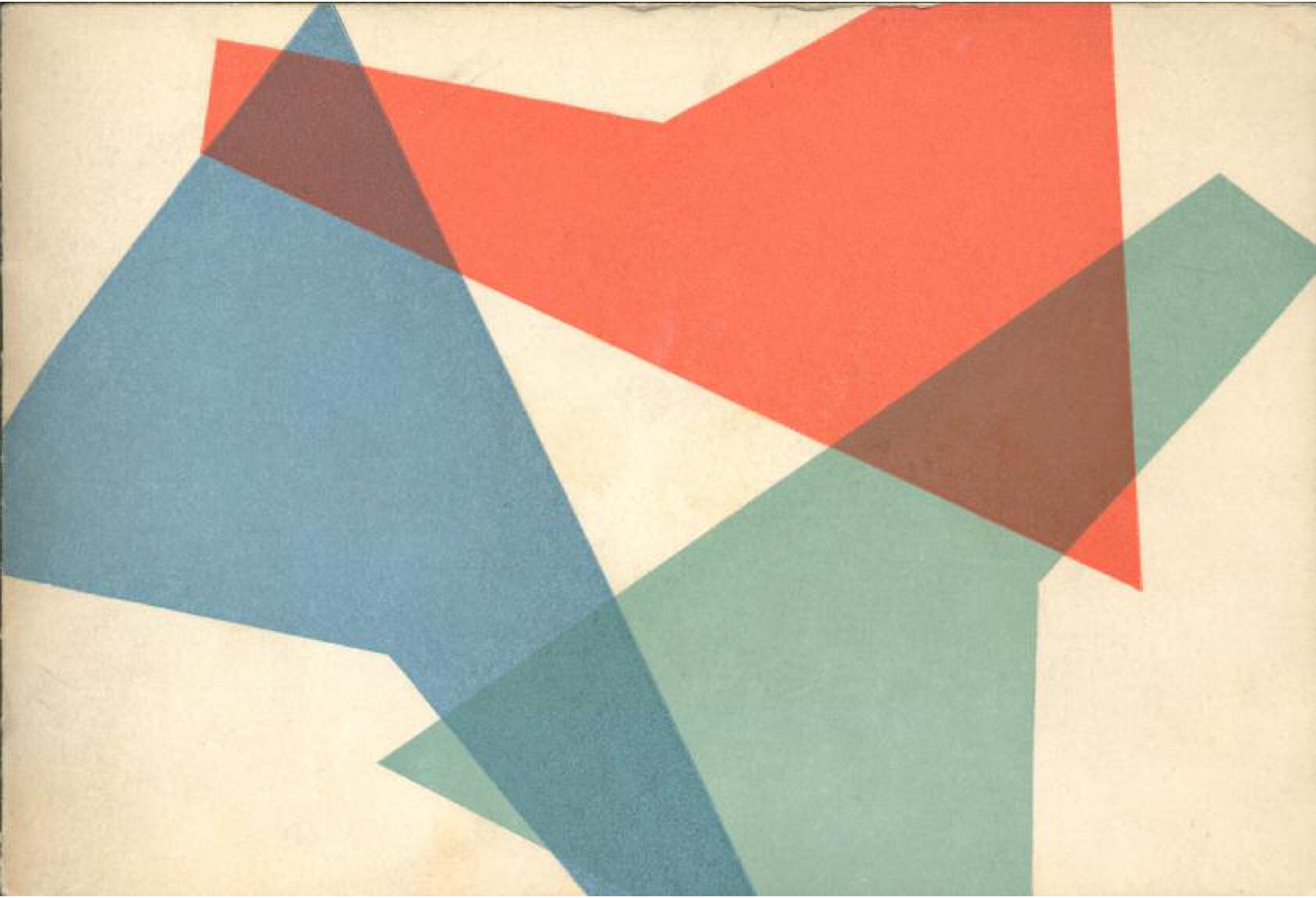


AN APPROACH TO COLOUR TELEVISION

A demonstration by

Marconi's Wireless Telegraph Company Limited

in London 1954

CONTENTS

See examples of photographic transparencies of 405-line Colour Television Pictures on page 3 of cover.

INTRODUCTION

In 1936 the British Broadcasting Corporation,
using the Marconi-E.M.I. system, opened the world's first public
television service from Alexandra Palace in London.
Further development was brought to a standstill
by the second world war and the post-war years have been devoted
to providing a complete national television network
using that same system.

FOR SOME CONSIDERABLE TIME, however, discussions have been taking place both in the United States and in Britain on the best system for transmitting and receiving colour television pictures. A final decision has now been made for the United States but has yet to be made for this country. The problems involved are ultimately economic, and considerable technical ingenuity has been employed in both countries in evolving systems and equipment to overcome them.

The Marconi Company adheres to its traditional policy of remaining aloof from such controversy at the policy level, holding that it is for Governments or operating administrations to choose such standards or systems as are best suited to the peculiar needs of their respective countries. Once these decisions have been taken the Marconi Company is willing and able to develop and manufacture any equipment to comply with the chosen standards.

The Marconi Company maintains, however, that the very best technical advice must be available to those who have to make these decisions and with this end in view they have assembled in London a set of experimental colour television equipment designed to give a reasonably full appraisal of a British version of the all electronic American system and some possible alternatives.

The Television Advisory Committee, in its report, recommends that any system adopted for use in Britain should be fully compatible—that is, that the method of colour transmission should be such that it may be received and displayed as a monochrome picture on ordinary television sets, without appreciable loss of definition, and without alteration to the receivers. Conversely, a colour television receiver should be capable of receiving monochrome transmissions and rendering them as such, with the same reservations.

These requirements have been fully met in the Marconi demonstration, and standard television sets of various makes are on view, reproducing (in monochrome) the colour transmissions.

Although the equipment at Marconi House is working to the B.B.C. 405-line, 25-frame standards, the systems are equally applicable to the standards of other countries.

Section One

PROBLEMS AFFECTING COLOUR TELEVISION

ALTHOUGH LONG FAMILIARITY with television has tended to make us take it rather for granted, nevertheless the engineering involved is one of extreme complexity.

Colour television, the logical extension of monochrome picture transmission, gives the engineer a very great number of additional problems to solve. The devising of a system of colour transmission, moreover, is not in itself enough, for if the service is to be in the best public interest it must be qualified by rigorous practical considerations, such as frequency-band allocation, the future use of higher frequencies, the cost of the service, and the cost of receivers—all problems which must be taken into serious account when designing a colour television broadcast service. Perhaps the most significant of these considerations is the cost of a colour receiver, and its reliability.

The demonstration at Marconi House does not present one system but two, each with several possible variants. The flexibility of the apparatus is such that the possibilities and limitations of each may be, to some extent, evaluated on a direct-comparison basis, although it is pointed out that this evaluation is an extremely complex and highly technical matter.

This section seeks to set out, in non-technical terms an outline of the problems involved in colour television, followed by a simplified description of the apparatus being demonstrated. It is not, therefore, intended for the engineer, who is already familiar with the matter in much greater detail than can be given here, but rather for those who require a fair approximation of the position in everyday terms.

It is realised that any such attempt must inevitably lead to an over-simplification of what is, in fact, an incredibly complicated piece of electronic engineering. With this reservation in mind, however, it is hoped that the ensuing description may be of some help in clarifying the issues involved.

General Principles of Monochrome and Colour Television

Before considering the colour aspect, it may perhaps be of assistance to recall the basic principles of monochrome television.

Monochrome transmission of pictures is initiated by sweeping an electron beam, or spot, systematically across every portion of an image of the scene which is being broadcast, the entire picture being swept or scanned (in the British standard of transmission) in 405 lines. In this manner 25 pictures, or frames, are scanned per second. Every variation of light or shade encountered in this process by the electron-spot is faithfully translated into variations in electrical impulses. These impulses, after amplification, are duly transmitted, to be picked up by the receiver.

In the cathode-ray tube of the receiver another electron-spot is scanning the fluorescent coating which forms the presentation screen, in exact synchronisation with the one scanning the image at the transmitter. Thus, when the transmitter scanning-spot is directed at the top left-hand corner of the image, the receiver's cathode-ray tube spot is likewise impinging on the top left-hand corner of the screen, and similarly throughout the whole scanning process the two remain exactly in step, maintained thus by synchronising pulses from the transmitter.

The light-variations, converted as stated into electrical variations and transmitted to the receiver, are fed to the cathode-ray tube in such a manner as to increase or decrease the flow of electrons in the beam. These electrons on striking the fluorescent screen, cause it to glow at the point of impact. The more electrons there are in the beam the brighter the spot, and vice versa. The amount of light emanating from any point of the transmitted scene is thus reproduced at exactly the same relative point on the receiver screen. The picture is in this way built up spot by spot, but the human eye, being comparatively sluggish in its reactions sees the result as a complete picture. In other words "persistence of vision" enables a continuous picture to be presented providing the frame rate is at 25 per second.

Colour Television represents a considerable extension of this process as in addition to the monochrome picture, information on the colours involved has also to be resolved into electrical impulses and transmitted together with a more complicated system of synchronising pulses.

In practice, matters are made a little easier by virtue of the fact that the transmission of three primary colours will suffice, for by combining these three in suitable proportions almost any colour can be produced. Red, green and blue thus combined in the correct proportions give white light: yellow is produced by combining green and red and so on.

In parenthesis, it is felt that the above statement needs some qualification, particularly to those with memories of watercolour paint-mixing, by whom green is regarded as a secondary colour, produced by mixing yellow and blue (cyan), and who know from experience that a mixture of red, green and blue pigments most certainly does not produce white paint.

The short answer is, that there are two basic systems of colour mixing, the "additive" and the "subtractive." The additive is concerned with the mixture of light sources; for instance, if a beam of pure green light is projected on to a white screen on top of a similar beam of pure red, the area of intersection of the two beams on the screen will appear as yellow. The additive system is the one used in television, with red, green and blue usually taken as the primaries.

The subtractive system (into which category water-colour paint-mixture falls) interposes a filter, or filters, between the light source and the eye. Certain light frequencies, or colours, are thereby subtracted by the filters and the eye sees what remains. Thus, if a cyan filter is laid upon a yellow, and the two are held between a source of white light and the eye, the light penetrating the two filters will be green.

The problem, therefore, apart from the additional synchronising problem, resolves itself into that of breaking down a multi-coloured image to its red, green and blue components, converting them to electrical impulses in such a manner that they may be identified in terms of colour at the receiver, transmitting these impulses, and reconstituting them at the receiver at the correct point on the screen, in correct colour and in correct proportion. Some idea of how this is done, with particular reference to the apparatus concerned, is given later.

It will be apparent that a colour television transmitter has to send out much more complex signal-information than its monochrome counterpart—in point of fact up to three times as much. Any transmitter, whether sending telegraphy, sound or vision requires ether-space in which to do it, and the more complicated the signal the more space it needs.

Of these three, the signals required to provide a television picture are by far the most complicated, and require the allocation of a wide band of frequencies. The standard channel width in Great Britain is 5 megacycles per second, of which 3 megacycles per second is occupied by the vision signal. Colour television, therefore, in the simplest approach could require three times the channel width to transmit it, which, on the face of it would mean an allocation of 10-15 megacycles per second of bandwidth in the ether. Unfortunately, on any given frequency-band there is accommodation for a finite number of stations, so that if each station doubled its bandwidth there would be room for only half the number. Some method has, therefore, to be found to compress the colour television information into a narrower bandwidth.

This problem of available ether-space is, of course, by no means peculiar to this country. In America the problem is far more acute, and the National Television Standards Committee (referred to as N.T.S.C.) was some time ago set up to examine the possibilities of compressing the colour-information, and if possible to evolve a set of workable standards.

After a vast amount of research (in which the Radio Corporation of America took a leading part supported by the Hazeltine Laboratories and others) and an unprecedented pooling of information within the American television industry, the Committee's recommendations and specifications were published for apparatus which will compress the colour-information and synchronising signal information into the same bandwidth as is now used by a monochrome television transmitter—a truly notable achievement. A technical specification of these standards is given in Appendix I.

The system achieves the desired result by means of two techniques, which can be described respectively as "Band Saving" and "Band Sharing." The "Band Saving" depends on the fact that the human eye gradually loses its power of colour discrimination in those parts of a scene or picture where the fineness of detail is increased. Furthermore, the occurrence of scenes in which colour in the fine detail is important, appears to be rare. Both these factors permit the definition (bandwidth) of the colour components of the signal, to be considerably reduced. The "Band Sharing" part of the system consists of fitting the reduced definition colour signals arising from the "Band Saving", into the Vision Signal, without increasing its bandwidth. This raises certain problems, particularly that of interference ("crosstalk") between the two sets of signals which have been "fitted together". In the American N.T.S.C. system many ingenious compromises have been achieved including reduction of crosstalk to a minimum.

Equipment built to N.T.S.C. standards but modified by Marconi's to meet British requirements in one of the possible ways is being demonstrated, along with a "Wide Band" system which avoids the crosstalk mentioned above. Some details of these systems are given in Section 2 and Appendix II.

To sum up, both the American National Television Standards Committee and the British Television Advisory Committee are unanimous that one basic requirement of any colour television system should be compatibility. Compatibility in this context means that any system of colour television should be of such a nature that existing monochrome television receivers should be able to pick up the colour transmission and render it (in monochrome, of course), without serious loss of definition, and without the need for modification to the receiver. It is likewise of equal importance that any colour receiver should be capable of receiving and displaying monochrome transmissions as such, as even with a colour television service in being it would seem improbable that every transmission would be in colour.

The Marconi demonstration concentrates on compatible methods of colour television.

Section Two

APPARATUS BEING DEMONSTRATED

ONE OF THE PRIMARY AIMS in the preparation of the Marconi Colour Television demonstration has been to produce within the convenient compass of the demonstration rooms not only a representative range of equipment to demonstrate colour television in itself, but also one which gives a comparison of systems and performances under practical working conditions.

To this end, the individual equipments have been designed with flexibility as a major feature, and the apparatus on demonstration can, by minor modifications only, satisfy the most diverse requirements likely to be met with in practice.

Among other things the following can be demonstrated as representative approaches to the major problems of colour television:

1. *The Colour Camera.*
2. *Colour Telecine and Slide Scanner.*
3. *Signal Coding Equipment built to British version of* N.T.S.C. *standards.*

4. *Effects of bandwidth alteration with above.*
5. *"Wide Band" colour system.*
6. *Effect of bandwidth alteration with above.*
7. *Comparison colour picture produced without bandwidth compression.*
8. *Compatibility, with particular reference to the effect of various forms of bandwidth-compression on this.*
9. *Receivers using tri-colour tubes.*
10. *Receivers using three projection tubes.*

A brief description of the equipment being demonstrated is given below:

Marconi Colour Television Camera

This experimental camera, of original Marconi design and development, is a two-tube camera, which is little bigger than the conventional monochrome versions.

Further details are given in Appendix III.

Flying-Spot 16 m/m Colour Telecine

Modern television studio technique demands that certain programmes—some plays, for example—shall be partly "live" and partly film. The Telecine provides for this, and also for the transmission of entire film programmes: the Colour Telecine is the logical extension of its principles for use with colour films.

The film is scanned by a spot of light from a cathode-ray tube designed to give "white" light with a very short afterglow; the light spot in passing through the film is modified to the colour of that minute portion of the film which it is scanning at any given instant. This coloured light passes through a special optical system which separates it into its red, green and blue constituents, which are each directed on to a separate photo-multiplier cell. The resultant simultaneous outputs from these photo cells, after amplification, can be viewed directly on a high-quality colour picture monitor, and also taken to the signal coding equipment, whence, after bandwidth compression, they can be fed into a transmitter for broadcasting.

Flying-Spot Slide Scanner

This device renders the same service for coloured slides ("still" pictures) as does the Colour Telecine for film. It is incorporated into the latter, so that either film or slides may be transmitted by the same machine.

Signal Coding Equipment

A television transmitter system, broadcasting both sound and vision, needs a wide band of frequencies in which to accommodate its signals. The more complex the information to be transmitted, the wider is the required frequency band. For the B.B.C. standard 405-line transmissions the bandwidth of each channel has been fixed at 5 megacycles per second, in which both sound and vision signals exist. The vision signals, being by far the more complex of the two, occupy about 3 megacycles per second of the total bandwidth.

Colour television signals, of course, are extremely complex and would normally occupy a very wide bandwidth. For example, the red, green and blue signal-outputs from the Colour Telecine each occupy a bandwidth of 3 megacycles per second, giving a total requirement of 9 megacycles per second. A wider band of frequencies, however, means that fewer stations can be accommodated in an allocated frequency band. It is obviously important that we compress this information into the narrowest possible bandwidth in order to make the best use of frequencies available.

The Signal Coding Equipment is provided for this purpose. The apparatus includes a British version of the American N.T.S.C. Standards which enables colour transmission to be effected within the same bandwidth limits as are assigned to monochrome.

By a rigorous pruning of the full 9 megacycles per second vision information, all non-essentials are excluded from the transmission. In this connection it should be noted that here an alternative presents itself. Either the red, green and blue components may be transmitted, or a monochrome signal and two colour-difference signals. The latter has certain practical advantages arising directly from the properties of human vision dealt with in Section I, whereby colour in fine detail may be sacrificed without apparent loss in picture quality.

As a first step band saving methods are applied, therefore, and the three colour components (red, green and blue) are combined to give a monochrome picture. This can, of course, be transmitted within the usual monochrome bandwidth of approximately 3 megacycles per second. The red and blue signal components now both contain certain colour information which is redundant, as it is already present in the transmitted monochrome signal. This redundant information is extracted from each, and the remaining signals, now known as colour-difference signals, are transmitted instead. The green component need not be transmitted, as this can be recovered at the receiver by reconstituting the red and blue and then subtracting these two colours from the monochrome signal, which is, as stated, a combination of all three. A valuable saving of bandwidth is thus accomplished, as the colour-difference signals can each be contained in diminished bandwidths occupying a total of approximately 1½ megacycles per second.

In that part of the coding equipment which produces a British version of the N.T.S.C. signal, the two colour difference signals are applied to a subcarrier within the main 3 megacycles per second Vision signal. The complete colour signal, therefore, occupies no more bandwidth than does an existing transmission in monochrome. This further signal compression constitutes the "Band-Sharing" already referred to. Such compression inevitably has a certain effect on picture quality, although this is not nearly so evident in a colour picture as it is when fed to a standard receiver and shown in monochrome.

An alternative, or compromise system has, therefore, been developed by Marconi engineers, and is also being demonstrated. This method, in brief, is similar in certain principles to the N.T.S.C. signal, but omits the band-sharing feature. The colour information is transmitted, not within the main channel on a subcarrier, but as an addition. The total channel-width is, as a result, increased by up to 50%, but a better colour picture results and compatibility is improved.

Colour and Monochrome Displays

Two R.C.A. tri-colour tubes and two projection displays made up from modified Philips-Schmidt projector tubes are on view during the demonstration. The R.C.A. tubes give pictures of 10″ × 8″ and the Philips-Schmidt projectors 12″ × 9″. One of the tri-colour monitors has an additional radio colour receiver incorporated for the display of colour pictures via a radio link.

Two Marconi high-quality laboratory monitors with 15″ metallised tubes are provided for appraising the compatibility of monochrome reception, while six standard production monochrome television receivers of various makes are also on view for compatibility tests; these receivers are being fed from a radio outlet from the signal channelling equipment.

It is pointed out that the descriptions given above are intended to be no more than a non-technical approximation of general principles, and are by no means complete in detail.

Appendix I

N.T.S.C.
COLOR TRANSMISSION STANDARDS

(A reprint of the full text of technical signal specifications adopted unanimously by N.T.S.C., *July* 21, 1953)

I—GENERAL SPECIFICATIONS

A. Channel

The color television signal and its accompanying sound signal shall be transmitted within a 6-mc channel.

B. Picture Signal Frequency

The picture signal carrier, nominally 1.25 mc above the lower boundary of the channel, shall conform to the frequency assigned by the Federal Communications Commission for the particular station.

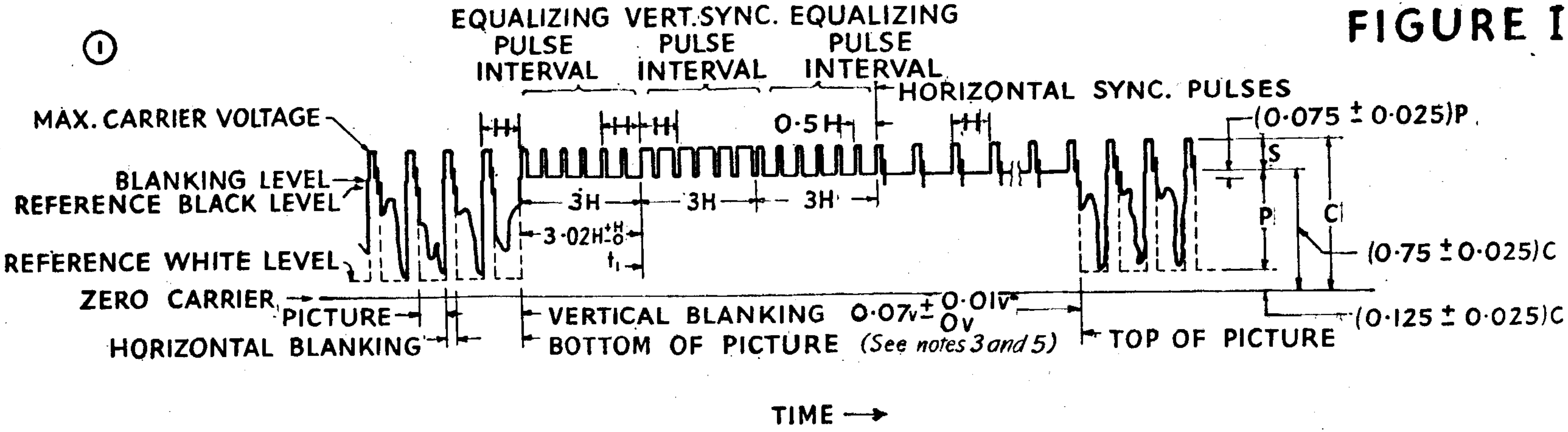
C. Polarization

The radiated signals shall be horizontally polarized.

D. Vestigial Sideband Transmission

Vestigial sideband transmission in accordance with Figure 2 shall be employed.

FIGURE I



NOTES

1. *H = Time from start of one line to start of next line.*
2. *V = Time from start of one field to start of next field.*
3. *Leading and trailing edges of vertical blanking should be complete in less than 0.1 H.*
4. *Leading and trailing slopes of horizontal blanking must be steep enough to preserve minimum and maximum values of $(x+y)$ and (z) under all conditions of picture content.*

*5. *Dimensions marked with asterisk indicate that tolerances given are permitted only for long time variations and not for successive cycles.*

6. *Equalizing pulse area shall be between 0.45 and 0.5 of area of a horizontal sync. pulse.*
7. *Color burst follows each horizontal pulse, but is omitted following the equalizing pulses and during the broad vertical pulses.*
8. *Color bursts to be omitted during monochrome transmissions.*
9. *The burst frequency shall be 3.579545 mc. The tolerance on the frequency shall be ±0.0003% with a maximum rate of change of frequency not to exceed 1/10 cycle per second per second.*
10. *The horizontal scanning frequency shall be $\frac{2}{455}$ times the burst frequency.*
11. *The dimensions specified for the burst determine the times of starting and stopping the burst, but not its phase. The color burst consists of amplitude modulation of a continuous sine wave.*
12. *Dimension "P" represents the peak excursion of the luminance signal from blanking level, but does not include the chrominance signal. Dimension "S" is the sync. amplitude above blanking level. Dimension "C" is the peak carrier amplitude.*
13. *Refer to text for further explanations and tolerances.*

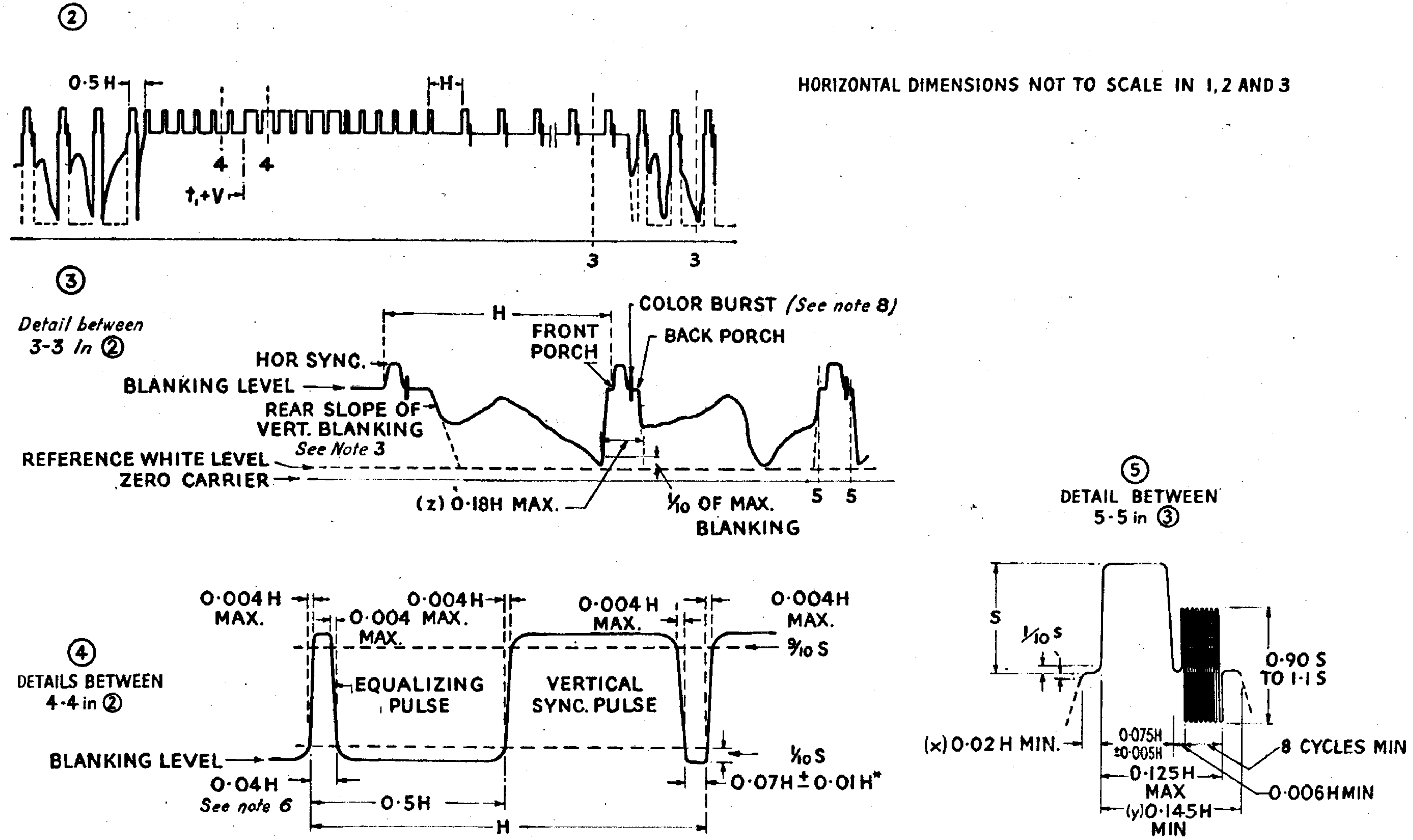


FIGURE I *continued*

E. Aspect Ratio

The aspect ratio of the scanned image shall be four units horizontally to three units vertically.

F. Scanning and Synchronization

1. The color picture signal shall correspond to the scanning of the image at uniform velocities from left to right and from top to bottom with 525 lines per frame interlaced 2:1.

2. The horizontal scanning frequency shall be 2/455 times the color subcarrier frequency; this corresponds nominally to 15,750 cycles per second (with an actual value of 15,734.264 ± 0.047 cycles per second). The vertical scanning frequency is 2/525 times the horizontal scanning frequency; this corresponds nominally to 60 cycles per second (the actual value is 59.94 cycles per second).

3. The color television signal shall consist of color picture signals and synchronizing signals, transmitted successively and in different amplitude ranges except where the chrominance penetrates the synchronizing region, and the burst penetrates the picture region.

4. The horizontal, vertical, and color synchronizing signals shall be those specified in Figure 1, as modified by vestigial sideband transmission specified in Figure 2 and by the delay characteristic specified in III.B.

G. Out-of-Channel Radiation

The field strength measured at any frequency beyond the limits of the assigned channel shall be at least 60 db below the peak picture level.

II—SOUND

A. Sound Signal Frequency

The frequency of the unmodulated sound carrier shall be 4.5 mc ± 1000 cycles above the frequency actually in use for the picture carrier.

B. Sound Signal Characteristics

The sound transmission shall be by frequency modulation, with maximum deviation of ± 25 kilocycles, and with pre-emphasis in accordance with a 75 microsecond time constant.

C. Power Ratio

The effective radiated power of the aural-signal transmitter shall be not less than 50 per cent nor more than 70 per cent of the peak power of the visual signal transmitter.

III—THE COMPLETE COLOR PICTURE SIGNAL

A. General Specifications

The color picture signal shall correspond to a luminance (brightness) component transmitted as amplitude modulation of the picture carrier and a simultaneous pair of chrominance (coloring) components transmitted as the amplitude modulation sidebands of a pair of suppressed subcarriers in quadrature having the common frequency relative to the picture carrier of + 3.579545 mc ± 0.0003 per cent with a maximum rate of change not to exceed 1/10 cycle per sec per sec.

B. Delay Specification

A sine wave, introduced at those terminals of the transmitter which are normally fed the color picture signal, shall produce a radiated signal having an envelope delay, relative to the average envelope delay between 0.05 and 0.20 mc, of zero microseconds up to a frequency of 3.0 mc; and then linearly decreasing to 4.18 mc so as to be equal to −0.17 microseconds at 3.58 mc. The tolerance on the envelope delay shall be ± 0.05 microseconds at 3.58 mc. The tolerance shall increase linearly to ± 0.1 microsecond down to 2.1 mc, and remain at ± 0.1 microsecond down to 0.2 mc.[1] The tolerance shall also increase linearly to ± 0.1 microsecond at 4.18 mc.

C. The Luminance Component

1. An increase in initial light intensity shall correspond to a decrease in the amplitude of the carrier envelope (negative modulation).

[1] *Tolerances for the interval of* 0.0 *to* 0.2 *mc should not be specified in the present state of the art.*

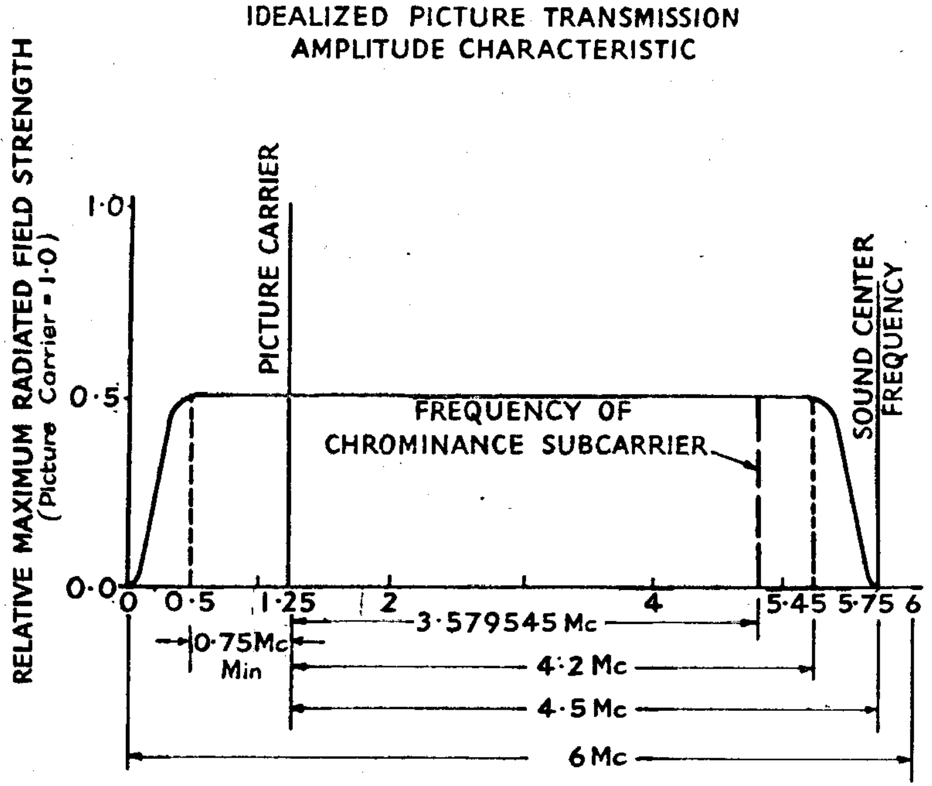


FIGURE 2

FIGURE 2

FIGURE 3

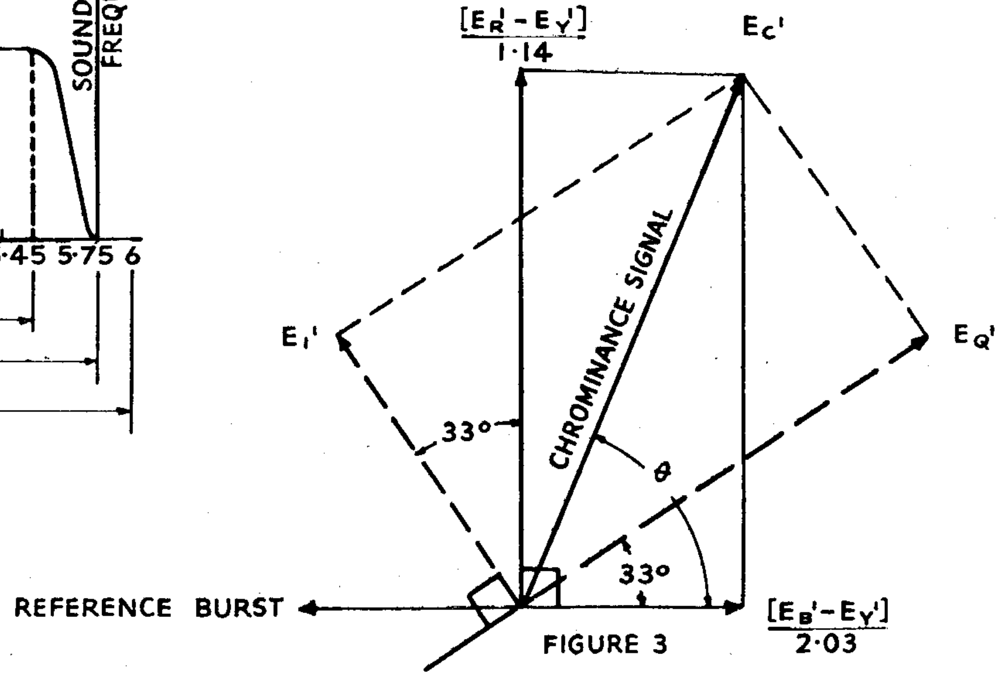


FIGURE 3

2. The blanking level shall be at (75 ± 2.5) per cent of the peak amplitude of the carrier envelope. The reference white (luminance) level shall be (12.5 ± 2.5) per cent of the peak carrier amplitude. The reference black level shall be separated from the blanking level by the setup interval, which shall be (7.5 ± 2.5) per cent of the video range from the blanking level to the reference white level.

3. The overall attenuation versus frequency of the luminance signal shall not exceed the value specified by the FCC for black-&-white transmission.

D. Equation of Complete Color Signal

1. The color picture signal has the following composition:

$$E_m = E'_Y + \left\{ E'_Q \sin(\omega t + 33^\circ) + E'_I \cos(\omega t + 33^\circ) \right\}$$

where

$$E'_Q = 0.41\,(E'_B - E'_Y) + 0.48\,(E'_R - E'_Y)$$
$$E'_I = -0.27\,(E'_B - E'_Y) + 0.74\,(E'_R - E'_Y)$$
$$E'_Y = 0.30\,E'_R + 0.59\,E'_G + 0.11\,E'_B$$

The phase reference in the above equation is the phase of the (color burst + 180°), as shown in Figure 3. The burst corresponds to amplitude modulation of a continuous sine wave.

Notes: For color-difference frequencies below 500 kc, the signal can be represented by

$$E_m = E'_Y + \left\{ \frac{1}{1.14} \left[\frac{1}{1.78}(E'_B - E'_Y) \sin \omega t + (E'_R - E'_Y) \cos \omega t \right] \right\}$$

In these expressions the symbols have the following significance:

E_m is the total video voltage, corresponding to the scanning of a particular picture element, applied to the modulator of the picture transmitter.

E'_Y is the gamma-corrected voltage of the monochrome (black-and-white) portion of the color picture signal, corresponding to the given picture element.[2]

[2] *Forming of the high frequency portion of the monochrome signal in a different manner is permissible and may in fact be desirable in order to improve the sharpness on saturated colors.*

E'_R, E'_G, and E'_B are the gamma-corrected voltages corresponding to red, green, and blue signals during the scanning of the given picture element.

The gamma-corrected voltages E'_G, E'_R, and E'_B are suitable for a color picture tube having primary colors with the following chromaticities in the CIE system of specification:

	x	y
Red (R)	0.67	0.33
Green (G)	0.21	0.71
Blue (B)	0.14	0.08

and having a transfer gradient (gamma exponent) of 2.2[3] associated with each primary color. The voltages E'_R, E'_G, and E'_B may be respectively of the form $E_R^{1/\gamma}$, $E_G^{1/\gamma}$, and $E_B^{1/\gamma}$ although other forms may be used with advances in the state of the art.

E'_Q and E'_I are the amplitudes of two orthogonal components of the chrominance signal corresponding respectively to narrow-band and wide-band axes, as specified in paragraph D.5.

The angular frequency ω is 2π times the frequency of the chrominance subcarrier.

The portion of each expression between brackets represents the chrominance subcarrier signal which carries the chrominance information.

2. The chrominance signal is so proportioned that it vanishes for the chromaticity of CIE Illuminant C ($x = 0.310$, $y = 0.316$).

3. E'_Y, E'_Q, E'_I and the components of these signals shall match each other in time to 0.05 microseconds.

4. A sine wave of 3.58 mc introduced at those terminals of the transmitter which are normally fed the color picture signal shall produce a radiated signal having an amplitude (as measured with a diode on the R.F. transmission line supplying power to the antenna), which is down (6 ± 2) db with respect to a radiated signal produced by a sine wave of 200 kc. In addition, the amplitude of the radiated

[3] *At the present stage of the art it is considered inadvisable to set a tolerance on the value of gamma and correspondingly this portion of the specification will not be enforced.*

signal shall not vary by more than $\pm$ 2 db between the modulating frequencies of 2.1 and 4.18 mc.

5. The equivalent bandwidths assigned prior to modulation to the color-difference signals E'_Q and E'_I are given by Table I.

TABLE I

Q-channel bandwidth	
at 400 kc	less than 2 db down
at 500 kc	less than 6 db down
at 600 kc	at least 6 db down
I-channel bandwidth	
at 1.3 mc	less than 2 db down
at 3.6 mc	at least 20 db down

6. The angles of the subcarrier measured with respect to the burst phase, when reproducing saturated primaries and their complements at 75 per cent of full amplitude, shall be within $\pm$ 10° and their amplitudes shall be within $\pm$ 20 per cent of the values specified above. The ratios of the measured amplitudes of the subcarrier to the luminance signal for the same saturated primaries and their complements shall fall between the limits of .8 and 1.2 of the values specified for their ratios. Closer tolerances may prove to be practicable and desirable with advance in the art.

Appendix II

BRITISH N.T.S.C. AND WIDE BAND SYSTEMS

(Apparatus to demonstrate various compatible methods of coding simultaneous Colour Television Signals)

THE EQUIPMENT has been built to investigate the possibility of introducing a Compatible Colour Television System in this country, using either a signal of the American N.T.S.C. type, or certain alternative "Wide Band" arrangements. The essential components of the apparatus, excluding the picture signal generators and displays for simplification, are shown in Fig. 4. The various signal output characteristics are given in Fig. 5.

Simultaneous 405-line red, green, and blue video signals, each occupying a 3 Mc/s channel, are provided from the picture generator, and are fed by line either direct, or after coding and decoding, to the various colour and monochrome picture displays provided. Certain of these displays are in pairs to facilitate comparisons between the systems.

The following basic signals are available from the equipment, details of which are given below and in Figs. 4 and 5:

I Simultaneous 3 Mc/s channels for red, green and blue respectively.

IIA Band Saving and Band Sharing (N.T.S.C. type)

System decoded to red, green, and blue signals.

IIB Band Saving (Wide Band) System decoded to red, green and blue signals.

IIIA	Coded Signal from IIA	For display on laboratory monochrome monitors.
IIIB	Luminance Signal from IIB	

(*All the above operate entirely at video frequency*)

IVA	Coded Signal from IIA	Modulated on a 45 Mc/s carrier for compatibility tests on standard production TV receivers.
IVB	Luminance Signal from IIB	

British N.T.S.C. System
(Signal IIA, Figs. 4 and 5)

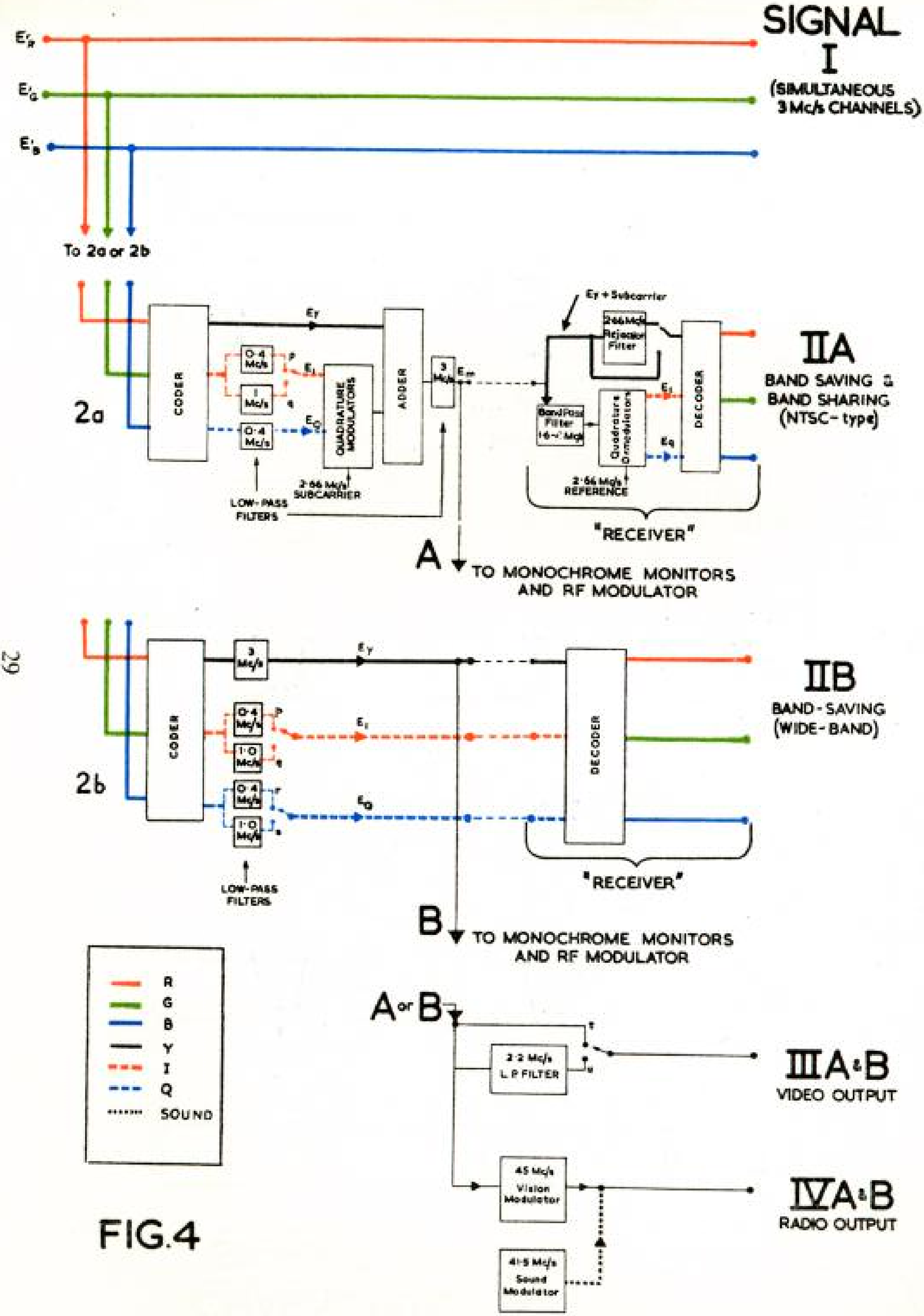
This is one of the many possible adaptations of the American N.T.S.C. colour signal to British 405-line standards. The colour video signal is designed to give three-colour presentation of the scene being scanned for video frequencies from DC to 0.4 Mc/s, two-colour presentation for intermediate video frequencies lying between 0.4 and 1 Mc/s, and monochrome presentation for the frequencies lying between 1 and 3 Mc/s, i.e., it is contained in a total video band of 3 Mc/s. The signal consists of:

(*a*) A full bandwidth component carrying the luminance information corresponding to any picture element (E_Y).

(*b*) Two-colour difference signals E_I and E_Q modulated on quadrature subcarriers. The choice of the particular colour difference signals is governed by the most desirable two-colour presentation.

Subcarrier frequency, and bandwidths allocated to luminance and chrominance information have been scaled down from American standards in the approximate ratio 3:4, while amplitudes of the quadrature components of the subcarrier have the same value relative to the luminance component.

No attempt has been made to alter the existing B.B.C. monochrome television signal waveform other than by (1) addition of such components as



SIGNAL I
(SIMULTANEOUS 3 Mc/s CHANNELS)
To 2a or 2b
2a
CODER
0·4 Mc/s
1 Mc/s
0·4 Mc/s
LOW-PASS FILTERS
QUADRATURE MODULATORS
2·66 Mc/s SUBCARRIER
ADDER
3 Mc/s
Ey + Subcarrier
Band Pass Filter
Quadrature Demodulators
2·66 Mc/s REFERENCE
DECODER
"RECEIVER"
IIA
BAND SAVING & BAND SHARING (NTSC-type)
A TO MONOCHROME MONITORS AND RF MODULATOR
2b
CODER
3 Mc/s
0·4 Mc/s
1·0 Mc/s
0·4 Mc/s
1·0 Mc/s
LOW-PASS FILTERS
DECODER
"RECEIVER"
IIB
BAND-SAVING (WIDE-BAND)
B TO MONOCHROME MONITORS AND RF MODULATOR
A or B
2·2 Mc/s L.P FILTER
IIIA&B
VIDEO OUTPUT
45 Mc/s Vision Modulator
41·5 Mc/s Sound Modulator
IVA&B
RADIO OUTPUT
R
G
B
Y
I
Q
SOUND

FIG.4

CHARACTERISTICS OF SIGNALS AVAILABLE

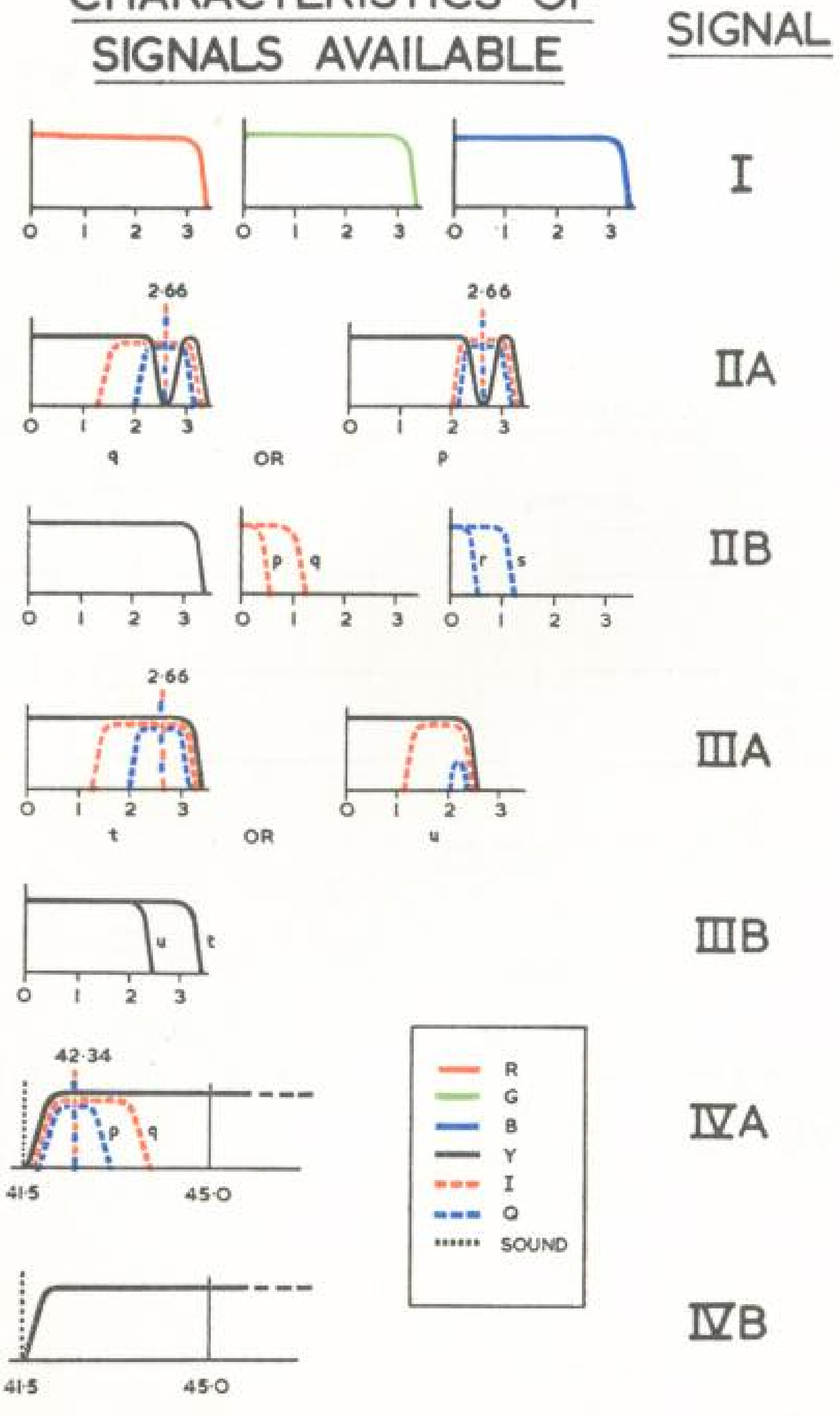


FIG. 5

HORIZONTAL SCALES IN MC/S

SMALL LETTERS CORRESPOND TO SWITCH POSITIONS IN FIG.I

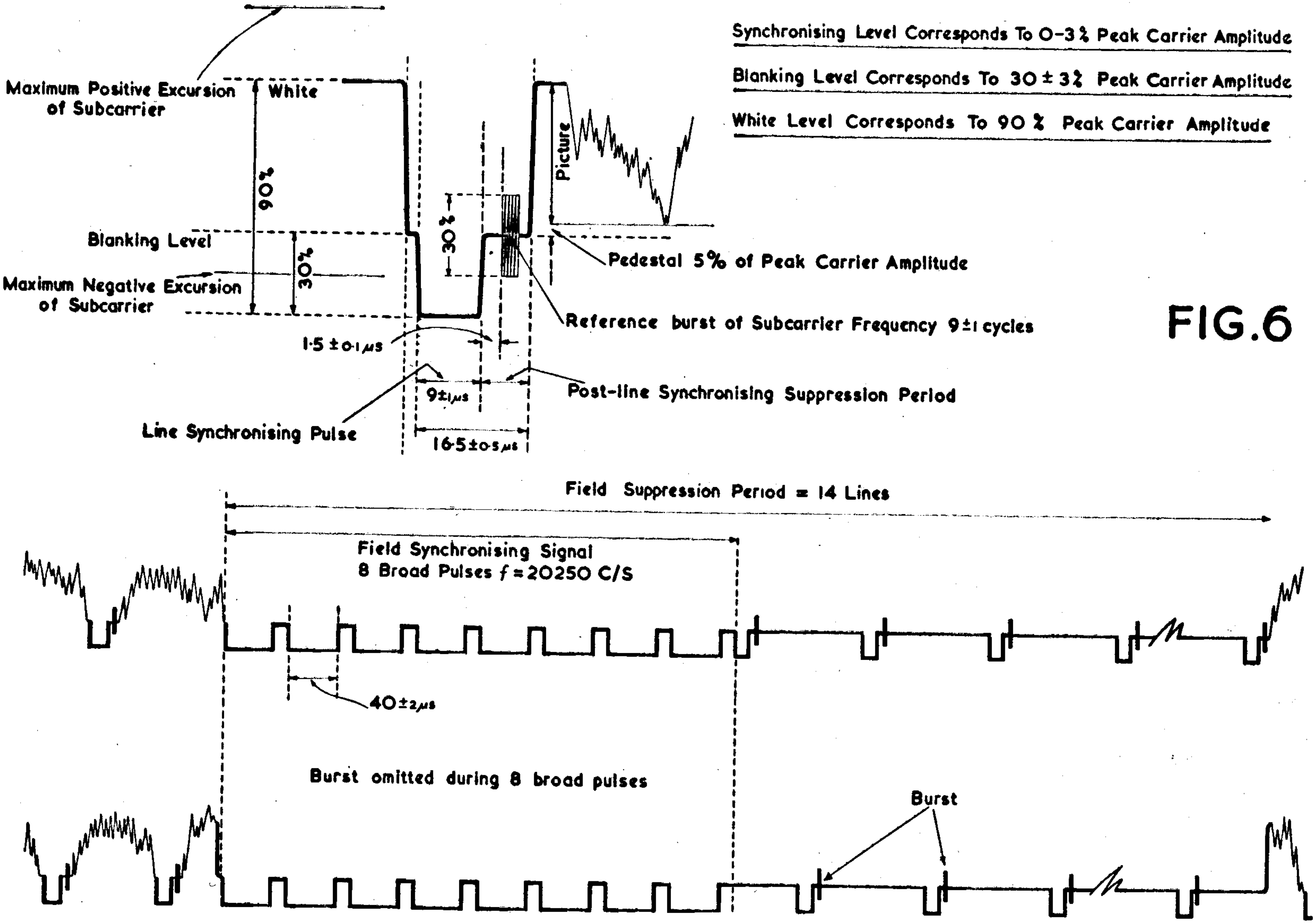
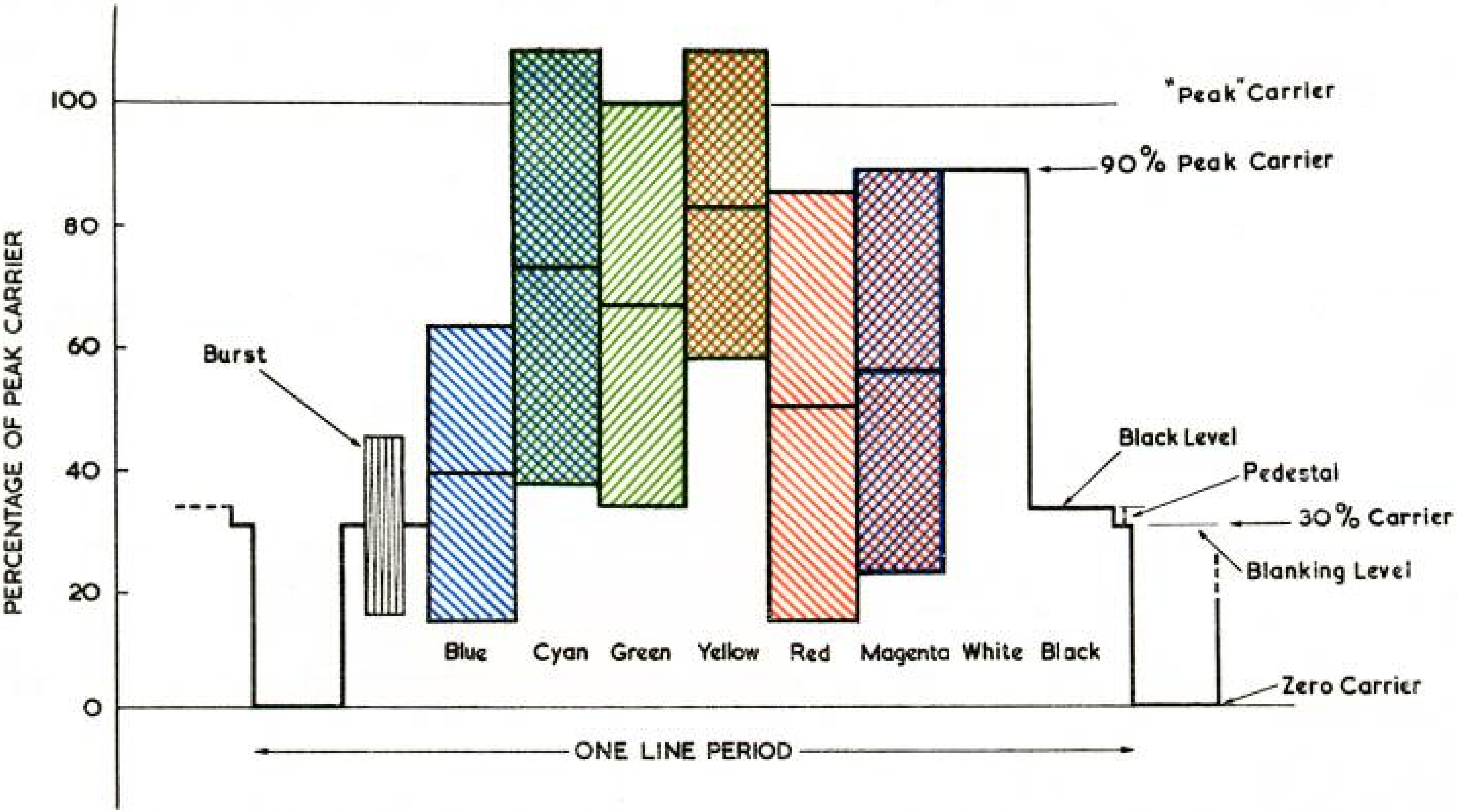


FIG. 6

ONE PROPOSAL FOR THE BRITISH ADAPTATION OF THE N.T.S.C. STANDARDS



VIDEO WAVEFORM OF SIGNAL CONSISTING OF SATURATED COLOUR BARS

ONE PROPOSAL FOR THE BRITISH ADAPTATION OF THE N.T.S.C. STANDARDS

FIG. 7

are necessary to transmit colour, namely, the modulated subcarrier, and the reference "burst," and (2) reduction of the peak white/sync ratio from 70/30 to 60/30 to accommodate partially the subcarrier overswing.

A complete specification of the colour signal as normally set up on the equipment is given at the end of this Appendix and in Figs. 6 and 7. The following variations are possible:

(*a*) The bandwidth of the E_I component may be reduced from 1.0 Mc/s to 0.4 Mc/s.

(*b*) The sound carrier amplitude and frequency may be varied to investigate sound/subcarrier cross-talk both on vision and sound.

(*c*) The synchronising pulses may be operated synchronously with the mains frequency, keeping the subcarrier frequency unchanged, thus destroying the "odd multiple of half line frequency" relationship.

(*d*) The amplitudes of various components of the picture signal may be changed, e.g., the subcarrier, the synchronising pulses, and the "burst."

At the "receiver," the subcarrier in the luminance channel is normally rejected. The sidebands, however, are still present and in order to remove these completely, the luminance bandwidth would have to be reduced to about $1\frac{3}{4}$ Mc/s. The rejector may be removed to demonstrate the consequent degradation in colour rendition.

Wide Band System
(Signal IIB, Figs. 4 and 5)

Better colour pictures result and compatibility is considerably improved if the chrominance information is outside the 3 Mc/s luminance channel. A 3 Mc/s bandwidth luminance signal E_Y is used in conjunction with two colour difference signals E_I and E_Q which can each have bandwidths of either 0.4 Mc/s or 1 Mc/s. In the demonstration each of the three components is allocated a separate channel, but in practice, the two chrominance signals could either be modulated on quadrature carriers, or for example each on its own separate carrier.

Monochrome display of the Coded signals from IIA and IIB (Signals IIIA and IIIB in Figs. 4 and 5)

A high grade laboratory monitor is used to display the "compatible monochrome picture" which would be obtained from either of the coded signals previously described. A low-pass filter of 2.3 Mc/s bandwidth may be inserted, to show the effect of reduced receiver bandwidth on chrominance cross-talk with Signal IIA.

R.F. output of the Coded Signals from IIA and IIB (Signals IVA and IVB in Figs. 4 and 5)

For the band-shared (N.T.S.C. Type) System a 45 Mc/s carrier is provided for compatibility tests on existing production monochrome receivers, together with a nominal 41.5 Mc/s modulated sound carrier which is variable both in frequency and amplitude. This output is also used to feed a complete colour receiver. In the case of the wide-band Signal IIB only the luminance component is modulated on the carrier, and the results shown on the production monochrome receivers indicate the best which could be obtained with such a system of transmission; the method chosen for transmitting the additional chrominance information, may produce some degradation of the compatible monochrome picture in practice, depending on the rejection characteristics of the receivers to the chrominance channel.

ONE PROPOSAL FOR THE BRITISH ADAPTATION OF THE N.T.S.C. STANDARDS

The following items of the N.T.S.C. Standards have been adopted without change:

$$E_M = E_Y + E_Q \sin(\omega t + 33°)^* + E_I (\cos \omega t + 33°)^*$$

where

$$E_Y = 0.30\, E'_R + 0.59\, E'_G + 0.11\, E'_B$$

$$E_Q = 0.41\,(E'_B - E_Y) + 0.48\,(E'_R - E_Y)$$

$$E_I = -0.27\,(E'_B - E_Y) + 0.74\,(E'_R - E_Y)$$

The phase of the colour burst is $\sin(\omega t + 180°)$.

* *For convenience in the present equipment, we are using zero degrees, in place of* 33° *on both the I and Q subcarriers.*

The symbols have the following significance:

E_M is the total voltage which when added to sync and burst is applied to the modulator of the picture transmitter.

E'_R, E'_G and E'_B are the gamma corrected voltages corresponding to the red, green and blue signals, during the scanning of a given picture element.

ω is the angular frequency of the colour sub-carrier.

The reproducing primaries have the following chromaticities in the C.I.E. system of specification:

	x	y
Red	0.67	0.33
Green	0.21	0.71
Blue	0.14	0.08

The colour signal is so proportioned that when the chrominance subcarrier disappears, the chromaticity reproduced corresponds to Illuminant C ($x = 0.310, y = 0.316$).

The remainder of the N.T.S.C. Standards have been modified to suit the British 405-line standard as follows:

The subcarrier frequency is 2.6578125 Mc/s $\pm$ .0025%.

The line scanning frequency is $\frac{2}{525}$ times the sub-carrier frequency, i.e., 10125 cycles/sec.

The bandwidth assigned to the complete video signal for test purposes on closed circuit operation is 3 Mc/s. The filter used has a rapid cut-off and a linear phase shift throughout the pass-band. There is no non-linear time-delay included to compensate for typical colour receiver characteristics.

The bandwidth assigned prior to modulation to the colour difference signals E_Q and E_I are given below:

I channel (nominal 1 Mc/s)
at 1 Mc/s less than 2 db down
at 2.5 Mc/s at least 20 db down

Q channel (nominal 0.4 Mc/s)
at 300 Kc/s less than 2 db down
at 375 Kc/s less than 6 db down
at 450 Kc/s at least 6 db down

E_Y, E_Q and E_I are matched in time to within 0.05 μsecs.

A possible value for the sound carrier to give minimum interference by sound/subcarrier beat is one spaced from the vision carrier by the 692nd harmonic of half line frequency. This would require a spacing of 3.50325 Mc/s instead of the existing 3.5 Mc/s.

The complete signal wave-form is shown in Fig. 6. The subcarrier amplitudes and DC levels of the signal for various saturated colours and peak white are shown in Fig. 7; this is, in fact, the line wave-form of the signal generated by the "colour bar generator" provided in the equipment for initial setting up purposes.

Appendix III

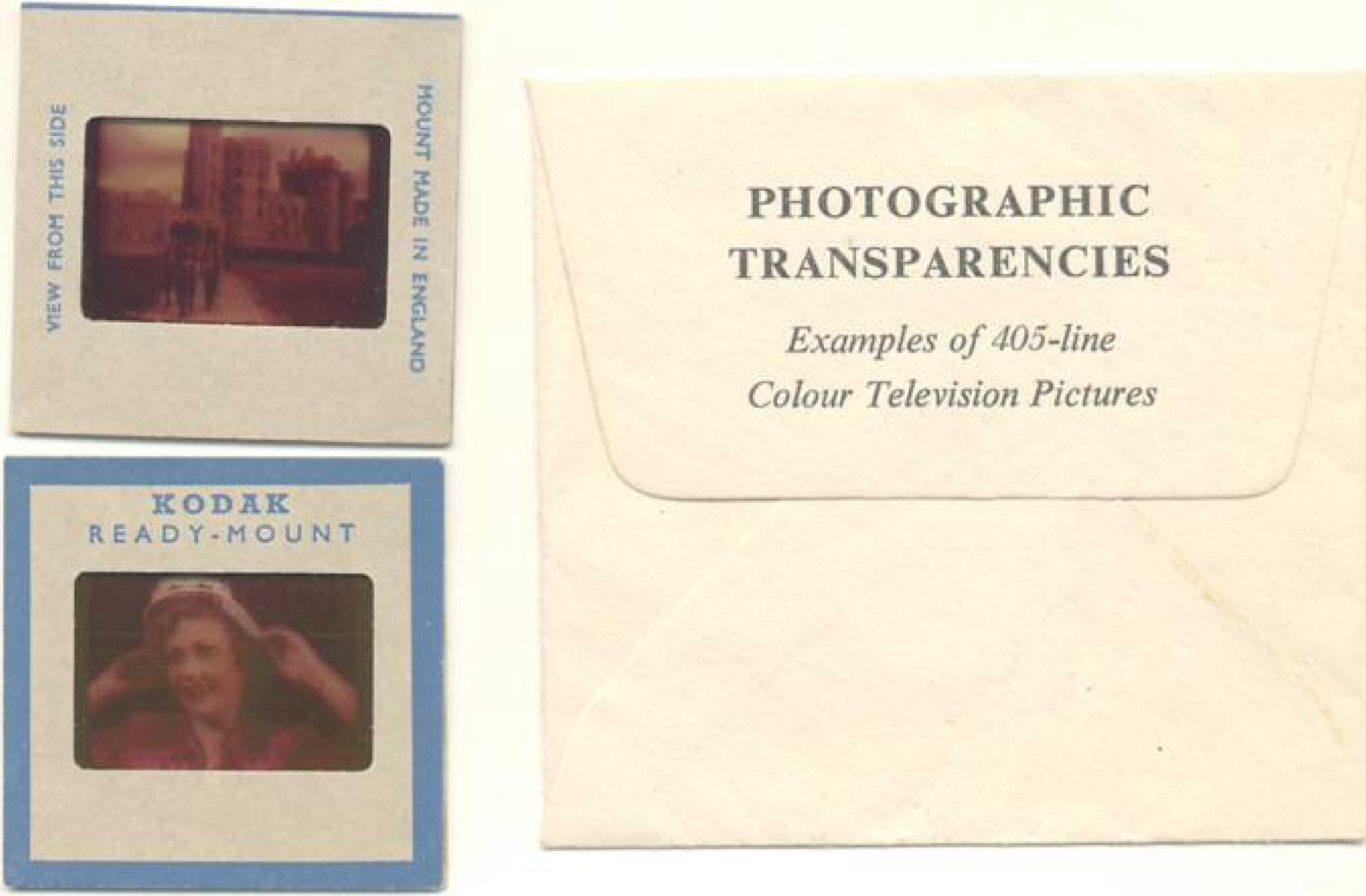
MARCONI EXPERIMENTAL TWO-TUBE COLOUR TELEVISION CAMERA

CAMERAS for compatible Colour Television, as currently demonstrated, are either of the three-tube type, or of the single-tube variety. In the former, red, green and blue optical images of the original scene are focused on the tubes, and red, green and blue signals of high definition are provided by their outputs. In the latter, there are two main sub-divisions. In one, a field sequential colour camera is used, i.e., a camera tube with a colour filter disc revolving in front of it. The output is fed to a converter or "coder" which turns the field sequential signal into a compatible one. The coder consists of three further cameras looking at the separate red, green and blue components of the field sequential image. In the other single tube arrangement, the optical image is made through a very fine pitch colour grid, consisting of red, green and blue stripes at right angles to the scanning lines, so that red, green and blue signals can be obtained from the camera output for each individual picture point. Whilst these single camera tube arrangements offer considerable saving in cost, size and weight, they involve technical difficulties associated with the increased definition demanded from them. With the field sequential arrangement it is necessary to feed the output of several cameras into a single coder in order to realise economy of cost and this means that all studio monitoring equipment must be field sequential and involve wide signal bandwidth. With the colour grid system, the colour grid must have a resolving power of two to three times that of the equivalent monochrome picture. This requirement for increased definition is quite contrary to the principle of restricting the definition of the colour information already enlisted in the compatible systems described above and being demonstrated today.

Marconi's Wireless Telegraph Company Ltd. is actively investigating the triple and single tube arrangements, and much useful experience has already been gained. An attractive alternative, however, which is being demonstrated today, is an experimental two-tube camera, arranged to take advantage of the characteristic of human vision already referred to, in which colour definition is considerably restricted. One camera tube produces a high definition monochrome picture of 3 Mc/s bandwidth in a conventional manner; the other tube is arranged to give two low-definition colour signals.

The Marconi two-tube camera is little bigger than the conventional black and white camera. Although no viewfinder is embodied in the experimental model being demonstrated, there is adequate room for one between the two tubes with the existing size of camera case. As with the three-tube camera, the signal output can be easily coded for routing through the normal type of studio monitoring equipment, thereby showing an advantage over the single-tube field sequential camera. Colour grids of higher resolution than black and white pictures are not required—in fact the reverse. The experimental grid being used in the camera as demonstrated gives exactly half the definition of the conventional black and white picture (i.e., 1.5 Mc/s). In addition to the obvious advantages of compactness and saving in cost, there are certain technical advantages of the two-tube arrangement. For example, as the two colour image is of low definition, the accuracy of registration between it and the green image is not so critical as that between the three images of the three-tube camera.

We believe this is the first occasion on which a colour television camera has been demonstrated, which makes use in its fundamental design of the inability of the human eye to see fine details in colour.


VIEW FROM THIS SIDE
MOUNT MADE IN ENGLAND
KODAK
READY-MOUNT
PHOTOGRAPHIC
TRANSPARENCIES
Examples of 405-line
Colour Television Pictures

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