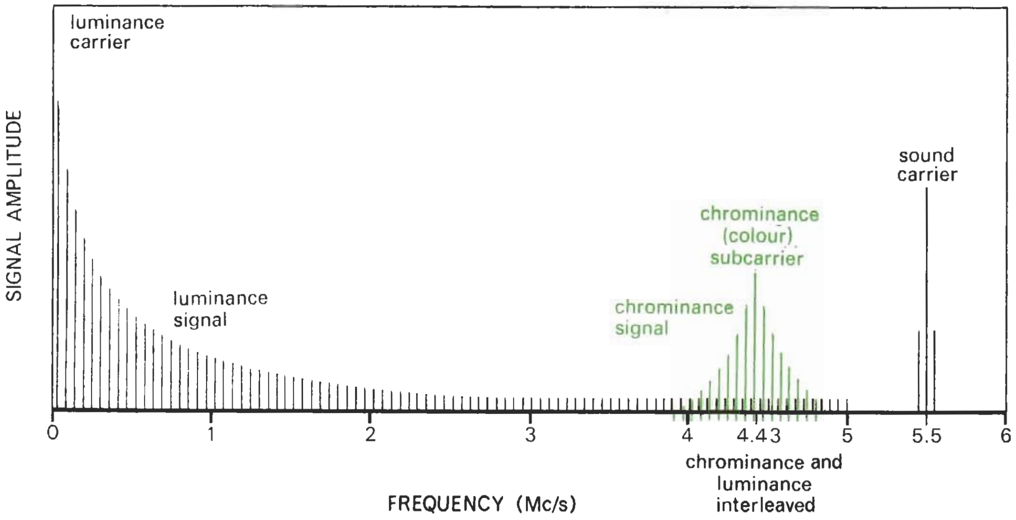
This means that the colour sub-carrier frequency must have a particular specific value at which it must be maintained with a high order of accuracy—as also must the line frequency. By maintaining this spacing to a high degree of precision a considerable improvement in overall performance is obtained. This principle of putting the chrominance modulation on a sub-carrier accurately spaced relative to the luminance carrier is an essential part of all colour television systems proposed. The optimum spacing of the colour sub-carrier varies slightly depending on the system—for example, that for the NTSC system is not quite the same as that for the PAL system—but it is always close to an agreed value of 4·43 megacycles per second (Mc/s).

Having arranged the colour sub-carrier in such a position that it causes the minimum of interference with the information on the main carrier, it is then necessary to determine the minimum amount of information to be sent on the colour sub-carrier to obtain adequate but not excessive colour performance. Many tests have been made on the acuity of human vision in colour. As a result, it has been ascertained that it is necessary to send only about one third of the detail in colour that we send in black-and-white, because the eye sees detail very sharply in black-and-white, but is much less conscious of detail in colour. We see this when matching colours with a thread of cotton. It is virtually impossible to tell whether colours match accurately by looking at a single thread; several threads or, preferably, the whole surface of a reel must be used. In 625 line black-and-white television about 5 Mc/s of information is sent on the black-and-white signal; in colour less than half the total bandwidth is sent, and this is divided between the two colour signals being transmitted.

THE NTSC, PAL AND SECAM systems differ chiefly in the transmission of the chrominance signal. I can explain this by first outlining the NTSC solution, which was the first national system to be adopted. In this case the chrominance signal is sent in two parts, the 'I' or in-phase signal and the 'Q' or quadrature signal. These are really complex signals but it is an acceptable simplification to consider them as green and red. The colour sub-carrier is divided into two components at right angles to each other. One of these components is modulated with the I signal and the other with the Q, after which they are combined to give a signal which is correspondingly modulated in amplitude and in phase.

Simple amplitude detection in the receiver would, of course, give only a composite signal containing both I and Q information. If, however, synchronous detection is used it becomes possible to resolve the phase of the signal and determine the values both in phase and in amplitude and hence determine the relative amounts of I and Q signal. To achieve synchronous detection a reference signal of the correct frequency and phase is necessary. This is provided by eight cycles of reference signal at the colour sub-carrier frequency, sent in the line suppression period, which serve to lock the oscillator in the receiver to give synchronous detection. A complete NTSC signal therefore consists of: eight cycles of reference sub-carrier sent in the line suppression period and called the 'colour burst'; the luminance signal, exactly as in black-and-white television; and the colour sub-carrier, modulated in amplitude and phase by the two chrominance signals and spaced at a distance from the main vision carrier by a precise amount corresponding to an odd multiple of half the line frequency. When no colour information is present in the picture this signal falls to zero, and it is at low level whenever the colours are unsaturated.

PAL was not the next proposal chronologically but it is the closest to the NTSC system. The colour sub-carrier is quadrature modulated as before but the phase of the I signal is reversed on alternate lines at the originating point and synchronously reversed in the receiver. Several means have been proposed for determining the phase of the I signal. The most attractive would seem to be to alternate the phase of the colour burst from line to line so as to give an indication of the required phase reversal position. This process of double phase reversal—once in the studio and back again in the receiver—has the effect that differential phase distortion on the I signal, which can occur at a number of points in the chain, is reversed in angle between successive lines. When the I signal is averaged between two successive lines the differential phase distortion cancels out. The PAL system can be used with or without a delay line in the receiver. In the former case the averaging of the two signals is done electrically; in the



TRANSMISSION of colour television is achieved by interleaving the luminance and chrominance signals. Energy peaks of the luminance signal occur in fairly narrow bandwidths centred on multiples of the line frequency. The chrominance signal (colour) is transmitted at frequencies lying between these on multiples of half the line frequency. This results in minimum interference between the two signals, but their frequencies must not vary

latter case the two signals are displayed in successive lines on the face of the colour tube and the eye does the averaging between them. If a yellow part of the picture is turned a greenish yellow in one line, by differential phase distortion it will appear as a reddish yellow in the next; at viewing distance an eye will see the sum of these as yellow.

The third system is SECAM. This avoids the use of synchronous detection by transmitting the I and Q signals in sequence—an I during one line and a Q during the next. In order to be able to add the I and Q signals to determine the missing colour signal, each line is passed through a delay line having time equal to one line period so that, by taking the output of the delayed line and the present line, both the I and Q signals are available simultaneously. The information in each line is thus used twice. There have been successive proposals known as SECAM I, SECAM II and SECAM III and further variants may be proposed. So far all have the same basic approach: all use frequency modulation of the chrominance carrier and the differences reside in such variables as the amplitude and composition of the chrominance signal and the amount of pre-emphasis in the transmissions and de-emphasis in the receiver.

In addition to the above three systems, other proposals have been made; all maintain the basic principle of separate luminance and chrominance signals but differ in the ways in which the chrominance signal is sent. As I noted at the outset, there are many different opinions upon the merits of the various systems. But it must be remembered that something like 95 per cent of the equipment in the studio and 95 per cent of the receiver is essentially the same whatever system is used. Real differences are confined to the coding and decoding of the chrominance signal. It is not easy to assess the competing systems, and almost impossible to get agreement from the bodies concerned that any appraisal is fair and accurate; but I will offer my own views.

The NTSC receiver has fewest components and so can cost the least. This system is in widespread use, notably in North America. It is remarkably immune from effects due to interference, gives the best black-and-white compatible picture and has the highest inherent picture quality. It needs a high degree of accuracy in programme distribution services and it makes exacting demands on the performance of video tape recorders, but operators of this system claim that none of these requirements causes any difficulty in practice and no country which has adopted NTSC has shown any wish to change.

The PAL system makes programme distribution by line simpler and gives improved results in video tape recording. On the other hand it gives a compatible picture which is slightly less acceptable than that from the NTSC signal and, because it incorporates the delay line and additional switching circuits, it has appreciably more receiver components than does NTSC. Consequently, the cost is higher but it is claimed that the receiver is easier to line up than an NTSC receiver and it has one less control button.

It is difficult to see that SECAM, with frequency modulation, is worth the complexity. Its compatibility is worse than that of NTSC or PAL. Its inherent picture quality is somewhat lower. Its resistance to interference at high signal levels is comparable to that of NTSC and PAL but on weak signals it is inferior to both. The delay line and associated circuitry require a complex receiver of correspondingly higher cost but it does have fewer control knobs.

If one system of colour could be used throughout the world it would clearly be advantageous. But the world has long been divided into areas having 50 c/s and 60 c/s power supplies and this has naturally resulted in 50 field and 60 field television areas. It would seem that this division must persist for many years in colour television. Unfortunately, as things stand at the moment, it looks as though there will be more than one colour system even in the 50 field areas, and there may be two, three or even four different standards.

This will clearly lead to difficulties although it should not greatly interfere with programme exchange between countries. It is possible without excessive deterioration in picture quality to transcode from one colour television system to another, provided both are on the same line and field frequency; the equipment needed to do this is not complicated. But the problem inside the receiver is more difficult, and viewers living near frontiers of countries using different standards may require a receiver capable of accepting both systems. The best way of doing this is now being studied in several countries.

Receivers for all systems are basically similar. The coded colour signals are transmitted and received in the normal black-and-white way. The synchronous detector in the receiver separates out the I and Q components and combines these with the luminance signal to produce the red, green and blue signals corresponding to those which came out of the camera. These signals must then be combined to produce the colour picture.

One method of combination is to display each signal on a separate cathode ray tube with an appropriate colour phosphor and then view all three through a dynamic dichroic mirror system transmitting the three screens in rapid succession. Very good picture quality can be obtained in this way but the device is cumbersome and superimposition is accurate only when the viewer is sitting square-on, which makes it impracticable for home viewing.

Accordingly, considerable effort has been expended upon the production of cathode ray tubes able to produce a full colour picture. So far only one is in satisfactory use but it is being produced at the rate of many millions a year; this is the shadow mask tube, originated by the Radio Corporation of America. Instead of a single electron gun it has three guns each controlled by one of the colour signals. The guns are very accurately converged to 'fire' at the end plate of the tube through a perforated plate known as the shadow mask. The latter has about 300,000 holes in it and the geometry of the tube is such that the electron beam from any one gun scans in turn through all the holes in the shadow mask in succession, line by line, but falls only on specific points on the tube face. Instead of being covered uniformly with a powder to glow white when bombarded, the shadow mask has 300,000 sets of three dots. In each group one dot has a phosphor which glows red when bombarded, one a phosphor which glows blue and the third a phosphor which glows green. When the red gun is energized its electrons pass through the successive holes in the shadow mask and fall on only the red phosphor dots to build up a red picture on the face of the tube. The same applies to the green and blue. This builds up on the face of the tube three superimposed pictures which are misaligned to the extent of the spacing of the three dots in each triplet. This is a very small error and, as far as the eye is concerned, the final picture appears to be perfect. Illustrations on page 50 show a black-and-white picture derived from the luminance signal only, the information contained in the chrominance channel (the sum of the I and Q signals) and the combined result.

The shadow mask tube is rather expensive to make because of the accuracy with which it must be constructed. It also restricts the picture brightness, since more than four fifths of the electrons never reach the tube face but are arrested by the metal mask. There is a definite limitation to the beam current and voltage if x-ray emission is not to be excessive; too great a beam current would also heat and distort the mask. Therefore, although the shadow mask tube gives a generally adequate picture, research is in hand to find a simpler tube giving a brighter picture.

One possibility is the 'chromatron' tube in which the shadow mask is replaced by a grid and the sets of dots by vertical phosphor strips arranged in red, green and blue sequence. By changing the polarity of the grid potential the beam can be deflected to the red, green or blue phosphors. To do this satisfactorily demands a very rapid switching system consuming an appreciable amount of power. Such power fed to a grid of the size required for the largest tubes can give rise to radiation interference at the switching frequency.

Another tube under investigation is the so-called indexing type. In the emission indexing variety the end plate is covered with a pattern of vertical red/green/blue phosphor bars, each set of three being separated by a thin strip of non-phosphorescent but electron emitting material. In the photo indexing tube this strip can be non-reflecting. Each time the sweeping electron beam strikes one of these emissive strips no light signal results but an electron signal is emitted which is picked up by a device inside the tube—a photocell or electron detecting device—to give a reference indicating the position of the beam in the red, green and blue cycle. Once a pulse of indexing information has been received the beam knows that it must send the red, green and blue signals at definite time intervals and in a definite sequence. By this means the tube can operate with a single gun and no shadow mask. Nevertheless, the indexing circuits are complex and it is difficult to achieve adequate definition.

A further possibility is to use a tube in which three guns are aligned in a planar instead of in conical formation, firing through a grid or shadow mask plate. This may give increased brilliance and reduce manufacturing costs. In practice, great difficulties are found in damping out mechanical vibrations in a fine wired structure mounted in a vacuum. Certainly the ultimate tube for colour television has not yet been found.

As far as the studio is concerned, costs for colour operation are only moderately greater than for black-and-white. The increase affects only technical costs which normally are only a small fraction of the total cost of a programme production. Means for exchanging colour programmes by video tape recordings, as well as by direct landline transmissions, already exist. Satisfactory methods of programme exchange by means of recorded photographic film have not yet been resolved but undoubtedly will come; already colour transmissions have been relayed by satellite. There is no reason to doubt that, within a decade, a very high proportion of all television throughout the world will take place in colour. The growth of world wide communications satellites will speed up the process.

FURTHER READING

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