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New Equipment and Methods for the Evaluation of the Performance of Lenses for Television

by

W. N. SPROSON, M.A.

(Research Department, BBC Engineering Division)

BRITISH BROADCASTING CORPORATION

PRICE FIVE SHILLINGS

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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

Part I of this Monograph provides an outline of the photo-electric method of testing lenses, together with some details of the two types of test pattern now in use in the BBC's Research Department and the form of aperture correction necessitated by the finite width of the scanning slit. The photo-electric test bench is described and a few preliminary results are quoted.

Part II deals with the problem of integrating the response curves obtained from the photo-electric bench to yield a single figure which indicates the performance of a lens over the whole of its field. Factors affecting the quality of a picture, such as variation in definition over the field and vignetting, are discussed. The experimental basis for an index is given and formulae are developed for monochrome television and colour television indices.

PART I

A NEW PHOTOELECTRIC OPTICAL BENCH

1. Introduction

This optical bench has been designed for testing lenses intended for use with television systems. It might be considered that the standard of definition used in television is relatively low and much below the limiting resolution of most lenses, so that no consideration need be given to the lens. This in fact is a simplification of the situation, because, although the limiting resolution of most lenses is very high (in terms of television definition), lenses do suffer some loss of contrast at the pattern frequencies corresponding to television picture detail.[1] Further, it has been found experimentally that a change of lens can make a noticeable difference to picture definition on a television monitor.

The order of magnitude of pattern frequencies involved in television images is ten patterns (or optical lines) per mm. In the case of an image orthicon with a photocathode diagonal of 40 mm., the pattern frequency corresponding to 3 Mc/s on BBC standards is eight patterns per mm. (ppm.). 3 Mc/s bars recorded on 35 mm. film correspond to twelve patterns per mm. and on 16 mm. film the figure rises to 26 ppm.

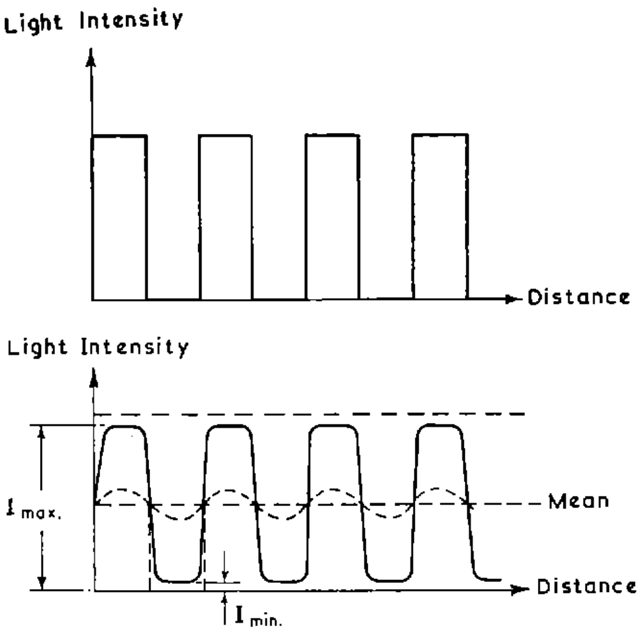

Fig. 1 — Original square wave grating pattern (above) and its reproduction by a lens (below)
Solid line represents a low pattern frequency and dotted line a much higher frequency

2. Method of Measurement

If we consider the reproduction of a square wave grating pattern of high contrast ratio (Fig. 1) by a lens, the image will not be a perfect copy of the original with merely a scaling factor for change of size. Some loss of contrast is encountered. At low pattern frequencies this is slight but at higher frequencies only a sinusoidal variation is found with relatively low amplitude. Modulation is here defined (for optical work) as

$$\frac{I_{max} - I_{min}}{I_{max} + I_{min}}$$

where I is the light intensity. This is identical with 'visibility' as defined by Michelson [2] and is a more useful scale to use than contrast ratio, although of course it is directly related to it.

An outline of the method is shown in Fig. 2. Light from a tungsten lamp is diffused by an opal diffuser and then passes through the test pattern. Colour filters can be interposed between the test pattern and light source if required. The lens under test images the test pattern and it is necessary to measure the variation of light intensity in the plane of focus. If it were easy to make slits of the order of 10μ width, the image would be measured in its own plane, but for convenience the image is magnified by a suitable apochromatic microscope objective and the magnified image is scanned by a slit in a box containing a photomultiplier. In an elementary form of the apparatus this box is mounted on a travelling microscope stand and thus can be made to traverse the image.

Variations in the light flux between different parts of the image cause variations in the photocurrent, which are read off on a meter. A d.c. amplifier with negative feedback is used to avoid the need for a very sensitive current-measuring instrument. The biasing arrangement permits easy setting of the meter so that the dark current of the photocell is not recorded.

Two sorts of test pattern are used (*a*) a series of square wave grating patterns, and (*b*) thin slits.

B. *Light source*
F. *Neutral and/or colour filter*
T. *Test pattern*
L. *Lens under test*
N. *Microscope (less eyepiece)*
P. *Narrow slit*
M. *Box housing photomultiplier*
S. *Scale of travelling microscope stand*

Fig. 2 — Method of measuring the modulation characteristics of lenses

2.1 *Square Wave Grating Pattern Method*

The modulation to square waves is recorded for a suitable range of pattern frequencies. The correction to be used for the finite width of slit has been evaluated on the assumption that the degradation of image quality of the square wave test pattern produced by the lens is similar to that produced by a lens limited only by diffraction. The set of curves thus obtained is shown in Fig. 3. In any practical case, the curves of Fig. 3 will be only approximately correct, but the main interest for television purposes centres around the 0 to 0·1 f/f_c region, so that the corrections are not large. Thus, errors in the correction have only a very slight effect upon the final result.

2.2 *Slit Method or Unit Impulse Method*

This method is the optical analogue of impulse testing in electronic circuits. A narrow slit is used as the test pattern and a determination of the intensity versus distance relationship in the plane of focus is made. The Fourier transform of this gives the modulation/frequency response but in this case it is the modulation to sine waves. Aperture correction is no longer subject to the uncertainties which were present in the case of square wave test pattern, and one can correct precisely for the finite width of both scanning slit and source slit. There is the further advantage that the sine wave response does give the response at one frequency only, whereas the square wave response is the sum of the responses over a range of frequencies.

Given the sine wave response of a lens, it is not difficult to calculate from the Fourier series its square wave response. Likewise the sine wave response can be deduced from the square wave response, although in this latter case the algebra is slightly more troublesome.

3. Description of the Bench

The photoelectric optical bench is a modification of a Mark I Optical Test Bench designed and built by Messrs Taylor, Taylor, and Hobson. This particular design has

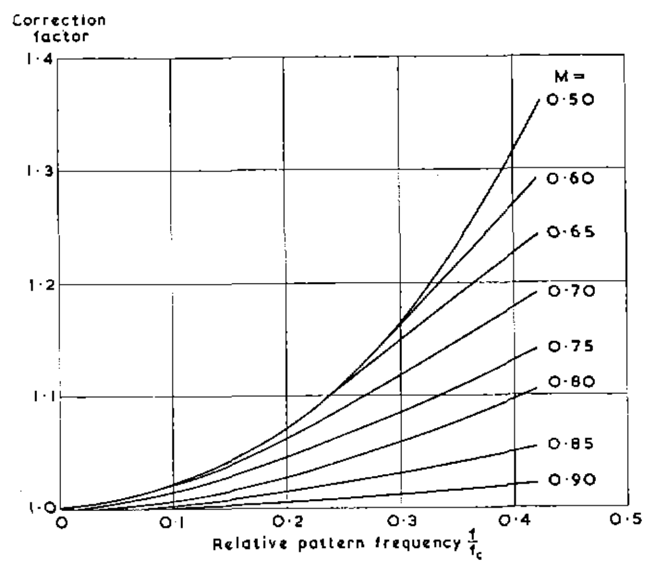

Fig. 3 — Aperture correction curves for square wave modulation

now been superseded by the manufacturers, but it offers the basic facilities that are required for photoelectric testing. As will be seen from Fig. 4, the bench consists of a light source (A), which, with a suitable condensing and diffusing system, illuminates the test object. The test objects are either square wave grating patterns or relatively fine slits, corresponding to the two methods just described. Sixteen different test objects are available from one test object disk, and the different test objects can be easily changed from the observation end of the test bench. Two other disks are mounted on the same horizontal axis behind the test object disk and contain neutral density filters and colour filters respectively.

Light from the test object is collimated by a 1524 mm. f/15 collimating lens (B) and passes on to the lens under test (C). This is mounted on a shake-free ballrace of large diameter (127 mm., 5 in.) (D), which is part of a carriage (E) that runs on a turntable (F). Light from the lens under test forms an image which can be accurately located in a plane which includes the vertical axis of a bearing which is located on the bridge of the optical bench (G). This bearing takes a vertical plate which holds the photographic plate holder which is used when photographic results are required: it is arranged that with a photographic plate in position the emulsion surface contains the vertical line through the centre of the bearing (H) on the bridge (G), Fig. 5. When the turntable is rotated, the lens can be adjusted to rotate about its rear nodal point and the distance from the lens to the central axis through the bearing is automatically increased by (sec $\theta - 1$) by the action of the Tee-bar (or sine bar) (I). Coarse and fine adjustments for both focus and turntable positions are provided (micrometers (1) and (2), Fig. 6), so that it is a relatively easy matter to set up a new lens (always provided that a suitable mounting flange is available).

So far the bench has been described substantially in the form in which it was originally made. The modifications which were carried out involved removing the original microscope from the bridge and fitting a microscope and photocell attachment which is capable of lateral and vertical movements so that the image can be scanned in two mutually perpendicular directions. A close-up of this is shown in Fig. 6. There are three metal blocks (K), (L), and (M), of which the bottom one (K) is fixed to the bridge. The second one (L) moves upon this in a direction parallel to the axis of the bench. Kinematic design principles are used here—3 ball-bearings moving upon 2 Vee's and a flat. The third block (M) moves on the second and is capable of movement perpendicular to the axis of the bench. It is driven by a micrometer (3) which is marked to 5μ intervals and can be estimated to 1μ by inspection. Upon the third block (M) a hollow cylinder (N) is mounted with its axis

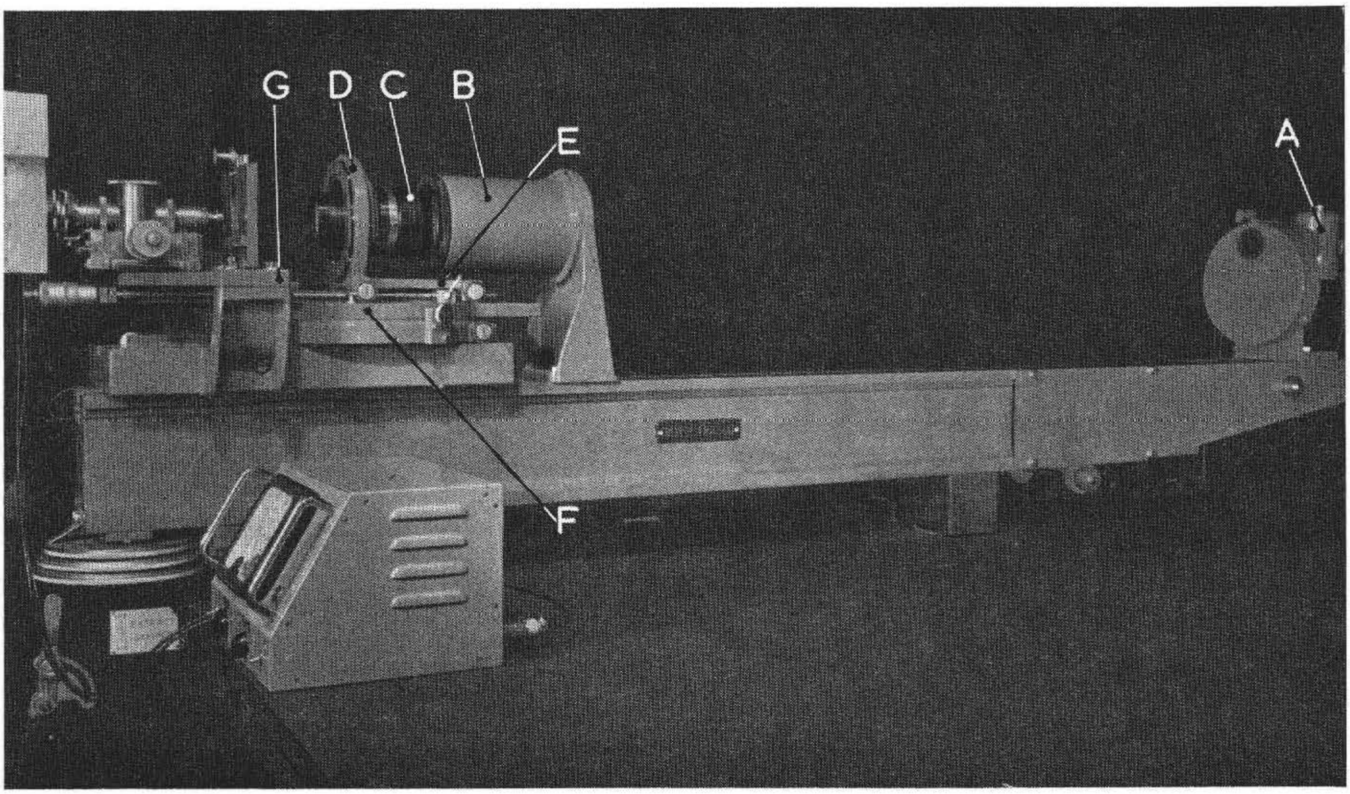

Fig. 4 — General view of the optical test bench

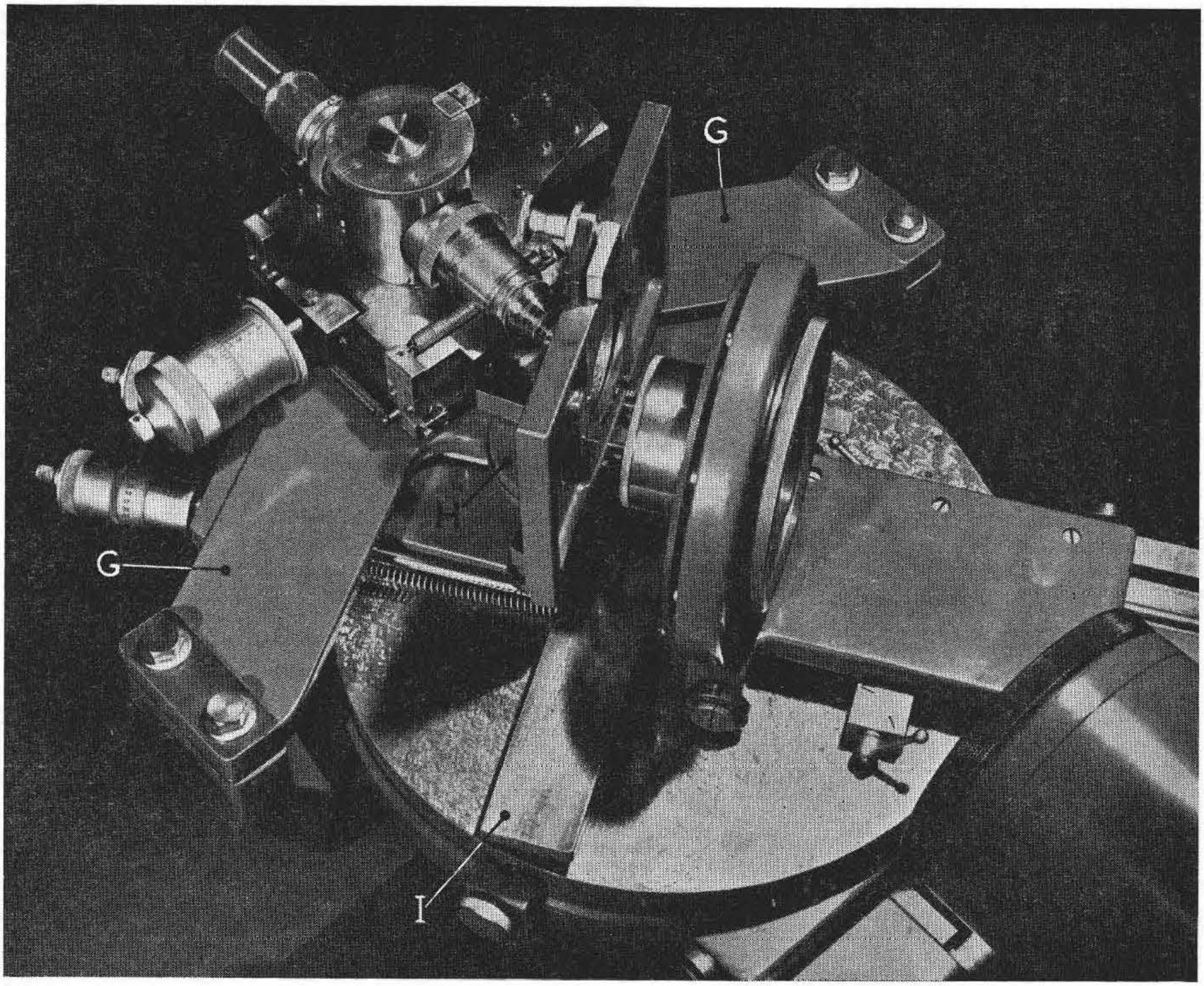

Fig. 5 — Nodal slide turntable of the optical bench
This view shows an eyepiece in place of the photocell housing: the eyepiece is used for setting-up purposes

vertical. Inside this cylinder is fitted another cylinder which takes the microscope tube (O). The inner cylinder can be driven up and down by a micrometer thread (P) and the movement can be measured by the scale markings on the upper milled head, which serves as a micrometer (4). In order to prevent rotational movements of the microscope tube, an arm (R), Fig. 7, is taken out from the inner (microscope) cylinder and is accurately located so that whilst vertical movement is permitted, maximum possible rotation is equivalent to much less than 25μ displacement on the part of the objective.

The whole assembly is kept a fixed distance from the datum plane (i.e. proper image plane) by a roller bearing (Q), Fig. 7, which is kept in contact with a bearing plate let into the photographic vertical plate mounting by two horizontal springs, one of which is shown as (T) in Fig. 6. The bearing plate can be adjusted by three screws, two of which are shown in Fig. 7, so that

(*a*) it is accurately parallel to the datum plane,

(*b*) the centre of the roller bearing (Q) is made to coincide with the vertical axis of the bearing on the bridge.

In this way, when the nodal slide is rotated, thereby causing the lens and photographic plate-holder also to rotate, the microscope will then follow the true image plane upon being given a lateral movement by micrometer (3). It is granted that the depth of focus of the microscope objective may well not be sufficient to image the whole field, but it is only the centre of the field that is used by the thin slit passing light flux to the photocell.

The same argument does not apply to vertical scans (when the slits and test pattern bars are horizontal) and here depth of focus is required to some extent. The results obtained to date do not suggest that there is serious trouble on this account.

Light from the aerial image is magnified by a suitable microscope objective (16 mm. or 8 mm. apochromat) and a small part of this light flux is selected by a variable slit (R), Fig. 6, and passes on to the multiplier photocell housed inside the box (S). The current from the multiplier photocell is amplified by a d.c. amplifier and read off on a moving coil milliammeter.

The bench has since been converted to automatic recording, [(3)] using a thin horizontal or vertical slit as a test object (section 2.2).

4. Typical Results

A few preliminary results are included. The curves include the effect of the collimator lens and microscope objective as well as the lens under test. There is some reason to believe that the effect of the collimator may not be entirely ignored and tests are being undertaken to measure this. The microscope objective, a 16 mm. apochromat of N.A. 0·3, is considered to be good over the frequency range concerned. Fig. 8 shows the modulation characteristics of a 50·8 mm. f/2 lens at f/2 focused at 0° for 7½ ppm. The modulation at 3 Mc/s (8 ppm.) is shown in the inset diagram.

If the same lens is focused for 60 ppm. the curves (Fig. 9) change in shape and the field is now much more constant right out to the periphery, but at a lower modulation level.

Fig. 10 shows the results of Fig. 8 converted to sine wave response.

Fig. 11 shows the results for another 50·8 mm. f/2 lens. This one does not show any marked dependence of its characteristic on the focusing frequency. It is of interest to note that it is better than lens (A) over the BBC television band, although not so good at 30 ppm., for axial imagery and off-axis imagery up to 15°.

Fig. 12 shows the results for a 152·4 mm. f/2 lens using the unit impulse method. Here the results were directly obtained as sine wave responses from the Fourier transforms of the space function.

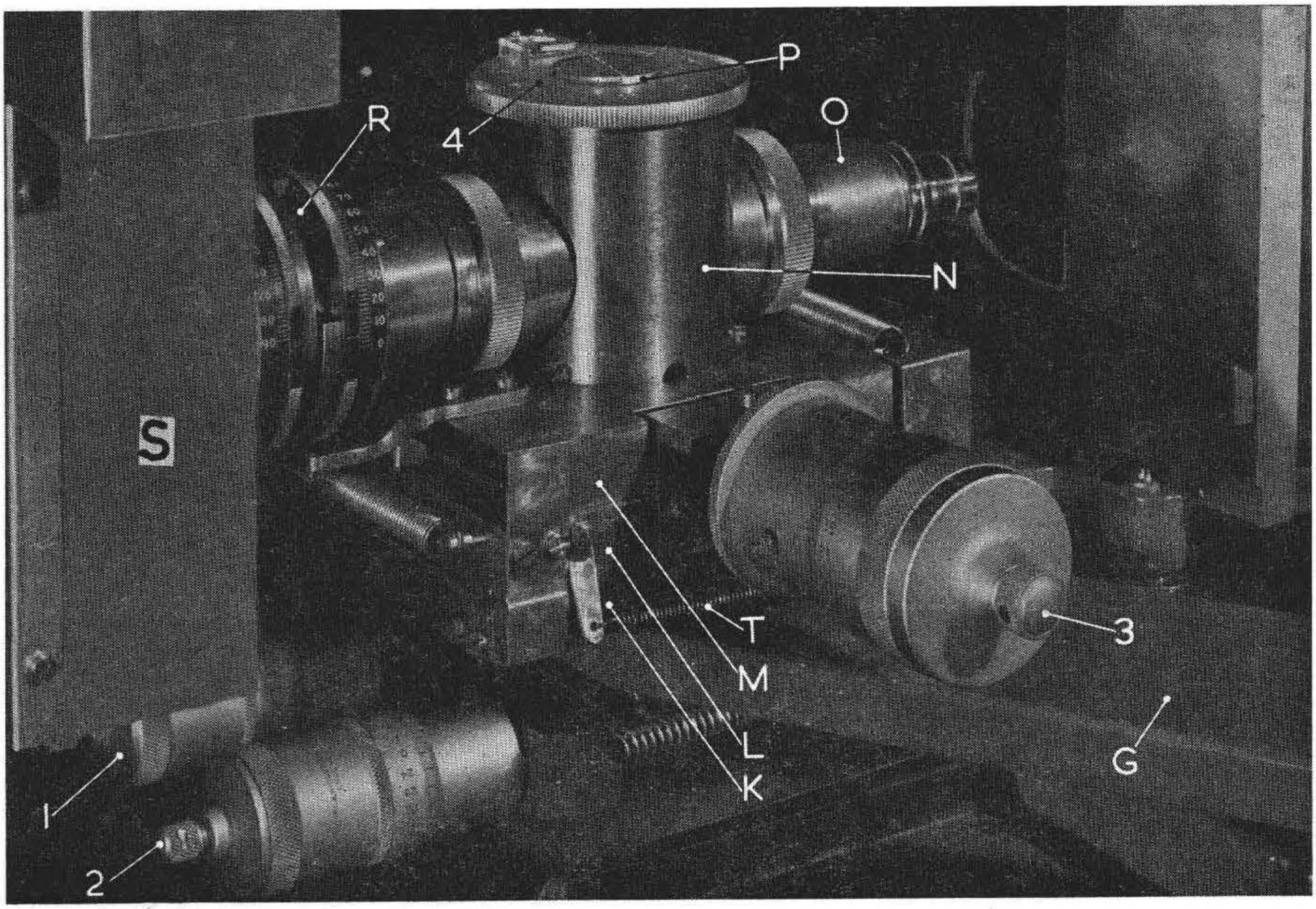

Fig. 6 — Details of the photoelectric scanning part of the optical bench

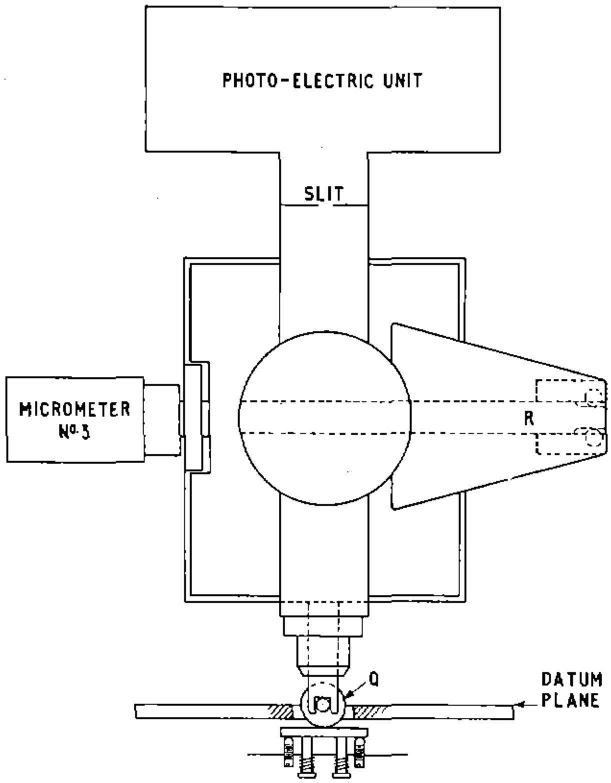

Fig. 7 — Plan of photoelectric bench to show correct position of roller bearing Q

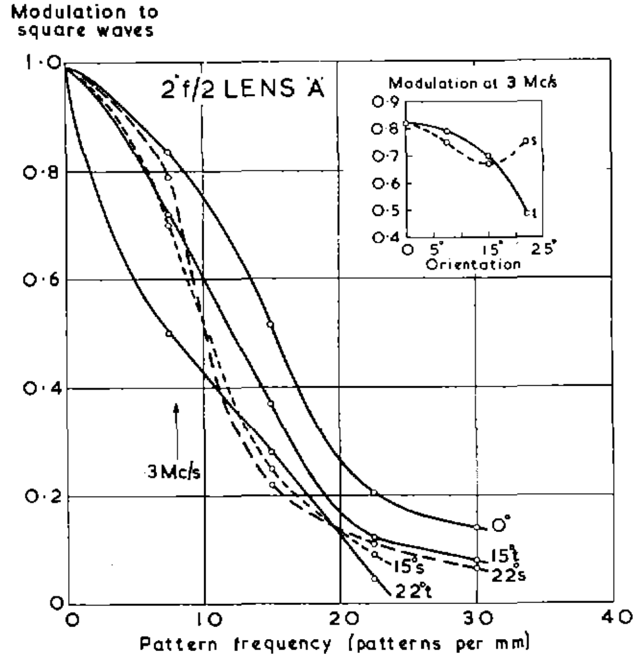

Fig. 8 — Modulation/frequency characteristics of 2" f/2 lens 'A'. Focus optimum for 7½ patterns per mm.

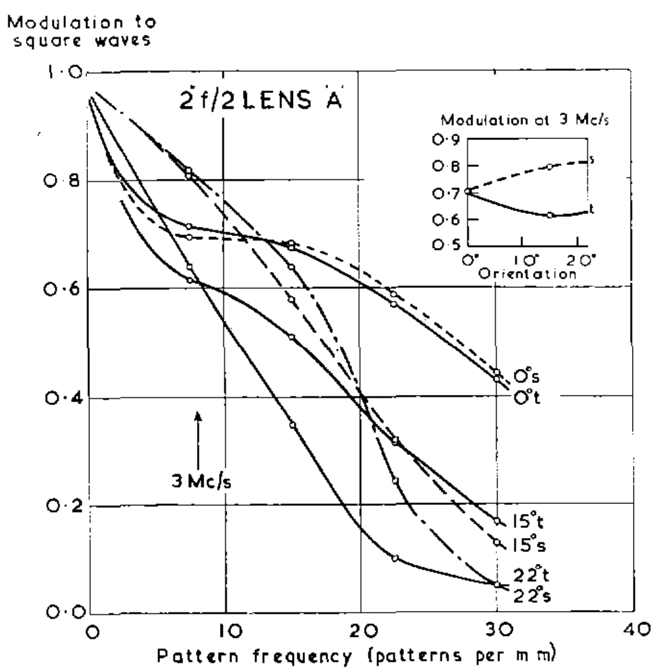

Fig. 9 — Modulation/frequency characteristics of 2" f/2 lens 'A'. Focus optimum for 60 patterns per mm.

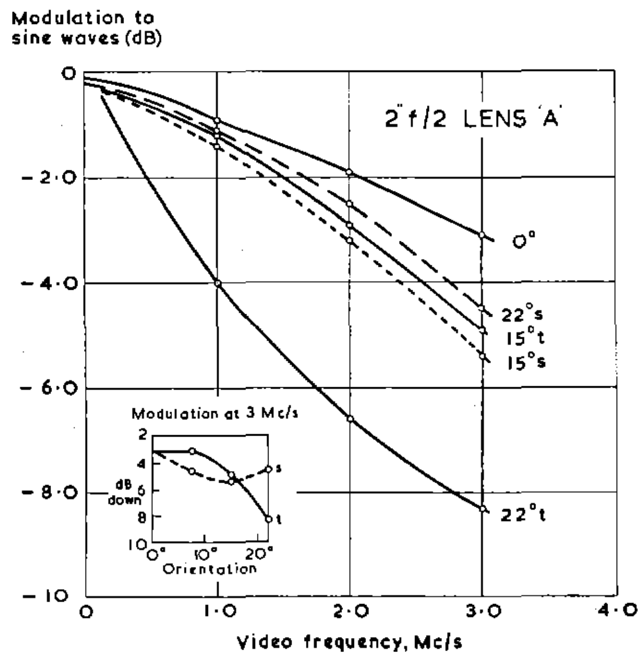

Fig. 10 — Sine wave modulation curves for lens 'A' with optimum focus at 7½ patterns per mm.

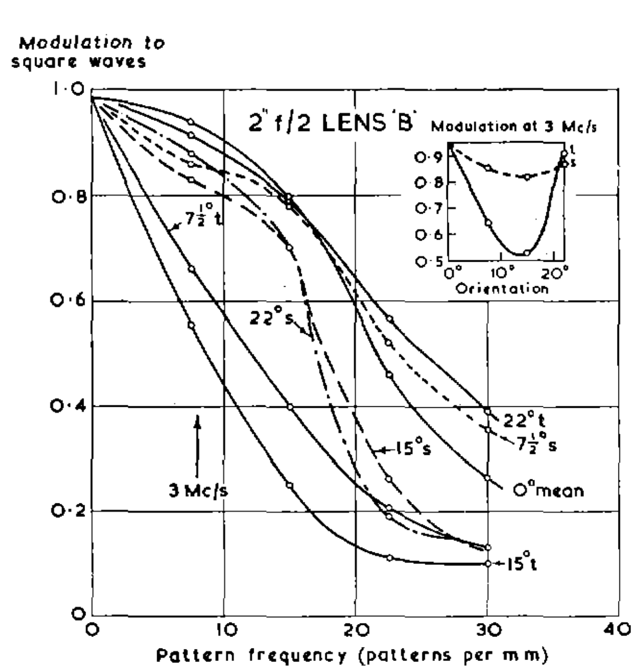

Fig. 11 — Modulation/frequency characteristics of 2" f/2 lens 'B'

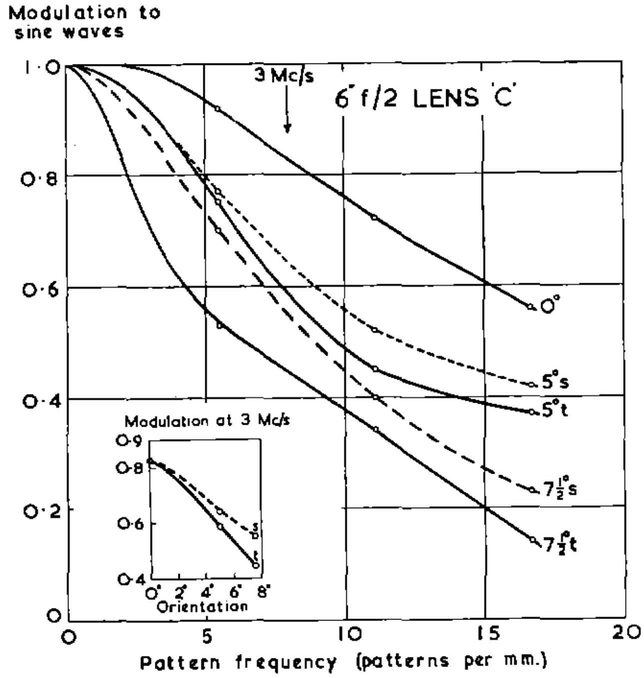

Fig. 12 — Sine wave modulation curves of 6" f/2 lens 'C'

PART II

A PROPOSED INDEX FOR THE EVALUATION OF THE PERFORMANCE OF A LENS FOR TELEVISION

1. Introduction

In Part I of this Monograph, a lens bench has been described which enables the intensity distribution in the image plane of a lens to be directly measured. Providing that the form of the test object is known, it is then possible to express the properties of the lens as a series of curves which describe, for several stated orientations, the response (or modulation) of the lens to a range of patterns having different spatial frequencies. Several sets of curves are shown in Figs. 8 to 12 of Part I, and although these curves give precise quantitative data about the lenses in question, the problem still remains of giving an overall assessment of the image-forming properties of the lens. A practical problem of importance is to assess which of two or more lenses of similar focal length, aperture and field, is the better for a specific application. One lens may have better central definition, although another maintains a more constant standard of definition right out to the periphery of the field. A further variable is the vignetting of the lens: this particularly arises with wide-angle lenses and must be taken into consideration when the coverage of the lens is not entirely adequate.

2. Subjective Sharpness of Television Pictures

The relationship between the subjective sharpness of a television picture and the response/frequency characteristic of the picture-producing device has been investigated.(4) A linear relationship was found between the subjective impression of picture sharpness and the area under the curve relating response and frequency (both measured in linear units). The area is considered from zero frequency up to the frequency of cut-off of the television system, and is shown as the shaded area in Fig. 13. It is convenient to describe the area as a fraction of the maximum possible response for a system with a given bandwidth (the dotted rectangle in Fig. 13), this fraction being called the sharpness factor. For a picture with full 3 Mc/s resolution it was found that a change in subjective sharpness of 1 limen* was produced when the sharpness factor was reduced from 1·00 to 0·89. Expressed in terms of equivalent rectangular bandwidth, this is a change from 3·00 Mc/s to 2·67 Mc/s. More generally, if a picture-producing device has a sharp-

* 1 limen implies that 50 per cent of the observers can perceive the change and 50 per cent are unaware that a change has been effected.

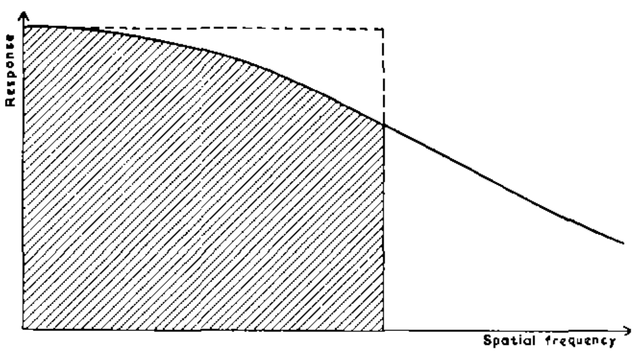

Fig. 13 — Typical response curve of lens

ness factor of S, then the degradation of the pictures as compared with those from a fully-resolved channel will be expressed by

$$L_s = 9 \cdot 2\,(1 - S) \qquad (1)$$

where L_s is the degradation due to lack of sharpness expressed in limens. 9·2 is the gradient in limens per unit sharpness factor of the appropriate curve quoted from reference 4.

3. Suggested Integration for the Image Due to a Lens

A lens produces an image with degradation which is a function of the distance from the centre of the field. It is also a function of the direction (i.e. sagittal or tangential) of the gradient of the radius vector from the centre of the field to the point in question. In integrating the whole field, it is convenient to assume initially that all parts of the field are equally important. It is further assumed that all orientations are equally important and hence the integration problem resolves itself into the description of a rectangle of aspect ratio 4:3 by means of a series of annuli of increasing radius. The solution of this simple geometrical problem is given in Fig. 14, which plots the weighting of the result (i.e. the area of the annulus) against the angular displacement. The weighting is zero at the centre because there is zero area for the central point: likewise it is zero at the periphery. The discontinuities in Fig. 14 arise when the increasing annuli reach the sides of the rectangle, first the long side and then the shorter one.

The assumption of equal importance for all parts of the field would be true for aerial survey purposes and photogrammetry, but it is not necessarily true of television. Jesty[5] has suggested that the peripheral definition need be only 50 per cent of the central definition and this figure was assumed in drawing an 'interest vs radius of zone' curve, Fig. 15, by which the weighting curve (dotted) of Fig. 14 was multiplied. The final curve is also shown in Fig. 14, together with ordinates at 0·1, 0·3, 0·5, 0·7, and 0·9 of the peripheral angle. This is the sampling which is chosen in practice, although no particular virtue is claimed in choosing five equispaced sampling points to evaluate the whole field.

It may be objected that 50 per cent is too great an 'interest value' to allocate to the periphery of the field, particularly as no modern television receiver uses a rectangular mask to define the edge of the picture, so that unless the line and field scans are intentionally reduced, the corners of the transmitted picture are never seen. While this may be true, such a relaxation might permit very poor definition in the corners and it is deemed the duty of the transmitting authority to transmit the whole picture irrespective of whether the picture is examined at the corners.

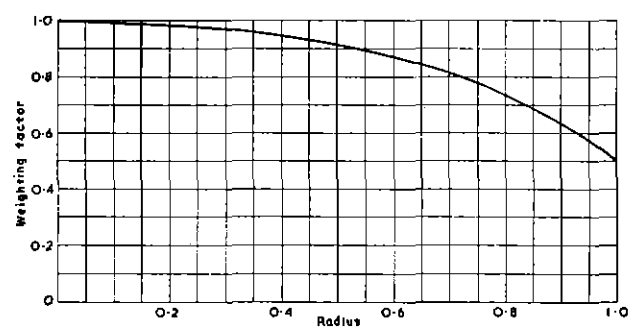

Fig. 15 — Weighting factor of interest value

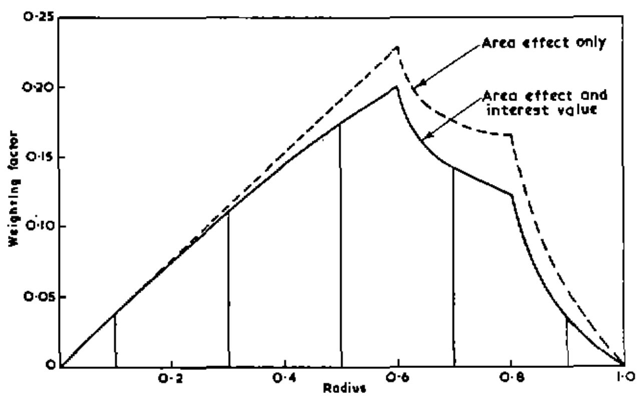

Fig. 14 — Suggested weighting factors as a function of the field angle

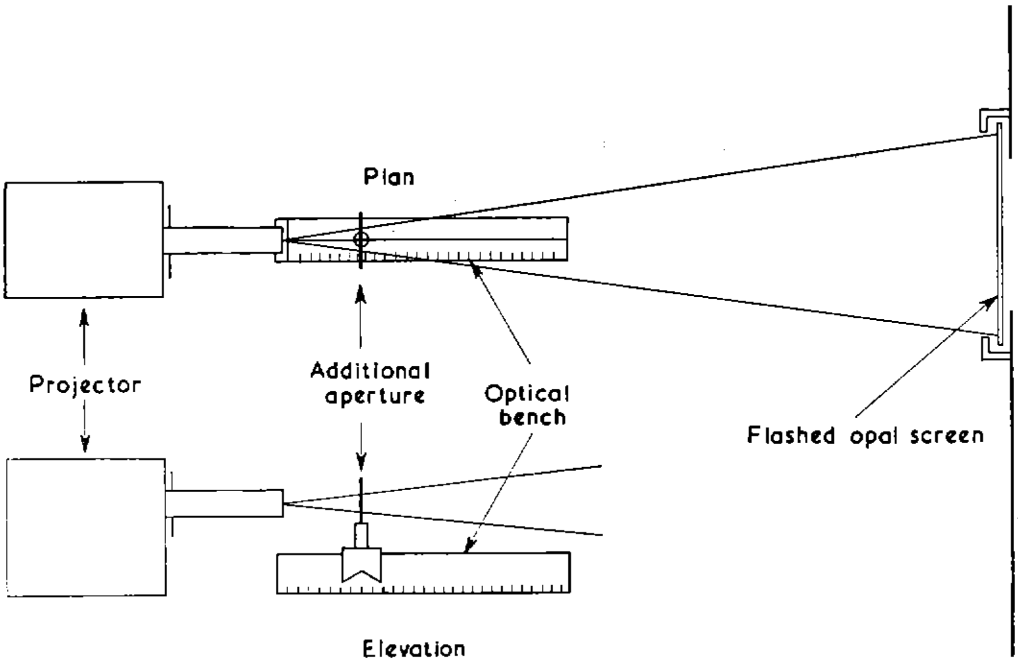

Fig. 16 — Layout of apparatus for vignetting experiment

4. Degradation of Image Due to Vignetting*

4.1 *Introduction*

The image due to a lens is not of uniform brightness over the whole field. According to classical theory,[6] the image intensity varies as $\cos^4\theta$, where θ is the field angle measured to the optical axis. In addition to this $\cos^4\theta$ variation, lenses frequently have 'barrel effect', which means that for off-axis rays, one of the lens elements restricts the emergent light pupil and causes further reduction in intensity. Except for short-focal-length lenses these vignetting effects do not usually have any noticeable effect on the image uniformity, because the eye is fairly tolerant to gradual changes in intensity over the field of a picture. Nevertheless, lack of uniformity of image intensity can cause visually perceptible degradation of the picture and experiments were made to obtain quantitative data on this subject.

4.2 *Apparatus*

A slide projector was used to produce a rear-illuminated image on a flashed-opal screen. An auxiliary aperture was mounted on an optical bench in front of the projection lens. The position of this extra aperture controlled the vignetting of the picture and the intensities at various positions on the screen were measured with an S.E.I. photometer for different positions of the auxiliary stop. In this way a calibration graph was obtained, relating the peripheral brightness to the stop position. The apparatus and calibration curves are shown in Figs. 16 and 17.

*Vignetting is used here to imply lack of uniform coverage due to $\cos^4$ effect, barrel effect and any other causes.

4.3 *Method*

Four monochrome and four colour transparencies were used as picture material. A number of presentations of each of the transparencies was made in random order, the

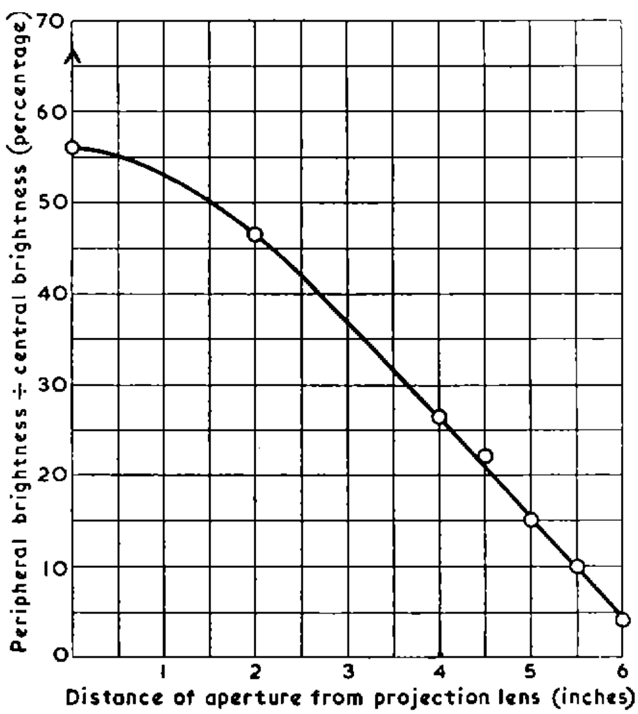

Fig. 17 — Calibration curve of apparatus shown in Fig. 16

randomness including the order of showing the four transparencies as well as the degree of vignetting. The schedule given below illustrates the manner in which this was done.

Presentation No.	*Slide*	*Stop Position* (inches)
1	A	4½
2	C	4
3	D	5
4	C	5½
5	A	2
6	B	5
7	D	4½
8	A	6
9	D	2
10	B	4
11	A	5½
12	D	6
13	C	0
14	A	4
15	D	4
16	A	0
17	B	6
18	D	0
19	C	4½
20	B	5½
21	A	5
22	B	2
23	D	5½
24	C	5
25	B	4½
26	C	2
27	B	0
28	C	6

Observers were tested individually and the procedure was to show the complete range of vignetting on one of the pictures before starting the experiment proper. The vignetting was quite obvious to all observers in the most forward position of the stop. The vignetting was assessed on the scale:

Grade	*Score*
imperceptible	0
just perceptible	1
easily perceptible	2

Each observer's results were 'unscrambled' and tested for self-consistency. While it is not possible to state at what level an observer should begin to notice vignetting, it is reasonable to expect his comments on any one picture to be consistent, so that when the vignetting is increased, his scoring should certainly not decrease. Many of the observers were completely consistent in this respect; some had one inconsistency only: a few had three or four inconsistencies, and the results from these observers were ignored.

The monochrome and colour transparencies were used in two separate and distinct experiments.

4.4 *Results*

The results are presented graphically with the arithmetical sum of the individual scores plotted as the ordinate and the logarithm of the peripheral brightness plotted as abscissa. Fig. 18 shows the results for monochrome transparencies and Fig. 19 for colour transparencies. It will be observed that the threshold for the commencement of scoring is lower for a colour picture than for a black-and-white one, but the gradient of the curve is higher for colour. The positions of the lines relating to the pictures showing the maximum and minimum sensitivities to vignetting are also shown.

A numerical expression for monochrome picture degradation caused by vignetting is

$$\left.\begin{array}{ll} L_v=3\cdot3\,(\bar{1}\cdot8-\log_{10}V) & \text{for } \log_{10}V<\bar{1}\cdot8 \\ L_v=0 & \text{for } \log_{10}V\geqslant\bar{1}\cdot8 \end{array}\right\} \quad \ldots.(2)$$

where L_v=degradation due to vignetting expressed in limens

V=peripheral brightness as a fraction of central brightness.

3·3 is the gradient of the mean curve in Fig. 18.

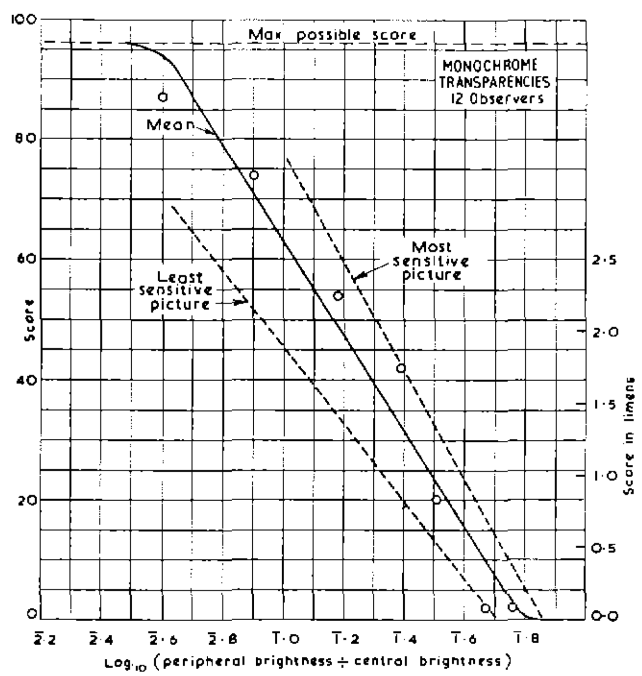

Fig. 18 — *Results for monochrome pictures*

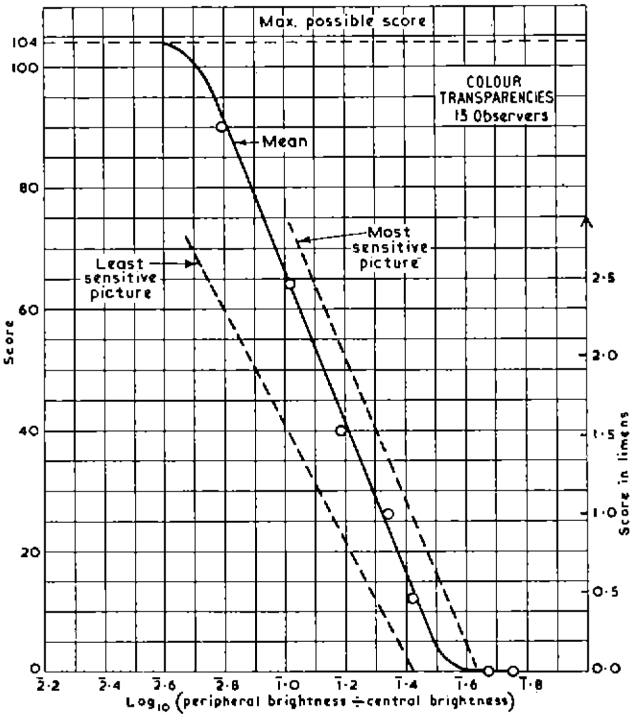

Fig. 19 — Results for colour pictures

For a colour picture the expression should read

$$\left.\begin{aligned} L_v &= 4\cdot 8\,(\bar{1}\cdot 53-\log_{10}V) && \text{for } \log_{10}V<\bar{1}\cdot 53 \\ L_v &= 0 && \text{for } \log_{10}V\geqslant\bar{1}\cdot 53 \end{aligned}\right\} \quad \ldots(3)$$

4·8 is the gradient of the mean curve in Fig. 19.

5. The Proposed Index

5.1 *Index for Monochrome Images*

The assessment of the sharpness of a television picture has been dealt with in Sections 2 and 3. For completeness, explicit formulae are given below.

$$L_s=9\cdot 2\,(1-S_{int}) \quad \ldots\ldots\ldots\ldots\ldots(4)$$

where S_{int} is the integrated sharpness over the whole field.

$$\left.\begin{aligned} S_{int} = {} & 0\cdot 0383\,(S_s+S_t)_{0\cdot 1\theta_p} \\ & +0\cdot 1111\,(S_s+S_t)_{0\cdot 3\theta_p} \\ & +0\cdot 1743\,(S_s+S_t)_{0\cdot 5\theta_p} \\ & +0\cdot 1418\,(S_s+S_t)_{0\cdot 7\theta_p} \\ & +0\cdot 0345\,(S_s+S_t)_{0\cdot 9\theta_p} \end{aligned}\right\} \quad \ldots\ldots\ldots(5)$$

S_s and S_t are experimentally determined sagittal and tangential sharpness factors for 0·1, 0·3, 0·5, 0·7, and 0·9 times the peripheral angle θ_p.

The coefficients will be observed to sum to 0·5, so that if S_s and S_t are unity over the whole field then $S_{int}=1$ and $L_s=0$ as it should be under the condition of perfect imagery up to the cut-off frequency.

The total degradation is assumed to be the sum of the degradations due to lack of sharpness and vignetting.

Hence the complete formula for the total degradation (L) of black-and-white images becomes

$$L=L_s+L_v$$

$$\left.\begin{aligned} &=9\cdot 2(1-S_{int})+3\cdot 3(\bar{1}\cdot 8-\log_{10}V) && \text{for } \log_{10}V<\bar{1}\cdot 8 \\ &=9\cdot 2(1-S_{int}) && \text{for } \log_{10}V\geqslant\bar{1}\cdot 8 \end{aligned}\right\}(6)$$

This formula has now been in use (at the BBC Research Department) for some time and the answers which it gives correlate well with general impressions of lens performance. Although the formula as a whole has not been tested experimentally, the two parts from which it is constructed are the direct results of experiment.

The suggestions in the next paragraph on an index for colour television are offered much more tentatively, as little or no experimental work has yet been done on this subject.

5.2 *Index for Colour Television*

For colour work it is suggested that the lens is first examined with tricolour red, green, and blue filters interposed between the light source and test pattern. The focus would usually be chosen to be optimum for green, as this contributes most powerfully to the sharpness of the complete image. The sharpness factors for red, green, and blue images can then be calculated and a suitable weighting of red, green, and blue sharpness is chosen, based either on relative luminance contributions or preferably on the requisite relative sharpness of the red, green, and blue components of a coloured image.[7] The following weighting is suggested as a result of Baldwin's work on the subjective sharpness of additive colour pictures.

$$S'_{int}=0\cdot 22S_{R\,int}+0\cdot 65S_{G\,int}+0\cdot 13S_{B\,int} \quad \ldots\ldots(7)$$

where S'_{int} = sharpness factor for whole field in colour
$S_{R\,int}$ = sharpness factor of red component for whole field
$S_{G\,int}$ = sharpness factor of green component for whole field
$S_{B\,int}$ = sharpness factor of blue component for whole field

The suggested index for colour then becomes

$$\left.\begin{aligned} L&=9\cdot 2(1-S'_{int})+4\cdot 8(\bar{1}\cdot 53-\log_{10}V) && \text{for } \log_{10}V<\bar{1}\cdot 53 \\ &=9\cdot 2(1-S'_{int}) && \text{for } \log_{10}V\geqslant\bar{1}\cdot 53 \end{aligned}\right\}(8)$$

Experimental work on the sharpness of colour pictures might show the need for a different coefficient by which to multiply the sharpness term, although any substantial change seems unlikely in the light of Baldwin's results.

6. Some Observations on the Index

Most of the geometrical aberrations of a lens are taken into consideration when the response/frequency characteristics are measured. Geometrical distortion is not included, however, and the index is lacking in this respect. Measurement on the geometrical distortion of most modern lenses shows that they are completely satisfactory in this respect: the usual difficulty with the geometry of television pictures is to secure adequate linearity of scan in the line and field circuits of both the camera and the receiver. Hence it is not considered necessary at present to include a term in the index to express the geometrical distortion of the lens.

The sharpness factor S integrates the response of the lens from zero frequency up to the cut-off frequency. This simple approach has been found to yield very good correlation with the subjective estimate of sharpness but it is not the only way of evaluating sharpness. Schade [8] and others have suggested an integration using the square of the response and this has the merit of agreeing with the information content of images calculated from information theory. One reason for not using this method of calculating sharpness is that a phase inversion in the response/frequency characteristic would be counted as adding to the information content (or sharpness). It is doubtful whether such spurious resolution adds to one's knowledge of an image unless one has *a priori* knowledge of the phase inversion and can interpret the image accordingly. The experimental data from the work on subjective sharpness of television pictures [4] have also been evaluated on the basis of the square of the ordinates of the response/frequency curve and the correlation between subjective score and objective variable is again very good. As the available experimental evidence supports the use of both the first and second powers of the response, the choice in this work has been for the first power as being the simpler hypothesis.

The excellence of the image produced by a lens can be directly deduced from the final result in limens. A lens can be regarded as producing negligible degradation when its index gives a figure of 1 limen or less at full aperture. This result has been achieved with some of the latest prototypes of lens designs for the image-orthicon camera (photocathode diagonal: 40 mm. and lens aperture f/2). In the case of the vidicon camera tube (photocathode diagonal: 16 mm.) the achievement of this high level of performance is more difficult, partly because the spatial frequency corresponding to a video frequency of 3 Mc/s is higher (viz. 20 patterns per mm.) and partly because the full aperture of the lens needed for a vidicon camera is larger than that for the image orthicon. In the case of studio productions, where the lighting is under control, image orthicons are usually operated with a lens of aperture f/5·6 and this occasions virtually no degradation due to the lens.

One further point: the performance of a lens measured in the manner described above does not assess its flare characteristics. To do this, the measurements are repeated in the presence of a surround field extending from the test object and illuminated to the same level as the peak white of the test object. The effect of a large-area-surround field is to produce a substantially constant low-level illumination in the image plane extending over the whole field. This reduces the contrast of all grades of detail, i.e. from very low spatial frequencies up to the highest spatial frequencies. The flare characteristics of a lens are considerably improved by 'blooming' the lens surfaces, and this also improves the transmission of the lens.

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A RECENT BBC DEVELOPMENT

A METHOD OF APPLYING D.C. BIAS TO A MAGNETIC RECORDING HEAD

Inventor

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It is a common practice in magnetic recording systems to apply to the recording head an a.c. bias in order to linearize the magnetic characteristics of the material of the recording medium during the recording process. It may be, however, that in some cases the use of a.c. bias is not possible owing to the losses which would occur in the recording head at the bias frequency necessary or because of the loss of very short wavelength response which occurs in the conventional recording head when a.c. bias is employed. In these circumstances it may be beneficial to use d.c. bias.

A convenient method of applying a d.c. bias is as follows:

The recording head is connected directly to the anodes of two cathode-coupled valves. A potentiometer in the cathode circuit enables the degree of d.c. unbalance of the stage to be set to give a convenient direct current flow through the head.

The signal to be recorded is applied in paraphrase to the grids of the valves and is developed across load resistances in the anode circuits, thus being applied with the d.c. bias to the recording head.

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