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ANALYSIS OF THE M113 PANORAMIC TELESCOPE RADIOACTIVELY ILLUMINA--ETC(U)

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REMARKS

Enclosed are ten (10) copies of a study entitled "Analysis of the M113 Panoramic Telescope Radioactively Illuminated Reticle prepared for Frankford Arsenal, Phila., Pa, Attn: FCA-A, under Contract DAAA 25-77-M0055 by Decilog, Inc., Melville, N.Y.

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ANALYSIS OF THE M113 PANORAMIC TELESCOPE RADIOACTIVELY ILLUMINATED RETICLE

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DECILOG TR-155

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Under Contract #DAAA25-77-M0055 NEW
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1. Introduction

Historically, reticles in optical instruments were illuminated by a battery powered incandescent source for use at night. The source luminance was controlled by means of a potentiometer, and was equipped with an On/Off switch. Thus, as evening twilight approached, and the dark lines became difficult to see against the scene, the reticle light was turned on. Initially, high reticle illumination would be used, and, as the scene became increasingly dark, the reticle would be dimmed.

When tritium activated sources of illumination became available, it became feasible to eliminate the battery and incandescent source with a concomitant savings in cost and increase in reliability. In the M113 Pantel, for example, the reticle is constantly illuminated by the radioactive source. Therefore, there exists a time at twilight when the reticle cannot be seen as either dark lines or lighted lines.

This report defines the problem, presents some short term solutions to the problem, and suggests an experimental program designed to create a reticle design data base and handbook. A quantitative analysis of the problem is also presented which should be read by anyone interested in the techniques which can be employed to solve such problems.

The technical activity described in this report was performed by Decilog, Inc., Melville, New York, under Contract DAAA25-77-M0055.

2. Theoretical Analysis of the Reticle Illumination Problem

The human eye perceives Contrast between luminances rather than luminances *per se*. As you are reading this page you are responding to the form of the characters (and some whole words) as coded in the contrast between the black lines of the characters and the "whiteness", or higher luminance of the paper. Similarly, when looking through a reticle, one "sees" a ratio of luminances, i.e., the luminance of a lighted reticle against a darker background or the luminance of a dark reticle against a lighter background.

In 1946, Blackwell (1) reported the Classical results of a very thorough study of human contrast vision. Thirty years later, this still represents the only reliable data available for analytic application to the reticle illumination problem.

Although writers use different definitions of contrast, (and often fail to inform the reader of which one they are using) we shall use the Blackwell definition. Applied to our problem the ratios are:

(1) $$C = \frac{B_R - B_S}{B_S}$$ for "brighter" appearing reticles

(2) $$C = \frac{B_S - B_R}{B_R}$$ for "dark" appearing scenes

where: B_R is the luminance of the reticle
B_S is the luminance of the scene

Or, in general:

(3) $$C = \frac{B_H - B_L}{B_L}$$

where: B_H is the luminance of the object of higher luminance
B_L is the luminance of the object of lower luminance

Using the above definitions we are able to construct the unusual, but highly illustrative representation in Figure 2-1. Shown in the left half of the graph are three lines of -1 slope, representing equation (1). These show the variation in the contrast of reticles of constant luminance as a function of scene luminance for reticles of luminance higher than that of the scene (Positive Contrast). Three luminances, 100, 300 and 700 uL are shown. The vertical axis is Log Contrast* of the reticle against the scene luminances shown on the horizontal axis. Note that this is merely the relationship of the physical contrasts, and, as such, is independent of size of the objects.

On the right hand side of the graph are the corresponding lines of +1 slope, depicting equation (2) and showing the negative contrast (scene brighter than reticle) for the reticles of 100, 300 and 700 uL. Starting at the upper right of the curves, and proceeding down a line of constant reticle brightness toward the horizontal axis, one is observing the effect of increasing darkness on the contrast of the dark appearing reticle. Obviously, during evening twilight the reticle is becoming increasingly difficult to see, as its contrast reduces.

Similarly, if one begins at the horizontal axis and proceeds upward along any of the positive contrast lines, one observes that the lighted reticle becomes increasingly easy to see. One may now evaluate the effect of reticle luminance on visibility through twilight by superimposing the Blackwell contrast threshold data on the above curves. The contrast threshold curve, shown in Figure 2-1 represents the minimum contrast for a 0.95 probability of detection of a circular object of 3.6 minute angular subtense. This would correspond to approximately a 1 to 2 minute reticle line width.

*Actually, the Log of (C+1) is plotted for convenience to permit linear representation of equations (1) through (3). The Blackwell Data is plotted to be consistent with this representation. Reticles of any luminance can be similarly drawn.

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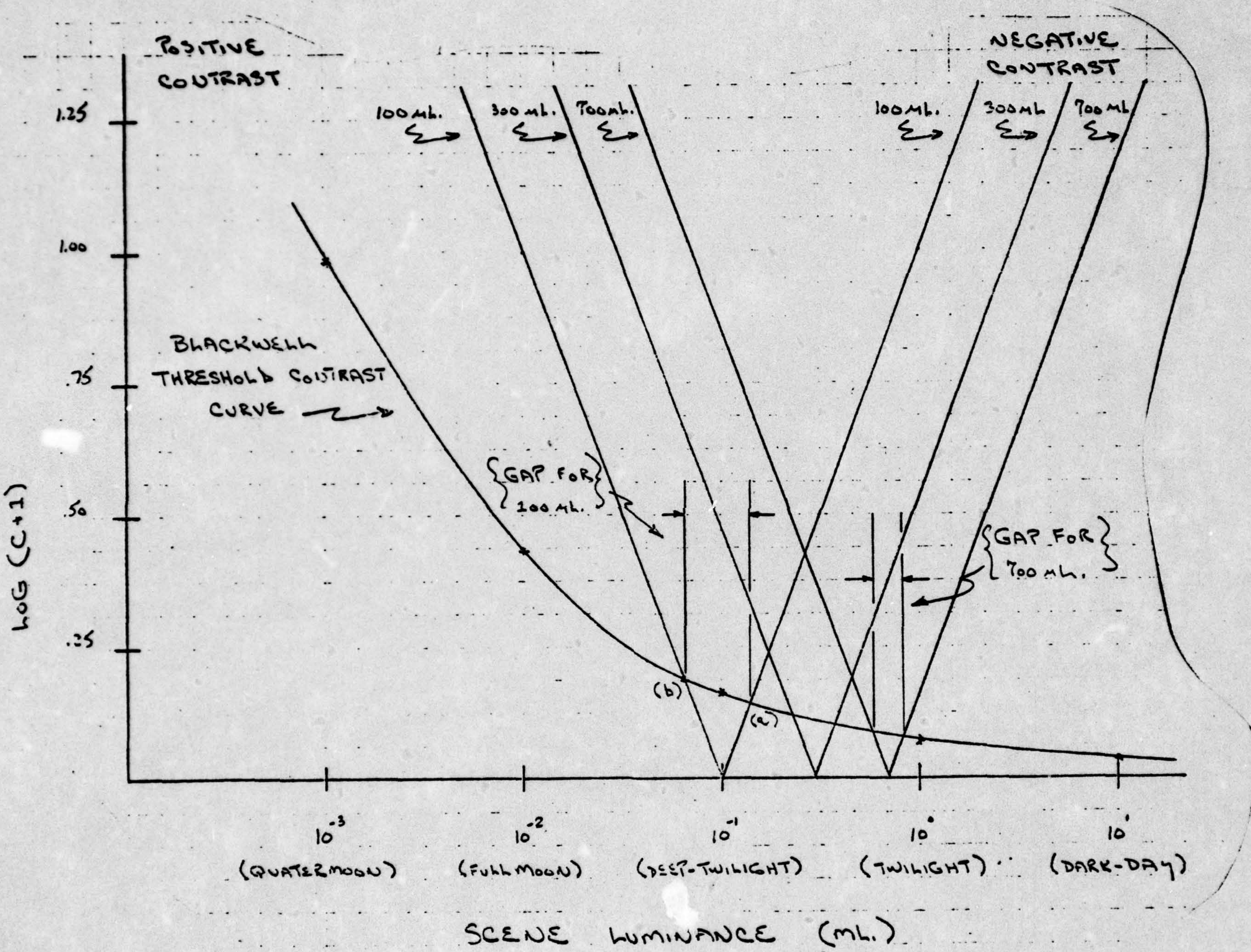

FIGURE 2-1. THE EFFECT OF RETICLE LUMINANCE ON VISIBILITY

A reticle of given luminance will be visible (as positive or negative contrast) for those background luminances where the reticle contrast lies above the threshold curve.

Consider the 100 uL reticle. The Blackwell data show that it will be visible, appearing dark, for daylight conditions until the scene luminance is in Deep Twilight (Point A). Similarly the 100 ul reticle should become visible again, appearing bright at Point B, when the scene luminance is between Deep Twilight and Full Moon conditions. This region, or, more properly, duration of lack of sufficient contrast to reach threshold, will be referred to as the "gap" in Section 3. This duration is shown in Figure 2-1. The reader is now invited to repeat this exercise for the 700 uL reticle. Note that the "gap" still exists, but is shorter. Obviously, this is due to the fact that the human contrast threshold, a logarithmic function, is decreasing (for positive and negative contrast) with higher scene luminance.

It is important to observe that while the required minimum contrast increases with decreasing scene luminance, the actual reticle luminance requirement decreases. Observe in Figure 2-1 that as the scene luminance decreases from Twilight to Full Moon, reticle visibility can be achieved with diminishing values of reticle luminance (i.e., from about 700 uL at Twilight to under 100 uL at Full Moon).

Figure 2-2 shows the reticle visibility curves with a second threshold contrast curve, labeled "Larger Object". The Blackwell data, unfortunately, do not provide an object size which truly corresponds to a line width of about 4 minutes. However, if one is willing to simultaneously make two extrapolations,* the Larger Object curve would correspond to a line width of about 4 minutes. This new threshold curve demonstrates the reduction in gap that is achieved by an increase in reticle line width.

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*The "larger object" is three times the 3.6' circular target in subtense, and results in a one log unit decrease in contrast threshold.

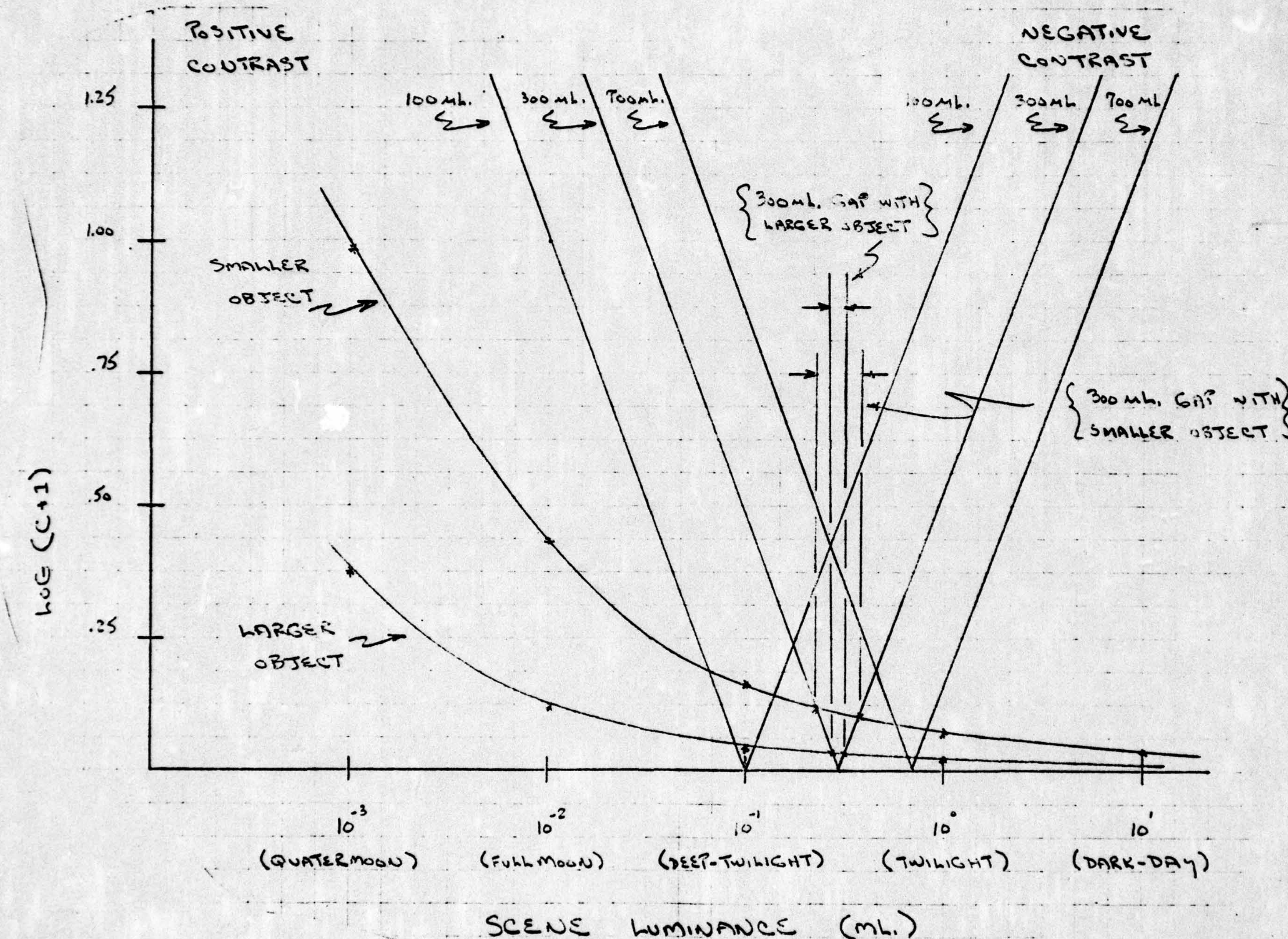

FIGURE 2-2. THE EFFECT OF RETICLE LINE WIDTH ON VISIBILITY

The threshold curves shown in Figures 2-1 and 2-2 are based on data for an adapted eye. This adaptation of eye sensitivity to the luminance in its field of view does not occur instantaneously. Full adaptation to a transition from light to dark, for example, may take as much as 35 minutes. Because of the relatively slow adaptation rate, the eye in twilight conditions may not have its optimum sensitivity. In the evening twilight, therefore, a threshold contrast, somewhat greater than that shown in Figure 2-1 and 2-2 would be required.

In morning twilight a somewhat lower contrast can be accomodated. The rate of change of the scene luminance in twilight has, therefore, some effect on the duration of the threshold gap.

The quantity that is of prime interest for operational considerations is the time duration of the threshold gap for any reticle brightness. The rate of change of scene luminance during twilight varies as a function of latitude, time of year and atmospheric conditions. Clear atmospheric conditions represent a worst case since any overcast has the effect of accelerating the rate of change of scene luminance for any location.

The worst case duration of a gap in scene luminance can be obtained for any location on earth from the Air Almanac, published quarterly by the Naval Observatory. The Almanac contains tabulated durations for twilight without cloud cover. A plot of scene luminance versus time taken at any latitude can be converted to any other latitude. The time history of luminance for any latitude can therefore be determined.

This analytic study of the reticle illumination problem is entirely based on the Blackwell data. Since these data are not directly applicable to the reticle problem, the results presented herein should not be taken as an exact solution to the problem. However, the methods suggested herein could be applied to a generalized lighted reticle design if the data suggested in Section 4 were available.

Suppose, for example, that in a given optical system design it has been determined that no reduction in scene luminance can be tolerated. Suppose further that one knew the decay curve for the illumination sources to be used in the system. Given a curve of the type of Figure 2-2 for reticle design, one could then specify the line width and initial luminance of the source required to eliminate the gap (or to reduce it to some tolerable duration).

Similarly, if one were given an initial source luminance, one could then specify the line width and useful life of the source. Or, alternatively, if one were given the luminance and required useful life, one could specify the line width and the maximum required reduction in scene luminance required (assuming now that reduction in scene luminance is tolerable).

In general, it can be seen that with curves of the type of Figure 2-2, based on reticle visibility it is possible to specify all the useful design parameters.

3. Engineering Application

When the radioactively illuminated reticle was substituted for the incandescent source, the capability in the M113 Panoramic Telescope for turning off and for varying reticle luminance was lost. Since the Pantel must be used in ambient light conditions ranging from full sunlight to full night, (a range of up to nine orders of magnitude in luminance) and, since the reticle is always illuminated, it may be shown that, regardless of reticle luminance, there must be some period of time when the reticle is not useable in the present design. This condition is illustrated schematically in Figure 3-1.

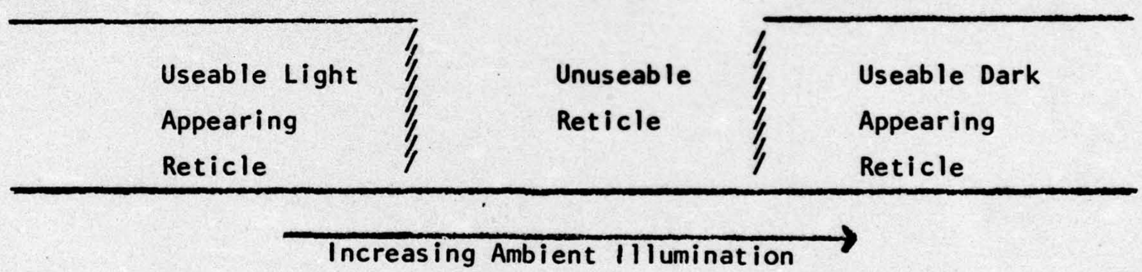

Figure 3-1

In the original Pantel reticle design, the gap appears to occur at background luminance of about 100 to 1000 uL (based on extrapolations from the Blackwell data of Reference 1).

This gap may, however, be reduced or even eliminated. Since the eye "sees" Contrast*, which is a function, in this case, of both reticle and scene luminance, and, since the eye's sensation varies with object size, there are several parameters which can be varied to eliminate the "gap". These are:

1. Reticle line width and character dimensions
2. Reticle luminance
3. Scene luminance (in the eyepiece)

*See Appendix 1, Definition of Terms

The following Sections will discuss each of these parameters. In all that follows, it should be kept in mind that reticle luminance levels must be those existing at the end of the useful life of the reticle.

3.1 Reticle Line Width and Character Dimensions

The minimum line width which can be seen is a function of line width and contrast. The angular subtense of a dark line seen against a brighter background can be as small as about 0.5 sec. and be seen. But, as background illumination decreases to .005 uL, the 0.50 probability of seeing occurs at 10.5 arc minutes (2)*. The subtense required to see the dark appearing line is estimated on the basis of Ref. 1 to be about 2-3 minutes when the background luminance is 50 uL. At this point a caveat is in order. The Blackwell data were obtained using achromatic, circular targets against a uniform background. They do not, strictly speaking, apply at all to the reticle problem. However, experience with similar problems has shown that extrapolations from these data usually yield good engineering approximations.

The angular subtense of the current Pantel reticle engraving is less than 1 minute. By increasing the line width, the dark appearing reticle will be useful for a longer period of time at evening twilight.

Exactly the same reasoning applies to the lighted reticle. Extrapolating from the Blackwell data (1), one would anticipate that increasing the reticle width from one to three minutes would result in its being useful at 1/10 the contrast required for the one minute width, i.e., sooner in evening twilight.

In the Human Engineering literature (2, 3) it is generally recommended that reticle lines subtend not more than two minutes, however, such a general recommendation, without consideration of the system accuracy and tolerable obscuration, should be considered advisory at best.

3.1.1 Numeral Characteristics

The nominal numeral height for the original Pantel reticle, when viewed through the eyepiece subtends 6' of arc. 20/20 vision of the very high contrast

*Numbers in parenthesis refer to references listed at the end of this report.

letters on the ordinary Snellen Chart is defined as a letter height of 5' of arc. Clearly, if the numerals on the Pantel are to be read with ease, their size should be increased.

For reliable reading at low contrast the characters should be 20 to 25 minutes high and 12 to 15 minutes wide. (Except the numeral 1, which should be one stroke width wide.) Stroke widths of 2-3 minutes (the same as the reticle lines) are satisfactory. Note, that the drawing (No. 8626209) for the Pantel reticle states that the "width of etched lines forming figures and letters is unimportant". This is obviously not true.

3.2 Reticle Luminance

The brighter the reticle can be made to appear, the earlier the light appearing reticle will be useful at evening twilight. Extrapolating again from the Blackwell data (1), whereas a 100 uL reticle with 1 minute lines should tend to become unuseable somewhere between Full Moon and Deep Twilight, a 300 uL reticle with the same line width should fade between Twilight and Deep Twilight. The dark appearing reticle of 100 uL should be effective at scene luminances from Deep Twilight to brighter (depending upon scene content). Thus, the 300 uL reticle shows a gap, but, it is narrower than that of the 100 uL reticle.

When one considers the one log unit decrease in threshold contrast when going from one minute reticle line widths to three arc minutes in combination with a 300 uL reticle, the Blackwell data would predict a gap duration of about 2 minutes at a probability of seeing of 0.95 at about 40° N Latitude in August.

3.2.1 Increasing Reticle Luminance

The Luminance of the reticle can be increased by increasing the source luminance and by increasing the flux transmission between source and reticle. Each of these methods will be discussed in the following Sections.

Increasing Source Luminance

One method of increasing source luminance is to increase the efficiency of the phosphor. Although it is not specified, P-2 phosphor is apparently being used in the sources. Phosphors far mor efficient that P-2 have been developed (for example, P-31). It may be assumed that the source manufacturer has continued to use P-2 for good reason (life, for example). This should be verified.

Since the manufacturer has the expertise in Tritium technology, it is unlikely that any increase in energy (above that presently being supplied) can be achieved by variations in the parameters relating to the power source.

A Note On Source Wavelength

Although the "conventional wisdom", for many years, held that red light should be used to illuminate reticles to preserve dark adaptation, this is certainly not necessary. At the levels of dark adaptation reached on even moonlit nights, the luminance level of a 300 or even 500 uL green source will not emit a sufficient number of quanta to adversely effect dark adaptation. Since green phosphors are most efficient and since the bandwidth of the green phosphors closely matches the sensitivity of the dark adapted (and light adapted, for that matter) eye, green should be used.

Figure 3-1 (taken from Cornsweet (4)), shows the relative sensitivity curves for both photopic and scotopic vision. As a matter of interest, the time of twilight to deep twilight (at 40° N) represents the transition from Light to Dark adaptation and is called the mesoptic region. Eye sensitivity is increasing from the light adapted to dark adapted state during this time period.

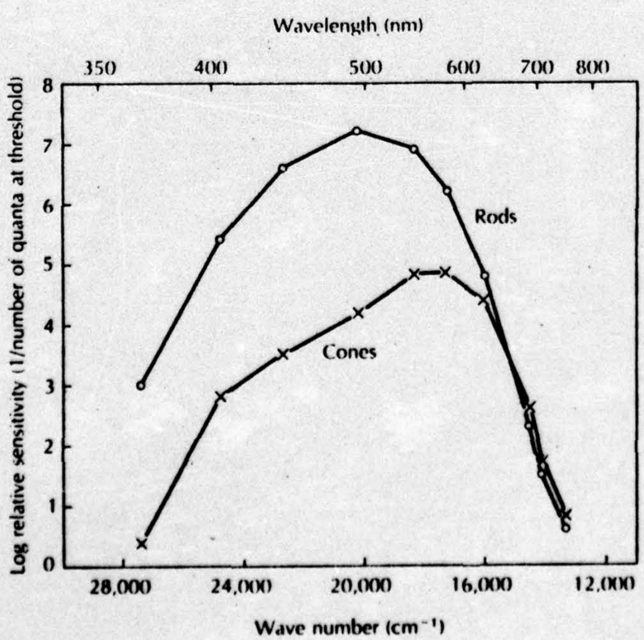

Fig. 7.8 Photopic (cone) and scotopic (rod) spectral sensitivity curves. [*After Wald* (1945).]

Figure 3-1

Increase in Flux Transmission Between Source and Reticle

Several relatively minor configurational changes may be incorporated into the design to increase the level of luminous flux transmission between the source and reticle. These changes, which are described below, would

1. increase the radiant flux in the direction of the reticle edge
2. directly couple the source radiation, only to that half of the reticle "sandwich" which contains the etchings
3. eliminate areas of energy loss

A recommended configuration for the illuminated region is shown in Figure 3-2 . In this figure, the radiant flux has been increased in the direction of the edge of the reticle disk by utilizing curved radiant sources with flat cross sections. Such a source would maximize the effective area of radiation for a given volume of radioactive charge.

The rear surface (away from the reticle edge) would be silvered or coated in such a way as to prevent the loss of energy due to transmission through this surface.

Wedges of RTV, or other optically transparent silicone potting compound would be used to couple the source with the reticle edge. The reticle edge should be polished and sufficient circumferential pressure applied to ensure good contact at the mating surfaces. Note that the wedge directs flux only to that half of the reticle sandwich which contains the etched markings. The edge of the other half of the reticle is not exposed. The source may be placed as far away from the reticle edge as necessary, to accomodate the largest source available within the geometrical constraints of the elbow housing.

If a significant portion of the wedge extends beyond the outer diameter of the bevel gear cylinder, the edges of the wedge should be coated, or covered.

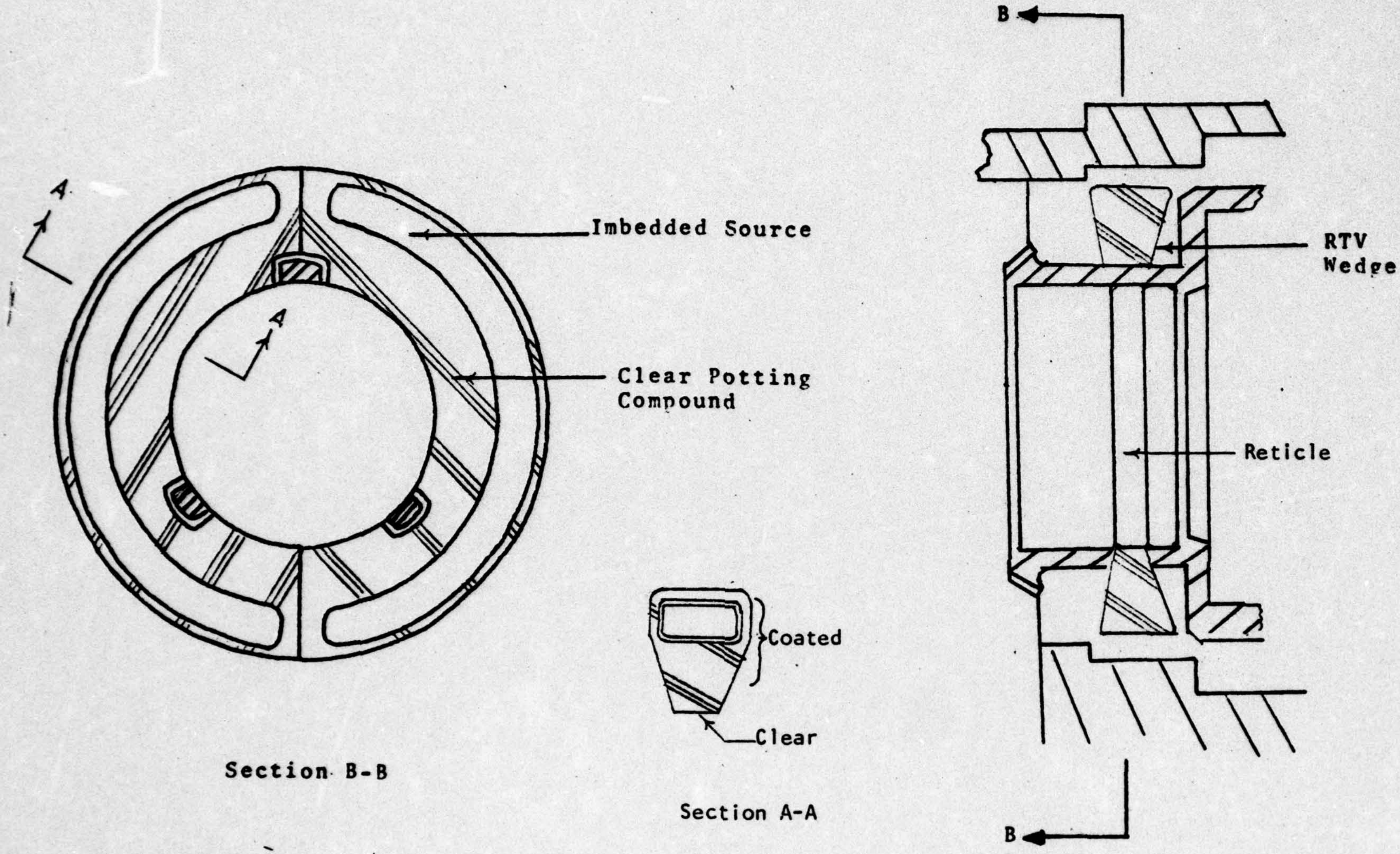

Figure 3-2. SOURCE CONFIGURATION

The configuration shown would be applicable for use with sources which subtend, 90, 120 or 180° degrees of arc. The bevel gear cylinder should contain, however, a minimum of three windows, in order to provide three webs to support the bevel gear. Figure 3-2 shows how two 180° sources could be used effectively with little loss in energy.

3.3 Scene Luminance

What one observes when looking through the eyepiece is the contrast between the reticle and the scene.

It has previously been shown that, with a fixed reticle luminance, it is possible to increase Contrast by decreasing the scene luminance. At evening twilight, it is possible to "bring night on sooner" by decreasing the scene luminance. This is a critical point, because this is how the "gap" between a lighted and unlighted reticle can be eliminated.* At some point in twilight, when the dark appearing reticle is barely visible, the scene luminance can be decreased (by introducing a stop, a beam splitter, a filter, or other means) for that critical time interval until the light appearing reticle is visible with full scene luminance. During the period of artificially induced lowered scene luminance, the reticle will appear lighted, because early darkness was produced. In effect, the time "gap" has been removed by artificially eliminating the ambient light conditions which prevail during the time "gap".

Clearly, the same effect can be produced at morning twilight. In this case "night" is effectively lengthened by reducing the incoming light, thereby increasing the duration of usefulness of the light appearing reticle. It is noted that, at morning twilight, the user is dark adapted at the start of twilight, hence the duration of the gap is shorter, since less contrast is required at high light levels than at low light levels. For this reason, lower contrast can be tolerated for a longer period of time.

There exists some "optimum" amount of scene luminance dimunition which results from a tradeoff between gain in contrast and loss of resolving power. One seeks to reduce the scene luminance to that required for a reticle brightness near the end of its useful life without significantly reducing the operator's ability to perceive fine detail in the scene.

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*It is also possible to eliminate the "gap" by providing a mechanism to block the light source from illuminating the reticle, but this may be a more complicated solution for the Pantel.

The amount of light to be excluded from the Pantel is a function of reticle luminance and size. When it is optimized for any latitude, it will be optimized for all, although the duration of decreased scene illumination will vary.

4. Development of Data Base on Reticle Visibility

For all continuously illuminated reticles the time gap during which the optical instrument is not useful must be minimized. In those cases where the gap is of such a duration that it is necessary to attenuate the scene illumination, this can only be done with a concomitant loss of perceived scene detail. It is recommended that a logical series of experiments be conducted to determine reticle brightness requirements. The objective of these experiments will be to develop a data base applicable to Optical and Electro-Optical reticles. These data will provide the basis for deriving threshold contrast curves and for ascertaining the loss in resolution experienced with reductions in scene luminance.

From this data base, the parametric values for all future reticle designs can be selected. It will then be possible to design reticles on the basis of quantitative data and provide a firm rationale for the selection of the reticle design.

A series of basic experiments will be performed initially in a laboratory, followed by parallel field validation of the experimental results and additional laboratory experimentation. The following sections describe recommended facilities, experimental procedures and field test validation.

4.1 Laboratory Facilities

The building in which the present reticle evaluation is being carried out is adequate for the installation of a suitable laboratory. The laboratory concept is modular, that is, starting with a minimum configuration, and adding additional sophistication as time (and budgets) permit.

4.2 Experimental Procedures

The initial experiments will be designed to determine the "gap" in scene luminance which can be anticipated as a function of reticle luminance for a homogeneous scene. A rear projection screen will be illuminated with a high intensity projector, fitted with a Neutral Density Wedge (See Figure 4-1). The Reticle under test will be equipped with a varying illuminance source.

For convenience, the so-called Method of Limits should be used. To determine the threshold for lighted reticle visibility, a uniformly illuminated surface would be viewed through the telescope. The luminance of the screen would be decreased until the reticle became visible, and that value of screen luminance recorded. The screen luminance would then be considerably decreased, and gradually increased again until the reticle just becomes invisible and the screen luminance again recorded. This "up and down" sequence is repeated with the same observer a considerable number of times, resulting in a Gaussian distribution of luminance values, with the Mean Threshold Screen luminance set equal to a Probability of Detection of 0.50. The same procedure is repeated for reticles of varying luminance levels.

This procedure would then be repeated for a number of observers under identical conditions. The Variance of the total sample can then be used to calculate the 0.95 (or 0.99) probability of detection.

The reverse procedure would be followed with the unlighted reticle, and that Threshold also determined. The difference (if any) in screen luminance between the two Detection Probabilities of 0.95 then determines the minimum acceptable reticle illumination at the end of the useful life of the source.

Since there would be both a single independent variable and a single dependent variable, the experimental design would be relatively straightforward. Important considerations include:

-Number and Type of Observers
-Number of Trials per Session
-Number of Sessions
-Balancing Observers within Sessions
-Environmental Control

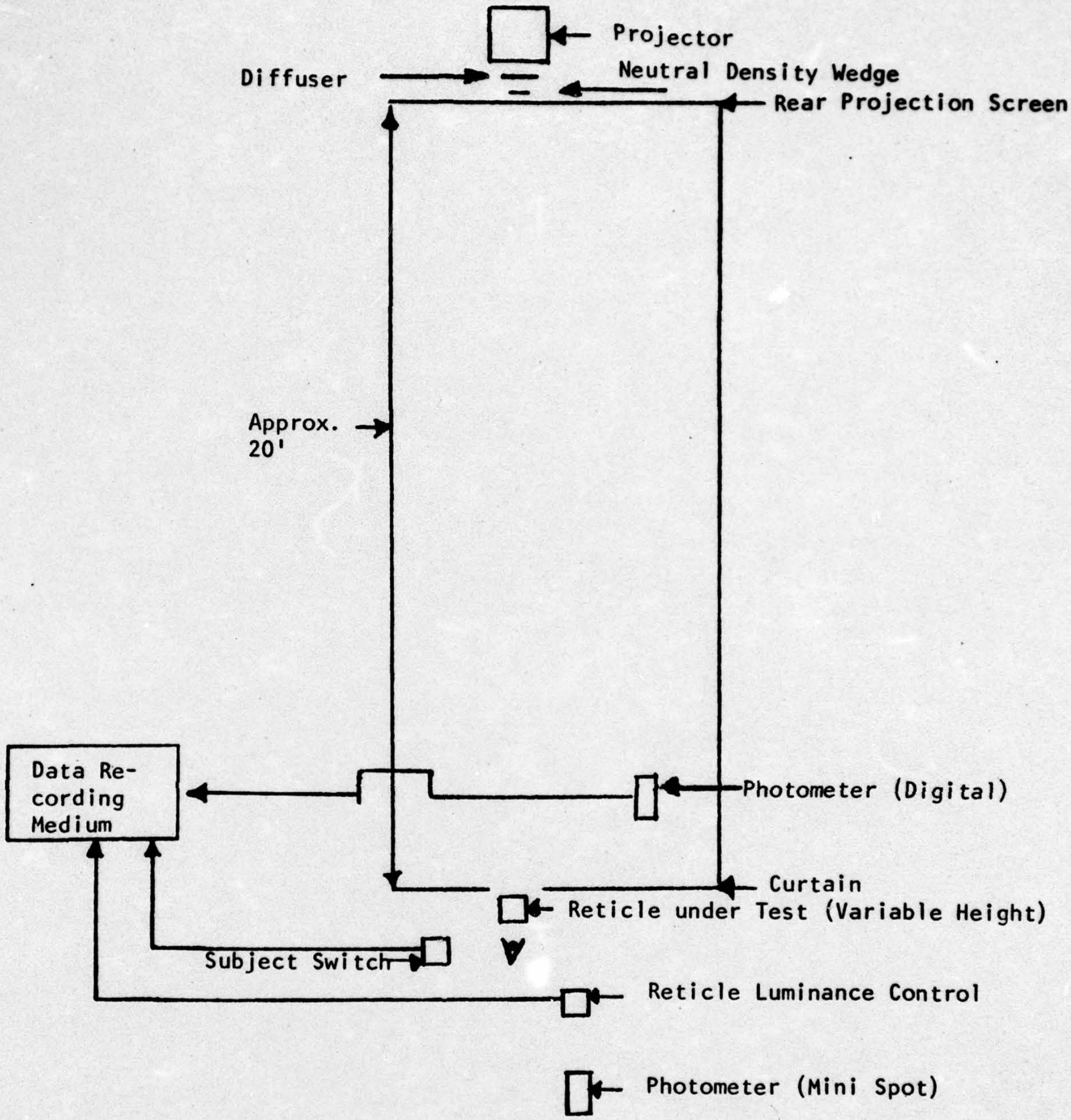


Figure 4-1. SCHEMATIC OF LABORATORY FACILITY

For the initial experiments the data (screen and reticle luminance at threshold) can be recorded manually. As early as possible, however, it is desireable to install a data collection system. Such a system would include a digital photmeter, a digital control for the reticle illuminator (or, alternatively, an A-D converter on an analog controller), a manually operated switch for subjects to indicate threshold, and a suitable recorder (Tektran or punched paper). Figure 4-2 shows the desireable data collection system.

After completion of the initial series of threshold determinations, two efforts should be conducted in parallel. First, the results of the early experiments with uniform backgrounds, should be checked by means of field tests. The field tests should be carefully controlled to determine the accuracy of the use of the uniform field in the laboratory tests. If the uniform fields provide a good approximation of the field test results, a future complication (namely, the introduction of filmed real life scenes in the laboratory) can be avoided.

Simultaneously, the effect of the reduction of scene luminance on visual resolution should be determined. Figure 4-3, taken from Cornsweet (4), shows a Human Visual System Describing Function (or, perhaps Modulation Transfer Function, as it is labeled, if an assumption about linearity is valid).

333 **Human Visual Modulation Transfer Functions**

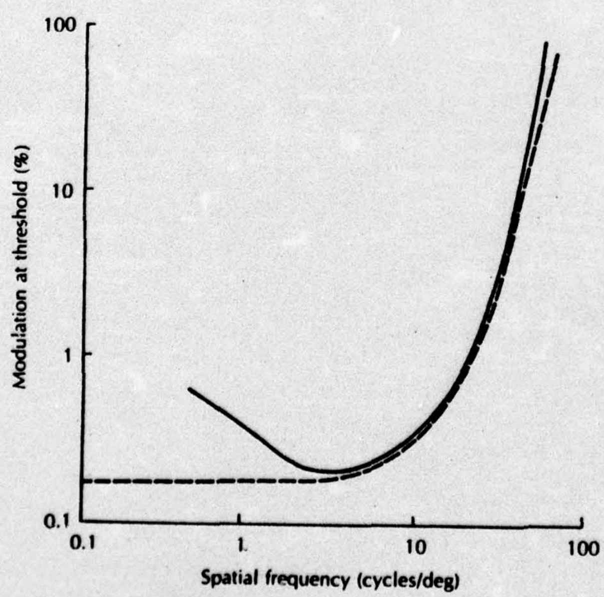
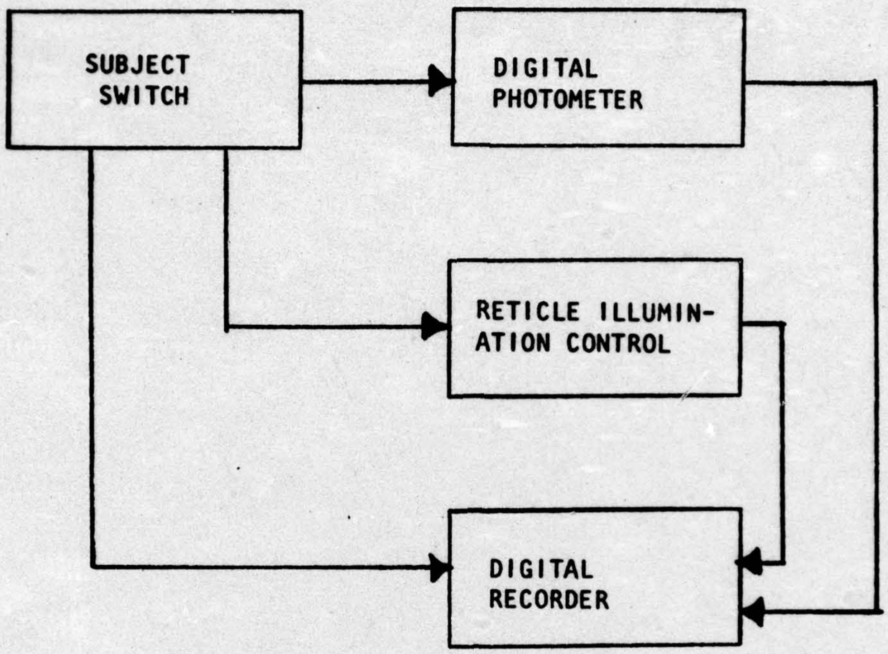


Fig. 12.13 **The solid curve is a describing function of the human visual system, obtained by measuring the threshold modulation at each spatial frequency. (100% modulation means that the troughs of the sine wave are completely dark.) The dashed curve is what would be expected for a lens under the same conditions of testing.** [*The solid curve is from Van Nes and Bouman (1965); λ = 525 nm, average intensity = 90 trolands.*]

Figure 4-3



OUTPUT FORMAT

Trial	Detect	Scene	Reticle
N	1	200	208

HEADER FOR RECORD (MANUALLY RECORDED)

Subject
Session
Date
Time (Start & Finish)

Figure 4-2. BLOCK DIAGRAM DATA COLLECTION SYSTEM

Sine wave charts will be substituted for the uniform fields used in the initial experiments. Since the threshold contrast region for reticles of various luminances will now be known, the so-called Temporal Forced Choice Method will now be employed. With a fixed reticle luminance, the Field will be presented briefly at a luminance level near threshold, turned off, and then presented briefly again at a luminance level just slightly higher or lower than the first. The subject is asked to indicate which was the brighter of the two, and told whether he was right or wrong (the data collection system requires modification). This procedure is repeated for sine wave charts of the frequencies which would meet the system requirements, for the range from unobscured to the obscured system. In this way, the maximum tolerable amount of obscuration for a range of reticle luminances is determined.

These experiments, involving multiple modulations and frequencies, (and, possibly, wavelengths) should be conducted as Multivariate Factorial Designs. Such Experimental Designs are efficient, economical, and are, in fact, the only designs which can properly handle multiple variables.

As with the first series of experiments, care must be exercised in the design of the experiments, to eliminate artifacts.

4.3 Field Tests

As stated above, the Field Tests must be carefully controlled, as to Subject selection, ordering, photometric measurements, etc., because the results of the Field Test will be used to validate the Laboratory Experiments.

Based on experience, it is expected that the results obtained in the Laboratory using a uniform luminance background will be generalizable to the field situation. If this expectation proves <u>not</u> to be true, it is suggested that time lapse motion pictures of several typical scenes be taken, and projected for the second series of laboratory experiments. Color photography, taken from several compass bearings of various scenes would be exposed, under photometer control. For example, exposures might be made at intervals of one mL in horizon sky luminance at evening twilight (one exposure per one millilambert decrease). These "motion" pictures would then be projected as a substitute for the uniform backgrounds.

Should this become necessary, it would again be required that these results be validated by means of controlled field tests.

5. Summary and Conclusions

This report presents an analytic technique which can be applied to specifying the required reticle luminance, reticle line width and scene luminance reduction in the design of optical systems.

The analytical technique is then applied, in a first approximation, to the design parameters of the M113 Pantel reticle. It is shown that the original design of this reticle and its method of illumination is, at best, marginal. The potential gains resulting from certain design changes are calculated.

Unfortunately, the technique could be applied to the Pantel only to a first approximation due to limitations on the available contrast visibility data. For this reason, it is recommended that a Data Base on reticle visibility be developed. The Laboratory facilities and experimental techniques which should be used to develop the data base are described.

References

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APPENDIX I

Definitions of Terms

Luminance: The flux per unit solid angle per unit area of an extended source of radiation (units: mL-MilliLambert; uL-microlambert).

Brightness: The subjective equivalent of luminance.

Lambert: The luminance of a perfectly reflecting and diffusing surface, (Lambertian) emitting 1 Lumen/cm^2 (One Foot Lambert (1 lumen/ft.^{2}) $\cong$ 1000 μL.

Contrast:

$$C = \frac{B_R - B_S}{B_S} \qquad \text{for light appearing reticle}$$

$$C = \frac{B_S - B_R}{B_R} \qquad \text{for dark appearing reticle}$$

where: B_R is the reticle luminance
B_S is the average scene luminance

Inverse Square Law: The flux per unit angle falls off as the square of the distance from the source. Applies only to Point Sources, not extended (Lambertian) surfaces.

Photopic Vision: Light adapted eyes.

Scotopic Vision: Dark adapted eyes.

Mesoptic Vision: The range between the two above terms, which occurs (without artificial light) at twilight.