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ABSTRACT

The CIE has recently published a method for assessing the Visibility Level (VL) of realistic visual stimuli (as defined by Commission Internationale de l'Éclairage, 1981). To implement the system, a visibility meter is required; the Blackwell Visual Task Evaluator, Model 3X was designed to be used with the CIE method. At the request of the Chairman of the CIE Technical Committee 3.1 on visual performance, our laboratory undertook an independent evaluation of the instrument. The findings are reported here. While there are several idiosyncratic features of the Visual Task Evaluator, many of these findings are applicable to other visibility meters.

RÉSUMÉ

La CIE a récemment publié une méthode pour déterminer le niveau de visibilité des stimuli visuels réels (tels que définis par la Commission internationale de l'éclairage, en 1981). Comme cette méthode requiert l'utilisation d'un appareil de mesure de la visibilité, on a conçu un appareil spécial : le "Blackwell Visual Task Evaluator, modèle 3X". À la demande du président du Comité technique 3.1 de la CIE sur la performance visuelle, nos laboratoires ont procédé à une évaluation de l'instrument. On trouvera ici les résultats de cette évaluation. Quoique le "Visual Task Evaluator" possède plusieurs caractéristiques qui lui sont propres, bon nombre de ces conclusions s'appliquent à d'autres instruments du même type.

TABLE OF CONTENTS

AN ASSESSMENT OF THE BLACKWELL VISUAL TASK EVALUATOR, MODEL 3X*

1. INTRODUCTION

The Model 3X Blackwell Visual Task Evaluator (VTE) is patterned after several earlier versions of the VTE (Blackwell, 1959, 1970; Blackwell et al, 1964); the various versions of the VTE were, in turn, patterned after several earlier visibility meters (Jones, 1920; Bennett, 1931; Luckiesh and Moss, 1934; Cottrell, 1951). The purpose of any of these instruments is to render complex, realistic stimuli to some visual threshold by a reduction in optical transmission (Dunbar, 1939; Eastman and Guth, 1960). Almost all of the later visibility meters (Finch, 1957; Eastman, 1968; Slater, 1975; Levy and Nelder, 1976; O'Donnell et al, 1976), including all of the versions of the VTE, attempt to reduce visual stimuli to a threshold contrast. These instruments are capable of adding light to the visual field as transmitted light from the external world is reduced. In this way the adaptation level of the operator is held relatively constant while the contrast of the stimulus is modulated.

The CIE method (Commission Internationale de l'Éclairage, 1981; Illuminating Engineering Society of North America, 1981) is based upon the determination of the threshold contrast of a task. While it is possible to evaluate the threshold contrast of abstract tasks by other psychophysical techniques, it was proposed in the CIE method that realistic, complex visual tasks should be evaluated with contrast reducing visibility meters. Therefore, visibility meters like the VTE are an essential tool in the CIE method for assessing visual tasks of interest to lighting practitioners. In fact, the VTE was designed to implement the CIE method.

According to the CIE method (1981), Visibility Level (VL) is a measure of how easy the task is to see. In this system, the VL of a task is simply the ratio of its physical contrast (C) to its threshold contrast ($\bar{C}$). Thus:

$$VL = C/\bar{C} \qquad (1)$$

VL is equal to unity at detection threshold, and it increases as a linear function of task contrast. For this reason, VL has been called the 'contrast metric' of visibility.

To be in correspondence with Equation (1), a visibility meter should reduce the contrast of the real task to threshold with perfect optical fidelity and without affecting the operator's adaptation level. For

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* This project was undertaken as an assignment from the Chairman, Prof. Dr. H. Bodmann, of the Commission Internationale de l'Éclairage, Technical Committee 3.1.

such an ideal visibility meter, VL is simply inversely proportional to its 'contrast transmittance' (CT). That is:

$$VL = 1/CT \tag{2}$$

This paper presents an assessment of the latest VTE, Model 3X, as a tool for accurately determining VL. Although there is no attempt in this paper to evaluate the validity of the VL formalism, it is clearly necessary to assess contrast reducing visibility meters like the VTE. Without verification of their accuracy, it is impossible to estimate the uncertainty associated with the determined VL for the task of interest, even for an ideal observer. There is also no attempt to compare the VTE with other visibility meters. However, many of the points made in this report are applicable to other instruments of this type.

2. GENERAL CHARACTERISTICS

The VTE is actually two pieces of apparatus: an optical unit and a control unit (Figure 1). The optical unit is basically a refracting telescope combined with a system of variable filters (Figure 2). Objects in the external world viewed through the VTE eyepiece can be made to appear brighter or dimmer by adjusting a 'contrast control' wheel (Figure 1) that drives a pair of variable density filters (X in Figure 2). Light produced by an internal lamp and transmitted through another, mechanically linked pair of variable density filters (Y in Figure 2) keeps the brightness of the viewed field relatively constant while the contrast of the viewed object is reduced.

The control unit regulates the various components of the optical unit. Meters on the control unit give the operational status of the optical unit. In this report the control unit is not specifically evaluated; in the subsequent discussion the term VTE will be used to describe only the optical unit.

3. CENTER AND SURROUND FIELDS

Through the eyepiece, the VTE operator can see two distinct luminous regions: a circular center field and an annular surround field (Figure 3).

3.1 General description

The surround field has an outer diameter of about 16°. The inner diameter, and thus the diameter of the center field, can be, nominally, 1.5, 3 or 6°, depending upon the size of the selected field aperture (Figure 3).

Depending upon the position of mirror shutters A, B and C (Figure 2) the center field of the VTE will give a view either of [1] a luminous patch or [2] some proportion of luminance from the external world and of a superimposed luminous veil produced by the internal lamp. For descriptive clarity, these two views will be called the substitution and the task fields, respectively.

3.2 The brightnesses of the fields

The brightnesses of the surround and substitution fields are determined by: [1] the output of the internal light source, [2] the position of the 'output control' dial on one side of the VTE [3] the position of the 'mode control' filter [4] the transmissions and reflectances of optional chromatic filters inserted in the filter nacelle and [5] the transmissions and reflectances of the optical components in the two paths. The brightness of the task field depends on [1] the brightness(es) of the external world, [2] the output of the internal source, and [3] the fixed and the variable transmissions and reflectances of the optical components in the path of the center field. The brightness of the external world can be reduced with the contrast control wheel on one side of the VTE. This wheel controls the position of the variable density filters (X, Figure 2) that attenuate part of the light coming from the external world. As the brightness of the image of the external world is reduced, light from the internal source is added to the task field through the mechanically linked variable density filters (Y). This keeps the brightness of the task field roughly constant as the contrast is reduced.

3.3 The operator's tasks

When making visibility measurements with the VTE, the operator must match the brightness of the annular surround field with the brightness of one or more luminous regions in the task field. To do this the operator must first set the contrast control wheel to the position that gives the maximum transmission of light from the external world. The surround field brightness is then adjusted to match the brightness of the view of the external world. This can be done by modulating the output of the internal source, by using a fixed range filter and by adjusting the position of the output control dial. As noted above, these manipulations also determine the brightness of the substitution field. The brightness-matched surround and substitution fields are intended to keep the VTE operator's adaptation level constant while making the visibility measurements.

A subsequent task is to reduce the contrast of the image in the task field to some visual threshold ($\bar{C}$), usually the boundary between visible and invisible. As noted in Section 2, the transmission of the VTE is reduced while a veil is added to the task field. Ideally, the VTE should exactly replace the attenuated luminance from a uniform field in the external world with luminance from a uniform veil created by the internal source; in this way the total luminance in the task field would remain constant. Such a system would modulate the contrast of the image of the external object without affecting its background brightness. Therefore, when the operator sets $\bar{C}$, the 'contrast transmittance' (CT) of an ideal VTE could be used to unambiguously determine the VL of the task of interest.

3.4 Field luminances

A problem with the VTE, discussed in some detail in subsequent sections, is that the luminances of the various fields are rarely, if ever, the same. Table I shows the relative luminances of the surround and center fields and describes the conditions under which they were obtained. All of the measurements reported here and those in subsequent sections were obtained with a focused Pritchard photometer carefully positioned at the VTE eyepiece.

4. OPERATION OF THE OUTPUT CONTROL

The output control dial drives a pair of variable density filters (Z in Figure 2). These filters largely determine the brightness of the surround and substitution fields, as well as the brightness of the luminous veil, for a given setting of the dial.

4.1 Control dial

The output control dial (Figures 1 and 2) is not suitable for precise measurement and reproduction of surround and substitution field luminances. Precision is limited by a large separation (up to 2 mm) between the analogue scale and the pointer. Backlash in the output control dial is especially troublesome; brightness settings must always be approached from the same direction to obtain reproducible readings.

4.2 Luminance

The output control dial drives variable density filters which vary the luminance of the surround annulus and the substitution field (Figure 2). The relative luminance of the fields for several output control settings is shown in Figure 4. The manufacturer's data agree well with those obtained in our laboratory.

The absolute luminances of the VTE surround and substitution fields were about 7% lower than reported by the manufacturer.

4.3 Veiling luminance

As noted in Section 3, the VTE procedures require the operator to vary the luminance of the surround (and therefore the substitution) field until the surround brightness matches the task brightness. However, this manipulation is not independent of the contrast transmittance. An added veiling light is applied to the task field as the brightness of the surround field is increased.

A photometer was positioned at the VTE eyepiece to measure the luminance change of the task field as the output control was varied. The contrast control dial was set at '000' to provide maximum transmission through the VTE; the mode control filter was set on LOW. Figure 5 shows how the luminance of a dark task field would change as a function of the output control setting. As the output control setting becomes lower (and the brightness of the surround field becomes higher) an added luminous veil is applied to the center field. Apparently, stray light, modulated by the output control dial, increases the luminance of the VTE task field. Also, when the output of the lamp is increased or when the mode control filter (Figure 2) is set on HIGH, the luminance in the task field produced by the stray light will be even greater than that shown in Figure 5.

This stray light in the task field also reduces the contrast transmittance of the VTE. A contrast transmittance value of 0.942 was reported in the Manual for the instrument at maximum transmission through the contrast control wedge. The manufacturer has not published any information as to how this value was obtained or why it is less than unity. In a personal communication, however, the manufacturer has indicated that, indeed, stray light from the internal source was measured and this produced a contrast transmittance value less than unity. It is implicit in the published information and from the personal communication, that the contrast reduction due to stray light should be a constant for the instrument.

Figure 6 shows the relationship between the output control and the percent contrast reduction due to stray light. Estimates of contrast reduction were derived from the ratio of the ordinate values in Figure 4 with the ordinate values in Figure 5. Contrast reduction is not constant, nor is it a monotonic function of the output control. If the output control setting is low, as with brightness matches between the surround field and bright target backgrounds, the contrast of the task will be reduced by as much as 5% because of stray light. This contrast reduction value is close to that which would be expected from the contrast transmittance value of 0.942 reported by the manufacturer. Based upon the personal communication with the manufacturer and this close numerical correspondence, it seems reasonable to infer that the contrast transmittance value reported in the manual was obtained with an output control setting of '0' and using photometric conditions similar to those reported above. However, Figure 6 shows that contrast reduction is less, and, therefore, contrast transmittance improves, with higher output control settings. Such conditions would occur when brightness matches were made between the surround field and dim target backgrounds. If one were to assume a constant contrast transmittance of 0.942, contrast thresholds would be systematically underestimated for these darker target backgrounds. In short, if precise estimates of contrast threshold are desired, the relationship between contrast reduction and output control setting should be defined (as in Figure 6).

4.4 Color

The color of the surround and substitution fields will obviously change with the voltage supplied to the incandescent internal lamp. Because they are not spectrally flat, the mode control filter (HIGH or LOW) and the output control filters will also affect the color of the fields. Figure 7 shows the change in CIE chromaticity coordinates of the surround annulus for HIGH and LOW modes for different output control settings at a constant lamp voltage. These are not drastic changes but are noticeable to a color normal observer.

5. OPERATION OF THE CONTRAST CONTROL

The contrast control wheel drives the variable density wedges (X and Y in Figure 2), and these wedges largely determine the contrast transmittance (CT) of the VTE.

5.1 Control wheel

The contrast control wheel (Figures 1 and 2) is rotated to place a contrast-reducing veil on the view of the external world seen through the VTE. The wheel linkage to the variable density wedges does not operate smoothly in some places. When setting thresholds, this can be an annoyance for smooth bracketing of the contrast threshold. Also, and probably more important, these rough spots can serve as clues to the subject, like dust on the wedge (Section 12), for reproducing threshold settings.

5.2 Transmission

Figure 8 shows the relative transmission of the contrast control wedge as supplied by the manufacturer* and as measured in our laboratory. These readings agree very well. Contrast transmittance (CT) is closely related to the relative transmission (RT) in Figure 8. In a perfect visibility meter that exactly substituted luminance from an internal source for luminance attenuated in the external world, CT = RT.

An absolute transmission of 0.104 was obtained when the contrast control digital volt meter (DVM) reading was '000'. This agrees well with a transmission of 0.101 supplied by the manufacturer.

5.3 Veiling luminance

A fundamental requirement for the VTE operation is that the luminance of the task field is constant for any setting of the contrast control wheel. Thus, the added veiling luminance should exactly compensate for the subtracted task luminance as the contrast control wheel is rotated (and vice versa). No data have been supplied by the manufacturer for this particular instrument that would validate that requirement. In an earlier publication by Blackwell (1970), however, such data were presented for a Model 3 VTE. In Figure 22 of that paper, log 'relative luminance' of the task field was plotted as a function of the contrast control setting. From a casual examination of the highly compressed ordinate in that figure and from the description in the text, one would conclude that, indeed, the luminance of the task plus the luminance from the veil is constant for any setting of the contrast control wedge. In fact, this conclusion would be incorrect.

Measurements were made of the total luminance produced in the center field. First, the internal lamp was turned off and the contrast

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* The manufacturer actually presents 'contrast transmittance' values for different contrast control readings.

control set at '000' to provide maximum transmission to the external world. The luminance of a uniform white card was then measured through the center field. Next, a setting of '1600' on the contrast control was established, and the output control dial adjusted until the luminance of the center field (now determined primarily by the veiling field) was equal to the center field luminance recorded previously. Luminances for contrast control readings between '1600' and '000' were then measured. This procedure was repeated several times. The 'high extreme' and 'low extreme' measurements are presented in Figure 9.

This figure reveals two distinct problems with the VTE. First, the fact that there are two curves rather than one demonstrates slippage in the counterbalanced, contrast control wedges (X and Y in Figure 2). Even though the exact position of one wedge is known from the potentiometer attached to it and the associated digital volt meter, the other, mechanically linked, wedge can slip, producing various luminances for a particular contrast control setting. Second, the two curves have a characteristic dip near the '300' setting. This dip corresponds to a luminance reduction of about 20%. Thus, the task and veiling fields are not accurately substituted. This 20% reduction is quite important when assessing VL for dark targets on bright backgrounds, but, parenthetically, such a reduction appears insignificant when plotted on a four decade logarithmic ordinate, such as was presented in Figure 22 of the Blackwell (1970) paper.

It should be noted that the relative luminance associated with the '1600' setting on the 'high extreme' curve is not equal to 1.0 as might be expected from the measurement procedures described above in this section. In Section 4.3, it was pointed out that scattered light from the internal source produced an added veil on the task field. The magnitude of the veiling light depended upon the output control setting (Figure 9). For the output control setting needed to match the luminance of the white card seen in the task field, a veil of scattered light increased the center field luminance by three percent when the contrast control setting provided maximum transmission (at '000').

6. OPTICAL FIDELITY

Optical systems are not perfect. Refracted rays do not always come to focus in the same plane because of scatter, aberrations and diffraction. Naturally VTE optics suffer from these limitations as well. Functionally these optical infidelities reduce the transmitted contrast of visual targets. Smaller targets or those with fine detail (ie. stimuli having higher spatial frequencies) are more affected by these optical infidelites than are larger stimuli (i.e., those with lower spatial frequencies). Thus, the contrast transmittance of the VTE will depend upon the size, or the spatial frequency content, of the task being viewed through the instrument.

The contrast of a luminous border can be measured through and without the VTE, and the ratio of these two contrasts can be considered as the contrast transmittance of the VTE for that stimulus. Contrast transmittance values of this type were obtained for two stimuli of different sizes. One stimulus was a black letter, stroke width about

0.5°, on a white background. The other comprised two large patches of paper, one black and one white; each patch completely filled the VTE field of view (6°). The VTE contrast control dial was set for maximum transmission and the internal light source was turned off. The contrasts of both stimuli measured under these conditions with and without the VTE are shown in Table II. One can see from these data that the contrast of the letter (with the higher spatial frequencies) against its background is reduced by about 4%. The contrast of the other stimulus, with low spatial frequencies, was not reduced at all, indicating that the VTE selectively reduces the contrast of tasks having higher spatial frequencies. Again, this result is typical of optical systems (Langford, 1977).

These results, and those obtained by others from a variety of optical systems, indicate that the absolute thresholds for small targets obtained through the VTE, or any other optical visibility meter, will be higher than those that would be obtained without intervening optics (i.e., for free viewing). More importantly, however, these thresholds will be differentially higher depending upon the spatial frequency content of the stimulus being evaluated. Thus, a simple correction factor like that implied by the contrast transmittance value is not valid. This differential attenuation of spatial frequencies implies that the CIE method (1981) does not adequately characterize VL because threshold contrast ($\bar{C}$) is not properly defined for spatially different stimuli. More specifically, two tasks estimated by the VTE to have the same value of $\bar{C}$, but with different spatial frequencies, will not necessarily be equal in VL in free viewing conditions, due to this differential attenuation of spatial frequencies.

7. DETERMINATION OF ADAPTATION LUMINANCE

According to CIE 19/2.1, one must be careful to correctly relate contrast threshold ($\bar{C}$) values to adaptation luminance. In this regard there is an error in the VTE Instruction Manual (June, 1978). In Section IV of the Manual, entitled "Determination of task background luminance", the manufacturer describes a procedure for estimating the task (adaptation) luminance. The method for obtaining the task luminance is similar to that used with a Macbeth illuminometer (Wyszecki and Stiles, 1982). A brightness match is made between a surround field of variable, but known, luminance and the task field*. From this match the luminance of the task field is determined. But the formula for this method using the VTE is incorrect in the Manual. The manufacturer writes:

$$TL = \frac{LK \times T}{Tc} \qquad (3)$$

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* Difficulties with the brightness matching procedure are described in Section 8 below.

where:

TL is the task luminance.

LK is the maximum luminance of the surround field (i.e., maximum transmission of the output control wedges) for a given mode control filter. This is known by prior calibration.

T is the transmission of the output control wedge.

Tc is the transmission of the various cubes in the optical path of the VTE.

To be clear, TL must first be better defined. If task luminance is to be taken as the luminance of the actual task with no intervening optics, then the formula should be written as:

$$TL = \frac{LK \times T}{Tc \times T_{VTE}} \qquad (4)$$

where:

T_{VTE} is the absolute transmission of the VTE (0.104, Section 5.2).

All other terms are defined as in Equation (3).

If task luminance is to be taken as the luminance of the surround field, and hence the brightness-matched task field, then the formula must be written as:

$$TL = LK \times T \qquad (5)$$

where all terms are defined as in Equation (3).

From the text in Section IV of the VTE Instruction Manual, it appears that the manufacturer intended to define task luminance (TL) as in Equation (4). Therefore, one must be careful to relate the correct adaptation luminance to contrast threshold ($\bar{C}$). The adaptation luminance for $\bar{C}$ is <u>not</u> the luminance of the actual task (defined in Eq. 4) nor is it as defined in Equation (3). Rather, it is the luminance defined in Equation (5), the task field luminance perceived at the eyepiece of the VTE. To relate $\bar{C}$ to the actual task luminance defined by Equation (4), one has two alternatives. One can either increase the actual task luminance by a factor of 9.6 (1/0.104, Section 5.2) and obtain a new $\bar{C}$, or one can assume a relationship between $\bar{C}$ and adaptation level (like the Visibility reference function in CIE 19/2.1) and then mathematically derive $\bar{C}$ at the actual task luminance.

8. BRIGHTNESS MATCHES

Brightness matching of the surround and center fields is quite easy when these juxtaposed fields are uniform and when they have the same spectral composition. In most situations where the VTE would be used, however, neither of these conditions exist.

8.1 Luminance and brightness

One of the operator's first tasks when operating the VTE (Section 3.3) is to make a brightness match between the task and surround fields. Brightness matches are not necessarily luminance matches, however. The larger the color difference between two equally bright fields, the larger the luminance difference (Alman, 1977). The color of the surround field, produced by the internal source, is not usually metameric with the color(s) of the view of the external world as seen in the task field. Consequently, the task and surround fields may not have equal luminances, even though their brightnesses are matched, because of the color differences in the two fields.

The CIE 19/2.1 formalisms define adaptation level in terms of luminance. These formalisms require visibility measurements of realistic stimuli at a specified adaptation luminance, but the VTE methodology for assessing adaptation level is based upon brightness. Therefore, there is an inconsistency between the CIE formalisms and the VTE methodology which was developed to implement the CIE system.

To circumvent the problem of heterochromatic brightness matches with the VTE resulting in different luminances for the task and surround fields, the manufacturer makes the following recommendation (p. 8, VTE Manual):

> "When there is a large and troublesome color difference between the luminance of the task background and the luminances produced within the VTE, consideration should be given to the use of chromatic filters to reduce or eliminate the observed color differences. Chromatic filters may be used to modify the 2848°K color temperature of all beams produced within the VTE by being inserted into the filter nacelle . . . ."

These "chromatic" filters are better described as "conversion" or "light balancing" filters (Eastman Kodak, 1973). Kodak provides a description of these filters, and this should be used to supplement the VTE operation because no details are given in the VTE Manual or in related published articles as to how colored filters could be used in the VTE to make task and surround fields the same color. Two points should be made about these filters, however. First, it is unlikely that an exact color match will be obtained between task and surround fields because only a limited number of filters are available to adjust the color temperature. Thus, only a crude color match can be expected in many circumstances. Secondly, discontinuous sources such as fluorescent lamps may have correlated color temperatures that will not be exactly corrected by the recommended conversion or light balancing filters.

There are inconsistencies between the manufacturer's color matching recommendation and his luminance calibration recommendation (Section 7). As the color correcting or light balancing filters are inserted into the filter nacelle, the luminance of the surround field is reduced. Thus, the output control wedge must be manipulated to increase the luminance of the surround. This luminance increase changes the color of the surround field slightly (Figure 7), and new color filters may be required to maintain a color match. This may be a minor problem because the color shifts are small when the output control wedge is varied.

There is a more serious difficulty with this recommendation. Inserting the color filters upsets the calibration of the surround luminance provided by the manufacturer (Section 7). According to the VTE Manual, the surround luminance should be used to determine the task luminance, and thus define adaptation level, but the actual adaptation luminance will be unknown without additional photometric measurements.

It is unlikely, despite the instructions in the VTE Manual, that one can accurately predict task or surround field luminances from the manufacturer's calibration and simple transmission measurements of the color filters because of the multiple reflections between color filters in the nacelle. One should make surround luminance measurements at the eyepiece for every stimulus condition. These measurements are both time-consuming and troublesome.

These measurements can be avoided if one knows the absolute transmission of the VTE and the actual luminance of the task. Simply multiplying the luminance of the external field by the transmission of the VTE determines the task field luminance at the eyepiece.

$$TL = FL \times T_{VTE} \times Tc \qquad (6)$$

where:

TL is task luminance at the eyepiece (similar to that described in Equation 5).

FL is the luminance of the external field.

All other terms are as defined in Equation (4).

This approach avoids the problem of continually having to do photometric measurements at the eyepiece. With this approach, however, an independent luminance determination of the external field stimulus must always be made, and, therefore, an additional instrument (i.e., a luminance meter) must be employed.

It should also be noted that Equation (6) is, strictly speaking, a different expression for task luminance than Equation (5) (Section 7). But when both the brightness and the color of the task and surround fields are the same, their luminances are the same.

The previous discussion in this section has dealt with the relationship between luminance and brightness for the task and the surround fields. A more important problem is associated with the relationship between the luminance and brightness of the tasks and the substitution fields. Assuming that the surround and substitution fields have the same luminous properties*, then the task and substitution fields will have different luminances when the task and surround fields are brightness-matched but are of different colors.

The transient channel in the human visual system has a spectral sensitivity similar or identical to V_λ (luminance). This channel responds best to sudden changes in luminance; a burst of activity occurs at the onset and offset of the change (Legge, 1978; Ingling, 1978). When the substitution and task fields are of different luminances, and are alternated temporarily in the VTE, then transient signals will be produced in the visual system. As noted in Section 10.3, these transient signals elevate contrast thresholds (Boynton and Miller, 1963) and thus introduce a brightness matching artifact into the VTE threshold data. Therefore, it is important to ensure that the color, as well as the brightness of the task and the substitution fields are the same. As discussed above, this ensures that the luminances are the same.

8.2 Task field complexity

It is difficult for the subject to make brightness matches between a complex task (e.g., a person's face) and the surround. The various luminances and colors make it hard for the subject to know what part or parts of the task he should use when making the brightness matches. It is also difficult for the experimenter to know what luminances in the complex field are relevant to measure and weight to describe task field luminance (Section 8.1).

In earlier versions of the VTE, Blackwell recommended that brightness matches be made between the surround and a defocused task field (Blackwell, 1970, p. 268). The assumption implicit with this method was that adaptation luminance was based upon the average luminance of the task field. Later in that paper (p. 280), the author recommended magnifying the highest contrast border and setting the surround brightness equal to the higher luminance. This assumes that adaptation level is based upon the highest luminance. Neither procedure can be recommended with confidence on theoretical grounds.

Multicolored tasks present a problem. First, it is difficult to know what color the surround field should be for a brightness match. Second, it is possible to have a visible boundary with equal luminance on both sides but different colors. Thus, VL can be greater than unity when the luminance contrast of the field, as defined in the CIE formalism, is below threshold. This failure of the CIE formalism to define color contrast at threshold actually makes it impossible to accurately describe VL for any multicolored stimulus.

9. MAGNIFICATION

The size of the task field image produced by the VTE optics is variable, but rarely equal to that of the physical task under

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* This is not the case, as pointed out in Table I.

free-viewing conditions. Therefore, the VTE must be further away or closer to the task than a free-viewing observer would be for a matched visual angle. This difference between the location of the VTE at the proper magnification and the location of a free-viewing observer may confound the visibility measurements due to the different 'body shadow' positions (i.e., lighting geometries). Further, because the apparent size of the stimulus is important to visibility (larger objects are generally more visible than smaller ones), the magnification of the VTE must be correctly determined and the position of the instrument adjusted to match the visual angle of the object seen through the VTE and seen by free-viewing. (There is no discussion of these points in the relevant published documents.) Therefore, without an awareness of these factors and the proper attention to position the VTE, one may find that the estimated values of VL are not correctly related to the free-viewing situation.

10. PULSING PROCEDURE

The VTE includes a pulsing mechanism, purported to simulate fixation pauses (Blackwell, 1970).

10.1 Appearance

The VTE may be operated in a static mode (no pulsing), a 'fixed pulse rate' mode of, nominally, 200 ms pauses, or in a 'variable pulse rate' mode. Neither pulsing mode satisfactorily mimics brief views following saccadic eye movements. The mirror shutter system occludes the task from top to bottom and then reveals it from bottom to top. Hence, the lower portions of the task are presented for a perceptibly longer time than the upper portions. Therefore, critical areas of the task in the lower portion of the task field will have lower thresholds than critical areas at the top of the task field. Fixational pauses are not characterized by this slow up-and-down occlusion procedure, but probably by an onset and an offset of the whole visual field similar to that following blinks (Riggs et al, 1981).

10.2 Temporal characteristics

These important issues of appearance aside, it is debatable whether one should have 200 ms presentations. This is a somewhat arbitrary presentation time and targets presented for slightly different periods will be characterized by different contrast thresholds (Kitterle and Corwin, 1979).

Figure 10 shows the luminance modulation of a uniform luminous task field produced at the eyepiece by the VTE in the fixed pulse rate mode. The 'on' and 'off' half cycles are not exactly the same duration, and neither are equal to 200 ms. The contrast threshold values obtained with this ramping procedure will be different from those that would be obtained with a flash for instance, because of temporal-spatial interactions in the visual system (Kelly, 1977).

When the VTE is in the variable pulse rate mode, typical 'on' half-cycles are as shown in Figure 11. The variable 'off' half-cycles may range from 0.7 s to 3.0 s, depending upon the delay knob setting (minimum and maximum delay, respectively). For a given setting of the delay knob, however, the 'off' half-cycles were not always the same duration. The largest variation in the 'off' half-cycle for a particular delay knob setting was 33%. The consequences of this variation for thresholds were not evaluated in this study.

10.3 Luminance transients

The luminance of the substitution field is higher than that of the surround field by a factor of 1.3 (Table I). The surround field is supposed to be brightness-matched to the task field. Ignoring the problem discussed in Section 8 on brightness matches, a luminance transient will be produced when the task and substitution fields are alternated. This can produce an artifactually higher contrast threshold than would be expected if the luminances of the task and substitution fields were equal (Boynton and Miller, 1963).

11. POLARIZATION

The VTE optical system can, through refraction and reflection, change the polarization of the light reaching the operator's eye. When focused on an unpolarized field, the VTE produced a horizontal polarization of 1.8% at the eyepiece (Rea, 1981). Plane polarized light from an external source was reduced by a similar amount after transmission through the VTE. This change is unimportant under most circumstances, but it should be taken into account if the polarization properties of targets are of interest.

12. USE AS A FIELD INSTRUMENT

The VTE is fairly heavy, and the handles are not well situated for lifting. It is difficult to transport and cumbersome to set on a tripod. The VTE is also a fragile instrument. The optics and internal parts require frequent realignment and adjustment. Further, the instrument is suseptible to dust and moisture; consequently it requires regular cleaning and attention. However, the instrument is not designed for convenient servicing; the chassis cover cannot be removed as a single unit. Instead, the side panels must be individually dismantled by the removal of many screws. Further, wires leading to various electrical components are attached to the side panels, so they must be unsoldered when servicing the instrument.

Parenthetically, the unavoidable dust particles that get on the contrast control wedges (X in Figure 2) can be especially troublesome in this instrument because subjects can occasionally use them to reproduce threshold settings. Subjects merely match the location of dust particles across trials rather than successively estimate the visiblity of the task. Even the most sincere subjects have difficulty ignoring them once they have been noticed.

13. SUMMARY AND CONCLUSIONS

The difficulties outlined above bring into question the ability of the Blackwell Visual Task Evaluator, Model 3X to provide accurate data for the computation of Visibility Level (VL). Some of the difficulties with the current model of the VTE can be easily overcome or reduced (e.g., insertion of a neutral density filter into the optical path of the substitution field). Other difficulties could not be easily overcome but would require a more serious redesign of the VTE (e.g., making it more impervious to dust, redeveloping the pulsing action, eliminating slippage at the contrast control wedges, reducing the weight).

There are other, more fundamental, difficulties with the visibility meter concept that cannot be easily or cheaply overcome. Foremost of these is that optical systems are imperfect; some spatial freqencies are preferentially reduced in modulation amplitude (e.g., contrast transmittance). Thus, visibility estimates of certain stimuli will be biased relative to free viewing. Without implementation of very expensive lens systems, careful alignment and rigid mountings, it is unlikely that a completely satisfactory portable visibility meter could be constructed.

The brightness matching method (setting surround, substitution and veiling luminances) also presents serious fundamental problems. Complex and colored fields create theoretical uncertainties as to the adaptation level of the observers. Further, the equations describing VL are based upon luminance whereas the VTE methodology is based upon brightness. This could be a serious inconsistency when the VL of colored targets (e.g., automobile tail lights or egress signage) is important. In short, these fundamental limitations of all visibility meters, including the VTE, may introduce artifacts into the threshold estimates that would not be present in real viewing situations.

In sum, both practical and theoretical problems with the VTE will lead to inaccuracies in estimating Visibility Level. The magnitude of these errors will depend upon the spatial, temporal and chromatic characteristics of the stimulus as well as such properties of the VTE as scattered light, optical infidelity, and optical-mechanical nonlinearities. We are not aware of any recent review of the practical and theoretical aspects of assessing Visibility Level. It seems that some more serious work in this area must take place before the VTE, or other visibility meters, can be confidently used with the model presented in CIE 19/2.1.

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Table I: Fields seen through VTE

Field		Relative Luminance
surround:	annulus	1.0
center:	substitution	1.34[a]
	task (maximum veil)	1.32[a]
	task (minimum veil)	?[b]

[a] Contrast control DVM reading set at "1600" (maximum attenuation of the external world), cap over the objective lens.

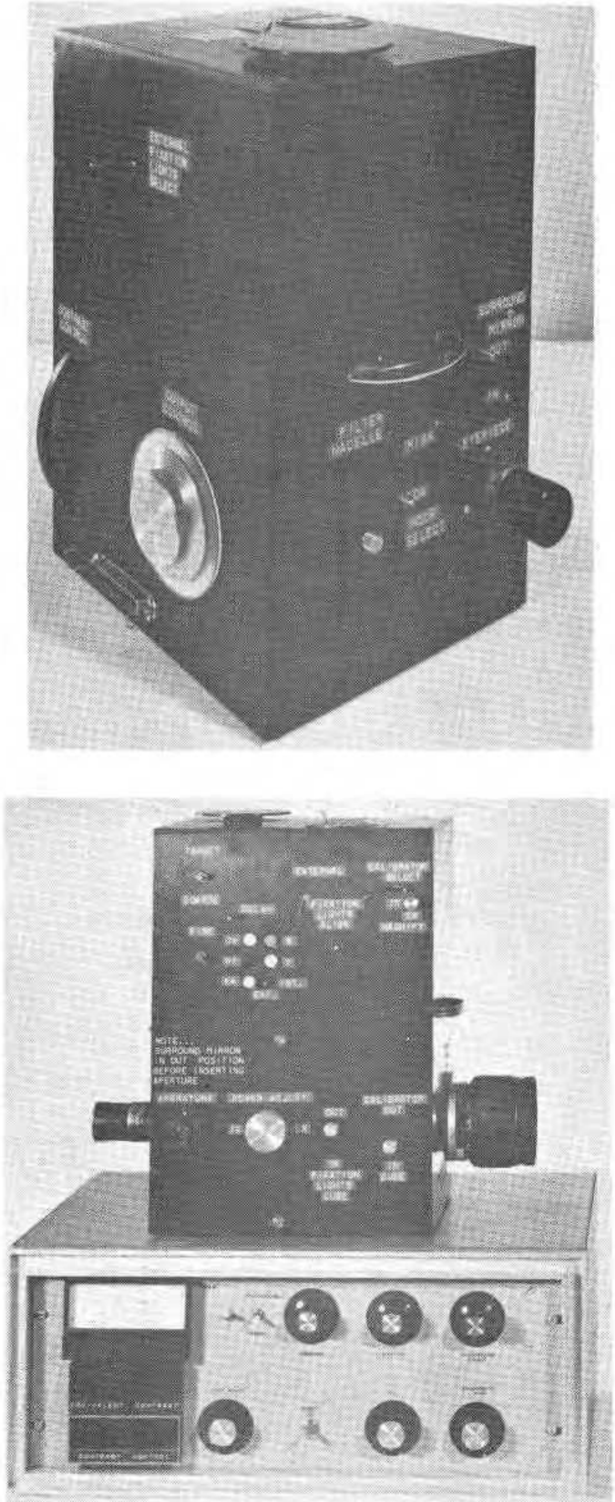
[b] The task luminance depends upon the operator's brightness matches between it and the (variable) annulus luminance. Because brightness matches are not equivalent to luminance matches under most situations, the relative luminance of the task field will vary depending upon the spectral composition of the task, the operator's spectral sensitivity, and the task stimulus complexity (both in luminance and color).

Table II: Contrast Reduction by the VTE

Spatial frequency	Contrast		% Contrast reduction
	With VTE	Without VTE	
High[a]	0.802	0.841	4.6
Low[b]	0.917	0.912	-

[a] Black printed letter of size 0.5° on white background.

[b] Two pieces of paper, one black the other white. Successively, each patch filled the VTE field of view (6°).



a

b

FIGURE 1

BLACKWELL VISUAL TASK EVALUATOR (VTE)

a) OPTICAL UNIT, SHOWING OUTPUT CONTROL AND CONTRAST CONTROL
b) OPTICAL UNIT AND CONTROL UNIT

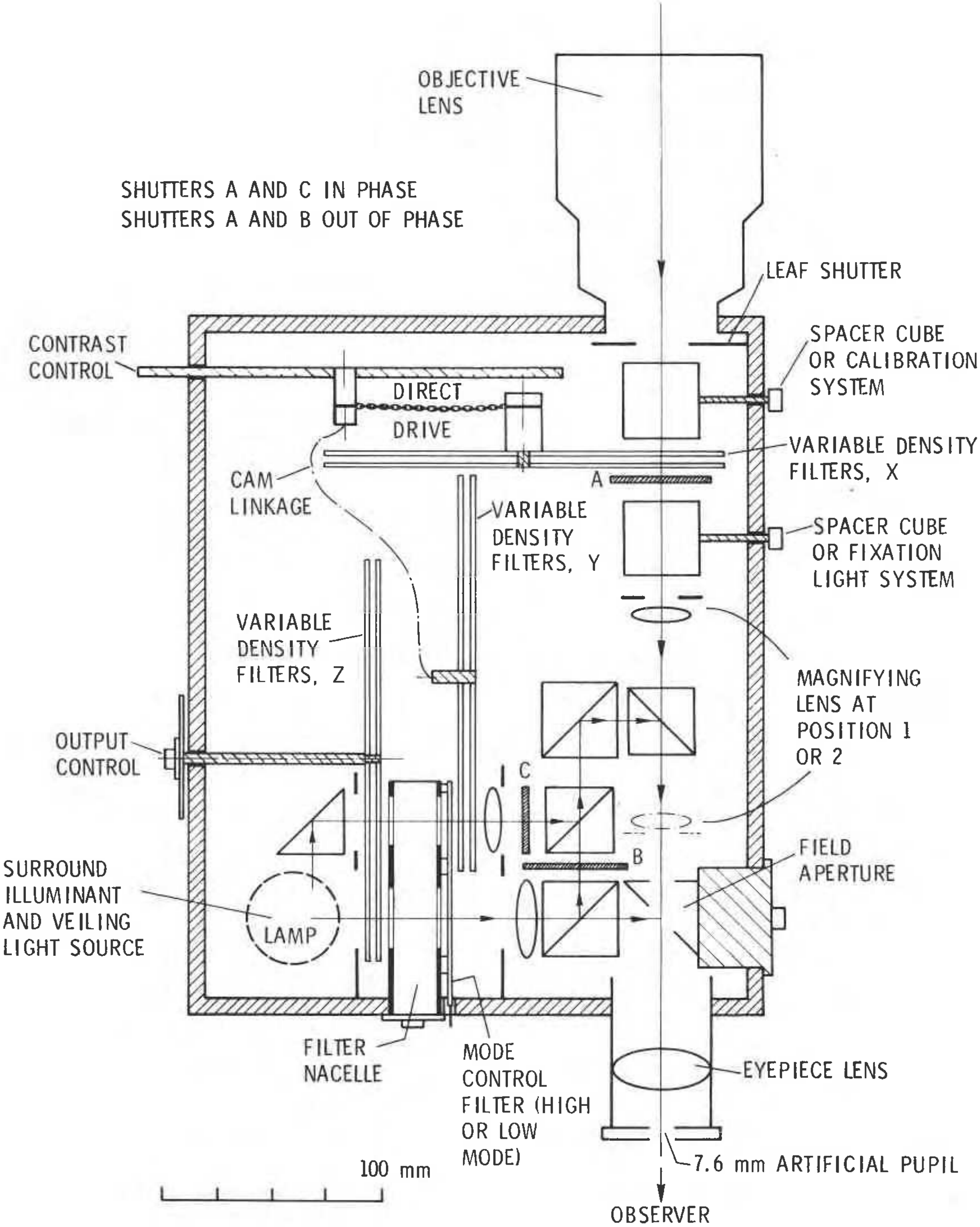


FIGURE 2

VTF OPTICAL SYSTEM

BR 6469 1

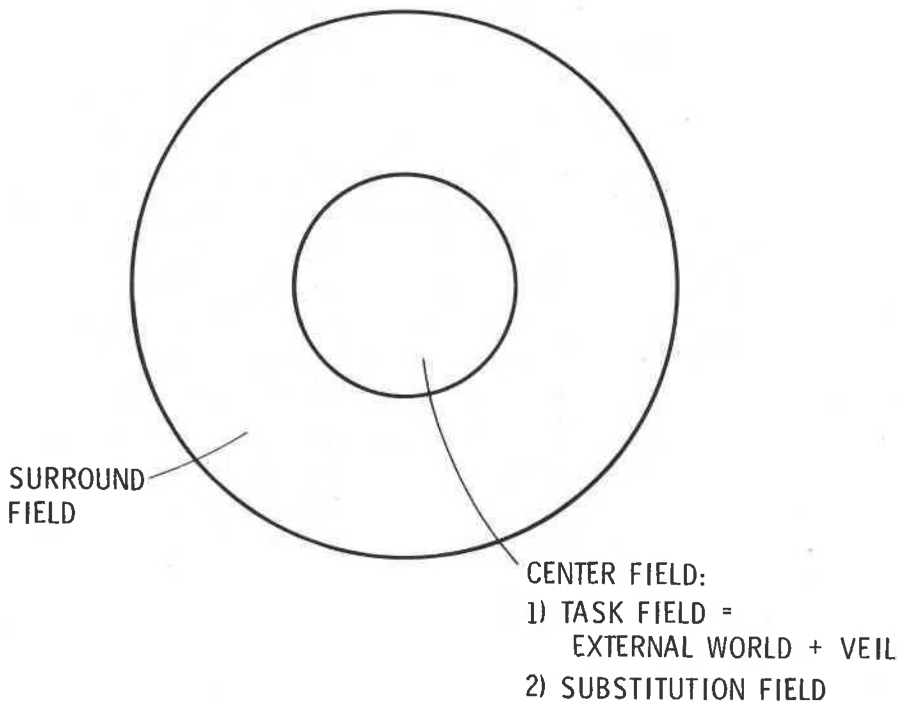


FIGURE 3

FIELDS VIEWED BY VTE OPERATOR

BR 6469-2

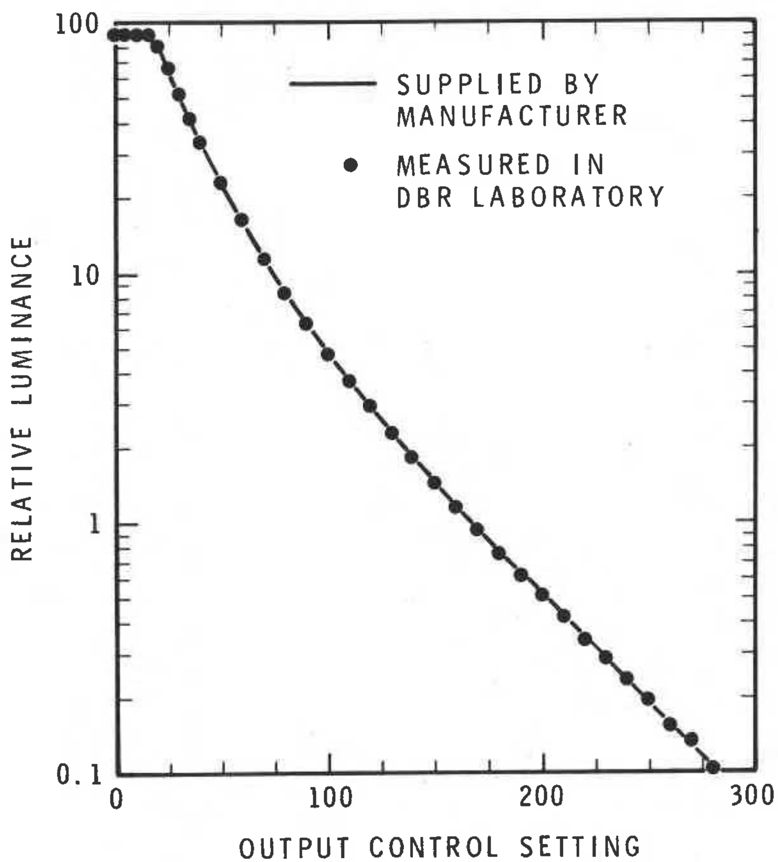


FIGURE 4

CALIBRATION OF OUTPUT CONTROL SYSTEM

BR 6469-3

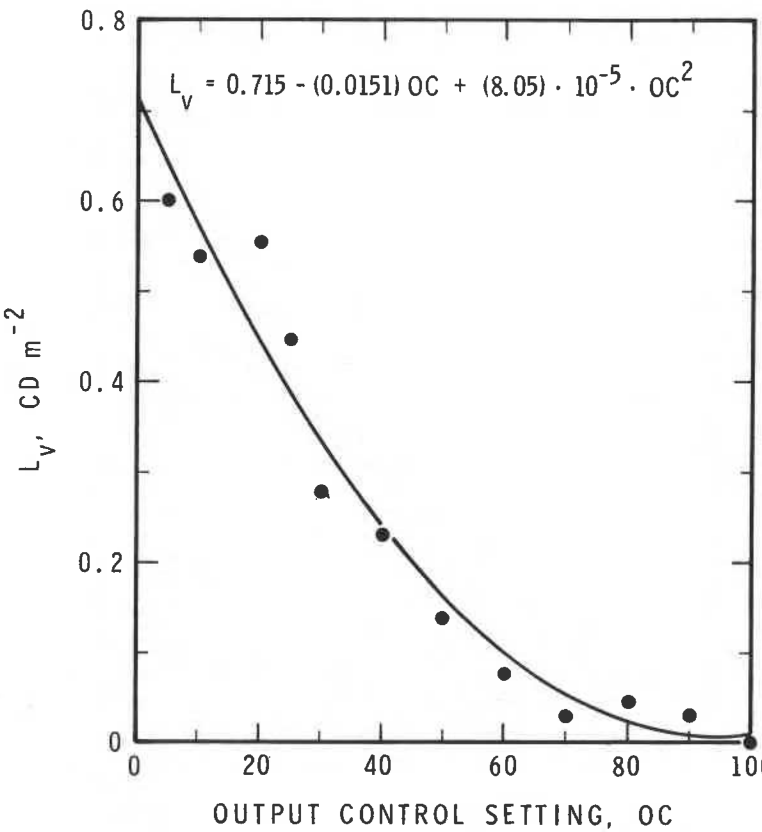


FIGURE 5

SCATTERED VEIL (L_V) AS A FUNCTION OF OUTPUT CONTROL SETTING (OC)

BR 6469-4

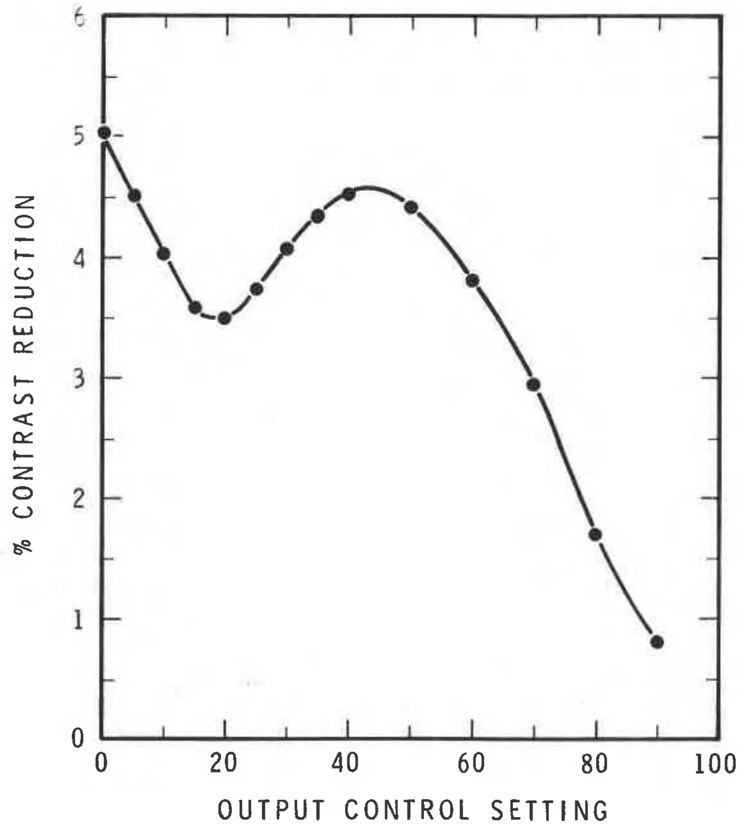


FIGURE 6

CONTRAST REDUCTION OF THE TASK FIELD DUE TO SCATTERED VEIL

BR 6469-5

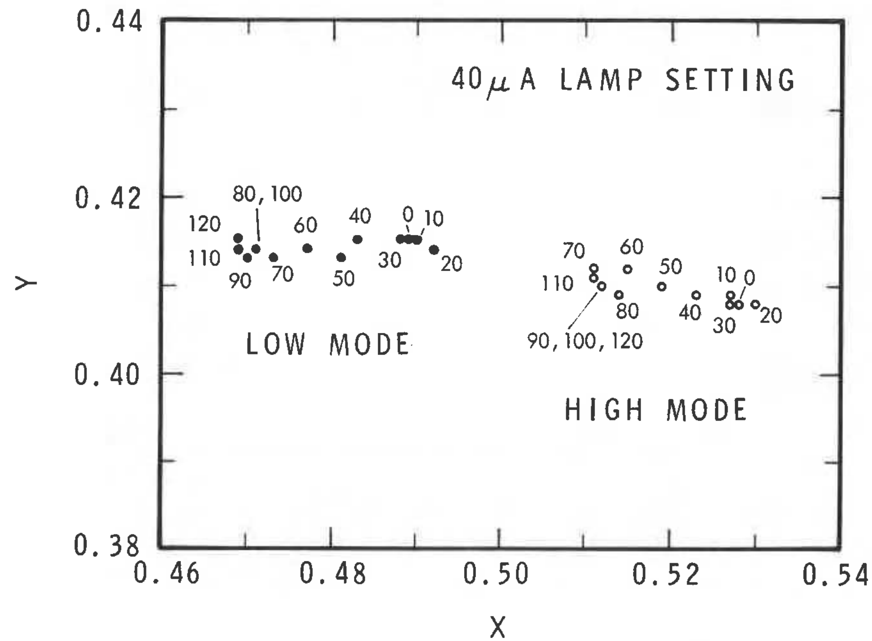


FIGURE 7

CIE CHROMATICITY COORDINATES OF VTE SURROUND ANNULUS FOR LOW AND HIGH POSITIONS OF MODE CONTROL FILTER. POINTS ARE LABELLED ACCORDING TO THEIR RESPECTIVE OUTPUT CONTROL SETTINGS

BR 6469-6

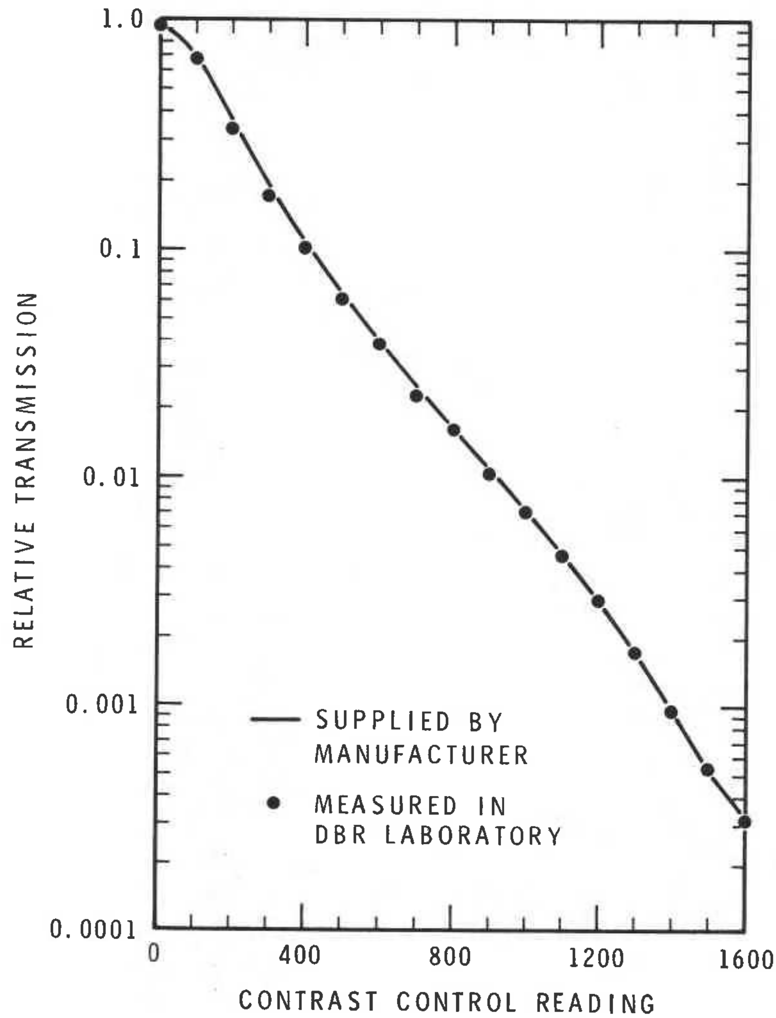


FIGURE 8

TRANSMISSION OF THE CONTRAST CONTROL WEDGE

BR 6096-3

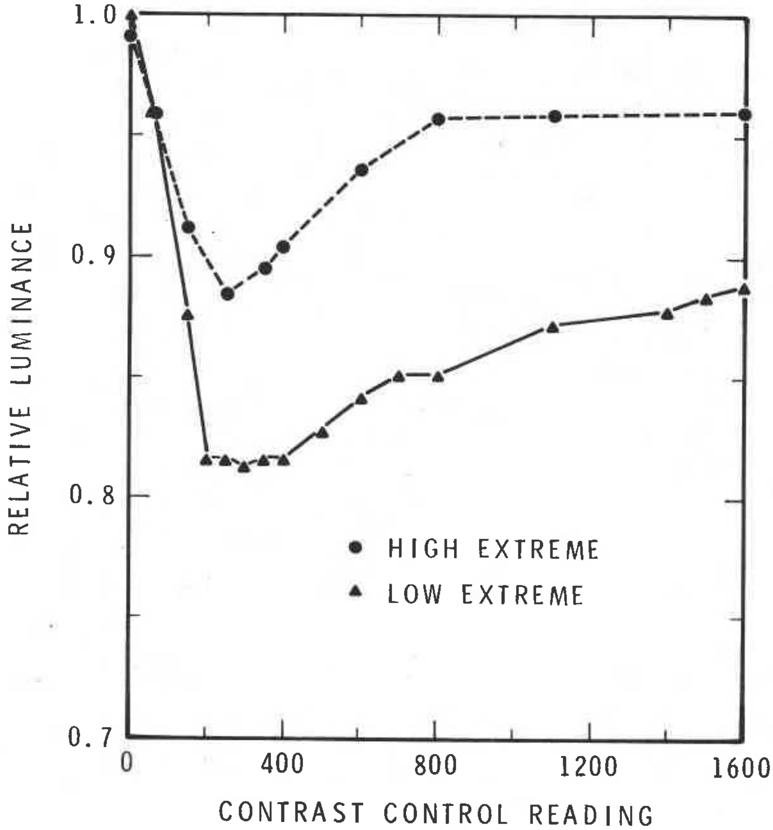


FIGURE 9

CALIBRATION OF LUMINANCE BALANCING SYSTEM

BR 6469-7

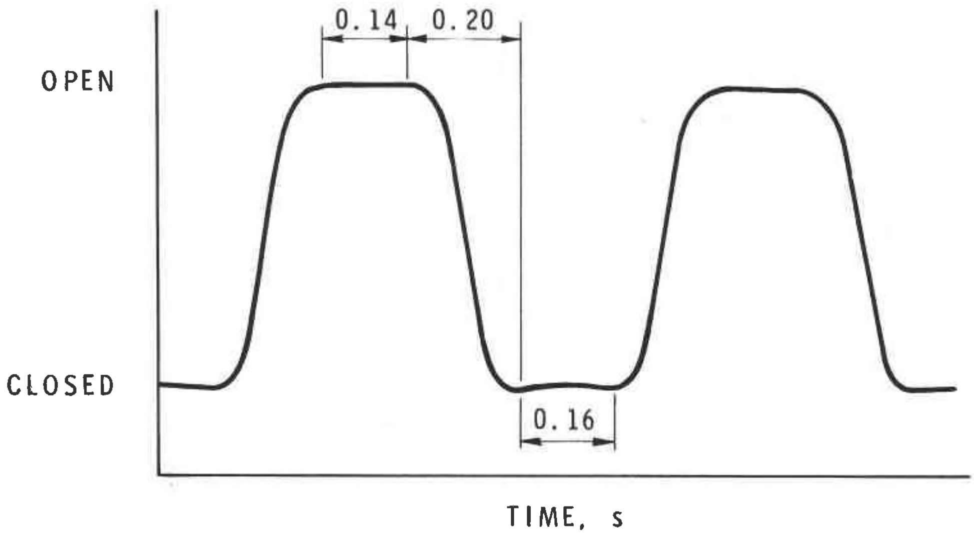


FIGURE 10

TEMPORAL WAVEFORM OF VTE SUBSTITUTION FIELD SHUTTER SYSTEM OPERATING IN FIXED PULSE RATE MODE

BR 6469-8

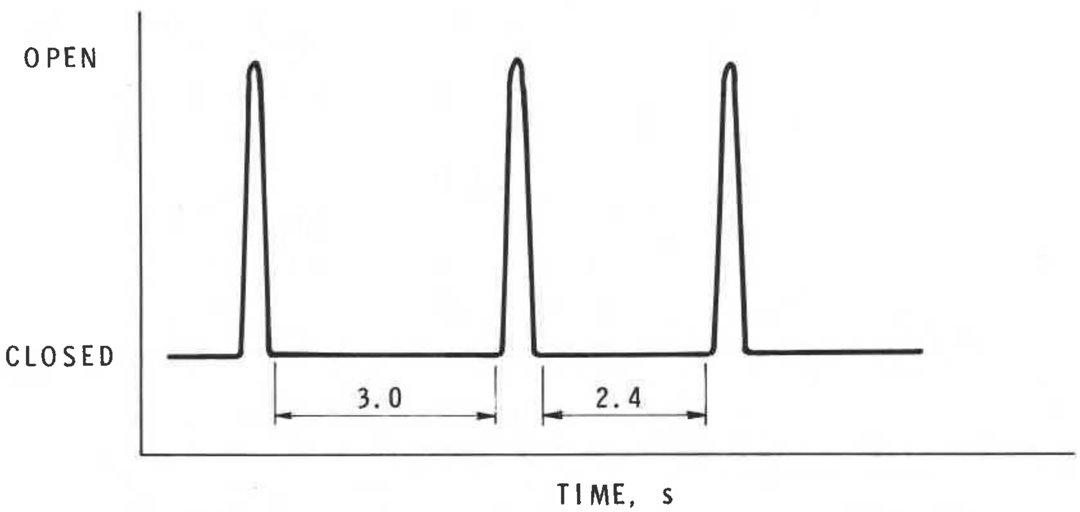


FIGURE 11

AN EXAMPLE OF THE TEMPORAL WAVEFORM OF VTE SUBSTITUTION FIELD SHUTTER SYSTEM OPERATING IN VARIABLE PULSE RATE MODE

BR 6469-9