THE DEVELOPMENT OF COMPATIBLE COLOUR TELEVISION

with particular reference to the different proposals for transmitting the chrominance signals

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Summary.

The stages in the development of colour television may be characterised by the different ways of assigning signals to the colour parameters. It was only by adopting the principle of separate signals for the luminance and the chrominance that the psycho-physical features of the sense of colour (imperfection in the recognition of detail in colour) could be utilised for reducing the frequency bandwidth. This led to the " compatible " transmission process which was first put into practice with the development of the American NTSC system. The special problem lies in the type of transmission and the accommodation of the two colour signals in the upper frequency region of the luminance signal. The article describes the variants of colour-signal modulation proposed by several laboratories in Europe and compares them by means of schematic diagrams.

In these days we hear a great deal about the problems of colour television, and so it may be useful, in a systematic survey, to explain the differences and also the common principles distinguishing the various colour systems. At the same time, it will be pertinent to recall other proposals which have brought about important contributions in this field. It therefore seems profitable to begin with a basic review of the problems in colour television, and of the stages in its development.

Basic principles of television transmission

In conventional television practice *(Fig. 1),* the picture content, which may vary abruptly from one part of the scene to another, is analysed over small elements of area, and reproduced in a similar manner at the receiving point. In this way a complete picture can be transmitted over a single channel linking the sending and receiving points. In the case of high-definition television pictures, we need to transmit a large number of separate pieces of information (at the rate of several million a second), and therefore a relatively large bandwidth (several megacycles per second) is necessary. The transmission of so wide a frequency band without distortion involves considerable cost, which must be kept within reasonable limits. Indeed, in any discussion or decision relating to future developments in television, the requirement of using the bandwidths available to best advantage (spectrum economy) must always be a prime consideration.

In *Fig. 1,* we can observe a significant peculiarity in the structure of a television signal. The doubly periodic scanning of the picture field gives rise to a discrete energy distribution in the frequency spectrum ; this takes the form of concentrations of energy density at the harmonics of the line and field scanning frequencies (this is only strictly true for still pictures, but is a good general approximation). This peculiarity makes it feasible to insert or interleave other information within the gaps in the discrete spectrum, without provoking interference. It was the exploitation of possibilities of this kind which opened the way towards the goal of compatible colour television.

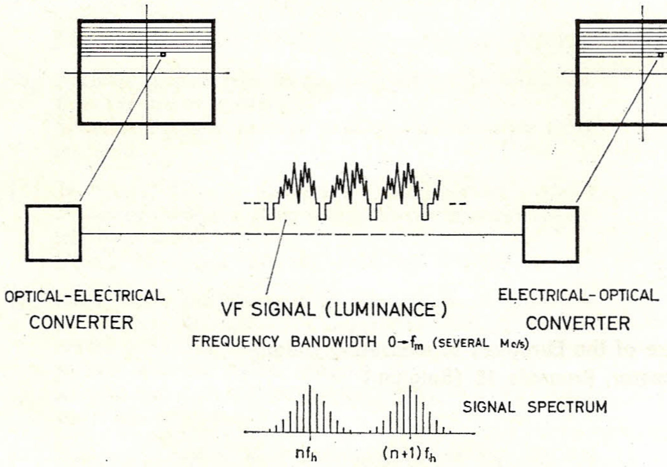

Fig. 1. — Schematic of the conventional transmission system for monochrome television.

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* Prof. Dr. Theile is Director of the Institut für Rundfunktechnik, Munich. This article is based on a paper read by him at the 4th International Television Symposium, Montreux, May, 1965. He is also Chairman of the E.B.U. Ad-hoc Group on Colour Television.

Associated signals.

It is of great importance to consider the form of signal associated with the parameters appertaining to colour. Two basic possibilities are illustrated in *Fig. 2.* It is manifestly relevant and logical to relate one signal to the *brightness* of a given picture element (the *luminance signal)* and to assign two other signals to represent the " kind of colour " (the *chrominance*) — that is, the *hue* and degree of *colour saturation.* Unfortunately, no picture source (camera or film scanner) exists which can directly provide signals in this form, nor is there at present any picture display device which can be directly actuated by such signals. We must therefore try another approach — analogous to the practice in other colour-reproducing processes — which is also illustrated in *Fig. 2.* The colour information is analysed and reproduced within three "sub-spectra" (red, green and blue) of the total visible spectrum. We have thus to deal with a triad of three signals, the intensity and mutual relationships of which contain, implicitly, the information regarding brightness and colour content. By means of these three signal components, we can adequately represent any colour which is likely to be of interest.

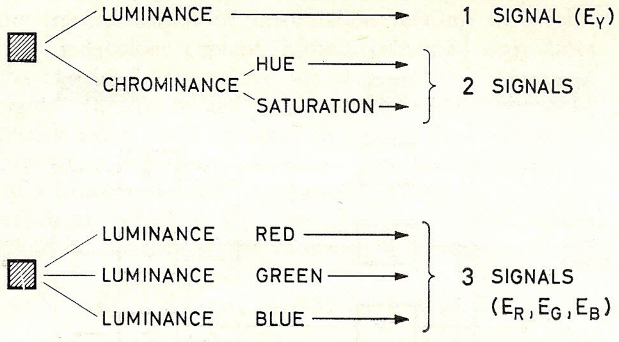

Fig. 2. — Correspondence between the signals utilised for the transmission of colour television.

There is an important stipulation here — the colour-television chain must always begin and end with the three primary colour signals E_R . E_G and E_B . What still remains to be settled is the form of colour signal leaving the transmitter and arriving at the receiver. It will be readily appreciated that the early development of colour television started with direct transmission of the three primary signals.

Direct transmission of colour-content signals.

A general outline scheme for the transmission of colour by the simultaneous radiation of three signals, expressing the picture content in terms of the primary colours, is shown in *Fig. 3.* Three complete transmission systems are used in parallel. The picture is split, by optical means, into three identical components which pass through colour filters to three camera tubes, the rasters of which are isochronously scanned. The outputs from these tubes provide the signals containing the " red, green and blue information ". At the receiver, these three signals control three synchronously-operated display tubes, the light output from each of which passes through the appropriate colour filter, and is combined optically (additive mixing) to reproduce the colour picture.

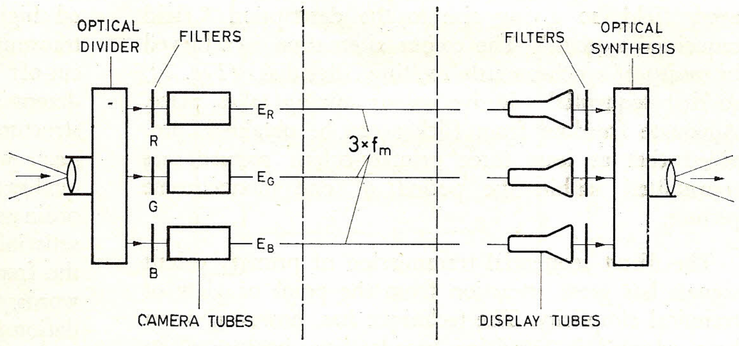

Fig. 3. — Simultaneous transmission of partial colour pictures with direct transmission of the primary colour signals.

Of greater technical significance was the *sequential* transmission of the primary colour signals, shown in *Fig. 4.* In terms of apparatus, the outlay involved is considerably reduced if the switching processes can be carried out optically, because then only one camera tube, one display tube and a single transmission channel are required. In practice, colour alternation takes place after

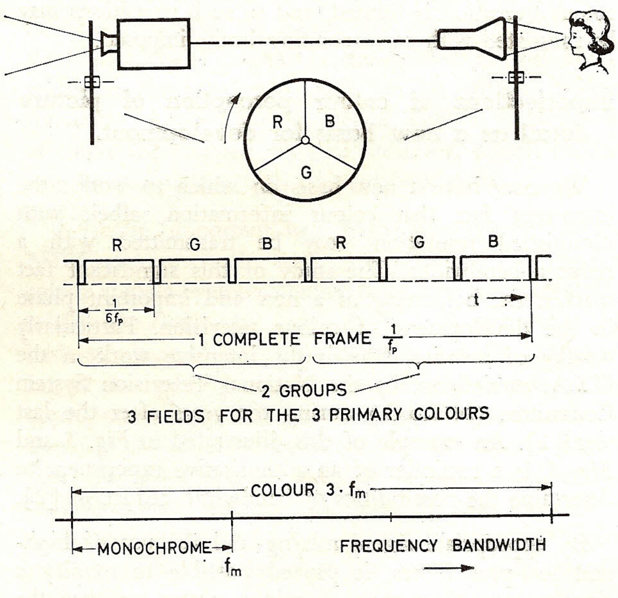

Fig. 4. — Sequential transmission of partial colour pictures with direct transmission of the primary colour signals.

every field, so giving rise to the description " field sequential system ". The colour alternation is achieved by means of synchronously rotating filter disks *(Fig. 4)*, so that sequential additive colour mixing takes place. Adequate freedom from flicker can be obtained, provided that at least three primary-colour pictures are transmitted within the period of one monochrome picture.

The direct sequential transmission of primary colour signals has great attraction from the point of view of technical simplicity. The technique has, however, never been adopted in television broadcasting, because of its overwhelming and fundamental disadvantages. This method is essentially wasteful in its bandwidth requirements ; it needs three times the bandwidth of a conventional monochrome transmission. Further, such a colour system is *incompatible* with the usual monochrome system, since the field-scanning frequency, as well as the bandwidth occupied, is three times as great ; reception of the monochrome information in the colour picture is therefore impossible. At this stage, the requirement of compatibility began to assume greater importance in the development of colour television.

Fortunately at this time new knowledge was becoming available, arising largely as a consequence of the criticism which had been levelled at the technique of directly transmitting the primary colour signals. Doubt began to be felt as to whether it was really necessary to transmit three component pictures in the primary colours, in view of the major disadvantage of requiring a three-fold increase in bandwidth.

This doubt was justified. A study of colour television, in terms of the behaviour of the human eye, makes it evident that the structures concerned with perception of colour and brightness differ materially in their sensitivity. Indeed, for psycho-physiological reasons, the eye's perception of fine detail in colour is negligible ; in other words, resolving power of the eye in respect of colour transition is limited, and so such transitions may be presented with corresponding limits imposed.

Imperfections of colour perception of picture detail as a new basis for development.

We now have a new basis on which to work : the important fact that colour information, albeit with diminished resolution, may be transmitted with a reduced bandwidth. The study of this significant fact marked the beginning of a new and important phase in the development of colour television. Particularly worthy of mention here is the intensive work in the U.S.A. carried out by the National Television System Committee (N.T.S.C.) during the years after the last war [1]. An example of this, illustrated in *Fig. 5* and *Fig. 6*, is a reminder of an authoritative experiment to determine the possibilities of bandwidth reduction [2].

By appropriate signal mixing and the use of high- and low-pass filters, it proved possible to modify a simultaneous three-channel colour system so that the signals delivered to the receiver were identical in the higher frequency range ($f_z \rightarrow f_m$) (principle of " mixed highs ") ; in this range therefore no colour was transmitted, but only brightness texture. By varying the cut-off frequency f_z of the filters, it was possible to determine the limit above which the horizontal picture structure lost its colour. Those taking part in the experiment were asked to give their opinion of the picture quality. The result is shown graphically in *Fig. 6* ; the ordinates indicate the percentage of observers who were satisfied with the picture quality for a given setting of the frequency f_z (marked on the abscissae) — in other words, the observers who failed to notice any degradation of quality relative to the condition $f_z = f_m$. As will be seen, it turns out that the transmission of colour pictures with a bandwidth in the vicinity of 1 Mc/s is quite acceptable.

In the course of further investigations, information was gained regarding also the dependence of the phenomenon of " colour-detail blindness " upon the colour transmitted. It was found that the perception of colour transitions along the orange-cyan axis (as represented

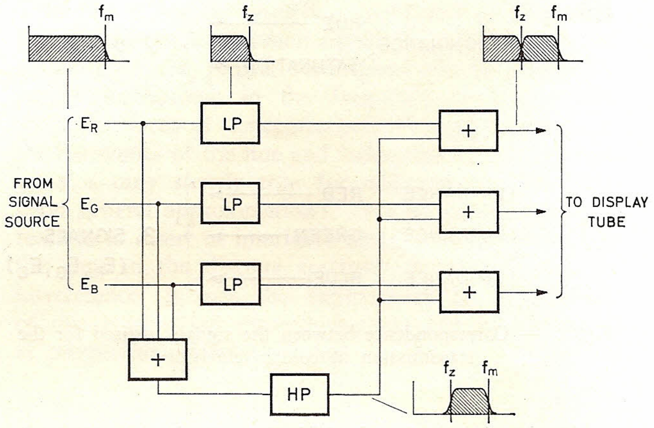

Fig. 5. — Experimental arrangement set up to determine to what extent the bandwidth f_z for the transmission of colour information might be reduced [2].

LP = low-pass filter HP = high-pass filter.

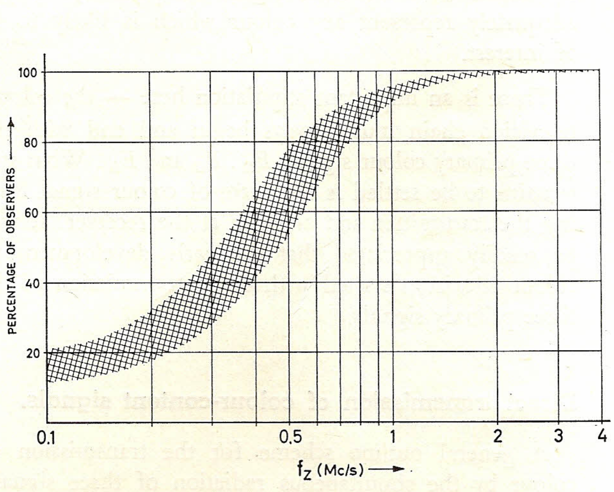

Fig. 6. — Results obtained with the experimental arrangement shown in Fig. 5 [2].

transitions along the orange-cyan axis (as represented on the usual colour triangle) is less easily lost than along other axes.

These investigations show that a satisfactory colour-television picture can be transmitted with considerable economy in bandwidth, since some 10 to 20 % of the bandwith f_m is ample for reproducing colour transitions. In order to put this newly-gained knowledge into effect, new and interesting methods of coding and channelling signals had to be devised ; such methods, by an admirable series of developments, led step by step to the NTSC system.

Development of the NTSC system : simultaneous transmission of luminance and chrominance as separate signals.

The first step which needed to be taken was to effect the transformation of information relating to brightness and colour content, hitherto obtained only from the three primary colour signals, into new forms of signal directly related to these parameters. By such means alone could economy in bandwidth be attained. The signal separation was achieved, as shown in *Fig. 7,* by a process of linear combination (coding) in matrix networks, whereby the three primary colour signals could be summed in the following proportions :

$$E_Y = 0.30\ E_R + 0.59\ E_G + 0.11\ E_B$$

The Y signal so produced corresponds with brightness or luminance *.

Two additional signals are needed to define colour information. By a very ingenious method, *difference* signals were introduced ; two of these are sufficient, e.g. the signals

$$E_{D1} = C_1\ (E_R - E_Y)$$

$$E_{D2} = C_2\ (E_B - E_Y)$$

Now the signal E_Y already contains additive information concerning the three quantities E_R , E_G , E_B , and it can therefore be the third quantity needed to reconstitute the three primary colour signals by a decoding process at the receiver.

The use of difference signals marks a significant step in development. These signals — assuming linear combination — contain information solely relating to colour content ; they vanish when a neutral (e.g. white or grey) picture is transmitted. They are a measure of the deviation of the colour content from " neutral ", and increase in intensity with the deviation from this reference point. Their amplitude is therefore a measure of colour saturation. The hue is characterised by the ratio and sign of the two signals.

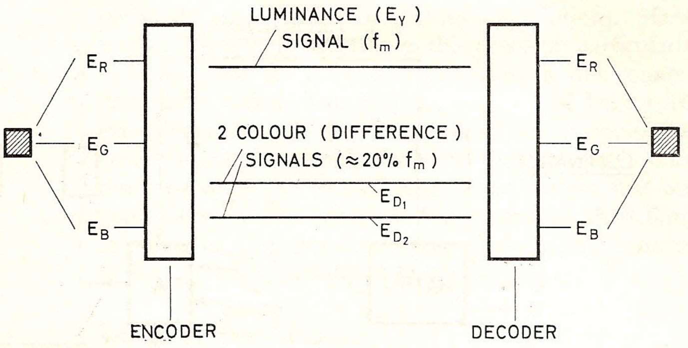

Fig. 7. — New correspondence between the signals transmitting colour television obtained by coding of the primary colour signals.

The logic behind the choice of these colour signals leads to a further improvement, by arranging that one signal relates to colour excursions along the somewhat critical orange-cyan axis. This can be achieved by a rotation-transformation through an angle of 33°, by a linear combination of the simple difference signals $E_R - E_Y$ and $E_B - E_Y$. The resultant signals are

$$E_I = C_1(E_R - E_Y)\ \cos 33^\circ - C_2(E_B - E_Y)\ \sin 33^\circ$$

$$E_Q = C_1(E_R - E_Y)\ \sin 33^\circ + C_2(E_B - E_Y)\ \cos 33^\circ$$

The I component corresponds to colour excursions along the orange-cyan axis.

The signal transformation just discussed makes feasible the desiderata of *bandwidth reduction* and *compatibility.* The Y signal is transmitted at full bandwidth in the usual way, and can be utilised by the conventional monochrome receiver. For the transmission of colour information, the two additional signals needed may be transmitted with reduced bandwidth.

A further important step in the development of the NTSC system was the bold concept of transmitting the colour signals by intercalating their frequency spectrum *within the luminance band.* As will be seen from the basic structure of the signal spectrum (in *Fig. 1*), sharing of the unoccupied spaces in the band is possible by appropriate staggering of the signal component frequencies. In order to minimise any consequent distortion, the colour signals must be accommodated at the high-frequency part of the band, in the form of a modulated sub-carrier of frequency f_c (chosen to give the best offset in relation to the luminance spectrum). This brings us to the general basic scheme in *Fig. 8,* which is self-explanatory, and has already appeared in an earlier survey by the author [3].

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* In the usual international notation, the colour signals are denoted by a *dash* (e.g. E'_Y). This is a way of expressing the fact that we are dealing with the pre-equalised colour signals usual in television practice. In this general survey however we must avoid discussion of the errors which can arise from pre-equalisation procedure, and content ourselves with the stipulation that the principle of coding and separation must hold, even when pre-equalisation is used. For these reasons, and in the interests of simplicity, we keep to the usual symbols - without the *dash.*

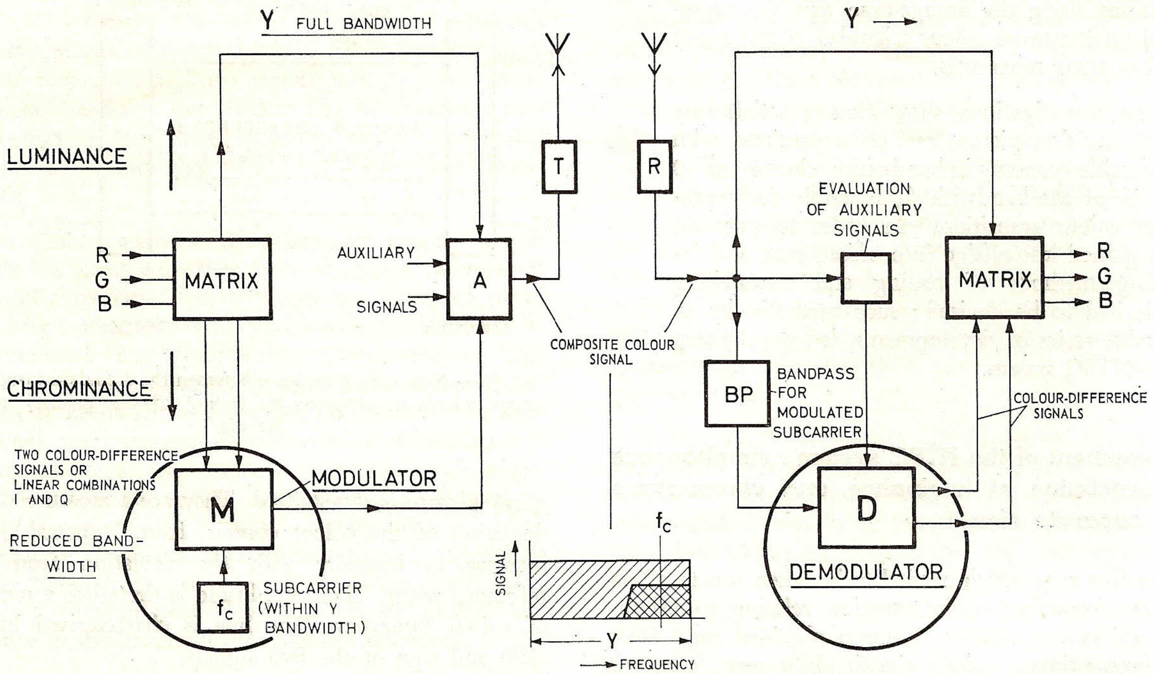
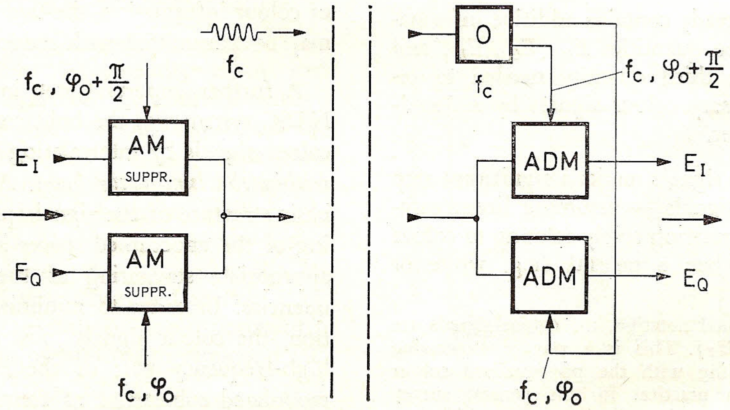


Fig. 8. — General schematic of the compatible transmission of colour television, with separation of the luminance and chrominance signals and insertion of the frequency bands of the colour modulation in the luminance band.

The problem still remaining was the choice of technique for transmitting the colour signals. It should be remembered that two signals have to be transmitted, both of which lie in the high-frequency range of the luminance band. In the original NTSC system, this was accomplished by a simultaneous double amplitude-modulation of the (precision offset) sub-carrier f_c, differing in phase by 90° (quadrature modulation). The general principle of this form of modulation is shown in *Fig. 9.* The amplitude of the sub-carrier varies in proportion to the intensity of the colour signal, and is therefore zero in the absence of colour information (suppressed carrier = suppr. in the figure). It follows that when a " neutral " scene is transmitted, no additional space in the luminance spectrum is occupied. This ingenious choice of modulation technique has the effect of still further reducing any remanent distortion in the compatible monochrome picture. The synchronous detection process at the receiver necessarily requires the provision of a synchronised oscillator. For this purpose, a control signal in the form of a " burst " is transmitted, in the line blanking interval, which acts upon the local oscillator, maintaining it at the correct frequency and phase.

The type of modulation just described produces an amplitude modulation and a " zero-phase modulation " of the sub-carrier. The *amplitude* is proportional to the *colour saturation,* and the *phase* to the *hue. Fig. 10* shows the relation between hue and phase with regard to the axes of the original or of the transformed difference signals (I and Q).



Original system.

Fig. 9. — Modulation and demodulation process of the colour signals in the NTSC system.

AM = amplitude modulator   ADM = amplitude demodulator   suppr. = suppressed carrier

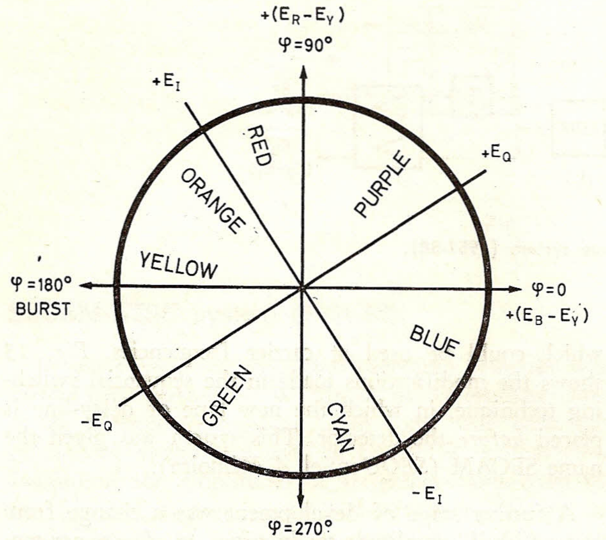


Fig. 10. — Vector diagram of the double amplitude modulation of the colour sub-carrier in the NTSC system showing the position of the reference axes for the original and transformed colour difference signals.

Further development of the NTSC system : different methods of modulating colour signals.

We have just examined the main features of the techniques used during the development of the NTSC system, for the transmission of compatible colour-television signals with reduced bandwidth. These techniques have justified themselves in practice, and even the expert continues to be impressed by the way in which this system manages to imitate the thrifty information-handling mechanism of our visual sense organs. Practically all subsequent developments followed along the same line, characterised by signal separation, the use of difference signals, and interleaved frequency bands. With regard to the technique of modulating the two colour signals, a whole series of proposals appeared for devising methods which would be proof against certain forms of distortion. The many variants in this context have been the subject of many discussions which we have had recently in connection with colour-television standards.

As reference to *Fig. 10* will show, in the NTSC system the phase of the colour sub-carrier frequency, relative to the reference phase of the synchronising signal, is all-important. This can lead to a characteristic form of colour-distortion, if the transmission itself is subject to distortion. *Differential phase* errors, or phase variations within the modulation range of the signal (from black level, where the reference signal is set, to peak white), which are a function of amplitude, can cause changes in hue. The vector representing the phase angle is thereby rotated, and when the composite colour is demodulated, the two colour components will be incorrectly reproduced.

It was the susceptibility to distortion of this kind which was the main reason for criticism of the method of modulation in the NTSC system. At this stage new proposals were made for alternative solutions. Many workers gave their attention to this problem, particularly in Europe. Of the many new proposals in this connection, some, which have shown promise and been tried experimentally, will now be discussed (in chronological order [*]) and compared. We shall here consider only those parts of the overall modulation system that are depicted within the circles in *Fig. 8,* and we shall limit ourselves to a cursory description of the salient features of the different techniques of modulation.

T.S.C. system (1956).

This proposal, developed and tried out some ten years ago by the Philips Laboratories at Eindhoven [4], sought to avoid the difficulties of double modulation by using *two* different sub-carrier frequencies, f_{c1} and f_{c2} for two colour signals (these being the ordinary primary colour signals E_R and E_B). *Fig. 11* reproduces the block schematic of this system. Conventional amplitude modulation is used (without carrier suppression and without a burst signal). New problems were encountered in connection with the compatible monochrome picture and with the stabilisation of the ratio of the two colour components which determines hue.

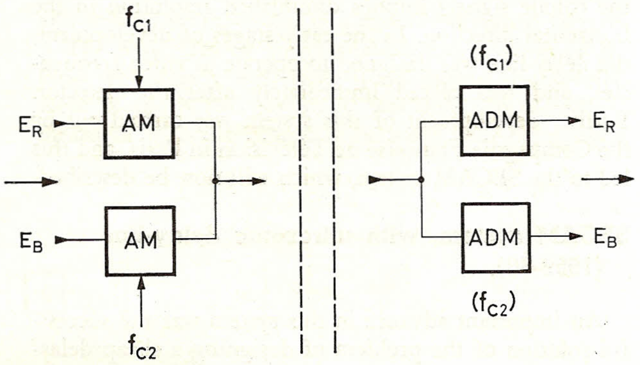


Fig. 11. — T.S.C. system (1956).

Henri de France system (1957-58).

At about the same time, an interesting proposal due to Henri de France [5] was being studied. This technique also avoids the use of double modulation ; only one colour signal at a time is impressed upon a sub-carrier at frequency f_c, but this sub-carrier is modulated, by sequential switching, *alternately by the first and second colour signal (Fig. 12).* Thus, at any given instant, one of the colour signals is absent. Conventional amplitude modulation was used, originally with the primary colour signals E_R and E_B, and later with the difference signals $E_R - E_Y$ and $E_B - E_Y$. The transmission of a burst signal is unnecessary with simple envelope-detection at the receiver, but a synchronising

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[*] The years to which reference is made relate, as far as is known, to the dates of the available reports of these developments. The author asks for indulgence if any errors have been committed.

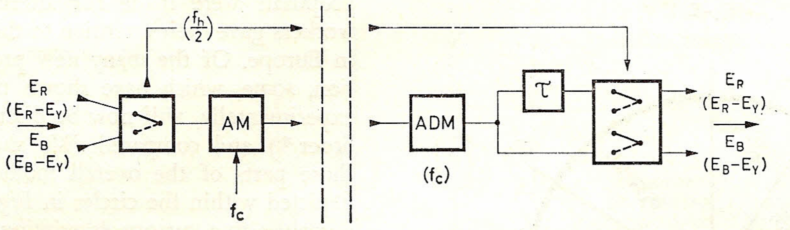

Fig. 12. — **H. de France system (1957-58).**

signal is transmitted in the field-blanking interval, in order to control the phase of the electronic switch in the receiver. The switching process follows a line-to-line sequence, and so the recurrence frequency is half the line frequency f_h.

At the receiver a new device is required, in the form of a delay-line, with a group delay equal to a line period. This is needed for storing the colour information transmitted during earlier line periods, in order to ensure a continuous flow of the signal information necessary for the reconstitution of the primary colour signals. There may be small errors (in the receiver) in the vertical direction which are nevertheless within acceptable tolerances, since the reduced bandwidth of the colour signals implies diminished resolution in the horizontal direction. In the early stages of development, the delay-line was designed to operate at video frequencies, and was placed immediately after the detector. Further development of this system was carried out by the Compagnie Française de Télévision in Paris, and this led to the SECAM system, which will now be described.

SECAM system, with ultrasonic delay-line (1959-60).

An important advance in this system was the successful solution of the problem of designing a cheap delay-line. The solution took the form of an ultrasonic line which could be used at carrier frequencies. *Fig. 13* shows the modifications made in the sequential switching technique, in which the new type of delay-line is placed *before* the detector. This system was given the name SECAM (*SEQU*entiel *A* *M*émoire).

A further stage of development was a change from conventional amplitude-modulation to *frequency-modulation* [6] *(Fig. 14)*. In order to reduce the effects of interference from the sub-carrier (which is always present with FM) upon the compatible monochrome picture, various remedial measures were tried — such as phase alternation of the sub-carrier frequency at every third line, and from field to field, as well as pre- and de-emphasis of the higher video and sub-carrier side-band frequencies [7].

FAM system (1960).

The technique used here, due to N. Mayer of the I.R.T. at Munich [8], eliminates sensitivity to the effects of differential phase errors by the use of different forms of modulation for the two colour signals *(Fig. 15)*. Conventional *amplitude-* and *frequency-*modulation are used ; synchronising signals are unnecessary, since conventional detector circuits are used at the receiver.

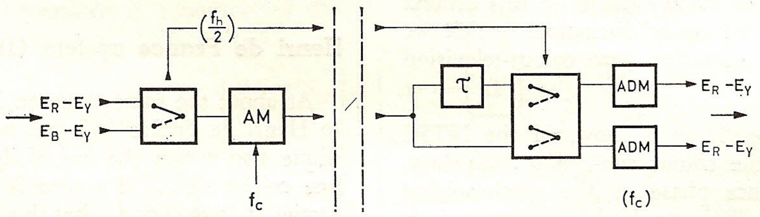

Fig. 13. — **SECAM system (1959-60).**

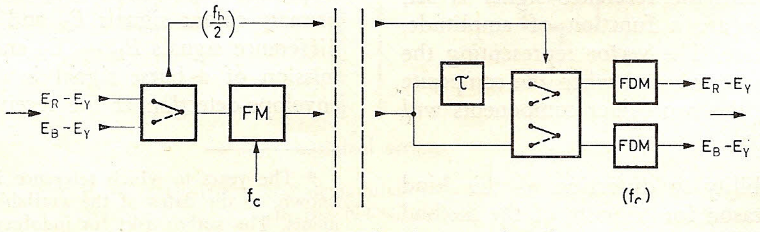

Fig. 14. — **SECAM system (1960).**

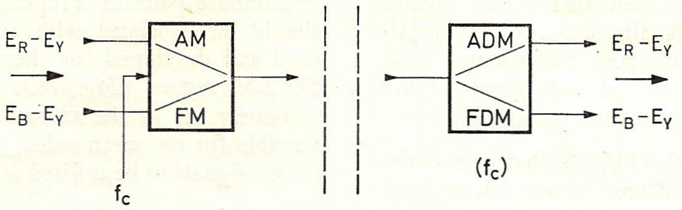

Fig. 15. — FAM system (1960).

SECAM-NTSC system (1961-62).

In this system, the sequential switching principle was carried still further by W. Bruch of Telefunken AG, in an attempt to combine it in some way with the method of modulation used in the NTSC system [9]. Instead of the amplitude- or frequency-modulation of the SECAM system, suppressed-carrier modulation is used. The use of synchronous detection makes a burst signal necessary to lock the receiver oscillator. In this system, as in the SECAM system, only one colour signal at a time is transmitted, and the phase sensitivity of quadrature modulation is avoided. An auxiliary synchronising signal is also necessary, to control the phase of the electronic switch at the receiver.

In the first version of the system *(Fig. 16)*, the delay-line was inserted in the video circuits of the receiver (as in *Fig. 12)*, but later ultrasonic delay *(Fig. 17)* was introduced. Further developments in sequential transmission, with suppressed-carrier modulation, led to what is known as the PAL system.

PAL system (1962).

In the PAL system, the sequential switching principle is concerned not with the *selection* of one of the signals to modulate the colour sub-carrier, but with the periodic *phase-alternation* of one of the two *simultaneously* transmitted signals. In this sense, the technique resembles that of the NTSC system, since the form of modulation amounts to quadrature amplitude-modulation of a sub-carrier. The difference — as shown in *Fig. 18* — lies only in the periodic switching, from line to line, of the phase of one of the component signals between $+\pi/2$ and $-\pi/2$. This corresponds to alternate changes in sense of the colour vector *(Fig. 10)*. The errors in hue due to differential-phase effects in transmission will therefore alternate in opposite senses, and will be averaged out in a suitably designed receiver.

The basic idea of an alternating transmission of this kind was already well understood during the development of the NTSC system. It was duly considered as a means of reducing cross-talk between wide-band, asym-

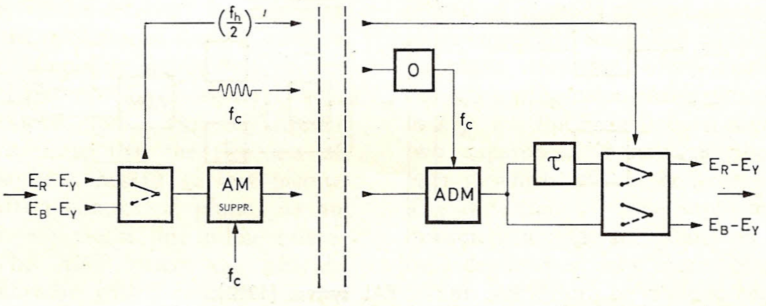

Fig. 16. — SECAM-NTSC system (1961/62)
(first version).

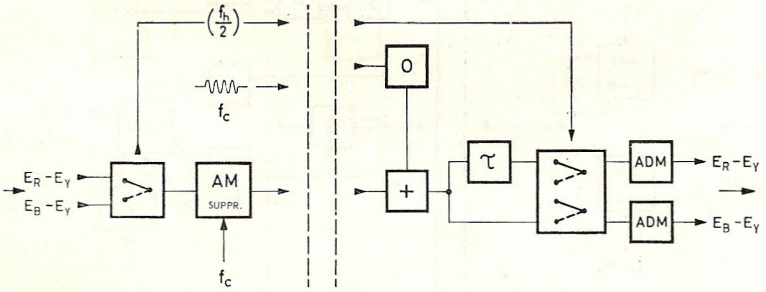

Fig. 17. — SECAM-NTSC system (second version).

metric sideband, quadrature-modulated colour signals [10]. In view however of the alternative of two signals differing in bandwidth, with a region of channel overlap within which both sidebands of both signals (*I* and *Q*) are transmitted, it was not further pursued.

The contributions of Bruch [11] resulted in material improvements in technique. Attention was concentrated upon line-to-line switching (PAL = *P*hase - *A*lternation - *L*ine), upon the choice of a suitable new sub-carrier frequency (within the luminance spectrum)

$$f_c = (284 - 1/4)\, f_h + 1/2\, f_v$$

(where f_h is the line frequency, and f_v the field frequency) and in particular, upon the utilisation of colour information contained during preceding line periods for deriving hue information free from the effects of transmission errors.

At the receiver, synchronous detection is essential, and the phase-alternation signals will need to be demodulated. If the receiver is restricted to making use of the colour signals as transmitted, the effects of transmission errors will be different and opposite in sense from line to line, and the integrated effect will be unnoticed by the eye. Reception of this kind is quite feasible (" simple PAL "), although in the presence of differential phase errors highly saturated colours tend to give rise to noticeable stroboscopic " venetian-blind " interference patterns. Properly used, the PAL principle should be associated with an ultrasonic delay-line, as used and developed for cheap mass production in the SECAM system *(Fig. 18)*. Such a delay-line, when accurately set to the correct group delay τ, makes it possible for the mean value, over two lines, of the two colour signals to be utilised at the receiver.

In the PAL system, two auxiliary signals are required : the burst, of sub-carrier frequency f_c, and the identification signals, at frequency $1/2 f_h$, for phase-locking the electronic switch ; the latter signal can be transmitted, as in the SECAM system, during the field-blanking interval. Following recent discussions in Sub-group 1 of the E.B.U. Ad-hoc Group on Colour Television (June, 1965), yet another proposal was tried out, in which the burst signal is made to perform both synchronising operations. As shown in *Fig. 19,* the phase of the train of oscillations of frequency f_c is displaced alternately from + 45° to — 45° relative to the reference axis [the $-(E_B - E_Y)$ axis]. The receiver oscillator adjusts itself to the correct average (reference) phase. Furthermore, the colour synchronisation signals can be applied to the oscillator-controlling discriminator, from which can be derived the signals controlling the phase of the electronic switch. This is shown on the right-hand side of *Fig. 19.* It was also agreed to

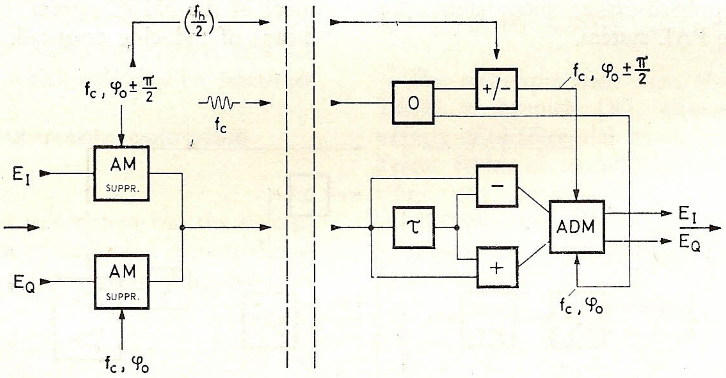

Fig. 18. — **PAL system (1962).**

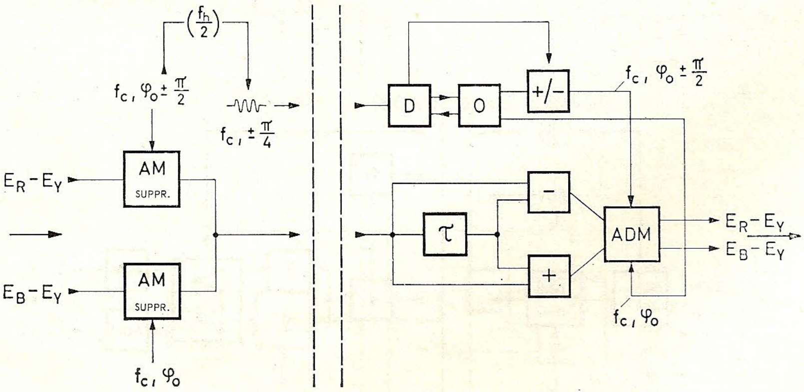

Fig. 19. — **PAL system (1965).**

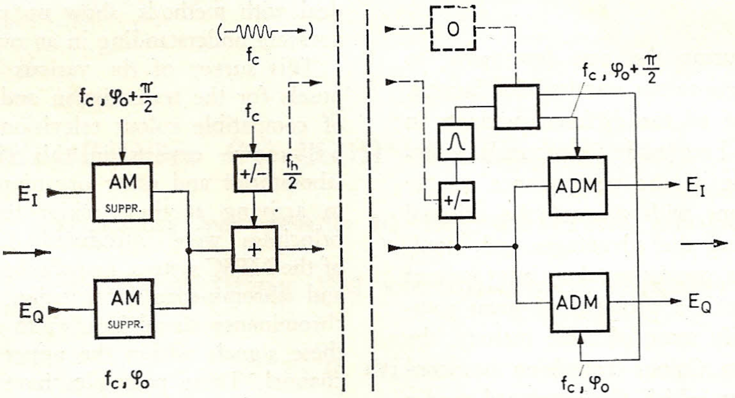

Fig. 20. — ART system (1963).

modulate with the simple, rather than with the transformed, colour difference signal with a maximum bandwidth, for both signals, not exceeding that of the *I* signal. This specification will lead to greater flexibility and cheapness in the design of receiver circuits.

ART system (1963).

To round off our survey, we shall now mention two recent proposals for reducing the effects of differential-phase distortion upon colour transmission which are noticeable in the NTSC system.

The proposal developed by N. Mayer and G. Holoch [12] of the I.R.T., shown in *Fig. 20,* makes use of a low-amplitude pilot or reference signal, superposed (and separable from) the main signal ; it therefore shares in any distortion to which the latter may be subjected. After recovery in the receiver, the reference signal is used to control the oscillator of the synchronous quadrature detector, so continuously maintaining correct phase lock (*A*dditional *R*eference *T*ransmission).

This superposed reference signal must be distinct from the colour sub-carrier, so that the two sets of information can be separated, that is, so that picture modulation shall not affect control of phase. As an identifying characteristic, a periodic line-to-line phase-reversal was chosen. The ART system can provide instantaneous steering, whereby, with a delay-line in the receiver, the reference signal information is extracted and operates directly upon the demodulator. Alternatively *(Fig. 20),* using a cheaper arrangement without a delay-line, the reference signal information, after periodic reversal, is applied *via* a selective filter to the oscillator of the synchronous detector. In this case, however, the error correction is an average over several line periods. Synchronisation may also be effected, if so desired, by means of a burst signal (see dotted lines in *Fig. 20*), so that, if the need should arise, receivers either of conventional NTSC design, or specifically intended for the ART system, can be interchangeable.

Multiburst technique (1964).

Another technique, developed by N.W. Lewis of the Post Office Research Station, London [13], is not related to methods of modulation, but is rather directed to automatically controlled equalisation of the differential-phase distortion which can arise in transmission chains carrying colour-television programmes. As shown in *Fig. 21,* the normal burst signal is accompanied by two superposed signals of the same kind (*multiburst),* which are set at grey and peak-white levels. The distortion of these supplementary signals can be measured at different points on the transmission path by a device *S,* and by means of another device *C,* correction signals can be made to control an equaliser.

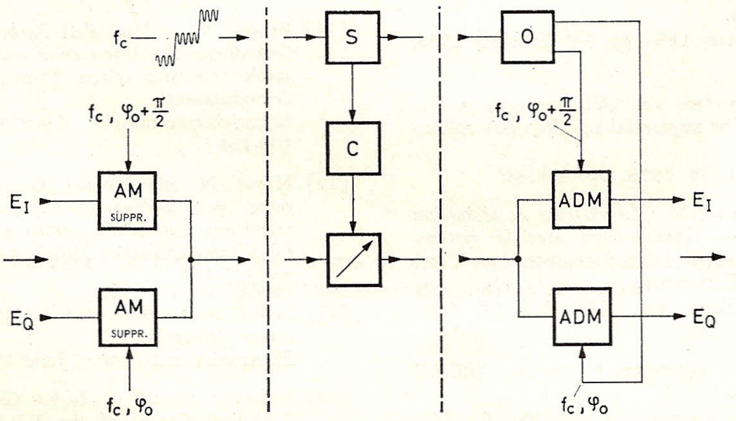

Fig. 21. — Multiburst technique (1964).

Conclusion.

In the endeavours, during the past few years, to reach agreement on a single colour standard for Europe, a comprehensive study of all the different variants in modulation technique has been made. In particular, comparisons have been made of the performance of the SECAM and PAL systems with that of the original NTSC system. In assessing the advantages and disadvantages of these systems, we have taken into account many points of view ; it is a problem of great complexity. In order to clarify some of these matters, the E.B.U. Ad-hoc Group on Colour Television has contributed much material, to which the interested reader may refer [14]. There are also the reports of various meetings (notably those of C.C.I.R. Study Group XI in Vienna, 1965) at which these questions have been discussed at international level.

It is impossible, within the framework of this survey, to give a detailed appraisal of the different parameters involved, nor is this the object of the investigations, which are impartial in their aims ; they should rather deal with methods, show up points of similarity and promote understanding in an overall review.

This survey of the various developments and proposals for the transmission and improved performance of compatible colour television, will show that many well-known experts in this field, as well as many laboratories and other organisations, have collaborated in arriving at these major technical solutions. New principles were introduced during the development of the NTSC system, namely the separation of luminance and chrominance information, the reduction of the chrominance signal bandwidth and the interleaving of these signals within the upper part of the luminance channel. These principles have proved their worth in all further developments. As we have seen, many different methods of transmitting colour signals have been proposed, and these, directly or indirectly, have been fruitful in furthering progress. Those developments too, which have not been singled out for mention, have made their significant contribution by provoking and stimulating discussion ; they should not be forgotten if — as we all hope — the reward of common endeavour and perseverance is agreement upon a single common standard for colour television in Europe.

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