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A New Survey of the BBC Experimental Colour Transmissions

by

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(BBC Television Service)

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(Operations and Maintenance Department (Television), BBC Engineering Division)

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BRITISH BROADCASTING CORPORATION

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FOREWORD

THIS is one of a series of Engineering Monographs published by the British Broadcasting Corporation. About six are produced every year, each dealing with a technical subject within the field of television and sound broadcasting. Each Monograph describes work that has been done by the Engineering Division of the BBC and includes, where appropriate, a survey of earlier work on the same subject. From time to time the series may include selected reprints of articles by BBC authors that have appeared in technical journals. Papers dealing with general engineering developments in broadcasting may also be included occasionally.

This series should be of interest and value to engineers engaged in the fields of broadcasting and of telecommunications generally.

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SUMMARY

This paper, which is in some respects a sequel to the previous BBC Monograph[1] on colour television, opens with a brief historical account of the programme of work on experimental colour television so as to place in perspective the work described in this paper.

The experimental programme transmissions which took place from Alexandra Palace between October 1957 and April 1958 are described in some detail and the results obtained are assessed and compared with the previous year's results. Some of the more important technical and operational experience obtained at Alexandra Palace is described. The experimental work and the experience obtained in connection with the application of colour to television from the point of view of the programme producer are reported.

The result of experimental work to determine the suitability of the existing distribution network for television programmes is given and is followed by an account of the small amount of experience gained in outside broadcast work. The paper ends with a description of the type of colour transmissions which have been radiated since the end of 1958, and are continuing at the present time.

1. Introduction

On 7 October 1954, the first 'compatible' type of colour television picture was radiated from the medium-power transmitter at Alexandra Palace. The pictures—slides and 16-mm motion pictures—originated from equipment working on 405 lines and employing an adapted form of the N.T.S.C.* system which had been adopted as the standard for colour television in the U.S.A. in December 1953. The details of the standards employed on this occasion differed little from those employed regularly from 1955 until the present time. (See Appendix A.) On this rather historic occasion only one colour television receiver, so far as is known, displayed the pictures, but there was a fair-sized audience viewing the compatible black-and-white pictures in their homes on normal domestic television receivers. Although many hundreds of tests were subsequently necessary to prove the point, it seemed to the observers of this first transmission, which was a co-operative effort of the Research Department of the Marconi Wireless Telegraph Company and the BBC Engineering Division, that in this adapted N.T.S.C. system there existed a standard capable of providing excellent colour pictures and compatible ones of good quality.

During the winter of 1955–6 a regular series of transmissions was radiated from the medium-power transmitter at Alexandra Palace, with the primary purpose of testing the compatibility of the pictures on a comparatively large sample of domestic receivers. Again, only slides and pictures from 16-mm motion film were used, this time the equipment being of BBC design and manufacture. In the meantime, Studio A at Alexandra Palace had been equipped with a single colour camera of Marconi design and the first occasion on which colour pictures including scenes from the studio were broadcast occurred on 3, 4, and 5 April 1956 during a special demonstration for delegates of Study Group IX of the C.C.I.R.† who were visiting this country as part of a world-wide assessment of the state of development of colour television.

By the autumn of 1956, Studio A at Alexandra Palace had been equipped with a second experimental colour camera and, a little later, a 35-mm Cintel film scanner was installed to supplement the slide and 16-mm film scanner. With this equipment and with the enthusiastic help of a small group of programme people, an ambitious and comprehensive series of programmes was broadcast, this time from the Crystal Palace transmitter, in the winter of 1956–7 and was observed in people's homes on specially developed experimental colour receivers and also, of course, on a large number of black-and-white domestic sets. The details of this series of tests and the results obtained therefrom have been fully described in Monograph No. 18.[1] On 30 and 31 January 1957, a special programme was broadcast and shown to a large audience of Members of both Houses of Parliament on six receivers installed in a room in the House of Lords.

During the winter of 1957–8 a further series of experimental programmes was broadcast from the studio at Alexandra Palace and was seen by a rather bigger audience on colour receivers than in the previous year. Section 2 of this Monograph describes these tests and their results. At the conclusion of these tests in 1958 the studio at Alexandra Palace was dismantled and the cameras installed temporarily in a van which carried out two 'outside broadcasts' which are described later. The slide- and film-scanning equipment was moved to the Lime Grove Studios whence a regular series of transmissions outside normal programme time has been given, beginning in the autumn of 1958 and continuing with only short breaks to the present time.

This long series of technical tests extending over nearly six years is exceptional. It is appropriate to ask, particularly when the rate of technical development of electronics is borne in mind, why colour television in the field of broadcasting has remained, at least in this country, in a state of suspended development, with the prospect of a colour broadcasting service apparently no nearer, for so long a period. So far as technical causes of this state of affairs are concerned, it can be said with confidence that the most important result which has emerged from the BBC's work is that the performance of the adapted N.T.S.C. system is not one of the contributory causes. As the Monograph[1] already referred to reported, and as the work described in this Monograph confirms, all the factors of the colour picture which aroused unfavourable comment belong to colour television *per se*, i.e. to that part of the system where the red, green, and blue signals exist as separate entities either in the camera or receiver. This view appears to be shared by authorities who were not at one time wholly favourably inclined towards the N.T.S.C. type of system, which now appears to be likely to be adopted by nearly all countries. The importance of this finding can hardly be exaggerated since the deficiencies of colour cameras and receivers can be removed by technological development, while any significant change in a transmission system is extremely difficult to make once it has been established for public broadcasting.

2. Programme Transmissions from Alexandra Palace, October 1957 to April 1958

2.1 *Purpose and Organization*

The main objective of the tests radiated from the Alexandra Palace studio in 1956–7 had been to assess critically the quality of the colour picture which could be obtained in the home under ordinary viewing conditions and in conditions at the transmitting end approximating to those encountered in running a broadcasting service. To meet this latter requirement, these transmissions included a substantial number of broadcasts from the studio with live cameras which would, as in any broadcast television service, have been the principal source of programme in the case of the advent of colour television broadcasting. The analysis[1] of the results obtained showed that in fact an acceptable colour service could be given. When, therefore, it was decided in agreement with the British Radio Equipment Manufacturers' Association, who had co-operated in the colour experimental work from its beginning, to radiate a further series of tests in 1957–8, some change of emphasis was made, and the objectives of the tests became:

* National Television System Committee.

† Comité Consultatif International des Radiocommunications.

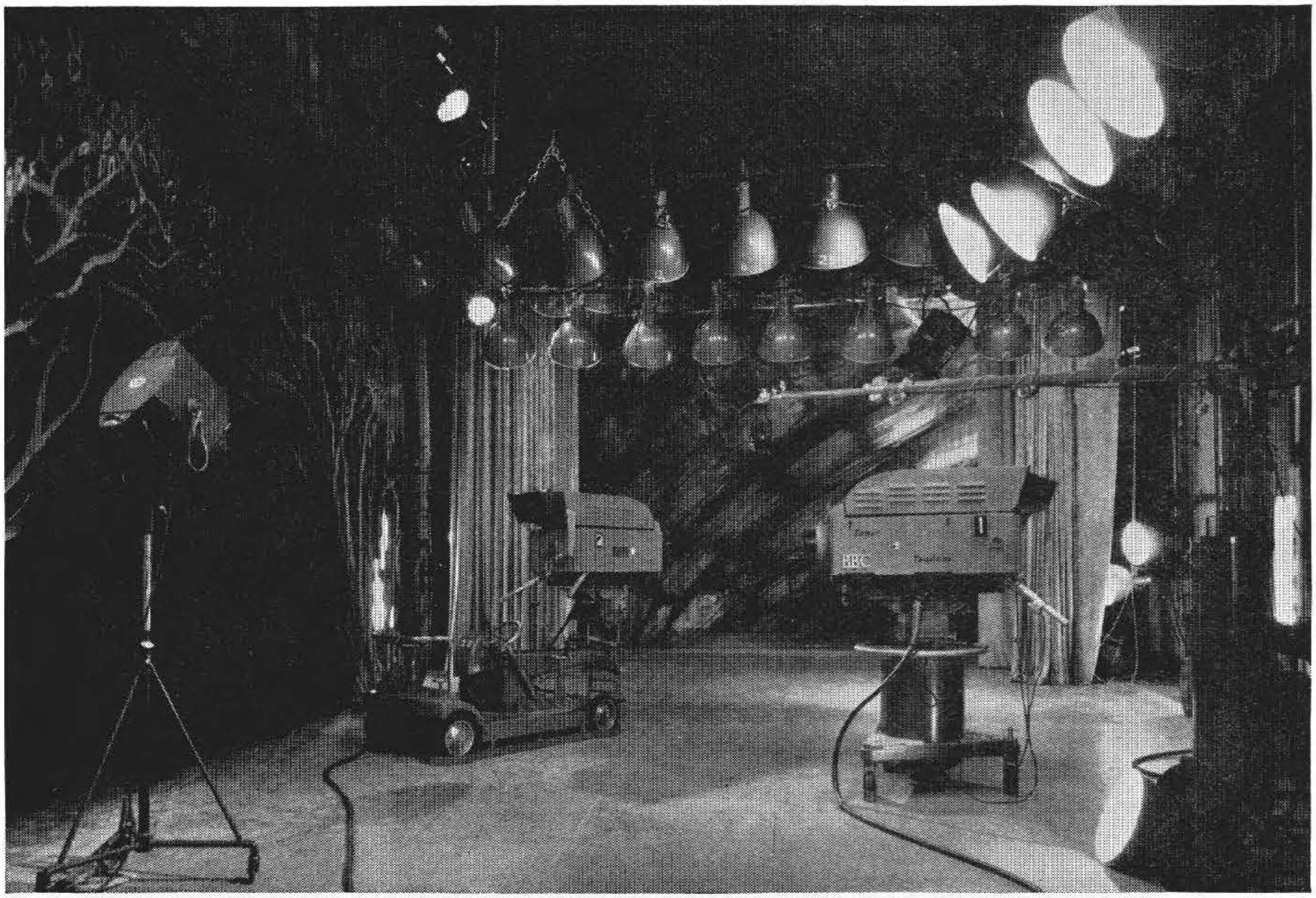


Fig. 1 — General view of Studio A

1. To gain further experience of the technical performance and operation of the camera equipment.

   The previous year's experience had shown that the quality of the picture obtained from the cameras depended greatly upon the methods employed for adjusting and setting up the cameras and associated equipment. A widening and strengthening of this experience could not have failed to be of great value had a colour television service been initiated using this particular type of equipment. Under this head, too, may be classed the intention to carry out technical experiments, some of which are described later in this paper.
2. To explore, admittedly to a limited degree in view of the small size of the studio, the artistic possibilities of colour television as a medium for programmes.

   The programmes broadcast from the studio during the previous year's tests had been made as varied and as interesting as possible and, naturally, had given some indication of the possibilities of colour television in adding scope and interest to television programmes but, in view of the primary aim of making a critical assessment of the quality of the colour picture, experiments in production and presentation had been abandoned if there was any possibility that the technical quality of the picture might suffer. The new series would allow some relaxation in this respect although the aim of good technical quality was to be kept steadily in mind. It was decided to have regular closed-circuit sessions in which the capabilities of the colour cameras for portrayal of colours of dress materials, paints for sets, make-up, and so on could be explored. Also, more time was allocated for setting the studio lighting and for rehearsals. It will be appreciated that this programme of work was in the nature of a 'trial run' on a small scale for a colour television service.
3. To make a further assessment of those technical qualities of the colour picture in respect of those features which had been criticized in the previous year's tests.

2.2 *Studio and Technical Facilities*

The studio from which the experimental programmes originated was the old Studio A at Alexandra Palace where the world's first public high-definition television broadcasting service had begun in 1936. It seemed singularly appropriate that the first experimental colour programmes to be radiated in the U.K. should also find their home in this place, using in all major aspects (with the addition of chrominance signals) the same scanning standards as those of twenty years before.

The studio has a floor area of some 2,000 sq. ft and was equipped with a lighting system of simple design capable of providing about 150 kW of power for the illuminators, which themselves were modern, as indeed they must be to meet the exacting requirements of lighting on which the quality of the colour picture depends absolutely. The two cameras were three-tube image orthicon types manufactured by the Marconi Wireless Telegraph Company. The sound facilities were provided by one boom-mounted microphone and five fixed points. It will be appreciated that these facilities are small compared with a normal modern television studio but they proved adequate for the purpose of assessing the performance of the colour cameras and of giving some insight into the potentialities and difficulties of colour television. Fig. 1 is a photograph showing a general view of the studio.

In an adjoining room was installed a flying-spot 35-mm colour film scanner manufactured by Messrs Rank Cintel and a combined flying-spot scanner, made by the BBC, for 2-in. or 3¼-in. slides, as well as 16-mm film. The signals from these machines and from the studio cameras were fed in R.G.B. form to the combined apparatus and production control room, where each source had its own coder from which the signal was obtained in its N.T.S.C. form. The mixer, a standard eight-channel type, operated on the encoded signals. All the ancillary equipment, such as the waveform generator, camera control units, and distribution apparatus, was also housed in the control room. The six microphone points in the studio and the sound from the desk and tape reproducers, the 16- and 35-mm film scanners were controlled by a seven-way mixer.

Three colour picture monitors based on the R.C.A. shadow-mask tube and designed and manufactured by the BBC were provided, one showing the picture on transmission, another previewing the picture to be next switched to transmission, and the third for general purposes including the broadcast picture as received from Crystal Palace. These monitors were placed so that they could be seen to the best advantage by the camera control operators, but could also be seen adequately by the producer and vision switcher. Fig. 2 is a photograph showing a general view of the control room, with the sound equipment at the far end, vision mixing equipment in the centre, and the two camera control positions on the right foreground. Three colour picture monitors and one black-and-white monitor are mounted above the control positions. Fig. 3 is a view from the other end of the control room showing in addition the coders and measuring equipment in the right background, while Fig. 4 shows the camera channels, distribution equipment, waveform generators, etc., mounted in apparatus racks along the fourth wall of the room.

2.3 *Transmitter and Receivers*

The programmes were radiated by the Crystal Palace transmitter, to which the programme was fed from Alexandra Palace by land line. The Crystal Palace transmitter[2] consists of twin transmitters having a common carrier drive and separate modulators and modulated carrier amplifiers which are paralleled to provide the required power into a common aerial. It would not have been unreasonable to expect that this arrangement might have presented some difficulties for the colour system since the latter is sensitive to small errors in the amplitude and phase angle of the colour sub-carrier. (Appendix A specifies the maximum permissible errors for the complete transmission system in respect of amplitude and phase angle of the colour sub-carrier as 2 dB and 10° respectively for any value of the luminance signal.) The fact that no significant difference could be measured when one or other of the transmitters was switched off indicates a remarkable similarity of performance in respect of linearity of the individual transmitters at the colour sub-carrier which, of course, lies near the upper limit of the modulation frequency band. The absolute linearity of the response is corrected by means of non-linear networks, which are capable of bringing the transmitter well within the limits given in the specification quoted above. The transmitter has normally been adjusted on full amplitude artificial colour bars which represent the maximum possible amplitude for the colour sub-carrier; the power for peak white is reduced to 10 kW, as compared with its normal 15 kW for monochrome transmission, in order to allow completely undistorted transmission of the cyan and yellow colour bars. To what extent this conservative adjustment of the transmitter is really necessary for the virtually undistorted transmission of colour pictures—which are unlikely to contain the high-energy chrominance values of the test colour bars—has not been established.

Because of the use of amplitude modulation for the sound of the British television system, it has been beneficial to lock the frequencies of the vision carrier, the colour sub-carrier, and the sound carrier in a proper relationship so that the beat products between any two of them are 'frequency interleaved' and have a minimum visibility on both colour and black-and-white receivers. The means by which this frequency locking has been obtained is described in Monograph No. 18;[1] mention is again made of it here because it is worth stating that not a single report has been made during the whole course of the colour transmissions of the pattern of approximately 800 kc/s produced by the beat between colour sub-carrier and sound carrier having been seen.

The colour receivers used by the BBC for installation in the homes of staff all employed the R.C.A. 21-in. shadow-mask tube. The majority of the receivers were manufactured by Messrs Murphy Radio Ltd[3] and were in the nature of 'commercial' prototypes in that the components and circuit techniques employed were similar in quality and cost to those used in domestic television receivers, although, of course, necessarily more complex. At any one time there were about eighteen of these receivers in use in the home. There were also a number of experimental receivers, mostly employing the R.C.A. tube, in the hands of members of B.R.E.M.A.

In contrast with the previous year, when most of the observers had been engineers and their friends, on this occasion a large proportion of the receivers were installed in the homes of non-technical staff. As in the previous year, they were moved about at frequent intervals so as to get as varied a sample of observers as possible.

2.4 *Programmes*

Altogether seven programmes were transmitted from the studio during 1957–8, on a regular monthly basis which began in October 1957. The programme was changed every month and was broadcast on six occasions in the first week of each month, three in the evening after the conclusion of the normal television programme, from about 11.15 p.m. to midnight, and the remaining three transmissions in the break in the afternoon programmes at about 3.30 p.m. A film was usually transmitted as a separate part of the same programme and additional film transmissions took place in the third week of each month on four occasions, two in the evening and two in the afternoon.

Of the seven programmes, three were of plays evenly divided between modern and historical settings, two revues, a programme in which the emphasis was on dancing including ballet, and a variety programme of songs, turns, and dances.

The film transmissions were all of 35-mm film.

2.5 *Assessment of Picture Quality*

In order to make the assessment of picture quality which was one of the objectives of the tests, observers were asked to fill in a questionnaire. The questionnaire which was used during the previous year's tests had contained twelve questions concerned with separate aspects of the reproduction of the picture. The results of that series showed that seven of those aspects aroused little criticism from observers and therefore the questionnaire for the 1957–8 tests contained only five questions on the remaining aspects. In any case since it was expected that a large proportion of the observations would be made by people without any technical knowledge who would, on most occasions, not have an engineer present to explain the nature of the defects on which comments were being asked for, it was essential that the questionnaire should be as simple as possible. The nature of the various defects was described in as non-technical a form as possible by means of notes on the reverse side of the questionnaire. The questionnaire is reproduced as Appendix B.

The same system of grading was used as in the previous year. The grading system permits the allocation of a score from 1 to 6 for each individual effect as shown in the scales below. The effects of the presence of 'Noise' and 'Misregistration' are assessed on Scale 1, while the positive qualities of 'Fidelity of Colour Reproduction', 'Picture Sharpness', and 'Overall Assessment' are assessed on Scale 2.

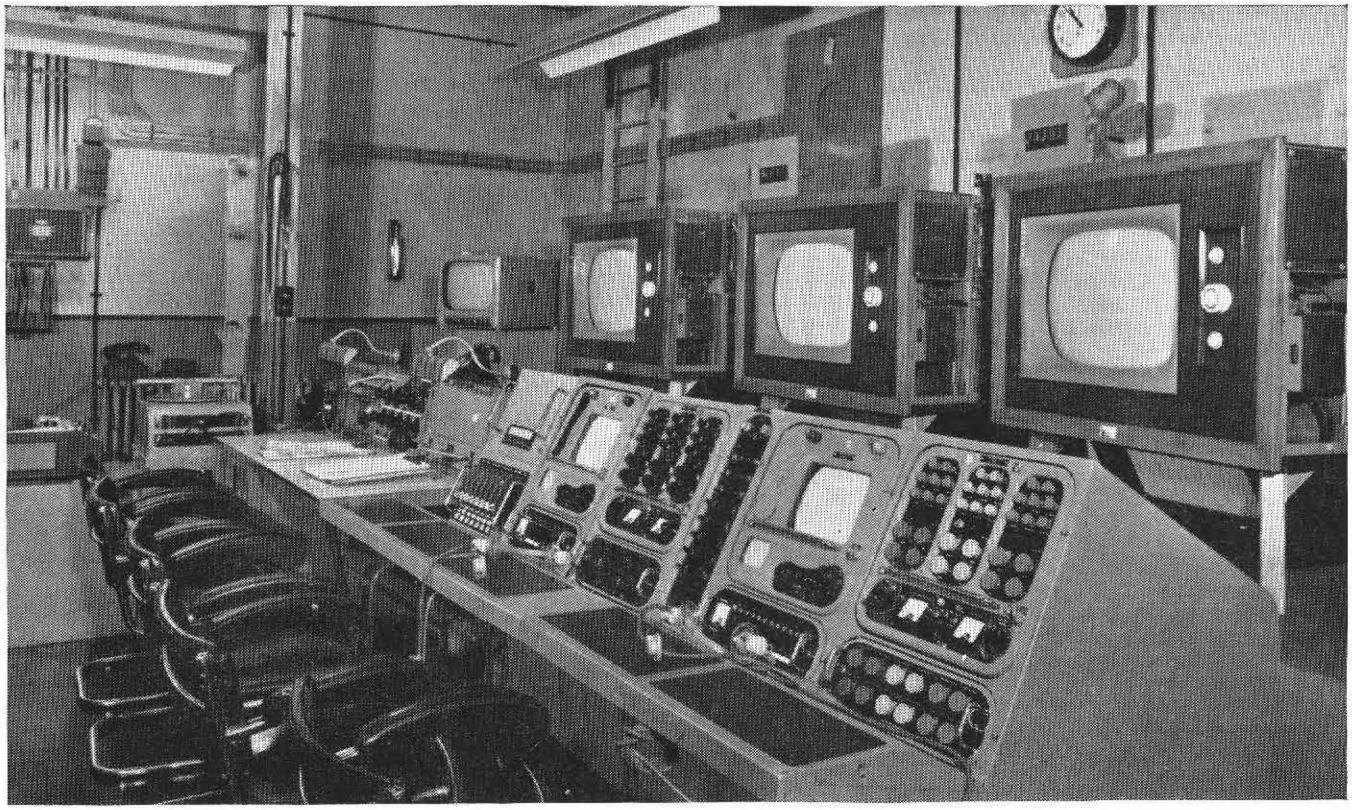


Fig. 2 (above) and Fig. 3 (below) — View of Control Room/Apparatus Room

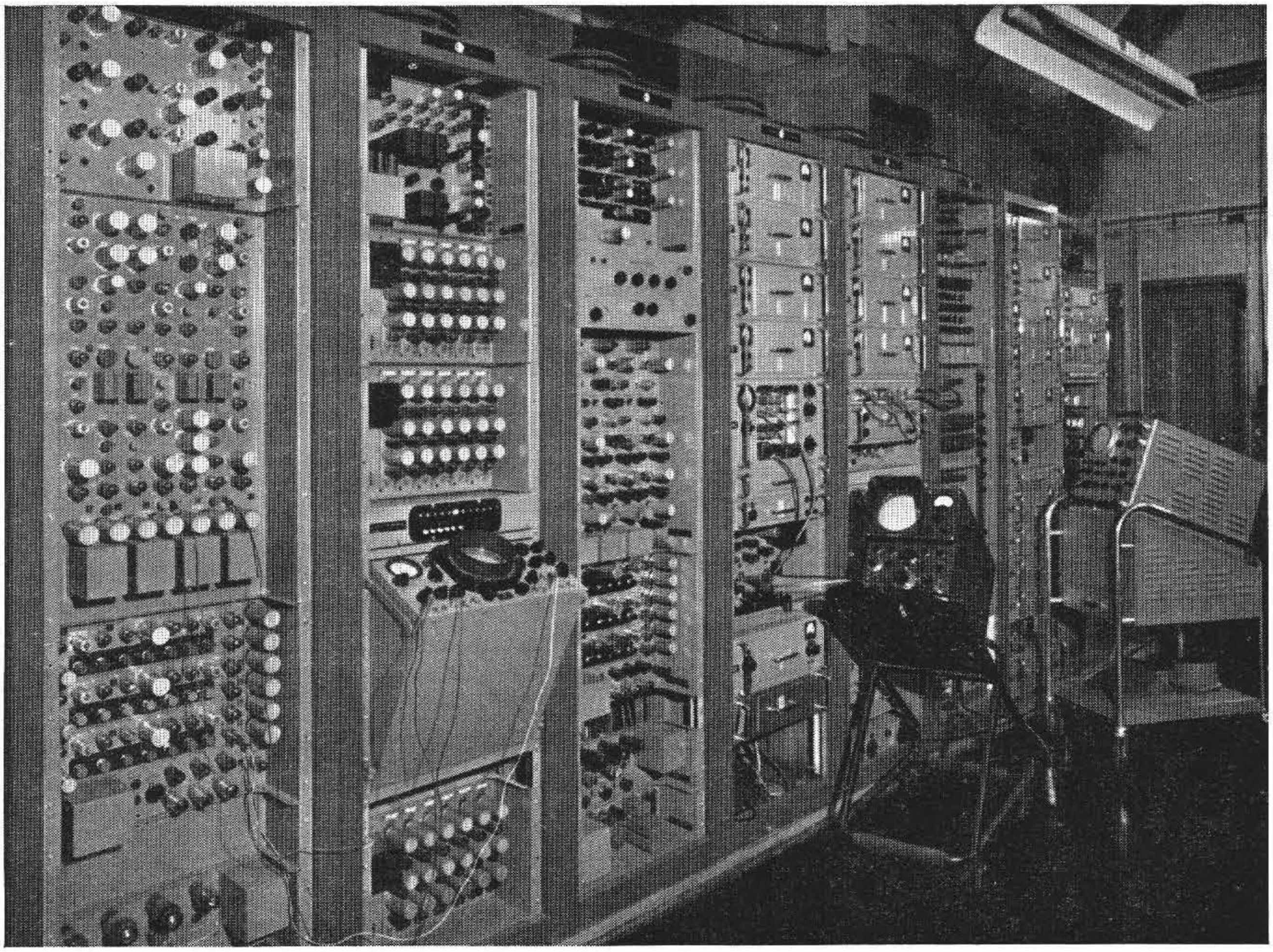


Fig. 4 — Camera Channel, Waveform Generators, and Distribution Equipment in Control Room/Apparatus Room

TABLE 1

Scale 1	*Score*	*Scale* 2	*Score*
Imperceptible	1	Excellent	1
Just perceptible	2	Good	2
Definitely perceptible but not disturbing	3	Fairly good	3
Somewhat objectionable	4	Rather poor	4
Definitely objectionable	5	Poor	5
Unusable	6	Very poor or absent	6

In both scales a low number indicates a favourable reaction and a high number an unfavourable reaction.

2.6 *Results of the Assessment of Picture Quality*

It is necessary at this point to repeat the definition of certain descriptive terms which were used in the assessment of the previous year's tests and which will again be used. The term 'mean grading' is almost self-explanatory; it is the average score of the total of the observations for the effect under discussion, the individual scores being chosen according to the scales shown in Table 2. For example, if out of 100 observations fifty obtained score 3 and fifty score 6, the mean grading would be 4·5. However, the mean grading by itself is not a sufficient standard of quality by which to judge the results and it is necessary also to take into account the number of observers placing their comments in grades 4, 5, and 6. The phrase 'acceptable' will be used when not more than 10 per cent of observers use grades 4, 5, and 6 to describe a particular effect, and if this condition is met a mean grading of less than 1·5 will be considered to be 'very favourable', one between 1·5 and 2·5 'favourable', and one between 2·5 and 3·5 'acceptable'. A mean grading below 3·5 is considered to be 'unusable'. This suggested interpretation is summarized in Table 2.

TABLE 2

Mean Grading	*Suggested Interpretation*
1·0 to 1·5	Very favourable
1·5 to 2·5	Favourable
2·5 to 3·5	Acceptable when detailed inspection of results shows not more than 10 per cent in grades 4, 5, and 6
	Unacceptable when detailed inspection of results shows more than 10 per cent in grades 4, 5, and 6
3·5 to 6	Unusable

TABLE 3

Characteristic	Percentage of Observers in Each Grade for Each Characteristic																	
	35-mm Film						*Camera Pictures*						*Slide*					
	Grade						*Grade*						*Grade*					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
A Fidelity of Colour Reproduction	18	47	28	6	1	–	10	39	39	12	–	–	8	47	29	9	6	2
B Misregistration	44	38	15	2	–	–	13	26	41	15	5	–	35	39	18	6	1	–
C Picture Sharpness	34	47	16	2	–	–	18	39	34	7	2	–	20	51	23	5	1	–
D Noise	49	28	15	4	2	–	44	28	18	8	2	–	53	30	12	5	1	–
E Overall Assessment	22	53	22	3	–	–	12	41	36	10	1	–	10	53	24	7	4	1

TABLE 4

Characteristic	*Mean Grading*			*Total Percentage of Observers in Grades 4, 5, and 6*		
	35-mm Film	*Camera*	*Slide*	*35-mm Film*	*Camera*	*Slide*
A	2·2 (1·9)	2·5 (2·5)	2·6 (2·0)	7 (2)	12 (14)	17 (4)
B	1·8 (1·7)	2·7 (2·6)	2·0 (1·7)	2 (0)	20 (17)	7 (3)
C	1·8 (1·9)	2·4 (2·5)	1·7 (1·9)	2 (0)	9 (9)	6 (1)
D	1·8 (1·4)	2·0 (1·8)	2·2 (1·4)	6 (1)	10 (13)	6 (0)
E	2·0 (1·8)	2·4 (2·5)	2·4 (1·9)	3 (0)	11 (11)	12 (2)

The figures in brackets are those for the previous year's tests

The results are summarized in Tables 3 and 4. For the camera pictures, in which, as has been explained, the major interest of this series of tests lies, the mean gradings are very similar to those of the previous year, which are shown in brackets. The number of observations from which the gradings have been obtained is approximately 270 for each characteristic, which is almost exactly the same as in the previous year, although with different observers. Although the mean gradings for all the characteristics are 'favourable', the results show that in respect of fidelity of colour rendering, misregistration, and overall assessment, the percentage of observers using grades 4, 5, and 6 is 'not acceptable'; the overall assessment is outside the 'acceptable' category by a very narrow margin. As before, the worst feature of these pictures appears to be misregistration; the results for this feature for film and slides also show a worse answer and because misregistration in these cases is a feature only of the receiver, it must be concluded that either the receivers were in a less perfect state of adjustment or that the audience was more critical, or even perhaps confusing this feature with some other defect. However, the number of observers using grades 4, 5, and 6 is so much greater for the camera pictures than for the others that it must be admitted that this is a defect of the cameras then in use and it was well known to those at the studios that this was indeed so. In section 3.1 some reasons are advanced why the cameras are prone to this form of distortion. Only in the case of noise has the assessment moved from 'unacceptable' to 'acceptable' but as will emerge from the discussion of this feature for film and slides, there is some reason to doubt whether observers were able to recognize this feature with any certainty.

For the 35-mm film, the results of about 350 observations were slightly worse than those of the previous year, which were based on the much smaller number of ninety observations. All the features have a mean grading which is at least 'favourable' and all are 'acceptable'. The 35-mm films have all been of good technical quality and many of them are interesting in the programme sense.

The results for the slides are quite anomalous, the gradings for fidelity of colour reproduction and the overall assessment having moved from being 'acceptable' to 'non-acceptable' in a most striking way. However, it is believed that there is an explanation for this change, which is perhaps a warning to those carrying out subjective tests. Prior to the tests, it had been agreed with B.R.E.M.A. that a slide would be prepared in large numbers so that it could be given to all the members of the Association who were co-operating in the work. The slide could then be projected alongside the colour receiver so that a direct comparison between the two could be made. In choosing the slide, one of the qualities which was sought was that of producing more or less equal signals in the I and Q channels of the chrominance signal. The search for this quality quickly revealed that most professional and amateur slides carefully avoided the colour combinations containing any appreciable Q signal and only one or two slides out of a hundred or more met this requirement. The one finally chosen, while not meeting the requirement for equality, was not too far from the desired result and was copied in large numbers and distributed to members of B.R.E.M.A. It was on this slide only that observers were asked to comment and it became clear that many people heartily disliked it as a colour picture, so much so that this feeling obviously affected their judgment. The scanning equipment used for transmitting the slide produces a picture of the highest quality and the assessment of the slides in the previous year's tests, when a variety of slides, not including the one under discussion, was used, correctly reflected the known technical quality of the pictures. The technical quality of this much-disliked slide was undoubtedly as high as any transmitted in the previous tests; it is ironical that it was precisely because of this known and consistent quality that observers were asked to comment on the slide as a means of deciding the consistency of their comments. Obviously it would have been desirable to change the slide but this would have interfered with the original intention of providing a basis of comparison, a purpose which it served very well. It is thought that nothing more significant need be read into the results obtained on the slide than that the organizers made an error of judgment in selecting it at all.

In concluding this portion of the paper, it may be said that the 1957–8 series of programme tests confirmed the results obtained in 1956–7. Ignoring the results for the slide, the consistency of the observers' reactions is remarkable, particularly considering that the audience was much less technical and that the camera pictures were frequently attempting to portray a more complicated and sophisticated technique of programme production. The same weaknesses of the camera pictures were observed, all of them difficulties of simultaneous colour television with the existing cameras and receivers. The excellent results obtained from 35-mm film confirm that the adapted N.T.S.C.

system working on 405 lines possesses an inherent quality which would provide a satisfactory colour service.

3. Technical Experience at Alexandra Palace

3.1 *Studio Cameras: Pick-up Tubes*

The studio cameras each employed three 3-in. image orthicon camera tubes. These tubes required to be closely matched for geometry and shading and transfer characteristic; for use in the studio with lighting at a colour temperature of about 3,200°K, the most sensitive tube was selected for the blue channel and the tube with best definition for the green channel. Initially tubes were matched and left in sets of three; if one tube failed all three tubes were changed, the remaining tubes being available for making up a new 'set' of three matched tubes. This, however, proved to be a lengthy and time-wasting procedure. With experience it was possible to test tubes individually and indicate in the tube log its main shading characteristics, definition, and sensitivity, and from examination of the log it was usually possible to select a suitable replacement tube for any single channel.

The tubes used were all the close-spaced type with a long linear transfer characteristic below the 'knee'. Up to March 1957, only R.C.A. image orthicon tubes type 6474 were used except for the demonstration to the Houses of Parliament on 30 and 31 January 1957 when one camera used English Electric image orthicons type P809 which were on loan from the English Electric Valve Company.

3.1.1 *Performance*

All the R.C.A. camera tubes were of the same type (6474) having a G5 (decelerator) electrode and no field mesh.

The majority of English Electric tubes were type P809. Since the ultimate sensitivity of the camera in the studio depends on the sensitivity of the tubes in the blue channel, a number of tubes having an antimony-caesium photocathode were tested at Alexandra Palace. Theoretically, these could have a sensitivity four times greater in the blue part of the spectrum than a conventional caesium-bismuth silver photocathode but the results obtained were disappointing, many being less sensitive, and even the best had only the same sensitivity as a good Cs-Bi-Ag photocathode. This tube lasted for only seventy-one hours before being withdrawn from service because of an ion burn.

The English Electric tube type P809 has a field mesh on the beam side of the target and for this reason gives less 'edge' effect and beam pulling, both of which can give effects similar to misregistration.

The resolution and noise figures are similar for P809 and 6474 as is the sensitivity, although there is a tendency for greater spread of sensitivity with the 6474.

Later versions of the P809 included a G5 electrode as well as the field mesh and this resulted in a marked improvement in 'black shading'.

Because tubes were always allowed to reach a reasonable temperature before being exposed to light, temporary 'sticking' of the image on the target, such as is encountered in normal programme work, was never troublesome except in tubes which had been in use for a considerable time and were nearing the end of their lives. However, permanent 'sticking' is difficult to avoid because of the lengthy periods (for example during registration) during which the tubes are exposed to test charts. During such periods it is worth reducing the photocathode voltage of the tubes not in use, in order to keep 'sticking' to a minimum.

3.2 *Studio Cameras: Dichroics*

The optical system of the cameras suffered from internal reflections which caused spurious red and blue images displaced horizontally by about 8 per cent of picture width on either side of highlights and a marked loss of definition in the blue channel. The former were due to reflections from the surface of the glass used to sandwich the red and blue reflecting dichroic mirrors: improved 'blooming' of these surfaces subsequently reduced the reflections to the satisfactory level of under 2 per cent, and also improved the definition in the blue channel.

3.3 *Studio Cameras: Viewfinders*

The camera viewfinder employed a 7-in. tube of good quality. The output of the red, green, and blue head amplifiers could be selected for viewing either singly or with red or blue superimposed on green or with all three outputs superimposed. These facilities were provided for use during the process of registration of the three images but proved of very limited value because the final picture when viewed on a 21-in. monitor showed errors quite invisible on the smaller 7-in. monitor. During programmes, the viewfinder was normally switched to the green channel, although exceptionally the red channel was used.

Because of the large size of the camera, the viewfinder was often at an inconveniently high position and an attempt was made to use a periscope attachment to lower the effective height. However, the periscope proved universally unpopular with the cameramen and was little used. The quality of the picture displayed by the viewfinder was inadequate because the signal was obtained from the head amplifier before the application of shading, gamma, and aperture correction.

3.4 *'Crispening' Techniques*

Since the tubes used in the colour camera have on the average a response at a resolution corresponding to a frequency of 3 Mc/s, which is 14 dB below that at low frequencies, it is very desirable to provide some form of correction, but because the tubes also have a poor signal-to-noise ratio the amount of normal aperture correction which it is possible to use is very limited. This is particularly so in a colour system which employs a sub-carrier at the upper end of the video band, since any high-frequency fine-point noise which is present in this part of the spectrum of the luminance signal is translated to a coarse and much more visible low-frequency structure by the demodulation process applied to the chrominance signal. A more successful method than normal aperture correction for improving the sharpness of the picture resulted from using the non-linear 'crispening' technique suggested by Goldmark.[4] As applied to the colour camera the signals in the R.G.B. channels are band limited to about 1·7 Mc/s by means of linear phase-shift low-pass filters,[5] this form of filter being very desirable because it produces its bandwidth limitation without appreciable overshoot. The band-limited signals so obtained, which now, of course, have their high-frequency noise components very much attenuated, are then passed through a non-linear differentiating circuit which can be adjusted to pass edges exceeding a predetermined amplitude and the differential so obtained is then added to the original band-limited signal from which it was obtained. So far as large areas of the picture containing no transitions are concerned, the crispener non-linear circuit remains shut so that noise components are added only at edges in the picture. The end result is a sharp picture without the addition of noise in plain areas, although, of course, the inherent resolution is less. On all occasions this crispening technique produced a sharper and more attractive colour picture than that given by the normal aperture correction technique, even with the best and least noisy pick-up tubes available. On other occasions, when noisy and poor resolution tubes were in use, as inevitably occurred from time to time because of the very many parameters of performance which the tubes in the colour camera must meet simultaneously, the crispening technique gave a picture which was comparable with that from good tubes. It seems very likely that this crispening technique will be beneficial for use with colour cameras at least as long as 3-in. image orthicons remain the type of pick-up tube to be employed.

3.5 *Camera 'Shading Correction'*

The colour camera requires careful adjustment for best shading because slight differences in the shading signals from the three image orthicons result in very objectionable patches of colour which are especially noticeable in the dark parts of the picture. If the shading signals from the three tubes were identical in shape and amplitude, they would combine to produce a colourless patch which is not nearly so objectionable, but it is seldom possible to obtain a set of three tubes matched as closely as is desirable. The colour camera is therefore provided with comprehensive shading correction signals operating in both the line and field directions and having sawtooth- and parabola-shaped waveforms.

The types of shading may be somewhat arbitrarily divided into two kinds; black shading, which is independent of the picture signal, and white shading, which varies as the signal changes in amplitude from black to white. It is therefore impossible to correct for both types of shading by the addition of a fixed amount of correction signal and a choice has to be made whether to do this wholly for black shading or to compromise at some intermediate level of the signal. Experience showed that it was essential to correct at black and to ignore the temptation to achieve a compromise. Every effort must also be made to reduce the shading signals to a minimum from the tube before the correction is added: this is a long and tedious business of adjusting the electrode potentials of the tube, some of which affect not only shading but also geometry. At times, after careful correction of the shading signals, an excellent result was obtained, but there is little doubt that one of the major deficiencies of the colour camera was this propensity to produce coloured patches of light due to inability to correct the shading distortion completely.

It is obvious that the final solution to this problem lies with the tube manufacturer, but at the present state of variability of tubes there is a palliative which is worth further investigation. This is to arrange that the three colour separation signals are automatically connected together at low amplitudes representing dark and near-dark tones so that a true neutral is produced, so removing the coloured patches of light which are so objectionable. Inevitably, some colour is also removed, but the rather limited amount of experiment which was possible suggested that this was to be preferred to the presence of the coloured shading signals.

3.6 *Contrast Law Correction*

It has been established that the non-linear power law characteristic of the shadow-mask display tube has an exponent which lies between 2·2 and 2·5 over an appreciable range of brightness, and since the pick-up tubes used in the camera are operated over the linear portion of their transfer characteristics, it is necessary to introduce in the camera channels a non-linear correction so that the overall transfer characteristic becomes something like unity. It appears that the tolerance which exists in black-and-white television for departures in the overall transfer characteristic from unity does not apply to colour reproduction, probably because both hue and brightness are affected by incorrect values for this characteristic. Experiment has shown that the most desirable exponent for the law of the non-linear corrector in the camera channel is approximately 0·4, which does in fact yield an overall transfer characteristic very close to unity. However, such an exponent demands greatly increased gains at those signal levels representing the dark tones in the picture and the distortions present, such as noise and shading, are accordingly magnified. It was therefore generally found impossible to operate with this desired exponent and on most occasions the practical range of correction for camera pictures was found to lie between 0·5 and 0·7, with a predilection to pick the lower level near 0·5 in the interests of better colour fidelity and in particular good facial tone reproduction. Both the experimental techniques described above of crispening and low-level amplitude 'commoning' are helpful in achieving the desired lower value of exponent since noise and shading are both reduced. For film reproduction, where the problems are by no means so severe, a correction exponent of about 0·4 was usually employed.

3.7 *Coders*

Two different designs of coder (sometimes referred to as encoders or colorplexers) were employed. The first, employed mainly with camera signal sources, was of commercial origin following American practice. This used balanced valve modulators in both the I and Q channels and in the early versions the balance of these modulators drifted very badly and required adjustment every few minutes. Later versions included an automatic carrier balancing circuit which sampled the signals during the blanking period and produced a correcting voltage proportional to the amplitude of the sub-carrier present due to unbalance.

The second coder was of BBC design and employed germanium diodes in a ring modulator circuit. The early versions of this coder suffered from about 5° of differential phase distortion, but a later version improved this to less than $\pm\frac{1}{2}°$. The stability of this coder was good and the later version even better; the balance obtainable from the ring modulator was not quite as good as that from the balanced valve modulator when manually adjusted, but was of the same order as the residual error in the latter when an auto-balance circuit was used.

In adjusting the coders it is necessary to measure both the amplitude and angle of the sub-carrier, the latter to a high degree of relative accuracy between a number of coders so that no change of picture quality will be seen when switching between sources. Two instruments, a colour signal analyser and a vectorscope, have been used for measurement of angle, the former being calibrated in steps of 0·1° and giving an accuracy of measurement much better than 1°. The absolute accuracy of the vectorscope was at best about 2° but as an instrument for measuring relative differences between signals it proved to have a high order of accuracy and is invaluable and essential in colour work with an N.T.S.C. type of signal. So far as the measurement of amplitude is concerned, both during the adjustment of the coders and at other points in the colour chain, relative accuracy between two or more voltages is of the greatest importance and an oscilloscope with a differential amplifier is an essential instrument for this work.

3.8 *Luminance Notch Filter*

A characteristic of the N.T.S.C. system is a sharing of the frequency spectrum for the chrominance signal and the high-frequency components of the luminance signal, and crosstalk from the luminance channel to the chrominance channel can cause a kind of interference patterning on the reproduced colour picture in the form of crawling dots at luminance transitions. This form of crosstalk (cross colour) can be reduced by the inclusion of a phase-corrected notch in the luminance channel of the coder with a maximum loss of about 12 dB at the colour sub-carrier frequency and a bandwidth of 500 kc/s between the −3 dB points. Such a notch was included in one of the coders for an experimental period and there is no doubt that in the case of certain still pictures its presence was beneficial. However, on camera pictures and on pictures from 35-mm film, no sign of cross colour was detected with or without the notch filter, and since the notch filter involved some loss of sharpness on pictures which were already none too good in this respect, notch filters were not provided in the coders for the cameras and for the 35-mm film scanner.

3.9 *Electronic Masking*

Due to the fact that the dyes used in all colour film processes are not 'ideal', i.e. no dyes have spectral absorption curves with infinitely steep sides and zero absorption for appreciable portions of the spectrum, a certain amount of cross coupling occurs between them. In televising colour films, after the colour information is in the form of voltages in the red, green, and blue channels, electrical cross coupling of an equal amount but of the opposite polarity can be introduced to remove these effects and improve the colour rendition. This process is referred to as 'electronic masking'.

A three-channel electronic masking unit was made by the BBC Research Department and this was used for about half the film transmissions from Alexandra Palace from the end of February 1957. It has been suggested in some American literature that in addition to correcting film rendition errors, a further improvement in reproduction of films can be obtained by adjusting the controls of the masking unit on a scene-by-scene basis calling for the exercise of artistic judgment by the programme director. There are, in fact, three controls for each channel; the master control, the mask amplitude control, and the balance control. This latter can be preset but this still leaves a total of six variable controls for a three-channel masking unit. In adjusting these controls generally without knowledge of the exact colour in the original scene, a more pleasing picture could often be achieved for a given scene but a subsequent scene could well be made far worse.

Accordingly, it was felt that any correction applied should correct only for film dye errors and for errors in the film scanner giving a similar effect. A method of obtaining the mask settings for various colour film materials was devised by photographing on each of the materials a set of colour bars produced by strips of coloured gelatine which were then compared, when reproduced by the film scanner, with the same signals obtained from a slide made of identical strips of coloured gelatine and reproduced by the slide scanner. Experience had shown that the performance of the slide scanner was sufficiently good for it to be used in this way as a standard, and by using the vectorscope as the instrument for comparison, settings of the masking unit could be obtained for each type of film.

This gave excellent results on many films but the masking process worsened the signal-to-noise ratio by about 3 dB and could not be used with dense film which already gave a poor signal-to-noise ratio. Poor white balance on a film was in general made more obvious by the use of masking and it also made the setting of the white balance of the film scanner more critical; thus electronic masking can improve a good film but can do little or nothing to help the reproduction of a dense or poorly balanced film. Because of these difficulties, the masking unit has been used since the autumn of 1958 to correct only for deficiencies in the colour analysing circuits of the film scanner (see 8.2).

3.10 *Matching of Film 'Insert' with Camera Pictures*

It is common practice in black-and-white television productions to introduce film sequences mixed in with live studio scenes, and even in this well-established medium, the change from film to studio quality is often obvious. The same facility would obviously be required for a colour television service and in an attempt to estimate the difficulties of the process, a number of film sequences, including some of test charts and contrast scales, were shot and attempts were made to match these to studio camera pictures. In shooting the film the lighting employed was similar to that used for the television cameras, great care being taken to obtain correct exposure; often, several 'takes' of the same scene were made, each with slightly different exposure, in order to select the most suitable. An attempt was then made to match the pictures as obtained from the film scanner with the camera pictures. It may be mentioned that the facilities for processing colour film are much slower in action than those which are available for black-and-white film used in television and this could be a factor of importance should a colour television service be established.

The first and most obvious difference lay in the definition, the film being markedly superior. Although this result was not unexpected, the contrast between the two pictures displayed side by side emphasized how much remains to be done to improve the sharpness of the camera pictures. There were other more subtle differences in grey scale and colour rendition, and attempts were made to correct these differences by adjusting the electronic mask settings subjectively. Some slight improvement was obtained but the match was still far from good. More improvement was obtained when the black level was adjusted slightly and further improvement in matching was obtained when the gamma correction applied in the camera channels was increased from about 0·5 to about 0·8.

At this stage acceptable matching was achieved if there was a complete change in scene, but if it was required to cut to a film of the same setting then in most cases the change was still felt to be too obvious.

More controlled tests could doubtless improve this matching further and provided great care is taken in shooting and processing the film it should be possible to mix film and camera pictures without undue difficulty.

4. Technical Operational Experience at Alexandra Palace

4.1 *Setting-up of Cameras: Registration*

The three tubes are initially allowed to warm up for twenty to thirty minutes as is usual with image orthicons and this also allows the electronic circuitry to settle down to a stable working condition. Each of the three tubes is then aligned and set up to give the best picture quality in a manner similar to that for a normal black-and-white image orthicon channel.

When the tubes are first inserted it is necessary to set them to focus together on the same object plane. Then the surface-silvered mirrors in the red and blue optical paths are set to centre the image on these tubes, to correspond with an image centred on the green tube. The tilt adjustment for vertical centring is set first since this produces some effective rotation of the image, and the rotational mirror adjustment then gives horizontal centring. Any image rotation produced by tilting the mirrors can be corrected by rotating the tube yokes. By centring the optical images it is possible to ensure that the maximum amount of the target is scanned to give the best possible definition and requiring a minimum of centring, so minimizing any drift due to variations of this current. Unfortunately the mirrors are not readily accessible for adjustment and the tendency was to set them only approximately. It is also necessary to ensure that the three tubes work on the same part of their transfer characteristic and neutral density filters are inserted in the more sensitive channels until all three tubes reach the 'knee' together whilst exposed to a neutral test card containing a peak white illuminated with a light source or sources of the same colour temperature as those to be used on the set.

Registration of the three pictures is achieved with the camera viewing a registration test chart whilst successive adjustment is made to the electrode controlling S distortion (G6) and the individual scan controls, i.e. amplitude, linearity, shift, and skew. This latter controls a small amount of frame scan introduced into the line-scan coils to centre the line scan by different amounts at the top and bottom of the frame so that correction can be made when the vertical lines of two superimposed channels are not parallel after the horizontal lines have been made parallel. The securing of fair registration, perfect perhaps only near the centre of the field, is not a difficult matter, but to improve on this is to invoke a law of rapidly diminishing returns. If the error reaches 0·2 per cent of the line length the grating of a 3 Mc/s test pattern of one colour becomes completely out of register (displaced by one half-cycle) from the same grating in the other colour. If any of the controls such as image focus, image accelerator, beam focus, alignment, G5, etc., are subsequently adjusted, registration may be affected and should be rechecked.

Two associated factors found in practice to give the appearance of misregistration on a coloured scene are the edge effects and beam pulling which occur at high contrast transitions. These effects, being different for the three tubes, and dependent on picture content, produce an effect which has been called 'dynamic misregistration'; this is of much smaller magnitude in the English Electric image orthicon (type P809), which has a field mesh, than in other 3-in. tubes.

4.2 *Adjustment of Camera Channels and Colour Balance*

In order to line up the complete camera channel in the control room, a sawtooth signal is applied simultaneously to the input of all three amplifier channels with shading correction switched off, and one of these is set to give the correct output level with the desired contrast correction law; the other two are then adjusted to give identical output waveforms by comparing them in turn with the first channel, using a differential amplifier. Thus the matching of the transfer characteristic of the three amplifiers is ensured before the three image orthicon tubes are matched.

The next step consists of setting the gain, lift, and shading of each channel to reduce to a minimum any colour errors in the reproduction of a standard RETMA logarithmic grey scale reflectance chart, illuminated evenly at the same level and colour temperature as the 'set'. For the camera to reproduce this as black and white, without coloration, the signals from the three channels must be identical. There are a number of methods of achieving this, but the method which experience has shown to be the best is to use a colour monitor together with a 'bridging' or 'shorting' switch or relay which connects together the outputs of all three channels. With the switch 'shorted' the three outputs must be identical and therefore ideal. With the switch unshorted the camera output is seen, and by successively shorting and unshorting, adjustment can be made until there is a minimum of difference between the two conditions.

Care must be taken not to confuse shading and tracking errors. There should be no colour change as the lens iris is opened up or closed down.

The setting of picture black levels is extremely critical. They are first set to be approximately the same by examination of the waveforms, and with the tubes correctly exposed to just below the 'knee' the gains are set to give 0·7 volt on the white, 60 per cent reflectance step of the grey scale, which has a contrast range of 20:1. Over this range the chosen exponent of the contrast law correction circuit was about 0·55 and with the addition of a small amount of 'lift' (in this equipment the 'lift' operates before contrast correction) the black step of the grey scale was brought to 0·16 volt. A large number of experiments with other contrast laws led to the conclusion that this was the best compromise for subjectively pleasing results and there is some satisfaction in the knowledge that the transmitted contrast law was quite close to the desired theoretical value over a range of picture contrast of 20:1.

A practical difficulty in this objective method of achieving the desired contrast law and colour balance lay in the measurement of the small voltage representing picture black, particularly in the presence of noise. Nevertheless it is to be preferred to the setting of camera picture black on the colour monitor whose own black level was equally difficult to set.

Variation of 'sit' varies saturation and colour balance, flesh tones tending to become red as the 'sit' is reduced. The 'master sit' control can therefore only be used for 'effects' to a very limited extent if at all. It can sometimes be reduced slightly to counteract the effect of 'flares' which tend to sit the picture up, but if practicable it is much preferred to leave this control set and to eliminate the flare.

4.3 *Alternative and Preferred Camera Tube Electrode Potentials*

The camera control unit provided a ready means of setting the target mesh potential to a preset voltage of about 2 volts above the target cut-off voltage. It has been suggested that improved linearity of signal output and colour purity result from raising the target (mesh) operating voltage to approximately 4 volts above cut-off. This could increase the effective sensitivity of the camera, since on increasing the target mesh voltage the tube output increases and beam limiting occurs. If, now, the output is reduced to the correct level only by reducing the exposure, i.e. stopping down or reducing light levels in the studio, an effective increase in sensitivity has been obtained. However, experience showed that this mode of operation was undesirable since on the several occasions when it was tried, the pictures so obtained always suffered from poor signal transfer matching and shading errors were pronounced.

The beam focus control originally gave a range of volts from below 100 volts to above 240 volts, giving three nodes of focus at or about 110 volts, 160 volts, and 220 volts. The 110-volt node gave noticeably worse definition and for this reason the range of control was reduced to 150 to 225 volts. There was little to choose between the 160-volt and 220-volt nodes on most tubes although the 220-volt node gave better separation between dynode focus and target focus on some tubes without the field mesh.

The potential of G3, the so-called multiplier focus, which controls the collection of secondary electrons at the second dynode, is set in the initial setting-up of the tube to give maximum output, but is finally adjusted to give the best results from the point of view of shading, which is also influenced by this electrode potential.

The range of potential provided for G5, the decelerator, is from 0 to 95 volts; there are conflicting requirements in the setting of this electrode. In order to avoid burning the dynode surface, it is desirable to scan as large an area as possible and this requires a high voltage. On the other hand, shading is worse at high voltages and, in the case of the R.C.A. tubes which have no field mesh, a high voltage also tends to keep the dynode in focus. Thus, a compromise must be achieved and, because adjustment of G5 potential also affects geometry at the corners of the picture, an alteration on one tube has usually to be followed by a similar alteration on the other two.

Alignment was adjusted with a modulating waveform superimposed on the beam focus potential and was not normally readjusted to correct shading errors.

The beam current control originally provided was extremely coarse and derived its potential from a very high impedance source; consequently slight changes in tube insulation which occurred from time to time caused appreciable beam current variation. In order to minimize this a low impedance source was provided and the control was made much finer. The beam current was so set that when the tubes were correctly exposed to a 60 per cent reflectance white the current was just sufficient to discharge the target. This ensures that no highlights extend around the 'knee' and highlights all limit at the same level on all tubes.

4.4 *Mixing and Monitoring Arrangements*

There has been considerable discussion as to the relative merits of providing an encoder for each picture source or a single encoder after R.G.B. mixing. The disadvantage of mixing and cutting of the three R.G.B. signals is that the gain, tracking, and terminations must be the same for all three channels and for all sources. Very slight drift in gain or variation of termination of any one channel can cause a change in colour balance and upset matching between sources. For previewing, extra distribution or bridging amplifiers are required and these must also match the transmission channel for gains and termination, etc. In a large installation the number of such amplifiers could be quite high. If previewing is R.G.B., then errors due to coding are not seen until they appear on transmission. If previewing via an additional coder is provided, then the need to match coders, which R.G.B. monitoring is intended to avoid, is again present and it is usual to provide at least two preview channels if not permanent previewing of all sources. For these reasons, all the sources were provided with individual encoders prior to mixing.

The mixer used at Alexandra Palace was a standard eight-channel unit used without a line-clamping amplifier and fed with composite coded signals from each source. In order that fades to black could also be made, one of the eight channels was fed with 'syncs. and burst'. Thus in order to maintain the proper picture/sync. ratio it was necessary to fade up a second channel as the first was faded down. This was sufficient for many pro-

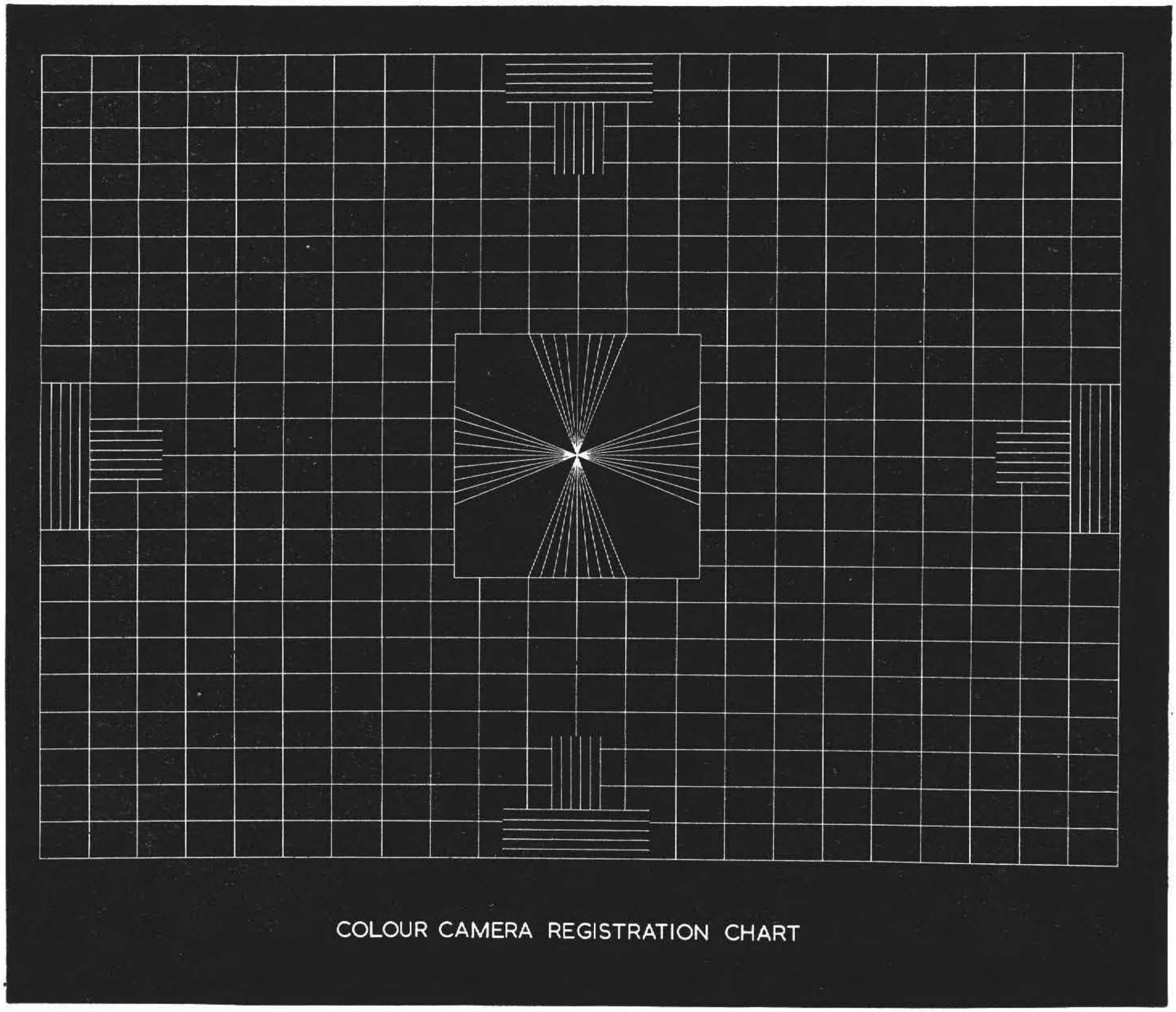


Fig. 5 — Test chart

grammes but it was not possible to superimpose two channels which required full modulation from each as, for example, in a vignetting technique, because the resulting double-amplitude colour 'burst' would have operated the chrominance automatic gain control circuits of receivers and reduced the saturation accordingly. This multi-channel mixing technique proved reasonably satisfactory for the very simple set-up at Alexandra Palace but it is doubtful whether multi-channel mixers would be practicable for a large-scale studio. Certainly, the two-sided mixer of the so-called A/B type presents a much simpler technical problem.

Four colour monitors were used at Alexandra Palace, one in the telecine room, one R.F. monitor in the control room to check transmitted pictures, and one 'transmission' monitor tied to the output of the mixer and one preview monitor. These last two could accept either a composite coded input or an R.G.B. input. This latter feature enabled camera adjustments to proceed independently of the coders and permitted accurate matching of cameras before coding and then gave a check on the coder line-up when switching to the coded input.

Since for many sequences only the two studio cameras were in use, an 'automatic' position was provided on the preview selector and this automatically switched the camera not on transmission to the preview monitor.

A black-and-white transmission monitor was also provided in order that a check could be kept on the compatible black-and-white picture.

4.5 *Test Charts*

For registration a black 'grille' pattern on a white background was originally used. However, the beam pulling which occurred (in 6474 tubes) caused the resulting registration of pictures to be not so good as it had appeared on the chart. Whilst beam pulling varies with picture content there will always be some 'dynamic' misregistration, but a better compromise between registration chart and average pictures was obtained when a grille of white lines on a black background was used. Since registration at the centre is all-important, a finer grille was required there and it was likewise desirable at the sides where most misregistration was likely to occur. Fig. 5 is a photograph of the test chart which was finally evolved.

The only other test chart used regularly in the studio was the RETMA logarithmic grey scale which was a 20-in. by 16-in. chart having ten neutral chips in equal brightness steps; the reflectance of the 'white' step was 60 per cent and the contrast ratio between white and black 20:1. It had two horizontal rows of these grey scales with the white of one scale vertically above the black of the other so that allowance could be made for the effect of shading across the picture.

The grey-scale test chart must be evenly illuminated at the same lighting level as the set and with light of the same colour temperature; this illumination was found to be best provided by two 'scoops', providing light from both sides of the card at an angle of incidence of 45°.

4.6 *Use of a Live Model for Camera Matching*

When the cameras have been lined up as detailed in section 4.2, they are finally panned on to a live model, sitting in the set, correctly illuminated and correctly made up to make possible an assessment of the accuracy of line-up that has been achieved. A live model was used since the successful reproduction of facial tones is the most critical task of any colour system and it is essential to check the system by a test no less critical than the one by which viewers will judge it. Colour photographs and similar test objects proved comparatively uncritical, admitting relatively large errors. The pictures from the cameras were viewed in turn on one monitor and if the pictures did not 'match', then one or both were panned back on to the RETMA reflectance chart and the last part of the colour balance and level setting procedure repeated. It was sometimes found that slight shading errors produced a greater variation in matching than had been anticipated and it was then necessary to adjust shading to move the error to a different part of the picture. It is very easy to confuse differences in backing and lighting angles, due to different shooting angles, with matching errors. To avoid this pitfall the cameras should be as close to each other as possible and using the same taking lens angle for matching. In use, of course, this seldom, if ever, occurs and the matching between cameras was often wrongly criticized because of this rather than because of actual matching errors. The temptation to improve matching between cameras by means of the 'master sit' control must be resisted; in the end experience has shown that better results are obtained by as strict an adherence to objective measurement as is possible. The use of a live model is a sensitive test; it should not be used as a means of adjusting the cameras by subjective guesswork.

4.7 *Major Difficulties and Deficiencies of Colour Cameras*

Although it might be thought that the large size and weight of the colour cameras (about 450 lb with lenses) would be major disadvantages, this did not in fact prove to be so. The special heavy-duty mountings and the counterbalancing provided to give easy and controllable panning and tilting made possible all normal camera movements with an ease that was superior to that experienced with many lighter cameras. However, rapid movement of the cameras around the studio sometimes presented difficulties and occasionally it was necessary to provide the cameraman with assistance for tracking shots.

An operational difficulty of the camera to which attention has already been directed lies in the difficulties experienced with the viewfinder, the fixed position of which is a disadvantage, particularly for short cameramen. It is suggested that the viewfinder ought to be capable of being tilted relative to the main body of the camera. The picture displayed on the viewfinder is not of sufficiently good quality for use in studio programme work due to its being produced by a signal which is derived directly from the camera head amplifier, whereas it should undoubtedly be taken from the fully corrected signal available at the output of the camera control unit.

Turning now to the electrical deficiencies of the camera performance, it will be clear from what has already been said that in no single respect is the camera entirely satisfactory. As is shown by observers' reactions, however, the worst feature is undoubtedly the failing to achieve registration over the whole area of the picture. It is likely that some of the criticism of colour fringing which is levelled at the camera is unjustified since colour receivers using the shadow-mask tube suffer from the same form of distortion particularly at the sides of the picture, where the camera is also usually at its worst. Moreover, the whole of the apparent misregistration produced by the cameras is not due to lack of geometrical perfection in the registration process; some is undoubtedly due to 'edge' effect which varies with picture content. However, effects other than geometrical misregistration which have a similar appearance only make more important the maximum possible precision of performance in this respect.

Next in order of importance is undoubtedly the inability to correct shading signals sufficiently accurately; the solution to this problem is probably mostly in the hands of the tube manufacturers.

The signal-to-noise ratio of the cameras is not adequate, particularly when combined with the poor inherent resolution of the tubes, and very little can be done to equalize the response by normal techniques. It should be borne in mind, moreover, that even if the horizontal resolution could be restored by equalization, the inherent loss of vertical resolution cannot so be equalized.

The lack of sensitivity is a nuisance as it necessitates the use of high lighting levels in the studio but improvements in this respect would not be seen in improved picture quality except in respect of increased depth of focus. Improved sensitivity would, however, gladden the heart of the programme producer precisely because of the better depth of focus, lack of which is an embarrassment to him at the moment.

Stability of performance is a difficult problem in any camera equipment but it is particularly so for a colour camera where any relative drift between the three channels is immediately obvious. A slow deterioration in the quality of the picture was visible over a period of some hours, not all due to the camera but, nevertheless, with reasonable attention, the stability of performance of the equipment was adequate.

To sum up, experience seems to indicate that improvements to camera performance are required in the following order of importance:

1. Registration (all causes).
2. Shading.
3. Signal-to-noise } Allied problems to some degree.
4. Definition }
5. Sensitivity.
6. Stability.

In Monograph No. 18[1] it was suggested that the difficulties due to poor resolution and shading signals would be greatly reduced if 4½-in. image orthicon tubes were used in the colour cameras. Later experience has reinforced this view, and also supports the belief that the apparent misregistration due to beam pulling and edge effects would be reduced if this type of tube were used. It is considered important that a colour camera using 4½-in. tubes should be tested when an opportunity presents itself.

4.8 *Studio Lighting*

Lighting for colour television has to meet three principal requirements:

(*a*) *A High Level of Intensity*
This arises from the inherent insensitivity of the colour camera.

(*b*) *Even Illumination over the Scene*
Matching of cameras has to be of a higher order than that required between monochrome cameras because the eye is

a more sensitive detector of hue than of brightness changes. As described in section 4.2, the electrical matching of cameras is obtained by a process of adjustment based on objective measurements. Once the controls are set, it is most undesirable to alter them, even the iris, and for this reason the lighting on the set has to be extremely even so that mismatching is not introduced by conditions external to the camera.

(c) *Uniformity of Colour Temperature*
Unlike the human eye, which adapts its assessment of colour of known objects so that the latter appear relatively constant in hue despite considerable changes in the colour of the illumination, the colour television camera has a non-adaptable process of analysis of the spectral reflectance of a coloured surface and movement within the set of such a surface must not change its spectral reflectance if the colour of the surface seen through the system is to remain constant. This is, for example, very important in respect of human faces in the scene; a change of colour appearance in the face of an actor as he moves about the set is obviously not generally acceptable. It is therefore of importance that the spectral composition of the incident light (i.e. its 'colour temperature'), which determines the spectral reflectance of coloured objects and surfaces, should be uniform over the acting area and for different viewing angles of backgrounds and settings.

4.8.1 *Level of Illumination*

For a camera having a set of pick-up tubes of average sensitivity, an incident scene illumination of 350–400 ft candles is adequate for satisfactory exposure at f/5·6. Obtaining this level with available equipment presents problems of its own. Lamps have necessarily to be closer to the subject; several lamps are required to cover an area where one would be sufficient in a monochrome studio.

Settings should be limited to a maximum contrast range of 25:1, and for preference should be restricted to 15:1. In practice a key-to-filler ratio of 1·5:1 has proved satisfactory where frontal keying can be employed, but where this is not possible it is necessary to increase the amount of filler light, resulting in a final key-to-filler ratio of approximately 1·25:1. Backlight intensity is purely dependent on the subject and it is essential that all areas are adequately backlit. Without backlight the colour picture loses sparkle and when viewed in monochrome results in a very flat picture.

4.8.2 *Evenness of Illumination*

To achieve even illumination it is necessary to know the exact action on the set and all levels must be set with an incident light meter. It is advantageous to set the levels of key, filler, and backlight separately, and it is essential to prevent backlight from combining directly on the subject with the key light. It is necessary to make extensive use of filters on individual lamps to achieve the required close control of illumination.

4.8.3 *Colour Temperature*

The colour temperature of all light sources should be checked and maintained at 3,100°K and colour-corrected soft light sources must be used. A variation between sources exceeding 100°K will introduce colour distortion but even this small range allows a limited but useful amount of dimming to be exercised assuming all sources to be uniform. With a nominal 115 volt supply, the permissible 100°K reduction in colour temperature is produced by a 9 per cent drop in voltage, and this is adequate for balancing and a limited degree of effects. Where differential lighting can be employed between acting areas and the set walls the illumination on the walls can be dimmed to a much greater degree than normal, provided no objects of a known colour are affected. The use of sources with different spectral compositions is only possible when used for effects purposes. Coloured light obtained by the use of filters is very useful for illuminating sky cloths, etc.; surfaces illuminated in this way should be white in the interests of efficiency as the light transmission characteristics of coloured filters are poor.

Provided the lighting requirements are met and full co-operation is forthcoming from the production staff, good colour pictures are obtainable. High key lighting produces the best results; low key lighting is far less predictable and tends to give muddy reproduction.

4.8.4 *Xenon Lighting*

Xenon lighting, which has a colour temperature of about 6,500°K, was tried experimentally, and with this, as with daylight, there is much more blue and less red light than with studio lighting at 3,100°K. Thus it is necessary for the most sensitive camera tube to be inserted in the red channel instead of the blue, and the colour balance of the camera must be set for this higher colour temperature. When this was done the gain in sensitivity was less than half of one lens stop. Xenon lighting is more costly than standard incandescent lighting and relatively complicated starting gear is required. When run off a.c. the lamps are noisy, only a limited range of illuminators was available, and the larger-size lamps required water cooling. A great deal of ultra-violet radiation is produced by these lamps and therefore U.V. filters must be used. In short, the disadvantages greatly outweigh the slight advantages.

4.9 *Use of Back Projection*

No unexpected problems were encountered in the use of back projection. Generally, the increased light level required means that with currently available projectors a smaller screen size has to be employed. A level of about 400 ft lamberts is required, and this gives a maximum screen width of 6 to 8 ft with yellow flame (colour) carbons in the projector running at 160 amp., and with 4 ft lamberts of spill light falling on the screen. The problem of spill light falling on the screen is greater in colour than in black and white, since much higher light levels are used. Some improvement might be effected by the use of more directional screens, but these would aggravate the degradation of picture caused by deviation from a 'square-on' shot, and even with standard back projection screens, matching is almost impossible when two cameras are looking at the screen from widely different angles.

Experiments were carried out using normal arc carbons and colour-correcting filters, and yellow flame (colour) carbons. The latter were found to give the better results but no tests were carried out on the colour balance of the slides used and it might prove practicable and more efficient to colour balance the slides for the normal 'blue' carbon. This would, of course, necessitate slides being specially prepared but this is likely to prove necessary in any case because the majority of 'stock' slides available proved to be unsuitable for one reason or another.

5. Programme Experiments at Alexandra Palace

5.1 *Introduction*

The transmission schedule for the 1957–8 series of experimental studio transmissions allowed the production unit to devote every fourth week to closed-circuit tests and experiments. The unit's brief was primarily to provide material which would enable the BBC Engineering Division to assess the capability of the colour system in producing consistently good quality colour and compatible black-and-white pictures under everyday programme conditions. Its secondary purpose was to study, as far as was practicable, in a form conditioned by the engineering tests, the problems of production colour. In practice, an experimental programme would reveal a particular difficulty which might be overcome at the time, or might be 'side-stepped' for the purpose of the transmission. A solution to the underlying general problem would be sought during a subsequent closed-circuit period. If found, the solution would be verified in the course of the next transmitted programme.

5.2 *Advantages or Otherwise of Colour for Various Types of Programme*

Subjective opinion must play a leading part, if not a solo role, in any assessment of colour as one of the many ingredients which go to make up a particular television programme. It was almost inevitable that most members of the production unit started with the issue, to some extent, pre-judged. Having seen colour films and being conscious of the rarity of the successfully realistic fictional film, they summed up their view of the suitability of a subject for colour television in the two words 'travel' and 'fantasy'. It is the more remarkable, therefore, that the pendulum of opinion swung the other way, to excess at first rather naturally, but steadying with the expressed conviction that

> 'the additional reality added to the picture (by colour) was in the nature of a further dimension and that where losses had been anticipated in cases where the system failed to reproduce accurate colour, these were, in fact, more than offset, leaving, in all but the most distorted instances, a very fair gain and, in the best instances, a most valuable asset.'

The traditional disadvantage of any television system, from the producer's point of view, lies in the fact that the viewer 'processes' his own picture, and this is increased in colour television. As well as setting brightness and contrast (beam current and gain) correctly, he is now required to control hue and saturation (sub-carrier phase and chrominance level). A 'realistic' colour picture depends on a restrained use of colour. Excessive saturation can make colour dominant and thus destroy or reduce the appearance of reality.

Colour is a clear, proven, and undeniable asset on the one hand where 'fantasy' and 'glamour' are concerned and, on the other, as an aid to exposition and demonstration. In both cases, it is possible and necessary to employ a relatively simple production technique and results can be remarkable. Between these two extremes, in the area of the realistic dramatic production, with its traditionally more complex studio techniques, colour must be subordinated to a point at which, at first sight, it is of little artistic value. This appearance is, however, deceptive. A glance at the compatible black-and-white picture shows that truly unobtrusive colour does add a quality of reality. This may in part be due to the internal illumination of the colour tube which results in a luminosity not encountered in other media.

5.3 *Range of Suitable Colours*

In view of the need to assess pigments and materials in terms not only of the colour, but also of the compatible picture, it was decided to attempt to establish a 'palette' on which designer and wardrobe supervisor could work. The Munsell notation of colours and neutrals was chosen. The Munsell grey scale ranges from 0 (nil reflectance) to 10 (100 per cent reflectance). Colours of the same reflectance will have the same value; thus, for example, neutral (grey) 7 has the same total reflectance as a red, value 7, in this case 44 per cent. Although the compatible version of the coloured scene is not fully panchromatic, experience has shown that the range of suitable colours need not be restricted on this account.

The colour camera, as at present lined up, will accept a contrast range in neutrals of from 3 per cent reflectance to 60 per cent reflectance. This approximately corresponds to Munsell values 2 to 8. The seven steps of the wedge included between these have been found to provide a convenient range. Colour television white has been established as Munsell N.8 (57·6 per cent reflectance). Nothing 'whiter' than this can be used in the colour studio.

Although the overall reflectance of a colour (with a given hue and value: Munsell scale) may be stated as a percentage figure, an individual primary component of this colour may exceed this reflectance where colour is heavily saturated or of a high value. As a result the corresponding pick-up tube in the colour camera will be made to operate at a point above the straight line of its characteristic. The three tubes no longer 'track' together and colour distortion is introduced.

The lightest colours which may be used have value 7. In some cases of deep saturation, value 6 is the upper limit. This has been established both theoretically and by experiment. At the other end of the scale, N.2 (3 per cent reflectance) is the C.T.V. black. In theory, colours of value 3 are the darkest which should be used, but, in practice, there are anomalies and it would appear that there are factors involved which have not yet been identified. As a working rule, colours below value 5 should be scrutinized before use.

At present, in the black-and-white service, painters are limited to a range of seventeen colours. It was considered that this would have to be increased for C.T.V. but that the increase should be kept to a minimum to simplify colour operation. An attempt was made to limit the number of C.T.V. colours to twenty-five. Five basic groups of colour were chosen, equally spaced around the Munsell hue circle, red, green, yellow, blue, and purple, and, to provide a selection of hue, four variations were selected in each, 2·5, 5, 7·5, and 10. The third and fourth variants, value and saturation (in the Munsell notation chroma, the 'strength' or 'intensity' of a colour), could only be provided, while limiting the total to twenty-five, by selecting shades and intensities which appeared to be most useful in themselves and offered the greatest flexibility in total. The intention was to provide the ideal requirement in terms of hue, value, and chroma according to which might be the most important from the designer's point of view. For example, the five colours in the red range are: 2·5R 5/6, 5R 3/10, 5R 7/4, 7·5R 6/8, and 10R 4/4.

In order to provide additional points of reference for the scenic artists, who are not restricted in their use of colour, twenty-five intermediates were selected on the same basis in the ranges yellow/red, green/yellow, blue/green, purple/blue, and red/purple.

The proposed 'palette' was evolved in the course of the 1957–8 studio experiments and has not yet been adequately tested under operational conditions. Some modification and adjustment may well be required in the circumstances of regular production.

5.4 *Subjective Effects of Errors in Colour Matching*

The eye is not, in general, very sensitive to errors of absolute hue, but will detect slight differences of hue as shown by two cameras holding the same subject in successive shots. Not only do the cameras need to be precisely matched, but the incident angle of light may be of importance where large uniformly coloured areas of low value but relatively high saturation are concerned. A series of experiments in which a colour 'chip' was placed in front of the camera and illuminated under correct conditions of light intensity and colour temperature, while an identical 'chip', also correctly illuminated, was compared with the result on the monitor tube, yielded results which suggest that

(*a*) there is evidence of inaccurate reproduction of colour particularly in the red and cyan ranges;
(*b*) this deviation from the original is, with present equipment and practices, consistent and therefore manageable, although varying in degree around the hue circle;
(*c*) a colour may be incorrectly reproduced because of hue changes; and
(*d*) a colour may be incorrectly reproduced because of saturation changes.

It was found that most colours tend to desaturate through the system. The extent of desaturation varies with hue. This, however, does not offset the tendency of any colour system to appear to intensify colour when compressing it within a small area.

There are, undoubtedly, other factors, both physiological and electronic, which are operative and a mis-match in the red range may be more distressing to one observer than to another whose sensitivity would appear to be greatest in, say, cyan.

5.5 *Relation of Production Lighting and Camera Angle*

5.5.1 *Clock Face Experiment*

The intention of the production unit in mounting the experimental programmes was to seek to retain the full value of light and shade in colour pictures. The exchange of well-lit three-dimensional black-and-white pictures for flat two-dimensional colour pictures was to be avoided.

In the course of the test transmissions, difficulties were encountered with the cameras in the 'cross close-up' position. This arrangement, in which two cameras take complementary 'over-shoulder' shots of two people and may be shooting simultaneously on the same subjects from positions separated by as much as 170°, is commonly encountered in dramatic production. If the circumstances of the scene dictated a relatively marked contrast between highlight and shadow and, at the same time, there was a difference in value of the flesh tones of the two subjects no greater than that, say, between a fair-skinned female and a sun-tanned male, acceptable pictures were sometimes unobtainable. The immediate solution was to reduce the highlight/shadow ratio of the lighting to a disappointingly low value or to abandon the cross close-up camera position.

A 'clock face' experiment, in which two subjects were placed at the centre of a dial marked on the floor with three camera positions at '3.45', '6.00', and '8.15', indicated that the incident angle of the key or modelling light must be between 4.00 and 8.00 if an appreciable contrast between highlight and shadow is to be satisfactorily obtained. Unfortunately this 'down-stage' approach is shared by the boom microphone in practice and very careful planning and rehearsal are required in order to avoid microphone shadows under operational conditions.

5.5.2 *Colour Temperature*

The acceptable limit of variation in colour temperature between one light source and another appears to be of the order of 200°K. Contrary to previous reports a difference of 200°K between key light (3,100°K) and filler (2,900°K) was clearly apparent on the screen. The variation in reproduced flesh tone —this is usually the most stringent test—was quite tolerable, but the result was marginal in the green/yellow range.

5.5.3 *Coloured Lighting*

There is no technical problem in the use of coloured lighting on backgrounds either stylized or realistic. It is purely a matter of artistic taste and judgment. Where the subject is to be lit with coloured light, however, there is a risk of the viewer mistakenly trying to 'adjust out' the colour on the face. The basic requirement, therefore, is that the reason for the coloured light source shall be obvious—pink and blue spotlights on a variety stage or yellowish candle-light shining out from a window perhaps. Greater difficulty was encountered from 'unexplained' reflections on the face from a brightly coloured surface which was just out of picture. It was then necessary to include the reflecting surface in the shot or to move the subject to a greater distance from it.

Arc light was successfully used as backlight in the correctly 'artificial' circumstances of the scene.

5.6 *Scenery and Settings*

With few exceptions the substantially pastel (desaturated), often monochromatic, setting gives the most pleasing results, and sets off performer and costume.

Generally the temptation to exploit colour as such can only lead to detraction of interest from the artist or subject of the shot. Colour on the artist's face or on the subject is the strongest asset in the degree of reality that it adds. Strong colour elsewhere in the picture is a potential danger unless it is closely watched in all circumstances. Strong artificial colour should only be used where its inclusion in the picture is designed to focus attention for production reasons. Any attempt to contrast the focal interest against a mass of colour by presenting it in neutral values can only succeed where lighting assists to give it complete dominance.

On the other hand, natural (as opposed to man-made) colours, such as green leaves, polished mahogany, and so on, can be quite intense in the background without detracting from the foreground subject of the shot.

The selection of already coloured materials, such as soft furnishings, is therefore more critical and time-consuming than is necessary for black-and-white production where textiles are comparatively 'versatile'. In particular, upholstery and cushions require great care in their choice because they will lie in the subject plane in the picture and be lit by the subject lighting.

5.7 *Costume*

The range of usable colours as in the case of set design should be restricted to the Munsell values 3–7. Colours should not be used in value 8. This is a restriction in the choice of women's clothing. Highlights on the shoulders are the primary danger point when pale shades are used. It is an unhappy fact that only in the most expensive garments and materials is there adequate choice in the most useful colour range (4–7). Less expensive clothing tends to be made in a more limited and crude range of colours and in the more washed-out and pale colours (value 8 and above).

The close co-operation between designer and costume supervisor, so desirable in black-and-white production, is absolutely essential when colour is involved. In some cases costume may be the starting point of the overall design and in some cases the setting itself, but, whichever way it goes, complete co-operation is essential. The selection of men's clothing can be of importance because of the need to use values 4 and above whenever possible, which brings even the so-called 'unobtrusive dark suit' within the critical range.

5.8 *Make-up*

Colour make-up is in general required to be rather more subtle and life-like than that for black and white, largely owing to a greater awareness of anything unnatural in the increased reality of the colour picture provided. If the operational conditions are correct very little make-up is required. Occasionally a rather thicker make-up will help to offset an off-peak performance of the equipment. There are, however, cases of abnormal skin coloration (red or pale) and excessive contrasts between artists appearing together which have to be dealt with as special cases.

Foundations should follow artists' own colouring in order to retain individuality, but should be slightly darker in most cases. Women's arms and necks need make-up unless the necessary slight darkening is present owing to natural suntan.

Although red skins reproduce badly, complete obliteration in the case of men produces an unpleasant mask-like effect. It has been found better to apply the make-up only on the more highly coloured areas and this must be checked both on the colour monitor and in the compatible picture.

It has been noted that excessive acidity in the skin can, after a time, affect the make-up and necessitate complete removal and reapplication.

As far as make-up is concerned, there appears to be a tendency towards a blue emphasis in the system. This necessitates the reduction to a minimum of eye-shadow and confinement to the true-red or orange-red ranges in lipstick. These should not be darker than Munsell value 5, if the mouth is not to appear to have a fuzzy edge. It is most important that lipsticks are checked on the compatible picture.

There is no doubt that the traditional 'milk and roses' English make-up makes the most stringent demands on production lighting. Variations in light level which may be unnoticed on a brown suntan make-up will cause the lighter face to appear magenta in some circumstances.

5.9 *Direction*

5.9.1 *Planning*

Pre-planning of a production is of crucial importance in colour. It must be more accurate and must be adhered to more rigidly than in a comparable black-and-white programme. Camera angles and other lighting information must be clearly defined beforehand because the much heavier lighting rig requires accurate setting up by means of some form of light meter. Consequently, both mis-information and change of plan take correspondingly longer to deal with in the studio.

5.9.2 *Pictorial Composition and Technique*

It seems that well-composed pictures in colour appear right also in black and white. The responsibility in this respect fundamentally lies with the designer, because it is obviously possible to produce a highly coloured picture in which luminance is constant, and which therefore would produce a blank screen on the compatible monitor. More practically, it can happen that dominant colour in one area of an otherwise fairly neutral picture will produce a good colour picture, but an unbalanced black-and-white composition. Fortunately this does not seem to occur very frequently in the normal course of studio operation unless it is deliberately aimed at. It is also fortunate that the necessity to produce an acceptable compatible black-and-white picture, as well as the colour picture, does not appear to lead to any significant practical difficulties in the composition of the scenes presented to the camera. Occasionally, the black-and-white picture conveyed a more intensely dramatic impression than was intended and in particular, it was found that a blue background which seemed quite gay in the colour picture, was more sombre in the black-and-white picture.

5.9.3 *Cutting and Mixing*

Again in the normal course of events there does not appear to be any difficulty in cutting from one colour picture to the next. A cut from a bright background of all one colour to another of a different colour is, of course, a violent shock, but if the colours in the two pictures are reasonably distributed around the colour circle, a change from one predominant hue to another appears to be quite acceptable. A great change, however, of brightness of background on a cut is, if anything, even more distressing than in black-and-white operation.

Slow mixes and superimpositions can be used with complete success. There is no mixing together of the actual colours in the two pictures so as to result in a third unrelated colour. The superimposed pictures are held quite separate in the viewer's mind and so also are the colours associated with them.

The colour frame contains more information than a monochrome frame, therefore the very short 'flash' may not give sufficient time for assimilation and, as a corollary, all shots can be held longer, if desired, without loss of interest. A singer, for example, can hold the attention without the cuts which would normally be used in black and white to maintain visual interest.

5.9.4 *Definition*

The reduced definition of the present colour system as compared with normal black-and-white operation makes it desirable to aim at a generally 'closer' technique. It is important to make good use of close-ups and in general all shots should be about 15 per cent 'tighter' than in a corresponding black-and-white production. Long shots should be carefully composed and 'held' for a shorter time than is possible in black and white. It appears to improve matters if the lighting is fairly contrasty on the more distant figures.

5.10 *Rehearsal-to-Programme-Time Ratio*

A considerable increase in studio time will be required during the introductory stages of a regular colour service. Production lighting is complex both because of the increased number of lamps required and because each requires setting with considerable accuracy. Total rehearsal time will depend on production techniques employed, which, in turn, will depend on the type of programme to be transmitted.

Modern methods of lighting control are particularly suited to colour production because it is possible to change over rapidly from one predetermined lighting arrangement to another; compromise adjustments suitable for two or more necessary conditions are no longer required. It is the compromises needed in television production that take the time. This rapid sequence of discrete, predetermined lighting arrangements is particularly suited to the light entertainment show and it is certain that the method will be developed and extended in the light of experience to cover all types of programme.

It also remains to be determined whether a change of the general rehearsal technique will produce better pictures in a shorter time. At present, the tendency is to achieve a rough approximation of the complete programme first and then gradually to polish by a series of repetitions. The alternative, known in the United States as 'blocking out', is to take considerably longer over the initial process giving each section a fair degree of polish before proceeding to the next.

The former method is preferable from the point of view of artists and performers, the latter is probably preferable from the point of view of studio technique. It is to be expected that the ultimate solution will be a compromise between the two.

Unless and until colour cameras become as sensitive as black-and-white cameras, it is inescapable that colour production will tend to take more time. Experience and modern methods, however, should rapidly reduce the difference to a practical level.

6. Transmission by Cable and Radio Links

The adoption of the N.T.S.C. system in the United States, where transmission distances are, of course, very large compared with those in this country, was a reasonable assurance that the signal could be transmitted by existing cable and radio links without the need to modify them in any drastic way. The question of whether the links in this country could similarly carry the adapted N.T.S.C. system was naturally of interest to the BBC and the major portion of the transmission network was tested with a view to finding out its performance in this respect. A certain amount of transmission equipment used for setting up temporary outside broadcast circuits was also investigated. So far as its operation is concerned, the network must also be considered to contain the amplifiers used in the internal distribution of the signal at studio centres and at switching centres.

6.1 *Transmission Characteristics Affecting Quality of the Signal*

In addition to the transmission characteristics which have an effect on the luminance signal in precisely the same way as they would on a normal black-and-white signal, there are other characteristics of which no account is normally taken for monochrome transmission, and, in addition, certain of the characteristics of monochrome transmission have to be looked at from a slightly different point of view. The principal characteristics of the latter type are:

(*a*) *Amplitude-Frequency Response*

Variations in that part of the amplitude-frequency characteristic towards the cut-off of the system are not very critical in normal monochrome transmission. Indeed, for some time the trend has been towards ceasing to specify this characteristic at all and to use in its place waveform response specifications. The one remaining control on the amplitude-frequency characteristic is a specification of the total amount by which the amplitude-frequency characteristic can rise at its upper end as compared with the response at low frequencies, with the sole intention of preventing overload, and accentuation of noise components. The present specification (see Appendix A) states that the colour sub-carrier shall not deviate by more than 20 per cent from its nominal value and it will certainly be necessary to maintain the response on an individual link to a much higher order of accuracy, because of the number in tandem. In the United States the specification of chrominance-to-luminance ratio has, in fact, been tightened to 10 per cent deviation from the nominal value and there is every reason to think that this tighter specification would be necessary in this country. The amplitude-frequency characteristic therefore, at least in respect of chrominance-to-luminance ratio, will be of increased importance as compared with monochrome working.

(*b*) *Delay Frequency Characteristic*

As with the amplitude-frequency characteristic, this is no longer used as a specification of performance of transmission links since it is one of the factors which are taken into account in the waveform method of measurement. However, as seen on the reproduced colour picture, delay distortion can cause displacement of the chrominance information with respect to the luminance. The specification referred to above states that variation in the displacement of the chrominance signal with respect to the luminance shall not exceed 0·07 μsec. Moreover, the delay distortion occurring within the chrominance band, which occupies the frequency spectrum of approximately 1·5 to 3 Mc/s, will have a different order of importance for colour than for monochrome.

(*c*) *Signal-to-Noise Ratio*

The signal-to-noise ratio of the circuits could have a significantly different effect on a colour signal than on a monochrome one. In the case of the latter, a noise-weighting network is used for specification and measurement so that the higher-frequency components in the spectrum of the noise are given less weighting than those at lower frequencies. This is because it is generally considered that the higher-frequency components, which give the noise a finer structure, are less visible on the picture. In the case of a colour signal, the noise occurring within the chrominance band eventually appears after demodulation in the chrominance detector as low-frequency noise. This noise is of much coarser structure than the original fine-point noise from which it is derived and accordingly could be more visible, although this factor is mitigated to some degree by the fact that in theory the chrominance components do not contribute to the luminance of the displayed picture. In practice, the necessity to use 'gamma' correction seriously interferes with the validity of the constant luminance characteristic of the N.T.S.C. system. Whatever its degree, therefore, it is likely that signal-to-noise ratios having a different specification will be required for colour as compared with those for monochrome transmission.

The two transmission characteristics which are uniquely important for colour signals are:

(*a*) *Differential Linearity*

This term has come into use to describe the effect of the change of gain of the system as the amplitude of the luminance signal varies. The present specification states that the gain of the overall system shall be constant for any level of the luminance signal to within ±20 per cent. In the United States this tolerance has been reduced to ±10 per cent, and there is no doubt that this tighter tolerance would also be necessary here. Transmission links and equipment which had been designed before a colour system of this type was concerned obviously had taken no account of this form of non-linearity at the upper end of the frequency spectrum, although non-linearity at lower frequencies had always been an important consideration. The performance of an existing network in this connection therefore required examination.

(*b*) *Differential Phase*

The chrominance sub-carrier of the N.T.S.C. system is also modulated in phase, and to a first order of approximation it may be said that the hue of the reproduced colour is determined by this phase relationship. The phase angle of the system can vary in a manner analogous to the way in which the gain varies as the amplitude of the luminance signal changes. This effect has been called differential phase distortion and is a property of the transmission system which is of no importance in monochrome transmission. It is, of course, a parameter of the greatest importance for colour transmission.

6.2 *Video Amplifiers and Transmission Circuits*

The video amplifiers which were in use in BBC studio centres, switching centres, and on such local transmission circuits as were set up by the BBC for its own use on pairs rented from the Post Office, were all of a similar type and were designed around the well-known 'feedback triple'. This consists of two stages of gain and a cathode follower, the feedback being taken from the final cathode to the cathode of the first amplifying stage. The two gain stages used high-frequency couplings of staggered time constants so that the feedback was beginning to fall off rather rapidly at the colour sub-carrier frequency, a condition which is unfavourable for the avoidance of differential phase distortion. In fact the differential phase distortion of these amplifiers varied a little from type to type but generally was of the order of 1°. This amount of distortion is inadmissible in amplifiers employed in considerable numbers in series in a complex distribution system such as is used by the BBC. Accordingly, the design of a new series of amplifiers, which was about to be undertaken when these investigations were made, took the requirements for colour transmission fully into account and the new amplifiers have a differential phase distortion of less than 0·1°. A number of experimental models of the new amplifiers were available for the series of tests beginning in the autumn of 1957 and since that date, the video equipment and the transmission circuits which use them in the London area for the conveyance of the signals from Alexandra Palace, and subsequently from Lime Grove, to Crystal Palace, have performed well on the colour signal and present no difficulties additional to those met with in normal monochrome working.

Provided that the requirement is known at a sufficiently early stage, there appears to be no particular difficulty in designing video equipment of all kinds which performs well on the N.T.S.C. signal.

6.3 *Long-distance Cable Circuits*

The long-distance cable circuits which the BBC rents from the Post Office are of two kinds:

(*a*) A system employing vestigial sideband transmission with a carrier placed at approximately 6 Mc/s and a carrier frequency band on the cable of approximately 3–7 Mc/s. D.C. amplitude modulation is employed and normal envelope detection is used.

(*b*) A vestigial sideband transmission system employing a carrier of approximately 1 Mc/s with a carrier frequency band of approximately 0·5–4 Mc/s. A.C. amplitude modulation is employed and envelope detection is used,

This cable system, besides being used extensively for providing circuits in the London area, connects London with Birmingham and Manchester and with Bristol, Cardiff, and Wenvoe. The system was tested on a looped circuit basis. No real difficulties of any kind were encountered, the only additional correction needed being a small amount of amplitude-frequency equalization to keep the chrominance/luminance amplitude relationship within specification on some of the circuits. The signal-to-noise ratio of the longest loop circuit, that to Manchester and back, was entirely satisfactory. The differential phase distortion of this complete loop circuit, which consisted of six separate video-to-video links in tandem, was of the order of 2°; the differential amplitude distortion was quite negligible and no effects of any kind could be detected due to imperfect response in either amplitude or phase characteristics within the chrominance band. It can be concluded that the existing permanent cable network which the BBC rents from the Post Office could satisfactorily transmit the adapted N.T.S.C. system.

6.4 *Permanent Radio Link Circuits*

At the time these measurements were made, the only permanent radio link in use by the BBC was that between Manchester and Kirk O'Shotts. This link was designed many years before any knowledge existed of the requirement for the transmission of a signal of the N.T.S.C. type. The link proved to have an extremely high degree of differential phase distortion amounting to some 90°. No detailed investigation into the cause of this distortion was made but it was probably due to the lack of group delay correction on the intermediate frequency amplifiers employed at the repeater stations. In respect of other characteristics the link behaved well; for example, the circuit from Alexandra Palace to Kirk O'Shotts and back, a total transmission distance of some 800 circuit miles and employing eight video-to-video links in tandem, was perfectly satisfactory from the point of view of signal-to-noise. There is no doubt, however, that this particular radio link would require extensive redesign and modification for the transmission of an N.T.S.C.-type signal.

6.5 *Temporary Radio Links*

As in the case of the permanent radio link, some of the earlier types of portable centimetric links used for outside broadcast purposes proved to have an unacceptable degree of differential phase distortion. However, later models which had been designed with this requirement in mind were satisfactory. A typical value of differential phase distortion for these latter links was 1°. In all other respects the O.B. links were as satisfactory for the N.T.S.C. signal as they were for monochrome transmission.

6.6 *The Compatible Picture*

(*a*) *Necessity for Compatibility*

It is recognized that for a colour television service to stand any chance of success, the signal carrying the colour information must be in a form which permits the design of black/white receivers capable of giving a good quality 'compatible' monochrome version of the colour picture. Moreover, in the case of the adapted N.T.S.C. system on 405 lines, it was also required that the existing domestic black/white receivers should perform satisfactorily, without any alteration, even though their design had not taken into account the modification of the transmitted signal caused by the presence of the chrominance information. The importance of this question was shown by the fact that the first tests of the system, in 1955 and 1956, were made to establish the degree of compatibility, and as reported in Monograph No. 18, a largely satisfactory answer was obtained. These compatibility tests were mainly concerned with interference-type effects such as 'dot pattern' and 'buzz on sound' which the presence of the colour sub-carrier could cause on some receivers. In order to test the ultimate possibilities of the system, the use of pictures obtained from high-quality flying-spot equipments avoided the difficulties of registration, poorer resolution, and less adequate signal-to-noise ratios which it was expected would be obtained from the studio cameras as then developed. When, therefore, the studio cameras came into regular use, their performance in respect of these latter aspects of compatibility was observed carefully and continuously. A further possible difficulty of the compatible picture lies in the fact that with the present techniques of gamma correction, all sources of colour pictures produce a luminance signal which gives a distorted rendering of the grey scale of a coloured scene.[6] The interference-type effects of compatibility, caused by the presence of the colour sub-carrier, do not differ significantly in colour pictures from different sources and will not be discussed further in respect of the performance of the studio cameras.

(*b*) *Tonal Gradation*

The application of gamma correction to the individual red, green, and blue separation signals causes the gamma of the luminance signal to be too high when transmitting coloured areas of the picture. The magnitude of the error can be very large; for example when transmitting the red primary, the monochrome version will be reproduced at only one third of its correct brightness and the blue primary at only one fourteenth. On the other hand, the range of contrast allowed in the colour studio was lower than is normally encountered in black and white practice, and, moreover, the transfer characteristic of the colour cameras had to be carefully controlled in the interests of the colour pictures. These opposing factors appeared to combine to produce on the whole a very pleasing compatible picture so far as tonal gradation was concerned.

(*c*) *Resolution*

The resolution of the compatible picture was less than could have been desired due to three principal factors:

1. Failure to achieve perfect registration of the three optical/electrical images.
2. The type of pick-up tube used in the colour camera had inherently poor resolution.
3. Due again to the present means of gamma correction some of the information about luminance transitions in coloured areas is conveyed by the chrominance signal which is ignored in this respect by the black/white receiver.

It is likely that the first two of these effects are of much more importance than the third and that the lack of sharpness of the compatible picture is similar in magnitude to the same effect which observers have noted in the case of the colour picture. It is a defect which will be remedied as the art advances.

(*d*) *Signal-to-Noise Ratio*

The signal-to-noise ratio of the compatible pictures appeared to be at least as good as that which would have been obtained from a black/white camera employing the same tube and no particular difficulties were noticed.

The overall impression received, both from careful observations at the studio and from comments made by viewers in their homes, was that the compatible picture, while being somewhat less sharp than could be wished, was pleasing and 'interesting' in the technical sense.

7. Mobile Colour Control Room

7.1 *Technical Arrangements in the Mobile Control Room*

At the end of the series of transmissions from the studio, in April 1958, a considerable body of experience had been built up in most aspects of colour television except that of outside broadcasting, and it was therefore decided, before finally stopping the work with cameras, to attempt an outside broadcast on a sufficient scale to give some idea of the sort of results to be expected. The two colour cameras and the associated equipment were therefore mounted in a large pantechnicon which before the war had housed one of the mobile Band I O.B. transmitters. Because it had been designed for studio work, almost all the equipment was of inconvenient size and shape for mounting in a vehicle and the operational facilities had to be pared down to the absolute minimum. Perhaps the greatest hazard was the high power consumption in a vehicle which had only the most elementary form of ventilation and in fact the equipment did reach high working temperatures, with effects on the quality of the pictures at which one can only guess. Experience at Alexandra Palace had shown that operational convenience is a major factor in the production of good colour pictures and the experience of an inconvenient layout on this occasion strongly reinforced that viewpoint.

7.2 *Pictures at the Festival Hall*, 25 *June* 1958

The first use of the mobile control room was at the Festival Hall on 25 June 1958, when a small interviewing studio was set up in the main assembly area on the occasion of the Soirée of the Institution of Electrical Engineers. Guests were invited to appear before the colour camera and were interviewed by Miss Sylvia Peters, at that time one of the BBC's television announcers. The experience in lighting and operation gained at Alexandra Palace was amply sufficient for this indoor 'O.B.', the only difficulty being the rather high intensity of the lighting which was, as usual, about 300 ft candles incident intensity. The signals from the studio were displayed on six receivers which were placed in various parts of the building. In contrast to the ease with which this simple set-up could be handled, an attempt to get pictures of dancers on the floor was a complete failure, the utter lack of sensitivity of the camera being all too obvious. The ordinary outside broadcast of indoor events, which black-

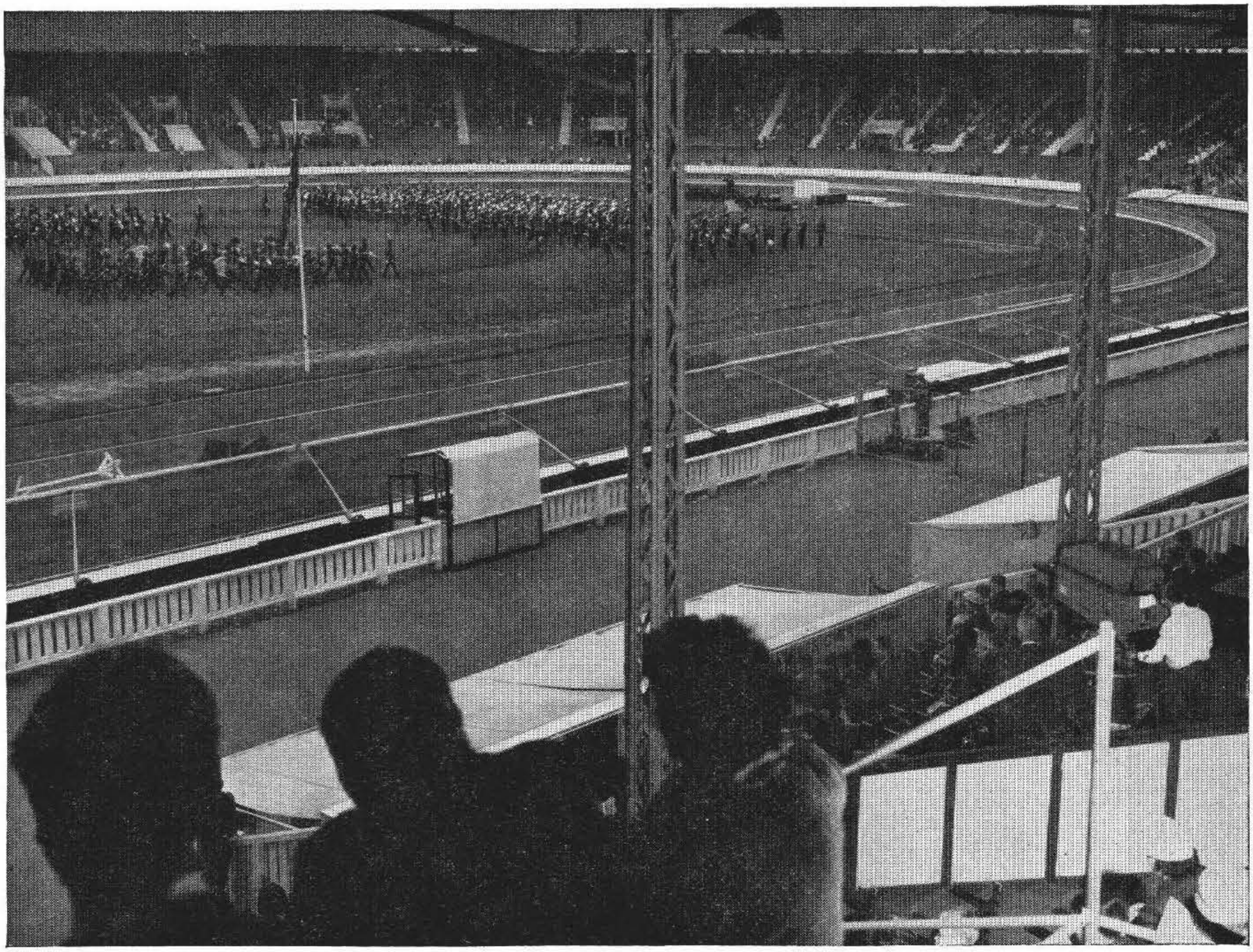


Fig. 6 — Outside Broadcast at the White City

and-white television handles with such ease and with such good picture quality, would be quite out of reach of the colour camera at its present state of development.

7.3 *O.B. of the Military Tattoo, White City, August* 1958

The Military Tattoo at the White City provided a subject which had many features which would probe the performance of the colour cameras. Most important of all it provided subjects containing plenty of colour; there was a good deal of movement and there was, at times, a mass of fine detail, and from the programme aspect it appeared to be just that kind of outside broadcast for which colour would be most desirable. The cameras were mounted, one fairly high up in the stands and the other down on the level of the arena, as can be seen in the photograph (Fig. 6), the camera on the stands using a zoom lens, primarily designed for use in the studio, with a range of focal length of 2¼ in. to 8 in. The signal was transmitted by cable to Broadcasting House, where it was viewed on closed circuit by a large audience, largely of engineers. The whole of the afternoon performance of the Tattoo was taken.

As can readily be imagined, there were, at times, very considerable areas in the view of the cameras which were flat scenes almost devoid of detail and often devoid of much colour, e.g. looking into the stands as the camera panned slowly. This presents a considerable difficulty to the cameras because of their tendency, previously mentioned, to produce shading in colours. During the preceding few days there had also been opportunities of looking at ordinary scenes and this effect proved most objectionable. A vari-coloured haze, even of low intensity and saturation, produces a most unnatural effect and is much more troublesome than the same effect in the studio where some feature of interest is usually arranged to attract the eye. The technique of commoning the three colour separation signals for tonal values below a certain amplitude (see 3.5), thus turning the coloured haze to a neutral tone, provided a degree of improvement, both on subjects of ordinary interest such as street scenes, buildings, etc., and for brightly coloured scenes against a sombre background such as the Tattoo. The loss of colour detail which this process necessarily imposes seems to be of little importance by comparison with the improvement in the general appearance of the picture.

During the three days during which tests were made the weather ran the full gamut of which an English summer is capable. Under bright sunlight conditions the iris control, by means of which the sensitivity of the camera is controlled, could not be sufficiently shut down and additional neutral density filters were required in the optical paths. The variation in the intensity of the light as clouds drifted across the sun proved very difficult to deal with, the speed with which this could happen being greater than the rate at which the iris opening could be controlled. The operational report written at the time gives a good picture of the events.

'In setting up on Monday, 11th (sunny periods), it was found that the cameras were working from f/8 and f/11 to f/22 (fully stopped down) and in the latter case were still over-exposed and additional neutral density filters were added. On Tuesday it was rather duller and these N.D. filters were removed—operating f/16 and f/8—and again on the morning of Wednesday, 13th.

'During the afternoon of 13th it gradually became more and more dull and a steady drizzle set in. At the start of the O.B. the stops in use were f/11 and f/8. Within fifteen minutes camera 1 opened up to f/8 and camera 2 to f/5·6; by 15.15 camera 1 was at f/5·6 and camera 2 f/4·5 (wide open) and the light was getting worse. By 15.30 camera 1 was wide open and camera 2 was only giving 50 per cent mod. (The sensitivity of this camera might have been improved if more time had been available for selection of camera tubes possibly prior to leaving A.P.)

'As there appeared to be little hope of the light improving the individual gains of camera 2 were increased. This meant that the colour balance had been re-set on picture and camera matching suffered—further the noise and shading errors became worse.

'Between 16.15 and 16.45 the light grew even worse and at times camera 1, wide open, was only giving 50 per cent mod. and camera 2, wide open, was only giving 25 per cent mod. Thus pictures were under-exposed and well below standard after the first forty-five minutes.

'This problem of wide variation in light levels is, of course, well known to O.B. staff but since exposure is much more critical in colour the problem is more acute and the colour camera has no provision for the insertion of additional N.D. filters.

'During the first forty-five minutes pictures were fairly good (some very dramatic shots were obtained on the firing of the guns of the King's Troop). Registration quite good, noise only fair—definition fairly good to good on camera 1 and fairly good on camera 2. Camera 1 using crispener. Camera 2 was using the standard aperture correction and the head amp "de-streak" controls were set to give some measure of "Bode" type correction. Camera 1 also had the low-level bridging circuit (at one point this was readjusted and the pictures went almost monochrome for a brief while).'

Some of the difficulties encountered were undoubtedly due to instrumentation and lack of experience, both of which time will remedy, but the insufficient sensitivity of the camera to take an outside broadcast in the middle of the summer shows how very limited outside broadcast work would be in this country at the present time. It is a great deal to ask for an increase in the sensitivity of the cameras of, say, some four to ten times: this almost certainly must be obtained by improving the pick-up tubes while maintaining, and if possible improving, the quality in other aspects of performance.

8. Experimental Transmissions, October 1958 to Present

8.1 *Purpose and Organization*

From October 1958 until the present time, a regular series of experimental transmissions has been radiated from the London transmitter at the Crystal Palace. The primary purpose of these transmissions is to provide a high-quality signal for the benefit of members of the television industry engaged in research and development on colour television. The pattern of the transmissions was agreed, as before, with B.R.E.M.A., who have co-operated continuously with the BBC from the beginning of the tests in 1955 until the present time. Up to the autumn of 1960, there were both morning and afternoon colour test transmissions, but the morning transmissions had to be discontinued from 19 September, when the schedule was rearranged to allow more time for schools broadcasts. On the mornings of Mondays to Fridays inclusive, colour slides and the monochrome test card were radiated during alternate quarter-hour periods, when programme requirements permitted. The afternoon colour transmissions, which are continuing, are on Tuesdays, Wednesdays, and Thursdays, when a half-hour programme showing pictures from 35 mm film is radiated at about four o'clock, again subject to programme requirements.

8.2 *Use of 'Masking' and 'Crispening' Techniques for Film Transmission*

The use of experimental 'masking' and 'crispening' techniques at Alexandra Palace has already been described. It will be recalled that the masking technique was used in an attempt to correct for deficiencies in colour film but was abandoned on account of the variability of the distortion from film to film. However, more recent tests showed that there was a significant amount of distortion in the form of optical crosstalk between the red, green, and blue channels of the 35-mm film scanner itself. An alternative way of expressing this defect would be to state that the curves representing the responses of the colour analysis filters were of the incorrect shape and the most direct method of attack on the defect would have been to alter these filters. However, it is by no means easy to attain the desired overall response from the combination of the individual responses of the scanning tube, the dichroic filters, and the photo multipliers because of the small range of choice of these components. The addition of colour-correcting filters is not desirable because of the loss of light which is introduced leading to a worsening of the signal-to-noise ratio which at the best is only just adequate. The alternative approach of employing masking whereby a cancelling 'crosstalk' signal of the required amplitude is introduced into the appropriate channel has proved successful. The amount of masking is constant for a particular combination of optical components and once the adjustment of the masking unit had been found, no further alteration was made. A very significant improvement in the quality of the colour television picture from film has been achieved by this simple means and the small loss of signal-to-noise ratio has been a price worth paying.

The removal of the desaturation due to the imperfect optics of the film scanner enabled the gamma of the scanner to be set at 0·4 for film densities up to 2·2, at which value experiments showed that a correct grey scale was reproduced on the receiver. This compared with the previous means of setting up by achieving a compromise between grey scale rendering and saturation, which was different for various films. A most important outcome of this work has been the almost complete removal of the need for adjustment on the film scanner during the running of a film or even from film to film which, so far as can be judged, is reproduced in colour rendering as faithfully as are the slides on the slide scanner, the latter providing a high standard of comparison.

The rather remarkable results obtained by the use of the crispening technique on the camera pictures at Alexandra Palace have already been described; the same technique had been tried experimentally on the film pictures with rather inconclusive results but in any case the need for this technique was so much more obviously required by the camera pictures that they were given first call on the limited amount of equipment available. Since the closing down of the studio some experimental work has been done with the crispening technique in connection with the pictures from the 35-mm film scanner with results that are of the greatest interest.

It will be remembered that the main advantage in using the crispener with camera pictures was that it provided a means of improving the transient response without increasing noise; the use of normal aperture correction for a band-sharing colour system is much more restricted than in the monochrome system because in the case of the latter the increasing amplitude of the high-frequency components of noise does not produce a very marked visual effect, while in the colour system these high-frequency components appear in the chrominance channel after demodulation as low frequencies lying between d.c. and the cut-off frequency of the chrominance channel and are consequently much more visible. The R.G.B. signals produced by the film scanner are of much better quality than those of the camera but nevertheless it is not possible to apply full aperture correction because of consideration of noise discussed above. Moreover, the use of the desired low gamma of 0·4 made possible by the employment of the masking technique increased the noise in the dark tones of the picture. It was apparent that the application of crispening to the film pictures resulted in an improvement in sharpness over those obtained in the normal way, and, moreover, with less noise. The loss of resolution appears to be quite unimportant, probably because fine detail and patterns occur rarely in normal pictures. Many competent observers have commented on the 'excellent resolution', in just those words, of the colour and compatible black-and-white pictures and, of course, the lack of chrominance noise is a pleasing feature.

Further experiments have shown, as would be expected, that the most desirable place of all for the crispener is in the receiver in the R.G.B. channels where these exist as separate entities. Used in this fashion there is less crosstalk from the luminance edges to desaturate the colour transitions, an effect described by Schade.[7] There appears to be here a useful field of investigation as to whether the use of non-linear differential equalization at the receiver should not be a specified part of a band-shared colour system.

8.3 *Improvements in Colour Receivers*

Throughout the work described in this paper all the receivers and monitors have used the R.C.A. tri-colour kinescope, type 21/AXP/22A, and as yet no other direct-viewing display tube has been produced on a commercial scale. So far as is known, receiver development has concentrated on the use of this tube and in the last year or so at least one development model of a commercial receiver of improved performance has appeared as a result of work in the research laboratories of the General Electric Company. A report of this work has been given.[8] The painstaking work which has gone into the design of this receiver has resulted in a picture of markedly superior quality to those on which the assessment of the colour television service was undertaken. Brightness, sharpness, and registration are all improved; it will be remembered that all three features were criticized in the assessments, the latter two particularly so. The stability of performance has also been improved, and while it would be necessary to prove the point in large-scale commercial production, this may well prove to be the most important step of all, since the necessity for frequent attention by a skilled person has undoubtedly been one of the principal points of criticism of colour television receivers and has contributed to the relative lack of success of colour television in the U.S.A.

9. Conclusions

In endeavouring to put on record some of the experience obtained of the adapted N.T.S.C. colour system, this paper has inevitably drawn attention to many of the failings of colour television at its present stage of development and the reader could be left with the impression that in some ways the best was being made of a poor job. This view might also be strengthened by the fact that the N.T.S.C. system has been established in the United States for nearly seven years and has made disappointingly small headway. However, the experience gained in the work described in this Monograph confirms the soundness of the N.T.S.C. signal. Continual experience has shown that it is a sturdy signal, well suited to the needs of broadcasting, and that it can give a picture of excellent quality. Of the difficulties which were experienced, almost all arose from the incomplete development of the apparatus in use. With all this apparatus, however, continual improvements were made during the course of the work and there seems to be no basic reason why further improvements should not be realized. At the present time, the studio camera is in the most need of development. The studio camera has not yet the ease and precision of performance which are required for the production of consistently good pictures, but, at times, it reveals a glimpse of the inherent high quality of reproduction of which the system will ultimately be capable and which is probably superior to that of any other system of colour reproduction.

The price of the colour receiver remains high but there are hopes that this cost, which has been greatly reduced since the first receivers were available, will in the future be still further reduced.

The experience of working in this field and the results obtained gave great satisfaction to all who were engaged in it.

10. Acknowledgments

The authors wish to acknowledge that the work described in this paper has been the product of a large number of people and wish to thank them for their enthusiastic and unstinted cooperation.

11. References

1. Sproson, Watson, and Campbell, BBC Engineering Monograph No. 18, May 1958, **The BBC Colour Television Tests: An Appraisal of Results.**
2. McLean, Thomas, and Rowden, **The Crystal Palace Television Station.**
   Cooper and Morcom, **Television Transmitter Design with Particular Reference to the Transmitter at the Crystal Palace,** Part B, I.E.E. Proceedings, Vol. 103, No. 11, September 1956.
3. Fairhurst, **The Development of an Experimental 21-inch Colour Television Receiver,** Journal of the Television Society, Vol. 8, No. 3, July–September 1956.
4. Goldmark and Hollywood, **A New Technique for Improving the Sharpness of Television Pictures,** Proceedings of the I.R.E., Vol. 39, No. 10, October 1951.
5. Weaver, BBC Engineering Monograph No. 17, April 1958, **The Design of a Linear Phase-Shift Low-pass Filter.**
6. Gouriet, **An Introduction to Colour Television,** 1955.
7. Schade, **On the Quality of Colour Television Images and the Perception of Colour Detail,** Journal of the Society of Motion Picture and Television Engineers, Vol. 67, No. 12, December 1958.
8. **An Experimental Colour TV Receiver: Setting Up and Adjustment,** Journal of the Television Society, Vol. 9, No. 4, October–December 1959.

APPENDIX A

SPECIFICATION OF STANDARDS FOR EXPERIMENTAL COLOUR TRANSMISSIONS

1. General

1.1 *Channel Width*

The colour television signal and sound signal will be transmitted in channel 1 in asymmetric sideband manner as in channels 2 to 5, thus occupying a channel width of 5 Mc/s.

1.2 *Picture Signal Carrier*

The difference in frequency between the picture signal carrier and the sound signal carrier will be a multiple of the line frequency in the television waveform. The exact relation will be

$$f_{c\,vision} = f_{c\,sound} + 350 f_{line}$$

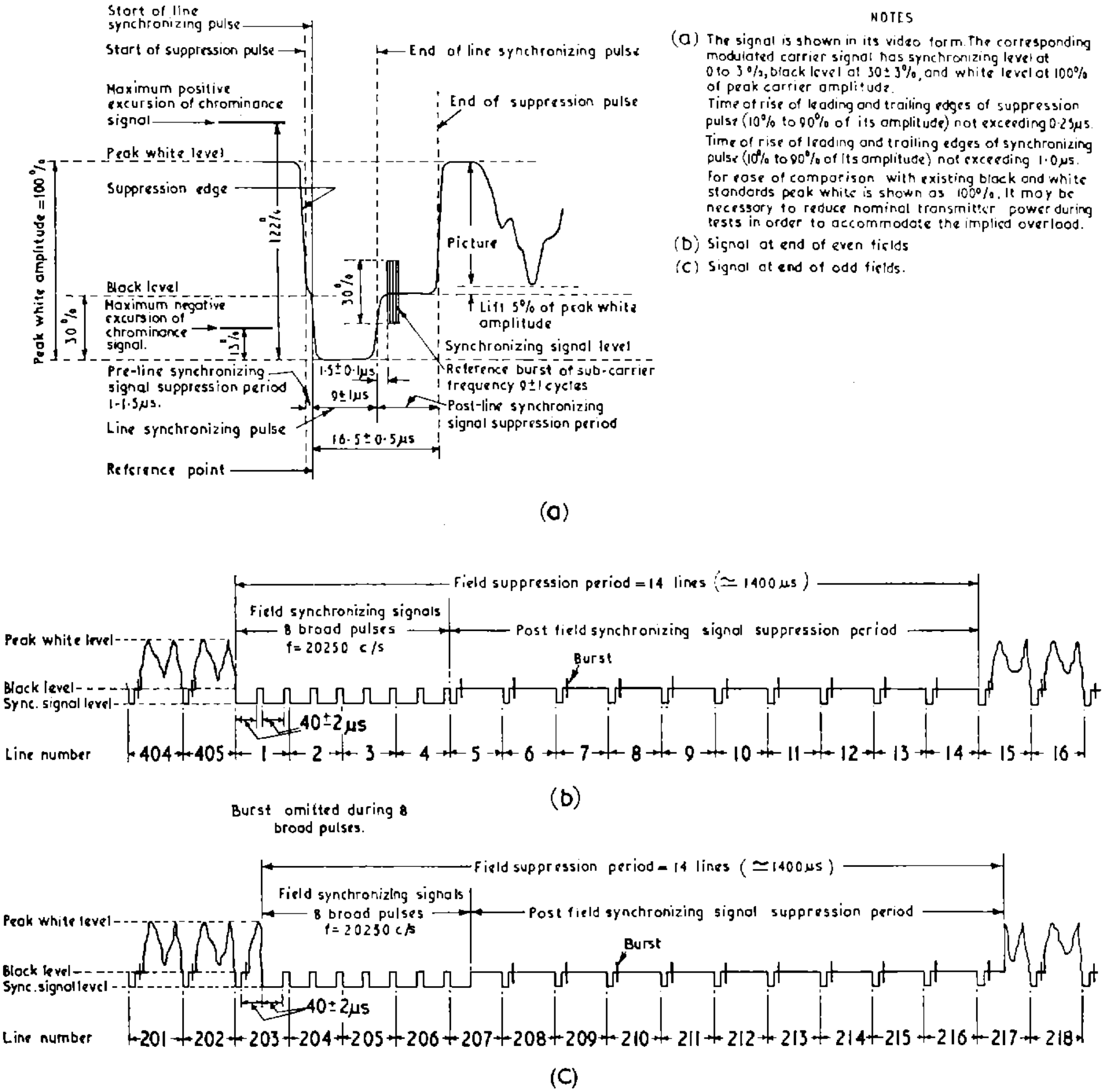
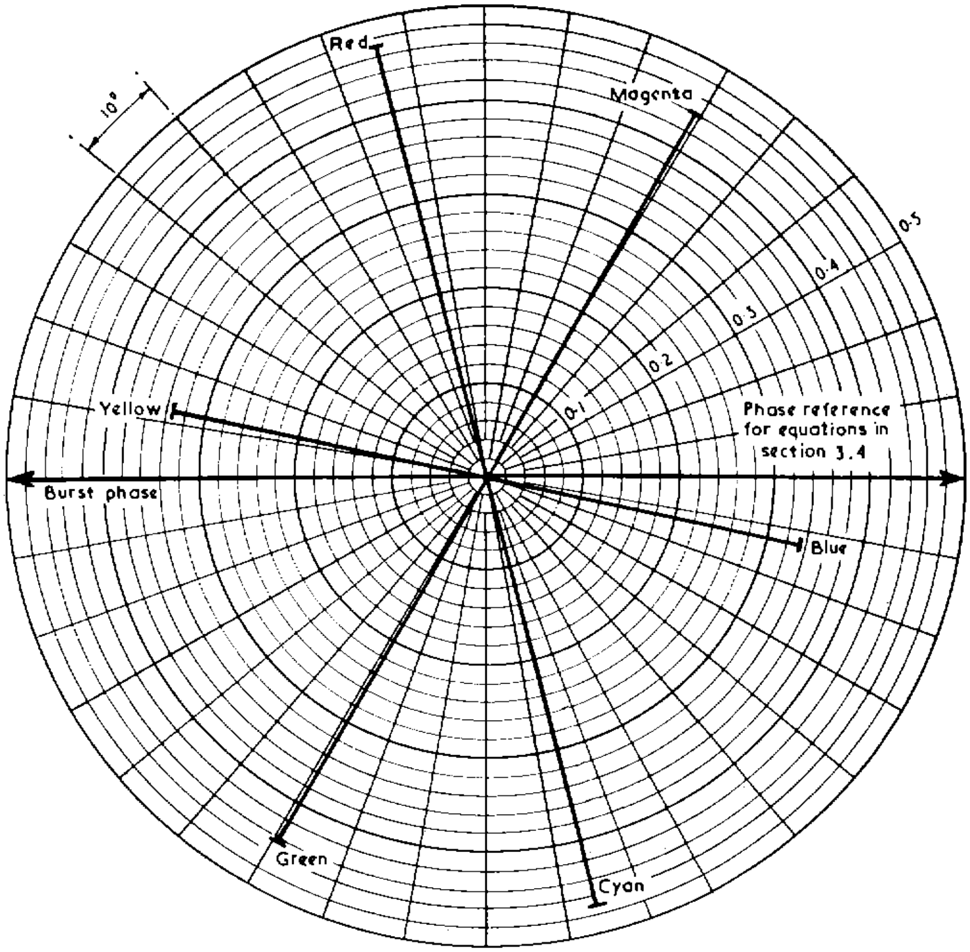


Fig. A.1



Luminance magnitude	Colour
0·23	Red
0·31	Magenta
0·08	Blue
0·53	Cyan
0·44	Green
0·67	Yellow

Fig. A.2 — Chrominance signal amplitudes and phase angles for saturated primaries at 75 per cent of maximum values of gamma — corrected signals

1.3 *Polarization*

The polarization of the sound and vision carriers will be vertical.

1.4 *Asymmetric Sideband Transmitter*

The picture signal will be transmitted from Alexandra Palace by asymmetric sideband amplitude modulation in accordance with present black-and-white practice in channels 2 to 5.

1.5 *Aspect Ratio*

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

1.6 *Scanning and Synchronization*

The colour picture signal shall correspond to the scanning of the image at uniform velocities from left to right and from top to bottom with 405 lines per field interlaced 2:1.

The horizontal scanning frequency shall be 405/2 times the vertical scanning frequency: for a nominal vertical scanning frequency of 50 c/s this corresponds to 10,125 c/s. The colour sub-carrier frequency will be 525/2 times the horizontal scanning frequency: for a nominal vertical scanning frequency of 50 c/s the colour sub-carrier frequency is 2·6578125 Mc/s.

The colour television signal shall consist of colour 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.

The horizontal, vertical, and colour synchronizing signals shall be those specified in Fig. A.1, as modified by the delay characteristic specified in 3.2.

2. Sound

2.1 *Sound Carrier Frequency*

The frequency of the unmodulated sound carrier will remain in accordance with present practice.

2.2 *Sound Signal Characteristics*

Double sideband amplitude modulation of the sound carrier will be used, in accordance with present practice.

2.3 *Power Ratio*

The ratio between the peak-white vision carrier power and the unmodulated sound carrier power will be approximately 4:1.

3. The Complete Colour Picture Signal

3.1 *General Specification*

The colour picture signal shall correspond to a luminance (brightness) component transmitted as amplitude modulation of the picture carrier and a simultaneous pair of chrominance (colouring) components transmitted as the amplitude modulation sidebands of a pair of suppressed sub-carriers in quadrature having the common frequency relative to the picture carrier of 525/2 times the horizontal scanning frequency. It is possible that experiments may be conducted in connection with asynchronous and synchronous operation of the system with respect to the 50 c/s mains. In the asynchronous condition the frequency of the colour sub-carrier will be 2·6578125 Mc/s ±8 c/s with a maximum rate of change of 0·1 c/s/s. In the synchronous condition the colour sub-carrier frequency and the difference in frequency between sound carrier and vision carrier will change directly as the mains frequency.

3.2 *Delay Specification*

The overall delay characteristics of the transmitted signal will conform to the shape set out in Table 1 to within ±0·07 μsec.

TABLE 1

f. Mc/s	*Envelope Delay μsec.*
0·1	+0·22
1·0	+0·22
1·5	+0·22
1·8	+0·19
2·0	+0·17
2·2	+0·133
2·4	+0·085
2·6	+0·015
2·8	−0·12
3·0	−0·355

3.3 *Luminance Component*

An increase in the initial light intensity shall correspond to an increase in the amplitude of the carrier envelope (positive modulation).

3.3.1 *Suppression, Black-and-White Level*

The composite colour signal consists of the addition of a chrominance signal to a luminance signal conforming to present black-and-white practice, see Fig. A.1.

3.3.2 *Attenuation/frequency Characteristic*

The overall attenuation versus frequency of the luminance signal will not exceed the value specified for black-and-white transmission.

3.4 *Equation of Complete Colour Signal*

(*a*) The colour picture signal has the following compositions:

$$E_M = E_Y' + K\{E_Q' \sin(\omega t + 33°) + E_I' \cos(\omega t + 33°)\}$$

where

$$E_Q' = 0{\cdot}41(E_B' - E_Y') + 0{\cdot}48(E_R' - E_Y')$$
$$E_I' = -0{\cdot}27(E_B' - E_Y') + 0{\cdot}74(E_R' - E_Y')$$
$$E_Y' = 0{\cdot}30E_R' + 0{\cdot}59E_G' + 0{\cdot}11E_B'$$

The factor K indicates that various ratios of chrominance to luminance between 1·0 and 0·3 may be used in certain experiments. Fig. A.2 is based upon the assumption $K = 1$.

The phase reference in the above equation is the phase of the (colour burst + 180°), as shown in Fig. A.2. The burst corresponds to amplitude modulation of a continuous sine wave.

NOTES:

For colour-difference frequencies below 340 kc/s, the signal can be represented by

$$E_M = E_Y' + K\left\{\frac{1}{1{\cdot}14}\left[\frac{1}{1{\cdot}78}(E_B' - E_Y')\sin\omega t + (E_R' - E_Y')\cos\omega t\right]\right\}$$

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 colour picture signal, corresponding to the given picture element.*

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_R', E_G', and E_B' are suitable for a colour picture tube having primary colours with the following chromaticities in the C.I.E. 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 γ (gamma exponent) of 2·2† associated with each primary colour. 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 (*e*).

The angular frequency ω is 2π times the frequency of the chrominance sub-carrier.

The portion of each expression between brackets represents the chrominance sub-carrier signal which carries the chrominance information.

(*b*) The chrominance signal is so proportioned that it vanishes for the chromaticity of C.I.E. illuminant $C(x = 0{\cdot}310, y = 0{\cdot}316)$.

(*c*) E_Y', E_Q', E_I', and the components of these signals shall match each other in time to 0·07 μsec.

(*d*) A sine wave of 2·66 Mc/s introduced at those terminals of the transmitter to which are normally fed the colour 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 within ±2 dB of that of a radiated signal produced by a sine wave of 100 kc/s. In addition, the amplitude of the radiated signal shall not vary by more than ±2 dB between the modulating frequencies of 1·5 and 3·0 Mc/s.

(*e*) The equivalent bandwidths assigned prior to modulation to the colour-difference signals E_Q' and E_I' are given in Table 2.

TABLE 2

Q-Channel Bandwidth at:	*I-Channel Bandwidth at:*
300 kc/s less than 2 dB down	1·0 Mc/s less than 2 dB down
340 kc/s less than 6 dB down	2·5 Mc/s at least 20 dB down
450 kc/s at least 6 dB down	

(*f*) The angles of the chrominance signal, measured with respect to the burst phase, when reproducing large areas of saturated primaries and their complements at 75 per cent of full amplitude of gamma-corrected signals, shall be within ±10° and their amplitudes shall be within ±20 per cent of the values shown in Fig. A.2. The ratios of the measured amplitudes of the chrominance signal to the luminance signal for the same saturated primaries and their complements shall fall between the limits of 0·8 and 1·2 of the values calculable from the equations in paragraph 3.4 of section 3, or from the table in Fig. A.2. Closer tolerances may prove to be practicable and desirable with advance in the art.

* 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 colours.

† At the present state of the art it is considered inadvisable to set a tolerance on the value of gamma.

APPENDIX B

BBC

EXPERIMENTAL COLOUR PROGRAMME QUESTIONNAIRE 1957/58

Name ....

Location of set ....
(address) ....

Make of set ....

Model No. ....

	Under 12"	12"-16"	Over 16"
Picture width in inches (measured) (state exact width but place in appropriate square)			

Viewing distance (feet) ....

Line visibility at this viewing distance (use score of scale 1 below) [ ]

Quality of interlace (use score of scale 2 below) [ ]

Lighting conditions	tick here
dark	
soft lighting	
normal room lighting	

Approx. distance from transmitter (miles) ....

Date of viewing ....

	Characteristic	Scale to be used	Slide	Film	Camera	Any Comments
A	Fidelity of colour reproduction	2				
B	Misregistration (presence of colour fringing)	1				
C	Picture sharpness	2				
D	Noise	1				
E	Overall assessment of picture (including all the above effects)	2				

Did the colour picture, generally speaking, please you? Yes [ ] No [ ] Please tick

Any other comments:

Scale 1	Score
imperceptible	1
just perceptible	2
definitely perceptible but not disturbing	3
somewhat objectionable	4
definitely objectionable	5
unusable	6

Scale 2	Score
excellent	1
good	2
fairly good	3
rather poor	4
poor	5
very poor or absent	6

Please return the completed questionnaire to Head of Designs Department

Please see over the page for explanatory notes

EXPLANATORY NOTES

A FIDELITY OF COLOUR REPRODUCTION

In attempting to assess the degree of faithfulness of the reproduction of colours, it is obvious that attention should be concentrated on objects, the original colour of which is known with reasonable certainty, such as the human face. As far as possible, any feelings of pleasure, or otherwise, at the scene presented by the coloured picture should not be allowed to influence your judgement. A separate question allows you to express your feelings in this respect.

B MISREGISTRATION

The colour pictures are made up of superimposed red, green and blue images. If the placing of one image on the other becomes inaccurate, colour fringes appear at edges and boundaries between one colour and another.

C PICTURE SHARPNESS

This is an effect which all observers are accustomed to judge on black/white television pictures, on photographs and on moving films. The effect is similar to that caused by good or bad focus.

D NOISE

This consists of a background of random continuously moving small points of light of varying brightness. It has been likened to moving sand or boiling porridge. It may occur over the whole picture area or be confined to particular areas, particularly those which are highly coloured, and may itself be either coloured or neutral in appearance. It should not be confused with the regular pattern of stationary dots which may be seen on close inspection of the picture. These dots are part of the structure of the display tube and are the means by which the colour picture is produced: generally, they are invisible to most people at a reasonable viewing distance.

E OVERALL ASSESSMENT OF COLOUR PICTURE

This is to include all the detailed features you have just described and any others that enter into an overall judgement of the quality of the colour picture.

The general information asked for on the questionnaire may be filled in at any time during the transmission.

Errata

On page 6 of Engineering Monograph No. 31, entitled 'The Power Gain of Multi-Tiered V.H.F. Transmitting Aerials', Equation (3) should read as follows:

$$W = 2\pi k E^2 \sin\theta \, \delta\theta \tag{3}$$

Equation (4) should read as follows:

$$G = \frac{2}{1 \cdot 64092 \int_0^\pi E^2 \sin\theta \, d\theta} \tag{4}$$

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