PRIVATE AND CONFIDENTIAL

RESEARCH DEPARTMENT

Comparisons between three colour television cameras

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THE BRITISH BROADCASTING CORPORATION
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COMPARISONS BETWEEN THREE COLOUR TELEVISION CAMERAS

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SUMMARY

Tests have been carried out to compare the performance of an experimental four-tube colour camera developed by E.M.I. Ltd., a three-tube plumbicon colour camera manufactured by Philips and a three-tube image orthicon colour camera manufactured by Marconi, the output of each camera being, in each case, an NTSC coded signal. Subjective comparisons are described and discussed of the pictures obtained when these signals were supplied to colour monitors by way of NTSC decoders, and also of the compatible pictures obtained by applying the camera signals directly to black-and-white monitors; some objective comparisons of camera performance are also included in this discussion. The aspects of camera performance which are evaluated include noise, colour errors, portrayal of fine detail, sensitivity, compatibility, lag and registration.

1. INTRODUCTION

An experimental colour television camera was loaned by E.M.I. Ltd. and set up in Studio H, Lime Grove between 12th March and 26th March 1964. Already present were the Marconi three-tube 3 in. image orthicon cameras which are the normal equipment of this Studio and also the prototype three-tube plumbicon camera on loan from the Philips Company of Holland.

The opportunity was therefore taken to conduct a number of comparisons between the three colour television cameras, since they represented three distinct types, all of which might be of interest for the start of a colour television service in this country. At the same time, however, it must be pointed out that none of the cameras is claimed to represent the best of its particular type.

2. EXPERIMENTAL DETAILS

A number of objective measurements were made to assist in the comparisons and also to assist in deciding the improvement in performance which might be obtained from a fully-engineered camera of similar type. Enough is known of the basic signal-to-noise ratios, resolution and sensitivity of the various camera tubes used in these

cameras for it to be possible to estimate with some accuracy the ultimate performance of any camera of a given type.

Details of the three cameras and associated apparatus concerned in the comparison are as follows:

(a) The E.M.I. four-tube camera

The luminance signal is produced by one 4½ in. medium-spaced image orthicon tube. Chrominance signals are produced by three 1 in. vidicon tubes, underscanned to give an 8 mm diagonal image. Signal processing is carried out by means of an E.M.I. 'multi-linear matrix' and coder which should result in a composite signal capable of being handled by a decoder of completely standard NTSC specification.

(b) The three-tube plumbicon camera manufactured by Philips

This contains three standard (non-red-sensitive) 30 mm plumbicon tubes with an image format having a 20 mm diagonal. Standard R,G,B outputs were fed to a BBC Designs Department NTSC coder.

(c) The three-tube 3 in. image orthicon camera manufactured by Marconi

The older model, using dichroic mirrors, was employed since the glass prism-block optical system of the more recent Marconi colour camera was known to give incorrect colour analysis.

2.1. Objective Measurements

2.1.1. Signal-to-Noise Ratios

In each case the signal-to-noise ratio was measured by means of the BBC Noise Measuring Set ME1/502, but there were some departures from our normal procedure in making these measurements. It is not possible to measure individual R,G,B colour separation signals in the case of a four-tube camera and it was therefore necessary to measure the signal-to-noise ratio of the compatible black-and-white picture at the coder output, the subcarrier having been switched off.

The plumbicon camera and the three-tube 3 in. image orthicon camera normally use crispener circuits in which a low-pass filter, having a cut-off frequency of 3·5 Mc/s, is included. This device has a fairly pronounced effect in improving the signal-to-noise ratio but it restricts the measureable resolution of high-frequency detail; the E.M.I. four-tube camera is not so equipped and comparisons between the three cameras must be made with this in mind. Signal-to-noise ratio measurements were also made at the R,G,B outputs of a standard NTSC decoder with input provided by each of the three cameras in turn. In these cases, it was necessary to place a low-pass filter having a cut-off frequency of 3·1 Mc/s in the feed to the noise-meter in order to remove the subcarrier, which would have given a spurious reading. The signal-to-noise ratios given are therefore valuable for comparison between the three cameras but cannot usefully be related to signal-to-noise ratio measurements made under different conditions.

2.1.2. Resolution of Test Cards

The ability of the compatible picture to portray the fine detail of a test card was measured by observing the depth of modulation at the coder output. Measurements were made with and without the low-pass filter and crispener circuits of the plumbicon and image orthicon cameras. It was decided that the performance of all three cameras without crispeners was of interest since the measured signal-to-noise ratio of the plumbicon camera was such that there is hope that an improved head amplifier would permit less severe filtering of the output signal. Comparisons between cameras with the crispener circuit present were made with 3·1 Mc/s test patterns. Where no crispeners were used, the resolution was measured with 4·7 Mc/s test patterns.

2.1.3. Sensitivity

Sensitivity was measured by exposing the camera to an E.I.A. logarithmic grey scale and adjusting the incident illumination until the camera was correctly exposed. In the case of cameras containing one or more image orthicon tubes, the correct exposure must be determined by the relationship of highlights in the scene to the knee of the light transfer characteristic. In the case of the plumbicon camera, the operating point is less positively determined and signal-to-noise ratio becomes the criterion. The normal working signal current, which gives a signal-to-noise ratio of 40·5 dB with the low-pass filter and crispener in circuit, was used when determing the sensitivity of the plumbicon camera in this comparison.

2.2. Subjective Appraisals

The subjective appraisals were made by panels of BBC engineers, all experienced in appraising colour television pictures. The appraisals were carried out in a number of separate viewing sessions and in all about 30 observers took part. The results for the separate sessions have been compared and it has been found that the subjective gradings were very consistent, despite the fact that it was necessary to re-align the camera and monitors before each session. The pictures provided by any two of the three cameras to be compared were displayed on a pair of identical 21 in. shadow-mask colour monitors, each fed by an identical NTSC decoder. Very great care was taken to ensure that the two channels were accurately balanced in all respects. The presentation of the pictures was so arranged that each camera was used twice on each given scene, the picture appearing once on the left-hand monitor and once on the right-hand monitor; this technique ensured that some compensation for differences in viewing distance was applied and would also average any differences in colour balance. The observers were not told which camera was being used to provide the pictures and the pattern of switching operations employed was sufficiently complicated to make identification difficult, although by no means impossible. Approximately eight observers took part in each of the first series of viewing sessions, but in a second series of viewing sessions, to be described later, it was necessary to restrict the number of viewers to four.

The subjective appraisals were designed to investigate those parameters of picture quality in which objective measurements do not give a very accurate impression of the performance of the camera. The visibility of noise, for example, cannot be compared directly on the basis of measured ratios of signal-to-r.m.s.-noise level

since the distribution of noise energy throughout the video spectrum of the signals differs from camera to camera. Similarly, none of the cameras (or indeed the display tube) gives objectively accurate reproduction of colour.

2.2.1. Subject Matter used for Subjective Appraisal

The scenes used provided a stringent test but care was taken to avoid material that was beyond the theoretical capabilities of the system or display. Considerable use was made of the fabrics specially designed on behalf of the E.B.U. for examining colour reproduction properties of colour television apparatus. Use was also made of BBC Research Department colour test boxes in which nine gelatine colour filters were rear-illuminated with light of the appropriate colour temperature. One such box was displayed to the camera and another similar box was placed adjacent to the colour monitors to allow visual comparison. More complete details of the picture material used for each test are shown in the Appendix.

It was later felt that further appraisals of the abilities of the cameras to reproduce colours should be conducted with particular reference to their ability to portray lipstick and facial colourings dependent on the red-sensitivity of the camera. This applied to the compatible black-and-white picture as well as to the colour picture. A second series of viewing sessions was conducted in which arrangements were made for the viewers to have a close-up view of the model through a colour-temperature-raising filter,* and, at the same time, to be able to see two colour monitors display side-by-side colour or compatible reproductions of the subject. The arrangement of the studio set and viewing booth is shown in Fig. 1.

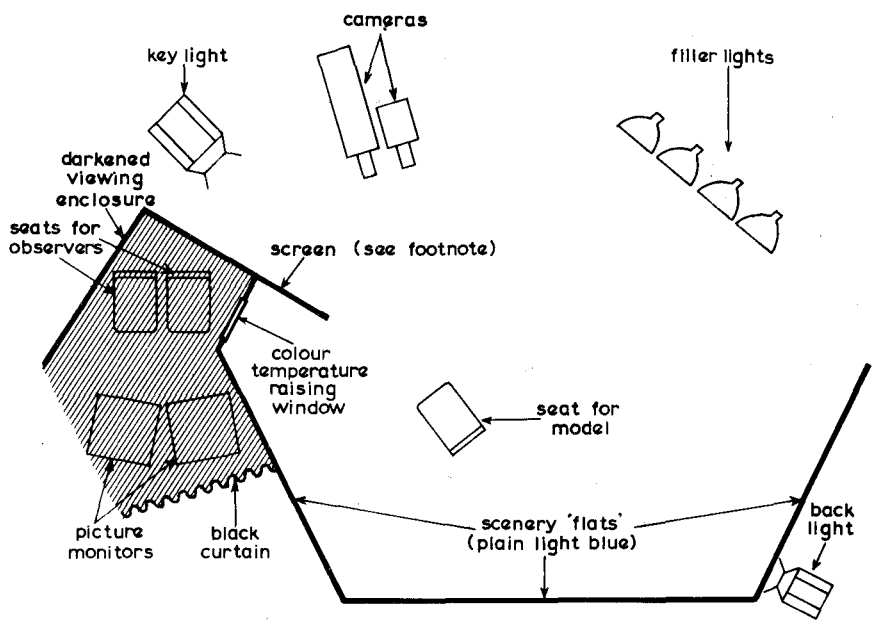

Fig. 1 - Experimental arrangement for second series of assessment sessions

Note: The screen was provided to shield the window from the set lighting in order to reduce glare effects.

* Modern display tubes produce a white that is much colder (more blue) than is the tungsten lighting used in studios. The eye is able to discount this change by an adaptation process, provided that the original scene is not seen at the same time. The filter used made the tungsten and displayed white the same.

2.2.2. Method of Assessment and Analysis of the Picture Impairment

The observers were asked to make all their assessments in terms of the degree of visibility of the impairments under consideration, using the subjective scale shown below.

TABLE 1

Scale of Subjective Grades

DEGREE OF VISIBILITY OF THE IMPAIRMENT	GRADE
The impairment is IMPERCEPTIBLE	1
The impairment is JUST PERCEPTIBLE	2
The impairment is DEFINITELY PERCEPTIBLE BUT NOT DISTURBING	3
The impairment is SOMEWHAT DISTURBING	4
The impairment is DEFINITELY DISTURBING	5
The impairment has RENDERED THE PICTURE UNUSABLE	6

In the analysis of the results, the mean subjective grade of the observers' assessments of each impairment was calculated for pictures derived from each camera and the standard deviations about these means were also calculated. In addition an estimate, based on the 'standard error' of the results, was made of the degree of significance that could be attached to the differences between the mean grades obtained from each camera for any given impairment.

3. RESULTS

3.1. Noise

TABLE 2

Measured Signal-to-Noise Ratios, and Subjective Impairments by Noise. 58 Observations.

		E.M.I. FOUR-TUBE CAMERA	PLUMBICON THREE-TUBE CAMERA	3 in. IMAGE ORTHICON THREE-TUBE CAMERA
Signal-to-noise ratio of coded luminance signal (measured)	Decibels	34·7	38·0	33·1
Noise in the displayed black-and-white picture (subjective grading)	Subjective grade	3·41	2·23	3·28
	(Standard deviation)	(0·60)	(0·75)	(0·74)
Noise in the displayed colour picture (subjective grading)	Subjective grade	3·42	2·22	3·29
	(Standard deviation)	(0·59)	(0·71)	(0·50)

Significant differences between grades are calculated to be those in excess of 0·18 grades.

The measured signal-to-noise ratio given for the plumbicon three-tube camera was that obtained when the light incident upon the scene was 152 ft-Candles with the lens aperture set to f/4. In the plumbicon camera, the distribution of the noise energy within its spectrum is triangular, whereas the noise from cameras which employ image orthicon tubes tends to be of a more uniform distribution throughout the spectrum. For black-and-white television, a triangular noise spectrum is advantageous and is usually valued in subjective trials as being worth an additional 6 dB in signal-to-noise ratio. For colour television applications, however, the triangular noise spectrum is not advantageous because of the cross-colour effect of high-frequency noise.

As stated in Section 2.1.1, the signal-to-noise ratio for the plumbicon and 3 in. image orthicon cameras was measured with the crispeners and low-pass filters in circuit, whereas in the E.M.I. four-tube camera, the luminance signal had a greater bandwidth.

TABLE 3

Signal-to-Noise Ratios in Decoded Colour-Separation Signals Limited to 3·1 Mc/s Bandwidth

CAMERA	RED	GREEN	BLUE
E.M.I. four-tube (without crispener)	31·9 dB	34·9 dB	29·1 dB
Three-tube plumbicon (with crispener)	37·6 dB	40·5 dB	37·0 dB
Three-tube plumbicon (without crispener)	32·0 dB	36·3 dB	28·1 dB
Three-tube image orthicon (with crispener)	35·5 dB	36·9 dB	35·6 dB
Three-tube image orthicon (without crispener)	34·5 dB	36·4 dB	33·5 dB

These results are useful as a measure of the subjective noise in the respective colours after coding and decoding, but they do not represent the signal-to-noise ratios in the original signals from the separate tubes of the colour camera.

As a further investigation, the head amplifiers of the three-tube plumbicon camera were examined to see whether the performance was comparable with that obtained in the more recent designs of a vidicon head amplifier produced by BBC Designs Department. With all aperture correction removed but with compensation present for the input time-constant of the head amplifier and for the camera tube capacities, the head amplifiers in the three-tube plumbicon camera gave a signal-to-noise ratio of 36 dB for a peak signal current of 0·3 μA. It is believed that a more sophisticated design can give signal-to-noise ratios under the same conditions some 8 dB better than this and it might therefore be decided that with improved head amplifiers, the plumbicon three-tube camera might not need to resort to the use of a low-pass filter and crispener circuit, but could be used to give higher depths of signal modulation while retaining an acceptable subjective level of noise. This point does, however, require experimental proof.

3.2. Colour Errors

TABLE 4

Colour Errors. Subjective Gradings

		E.M.I. FOUR-TUBE CAMERA	PLUMBICON THREE-TUBE CAMERA	3 in. IMAGE ORTHICON THREE-TUBE CAMERA
Colour reproduction of faces and general scene (58 observations)	Subjective grade	4·22	2·86	2·85
	(Standard deviation)	(0·81)	(1·27)	(1·07)
Colour reproduction of E.B.U. reflective materials	Subjective grade			
White		1·84	1·74	1·82
Yellow		3·62	2·78	3·22
Cyan		3·48	3·49	3·53
Green		3·61	2·55	2·89
Magenta		5·16	3·93	3·04
Red		3·88	2·66	2·14
Blue		3·35	2·24	2·74
Mean of all E.B.U. colours (308 observations)	(Standard deviation)	3·56	2·77	2·77
		(1·29)	(1·14)	(1·05)
Colour reproduction of colour box	Subjective grade			
Green		3·25	3·06	3·04
Yellow		2·90	2·88	2·46
Orange		3·18	2·74	2·93
Cyan		3·24	2·46	2·84
White		3·06	1·80	2·06
Red		3·54	3·17	3·17
Blue		4·38	3·13	4·08
Magenta		4·32	3·61	3·74
Light Magenta		4·95	3·18	3·63
Mean of all colour box colours (378 observations)	(Standard deviation)	3·65	2·89	3·10
		(1·13)	(0·92)	(1·10)
Colour reproduction of lipsticks	Subjective grade			
Lipstick 1 (Orange)		-	2·43	2·22
Lipstick 2 (Magenta shades)		-	2·40	2·07
Lipstick 3 (Magenta shades)		-	2·43	2·17
Lipstick 4 (Magenta shades)		-	2·68	2·29
Lipstick 5 (Magenta shades)		-	2·51	2·11
Lipstick 6 (Cherry red)		-	2·72	2·22

TABLE 4

Colour Errors. Subjective Gradings (Continued)

		E.M.I. FOUR-TUBE CAMERA	PLUMBICON THREE-TUBE CAMERA	3 in. IMAGE ORTHICON THREE-TUBE CAMERA
Mean of all lipsticks (216 observations)		-	2·53	2·18
Standard deviation		(-)	(0·75)	(0·70)
Reproduction of lipsticks on black-and-white display	Subjective grade			
Lipstick 1 (Orange)		-	1·58	1·39
Lipstick 2		-	1·72	1·62
Lipstick 3 Magenta		-	1·88	1·53
Lipstick 4 shades		-	2·00	1·40
Lipstick 5		-	2·08	1·68
Lipstick 6 (Cherry red)		-	2·40	1·68
Mean of all lipsticks (216 observations)		-	1·94	1·55
Standard deviation		(-)	(0·76)	(0·58)

Significant differences between mean grades are calculated to be those in excess of 0·1 grades.

In considering the colour errors of the E.M.I. four-tube camera, it should be noted that the decoding method of the NTSC system is based upon the luminance information being of the form:

$$E'_Y = \left(0{\cdot}3\ E_R^{\frac{1}{\gamma}} + 0{\cdot}59\ E_G^{\frac{1}{\gamma}} + 0{\cdot}11\ E_B^{\frac{1}{\gamma}}\right)$$

This implies, but does not necessitate, the three-tube source of signals. A rather complicated correction is required when the signals from a four-tube camera are to be transmitted in such a form that they can be reproduced by a standard NTSC colour receiver without the introduction of severe colour errors in large areas. In the E.M.I. camera, the correction is obtained by means of a device called a 'multi-linear matrix'. This device, or other arrangements for correcting the signals from a four-tube source, may require that the light transfer characteristic of the chrominance tube shall at some stage of the process be accurately corrected to a simple power law. This is difficult to achieve with vidicon camera tubes and therefore the accuracy with which a colour television system can reproduce colours is of particular interest when it employs a four-tube camera having vidicon camera tubes in the three colour channels.

3.3. Portrayal of Fine Detail

TABLE 5

Portrayal of Fine Detail

		E.M.I. FOUR-TUBE CAMERA	PLUMBICON THREE-TUBE CAMERA	3 in. IMAGE ORTHICON THREE-TUBE CAMERA
Measured horizontal resolution of test cards. Normal aperture correction. (With crispener).				
1·5 Mc/s	% Modulation	-	95%	95%
3·0 Mc/s			75%	50%
5·0 Mc/s			0%	0%
Measured horizontal resolution of test cards. Normal aperture correction. (Without crispener).				
1·5 Mc/s	% Modulation	90%	100%	70%
3·0 Mc/s		65%	79%	17%
5·0 Mc/s		25%	60%	6%
Subjective lack of sharpness (With crispener)				
Black-and-white pictures	Subjective grade (Standard deviation)	2·41 (0·79)	2·97 (1·00)	3·50 (1·00)
Colour pictures	Subjective grade (Standard deviation)	2·99 (0·80)	3·15 (1·02)	3·32 (0·85)

Significant differences between mean grades are calculated to be those in excess of 0·25 grades.

At times the E.M.I. four-tube camera showed considerably enhanced edges on black-to-white transitions, but it does not employ a crispener. Measurements of the three-tube image orthicon and three-tube plumbicon cameras were therefore carried out both with and without their crispeners, but in considering the 'without-crispener' results, it must be remembered that the noise usually appears significantly worse and may be unacceptable when this device is removed from the circuit.

3.4. Sensitivity

TABLE 6

Sensitivity

		E.M.I. FOUR-TUBE CAMERA	PLUMBICON THREE-TUBE CAMERA	3 in. IMAGE ORTHICON THREE-TUBE CAMERA
Minimum incident illumination required to expose the E.I.A. step-wedges	ft-Candles	170	152	580

The plumbicon camera was operated with its zoom lens at maximum aperture f/4. The three-tube image orthicon camera was therefore operated at f/8 to give the same depth of field as that obtained from the plumbicon when the latter is at f/4. Under normal working conditions, a smaller depth of field is accepted from the image orthicon camera and the present working incident illumination is 350 ft-Candles. It should be noted, however, that recent measurements have shown the optical colour analysis arrangements of the Marconi three-tube image orthicon cameras to have only 50% the efficiency of similar arrangements in R.C.A. cameras. The performance of R.C.A. optical components, together with the employment of special orthicons having tri-alkali photocathodes is thought to promise as much as 5 : 1 sensitivity improvement over the present Marconi cameras. This would make the light requirement at f/8 only 116 ft-Candles - less than those required by either the three-plumbicon or E.M.I. four-tube cameras in their present forms.

The E.M.I. four-tube camera has no iris adjustment; the effective depth of field in the luminance tube image is said to be that associated with f/11. Minimum light requirements are set by the three vidicon tubes which are operated with a large effective aperture of the order of f/1.

3.5. Compatibility

TABLE 7

Compatibility

		E.M.I. FOUR-TUBE CAMERA	PLUMBICON THREE-TUBE CAMERA	3 in. IMAGE ORTHICON THREE-TUBE CAMERA
Subjective appraisal of visibility of subcarrier pattern, overshoots on edges, etc. on black-and-white display	Subjective grade (Standard deviation)	3·04 (0·70)	3·04 (0·75)	3·44 (0·89)

Significant differences between mean grades are calculated to be those in excess of 0·27 grades.

3.6. Lag

TABLE 8

Lag

		E.M.I. FOUR-TUBE CAMERA	PLUMBICON THREE-TUBE CAMERA	3 in IMAGE ORTHICON THREE-TUBE CAMERA
Subjective appraisal of visibility of trailing images of moving object (colour display)	Subjective grade	4·19	3·96	4·02
	(Standard deviation)	(0·58)	(0·95)	(0·93)

Significant differences between mean grades are calculated to be those in excess of 0·27 grades.

3.7. Registration

TABLE 9

Registration

		E.M.I. FOUR-TUBE CAMERA	PLUMBICON THREE-TUBE CAMERA	3 in. IMAGE ORTHICON THREE-TUBE CAMERA
Subjective appraisal of visible misregistration upon tilting the camera (colour display)	Subjective grade	3·90	2·28	2·45
	(Standard deviation)	(0·97)	(1·15)	(0·68)

Significant differences between mean grades are calculated to be those in excess of 0·29 grades.

The E.M.I. camera is said to contain no screening against the effect of the Earth's field. When the camera is panned or tilted, there is an obvious misregistration between the luminance and the three chrominance tubes.

4. DISCUSSION OF RESULTS

When comparing three colour television cameras in a fairly wide variety of tests, it is inevitable that the detailed results become somewhat complicated. In the discussion which follows, only the overall result of each test is considered.

4.1. Noise

The three-plumbicon camera is one whole subjective grade better than either the three-tube image orthicon or the E.M.I. four-tube cameras which are not signifi-

cantly different from each other. This applies to the black-and-white picture as well as to the colour picture. As already stated, the plumbicon camera contains a crispener and low-pass filter circuit which reduces the visibility of noise considerably. A known design of head amplifier is, however, capable of giving equally acceptable noise performance without reduction of video bandwidth.

4.2. Colour Errors

Some assistance in evaluating the results of colour errors could be gained from Fig. 2 in which the mean results are shown in diagrammatic form. The mean subjective grade given by the observers is shown for each camera and the height of each rectangle in the diagram is made to conform with the significance level calculated from the number of observations and the standard deviation. It can therefore be taken that the difference between the grades given to each of the cameras is not significant whenever the rectangles overlap.

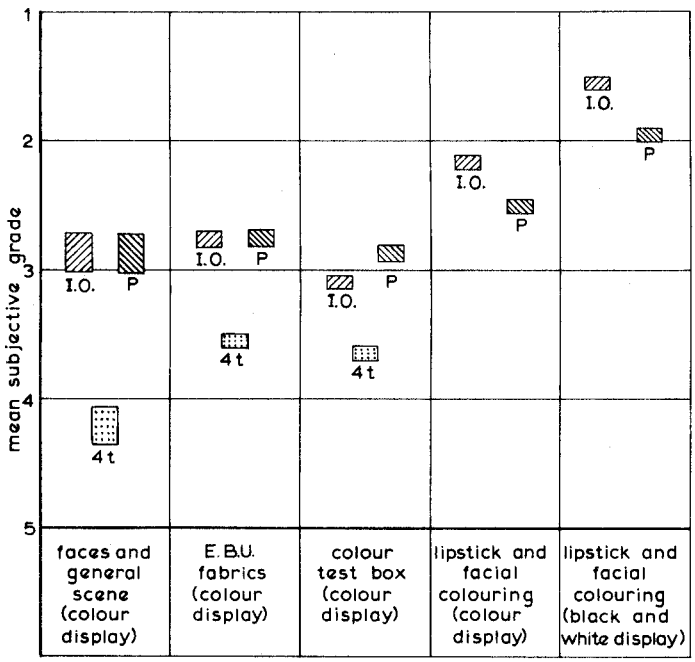

Fig. 2

Colour Errors : Mean Subjective Grades

I.O. Marconi three-tube 3 in. image orthicon camera

4t E.M.I. four-tube camera

P Philips three-tube plumbicon camera

All three cameras were used in three of the four colour tests shown in the diagram above. The fourth test was conducted after the E.M.I. four-tube camera had been returned to the manufacturer and only the plumbicon and image orthicon cameras were used. In each of the first three tests, the E.M.I. camera was significantly worse than either the plumbicon or the image orthicon cameras. Only in the overall results of the colour test box was there any significant difference between the three-tube plumbicon and the three-tube image orthicon cameras and here the plumbicon was slightly superior, due to the failure of the image orthicon camera to handle colours containing energy in the blue parts of the visible spectrum. This is a known defect of the colour analysis of this particular camera. In the lipstick test, the three-tube image orthicon camera showed itself to be better than the plumbicon by a little less than half a grade; this is due to the well-known deficiency of the standard plumbicon to wavelengths in excess of 630 mμ. In a test of the portrayal of lipstick

and facial colouring in the compatible (black-and-white) picture, the darker rendering of the plumbicon was again assessed at about 0·5 grades worse than the three-tube image orthicon camera.

4.3. Portrayal of Fine Detail

As expected, it was in this test that the E.M.I. four-tube camera showed some superiority. In the compatible black-and-white picture, it was a little more than half a grade better than the plumbicon camera, which, in turn, was half a grade better than the three-tube image orthicon camera. In the colour picture, the results were very close and there was really no significant difference between the E.M.I. four-tube camera and the plumbicon camera. This is rather disappointing, particularly when it is remembered that both the plumbicon and three-tube image orthicon cameras were using crispener circuits in which the video bandwidth of the output signals was limited to 3·5 Mc/s. Misregistration between the luminance tubes and the chrominance tubes in the four-tube camera may account for some of the failure to produce a picture comparable in sharpness with the conventional black-and-white camera. Moreover, an image orthicon tube used as a separate-luminance tube must be operated less far around the 'knee' of the light transfer characteristic than a similar tube in a monochrome camera. It has been found that this operating condition impairs the subjective sharpness of the compatible picture. The depth of modulation at 5·5 Mc/s drops by about 12% when the exposure is reduced to about half-a-stop below the 'knee'.

4.4. Sensitivity

Comparisons between the plumbicon and cameras containing an image orthicon are difficult because the former has no fixed operating point and can be operated with more, or less, light in exchange for signal-to-noise ratio. The working point for our comparison was simply based on that which operational experience had found to be a satisfactory compromise between illumination and signal-to-noise ratio. There was little significant difference between the E.M.I. four-tube and the three-tube plumbicon cameras, both of which were more superior to the three-tube image orthicon camera for sensitivity. As already stated, however, it is believed that a substantial improvement could be achieved in the three-tube image orthicon camera by the provision of more efficient optical components for colour analysis and image orthicon tubes having tri-alkali photocathodes.

4.5. Compatibility

It was expected that edges in the picture provided by the four-tube camera might have been enhanced by the additional signal processing which is necessary. Such edges were, in fact, observed, but this was not reflected in the subjective grading. The low saturation produced by the four-tube camera made the subcarrier less obvious in the compatible picture and the fact that the three-tube image orthicon camera was 0·5 grades worse than the other two cameras is probably due to its somewhat superior colour saturation.

4.6. Lag

There was no significant difference in the performance of the three cameras for this test.

4.7. Registration

The E.M.I. four-tube camera was substantially worse than the plumbicon and image orthicon cameras. As stated in Section 3.7, the camera contains no screening against the effect of the Earth's field and it is not known whether a properly-constructed camera containing dissimilar camera tubes can be made to have the same registration properties as a three-tube camera.

5. CONCLUSIONS

To a large extent, comparison between the four-tube camera and the two three-tube cameras was invalidated by the poor instrumentation of the former. There is no fundamental reason for the large-area colour performance of a separate luminance camera to be worse than that of a three-tube camera, providing one of a number of suitable processes of correction is rigorously applied. The colour accuracy of the E.M.I. camera was, however, found to be significantly inferior, and there is some doubt whether a four-tube camera containing vidicons can be successfully corrected because of the great difficulty of gamma-correcting vidicons to a pure power-law. Inability to operate the separate luminance image orthicon tube of the four-tube camera around the knee as practised in black-and-white cameras results in less advantages from the point of view of sharpness in the compatible picture than might be expected.

The advantages of adopting a four-tube arrangement seem rather uncertain. The main point of the four-tube camera lies in its claim to superior resolution, particularly in the compatible picture; this is only partly justified since, as already stated, the operation of the P.822 image orthicon tube below its knee leads to a significant loss of resolution. If, however, the camera contained four plumbicons, the advantage in resolution over a three-plumbicon camera would be restricted to the re-couping of losses accounted for by registration errors, and the best possible compatible performance would be substantially less than that of an image orthicon luminance tube.

The three-plumbicon camera performed surprisingly well in the comparisons of colour accuracy, despite its well-known insensitivity to long-wavelength red light. Its colour performance was equal to or better than that of the three-tube image orthicon camera in all except the lipstick tests. Its performance in the portrayal of fine detail was also closer to the four-tube camera than had been expected, and, given a better head amplifier, the horizontal resolution could be improved for the same subjective noise value. Blemishes on the targets of the plumbicon tubes were rather distracting.

6. ACKNOWLEDGEMENTS

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All the subjective appraisals and some of the measurements were carried out in StudioH, Lime Grove. The assistance of Mr. A.R. Stanley and the staff of Studio H

in providing all the facilities, operating the plumbicon and image orthicon cameras and giving their customary whole-hearted co-operation is also acknowledged. The studio tests were arranged by Mr. E.W. Taylor, Image Scanning Section, Research Department, who also supervised the statistical analysis of the results; the decoding and display of the signals for comparison was supervised by Mr. J.R. Sanders, also of Image Scanning Section.

Finally, it is desired to thank all those members of Engineering Division who took part in making subjective appraisals of the picture display.

APPENDIX

Picture Material Used During The Tests

PICTURE IMPAIRMENT UNDER CONSIDERATION	SCENE(S)
Noise	Red, green and blue E.B.U. colour fabrics, each occupying about 1/3rd of the picture area.
Errors in colour reproduction	(1) Two girls standing beside large areas of red, green and blue E.B.U. colour fabrics: three detergent packets also included. (2) Yellow, cyan, green, magenta, red and blue E.B.U. colour fabrics arranged in vertical 'colour-bar' stripes, together with a white stripe, and occupying the whole of the picture area. An identical set of fabrics was available in the viewing area for comparison. (3) Green, yellow, orange, cyan, white, red, blue, magenta and light magenta gelatine colour-filters arranged in a 3 x 3 matrix and illuminated from behind. Each colour shown at 100% and 25% transmission levels. An identical set of filters was available in the viewing area for comparison. (4) Close-up of girl's face; a sequence of six lipstick shades was used. The original scene could be observed through a colour-temperature-raising window.
Lack of portrayal of fine detail	Two girls seated on a settee, with an in-focus background of newspaper cuttings.
Lack of compatibility	Two girls standing beside large areas of red, green and blue E.B.U. fabrics; three detergent packets also included.
Lag	Swinging pendulum, viewed against dark background. The active length of the pendulum consisted of bands of white, yellow, red, green and blue; the period of the pendulum was about 5 seconds.
Registration	Vertical and horizontal narrow stripes of orange, green, yellow, blue and red. The cameras were tilted upwards by approximately 15 degrees from their usual operating position while this test was in progress.

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