October 6-7, 1958

IMAGE INTENSIFIER SYMPOSIUM

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Image Intensifier Symposium, Fort Belvoir, Va., 1958

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PROGRAM

IMAGE INTENSIFIER SYMPOSIUM

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Monday, October 6 — Humphrey Hall

Welcome - Colonel A. H. Davidson, Jr.
Director
USAERDL

Introduction - Dr. Robert S. Wiseman
Chief, Warfare Vision Branch
Electrical Engineering Dept.

PART I

IMAGE CONVERTER TUBE INTENSIFIER RESEARCH

Chairman: Dr. George A. Morton
Radio Corporation of America

PART II

IMAGE INTENSIFIER RESEARCH IN EUROPE

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Chairman: Dr. W. A. Hiltner
Yerkes Observatory
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Tuesday, October 7, 1958

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Chairman: Myron W. Klein
USAERDL

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APPLICATIONS, SPECIAL PROBLEMS, AND PROGRAMS FOR IMAGE INTENSIFIERS IN

Chairman: Dr. Merle A. Tuve
Director
Department of Terrestrial Magnetism
Carnegie Institute of Washington

ANALYSIS OF IMAGE FORMING SYSTEMS

John Johnson
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A. INTRODUCTION

In recent years, electro optical image intensifier devices have been extensively developed for use in military activities requiring visual surveillance under extremely limited visibility conditions. In principle, these sensitive light pickup elements allow a considerable increase in visual target acquisition and image display capability. Low level images may be intensified enormously by electronic amplification. Quantum limited signals may be integrated for long time periods and readout by continuous non-destructive readout techniques. Active light pulse storage systems may be used for the storage and continuous display of transiently illuminated scenes. Active infrared intensifier systems are feasible which combine a high degree of performance with a relatively high level of visual security for the user.

The variety and complexity of intensifier devices which are possible and the development cost associated with each indicate the need for realistic system selection and performance evaluation techniques. This paper presents a brief survey of the methods and procedures which may be utilized for the solution of problems involving military visual surveillance thru image intensifier devices under low light level conditions.

B. GENERAL SYSTEM CONSIDERATION

The image intensifier may be considered as in the nature of a black box with input and output terminals coupling a target message located in object space to the visual communication channel of the human network with interpretive and decision making capabilities. In battlefield surveillance radiation patterns modulated by ground objects travel through long air paths into the input terminals of the intensifier, the objective lens. After undergoing suitable modification and alternation by electronic processes, an output visible image is presented to the human observer for interpretation and decision making. The complete system is shown in Figure 1.

We may consider that the interpretation process does not contain a continuum of values but is restricted or quantized into five distinct levels of activity:

1. No detection
2. Detection
3. Shape orientation
4. Shape recognition
5. Detail recognition

In other words these are the five distinct degrees of freedom or states of image intensifier system. Obviously these decision states depend on the characteristics of the optical message, the properties of the intensifier device and the physichological responses of the human readout processes. What is required for evaluation purposes is a transformation arithmetic which allows determination of the most probable value of the decision state of the complete system as a function of the various component variables.

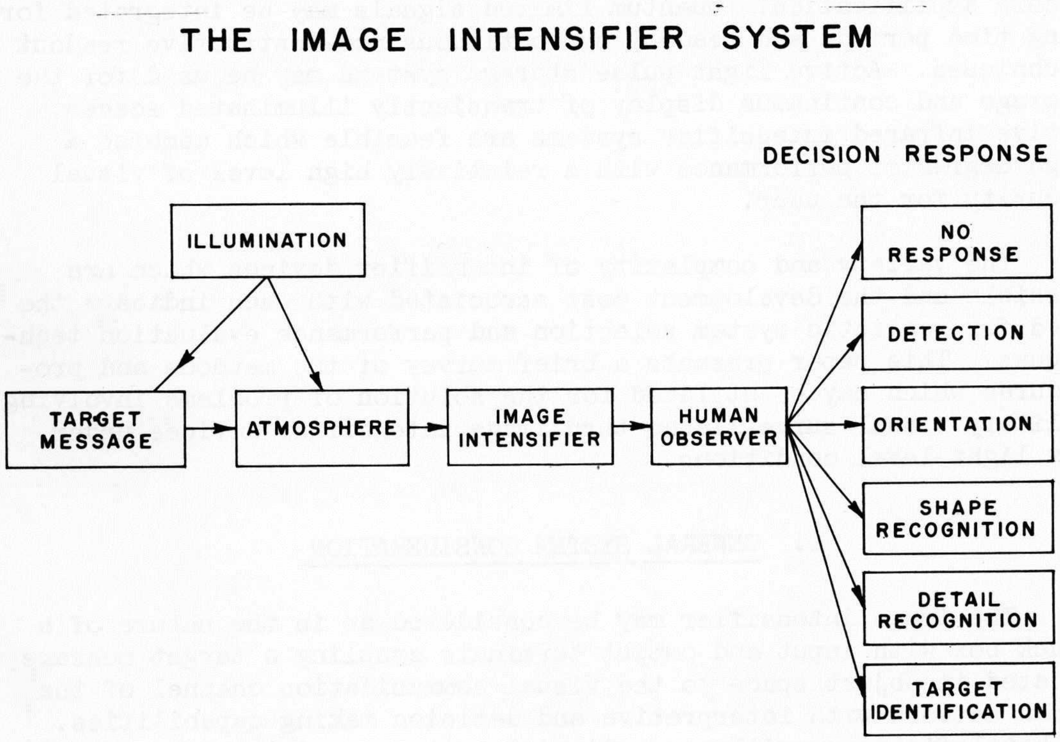


Figure 1

C. DEFINITIONS OF INFORMATION FLOW

The choice of a fundamental quantity to act as an information carrier in an image forming system corresponds to the selection of a suitable coordinate system in which to cast and examine a physical problem. While many coordinate systems are possible there are a preferred few in which the problem may be solved in as simple a manner as possible. In like manner, the definition of information flow for any image forming system is a relative concept whose justification lies in the simplicity introduced into the solution of visual imagery problems.

There are two general frameworks in which problems involving images may be cast:

1. Space Domain
2. Space Frequency Domain

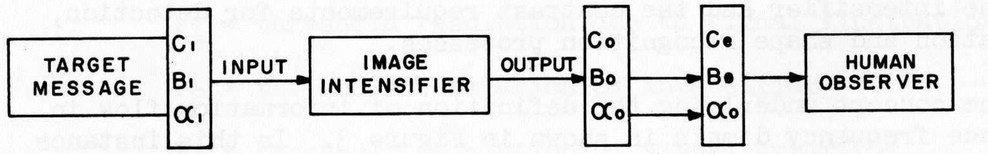
The definition of information flow in the space domain is presented in Figure 2. The input message to the intensifier is a real target with characteristics:

Target brightness B_1

Target contrast C_1

Target angular subtense α_1

DEFINITION OF INFORMATION FLOW



C_1 = input target contrast

B_1 = input target luminance

α = input target angular subtense

C_o = output target contrast

β = output target luminance

α = output target angular subtense

C_e = contrast threshold of eye

$$Q \text{ (INFORMATION FLOW)} = \left(\frac{C_o}{C_e} + 1\right)_{B_o,\,\alpha_o}$$

Q IS THE NUMBER OF DETECTION DISCRIMINATION LEVELS PER VISUAL INTEGRATION TIME FRAME

Figure 2

The intensifier modifies these image quantities and presents to the eye values of

target contrast Co

target brightness Bo

target angular subtense αo

Ce = visual contrast threshold

For particular values of target brightness and angular subtense, the visual network has a minimum requirement of contrast necessary for a specific act of vision. If the output contrast of the intensifier exceeds the visual threshold of the eye, then information is transmitted thru the system. The greater the excess of contrast available, the higher the rate of information flow since the excess contrast may be utilized to recognize or identify the target. The definition of information flow in the space domain is

$$Q = \frac{Co}{Ce} \tag{1}$$

Q is the number of discrimination levels per visual integration time frame. In order to relate information flow Q to decision level activity it is necessary to determine both the output image contrast from the intensifier and the contrast requirements for detection, orientation and shape recognition processes.

The concept underlying the definition of information flow in the space frequency domain is shown in Figure 3. In this instance the input message to the intensifier is not a real target but an abstract pattern consisting of alternate black and white lines. When this message, located a distance L, is just resolved the system resolution Ps is:

$$Ps = \frac{1}{\alpha_s} \text{ minutes}^{-1} \tag{2}$$

The width of a single line pair at this distance is $\frac{\alpha_s L}{3440}$ feet if L is expressed in feet.

We shall define information flow in space frequency domain as the number of resolved line pairs per foot of target space.

$$W = \frac{3440}{\alpha_s L} \quad \text{(resolution bits per foot)} \tag{3}$$

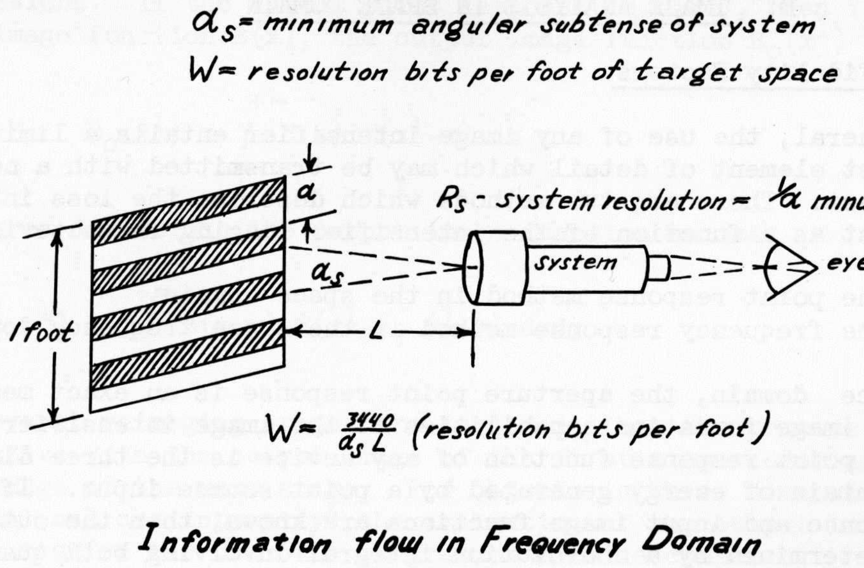


Figure 3

The great advantage to working in the space frequency domain is the relative ease with which the effect of the components on system resolution may be accounted for. For instance if:

Ps = system resolution in minutes^{-1}

P_1 = threshold resolution due to signal fluctuations

P_2 = threshold resolution of intensifier

P_3 = threshold resolution of visual apparatus

Then, referred to the object plane,

$$\frac{1}{Ps} = \sqrt{\left(\frac{1}{P_1}\right)^2 + \left(\frac{1}{P_2}\right)^2 + \left(\frac{1}{P_3}\right)^2} \qquad (4)$$

On the other hand, in the frequency domain the targets are abstract patterns and do not have any obvious relationship to real targets. Recourse must be made to empirical transformations which in effect translate complex real objects to visually equivalent resolution frequencies for various decision state activities.

In the space domain while the image forms are familiar, each target form requires a separate analysis which involves the resolution of complex and cumbersome mathematical forms.

We shall now consider both information flow formulations in some detail.

D. IMAGE ANALYSIS IN SPACE DOMAIN

1. Image Fidelity Factors

In general, the use of any image intensifier entails a limit on the smallest element of detail which may be transmitted with a non zero contrast. There are two methods which describe the loss in output contrast as a function of the intensifier imaging characteristics:

1. The point response method in the space domain.
2. The frequency response method in the space frequency domain.

In the space domain, the aperture point response is an exact measure of the image formation capabilities of the image intensifier device. The point response function of any device is the three dimensional mountain of energy generated by a point source input. If the point response and input image functions are known, then the output image is determined by a convolution integral involving both quantities. In Figure 4, this is illustrated by an example in two

IMAGE INTENSIFIER RESPONSE FUNCTIONS IN THE SPACE AND FREQUENCY DOMAINS

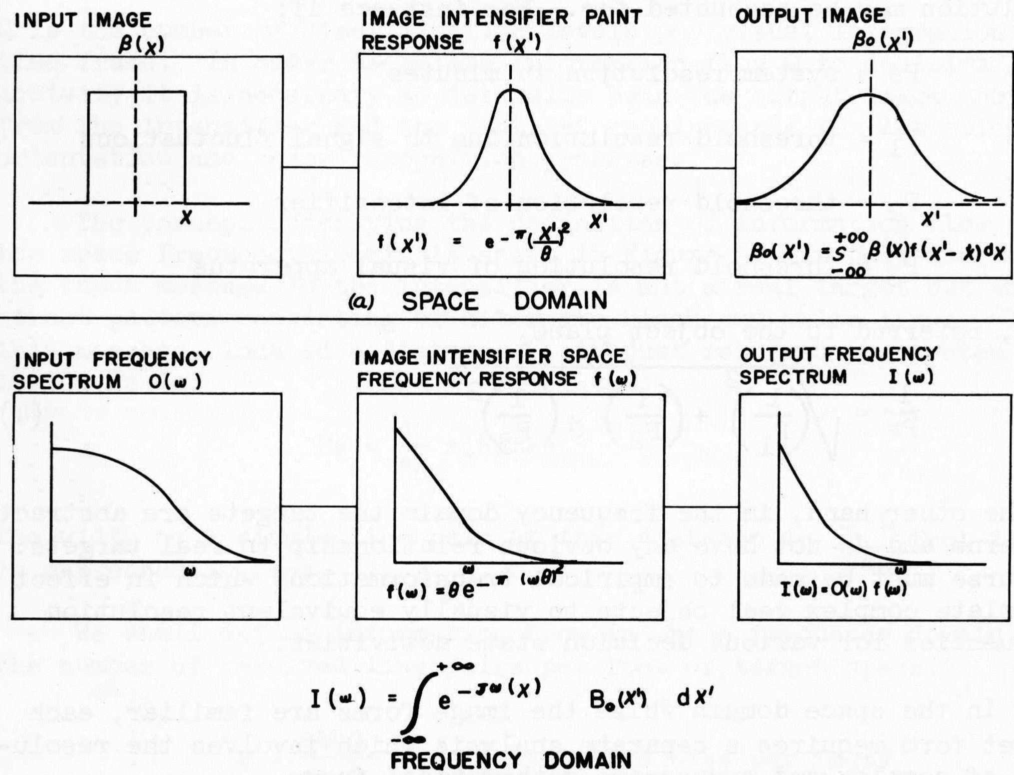


Figure 4

dimensions. If the system point response is $f(x^1)$, then for an output image function $B(x)$, the output image function $B_o(x^1)$ is given by

$$B_o(x^1) = \int_{-\infty}^{+\infty} B(x)\, f(x^1-x)\, dx \qquad (5)$$

In three dimensions the output image function becomes

$$B_o(x^1,y^1) = \iint_{-\infty}^{+\infty} B(x,y)\, f(x^1-x,\, y^1-y)\, dxdy \qquad (6)$$

If several reimaging stages are involved, then the process is reiterative with the output image of the first stage becoming the input image of the next stage. For objects in three dimensions (two spatial and one intensity) the evaluation of the output image functions require the use of a programmed machine computer.

In Figure 5a, the results of output image functions are shown for circular input objects of varying diameter. The point response function $f(x)$ is taken as a Gaussian distribution with a diameter of d_r at the 3% point as shown in Figure 5b. As the image diameter d, decreases below the dimensions of the point response diameter d_r, the peak amplitude of the output image functions in Figure 5a, falls rapidly. By expressing the results in a normalized form as a function of the ratio of the point response diameter to the circular image diameter $\frac{(dr)}{d}$ we may plot a spatial intensifier response Rs which indicates the loss in effective image intensity as a function of target image size. This is shown in Figure 5c for both circular and rectangular object functions.

If C = input target contrast

Rs = intensifier spatial response

B_o^t = output target brightness

Bo = output background brightness

B_I^B = input background brightness

B_I^T = input target image brightness

C_o^S = output image contrast

B_o^N = intensifier background noise

K = intensifier scatter co-efficient

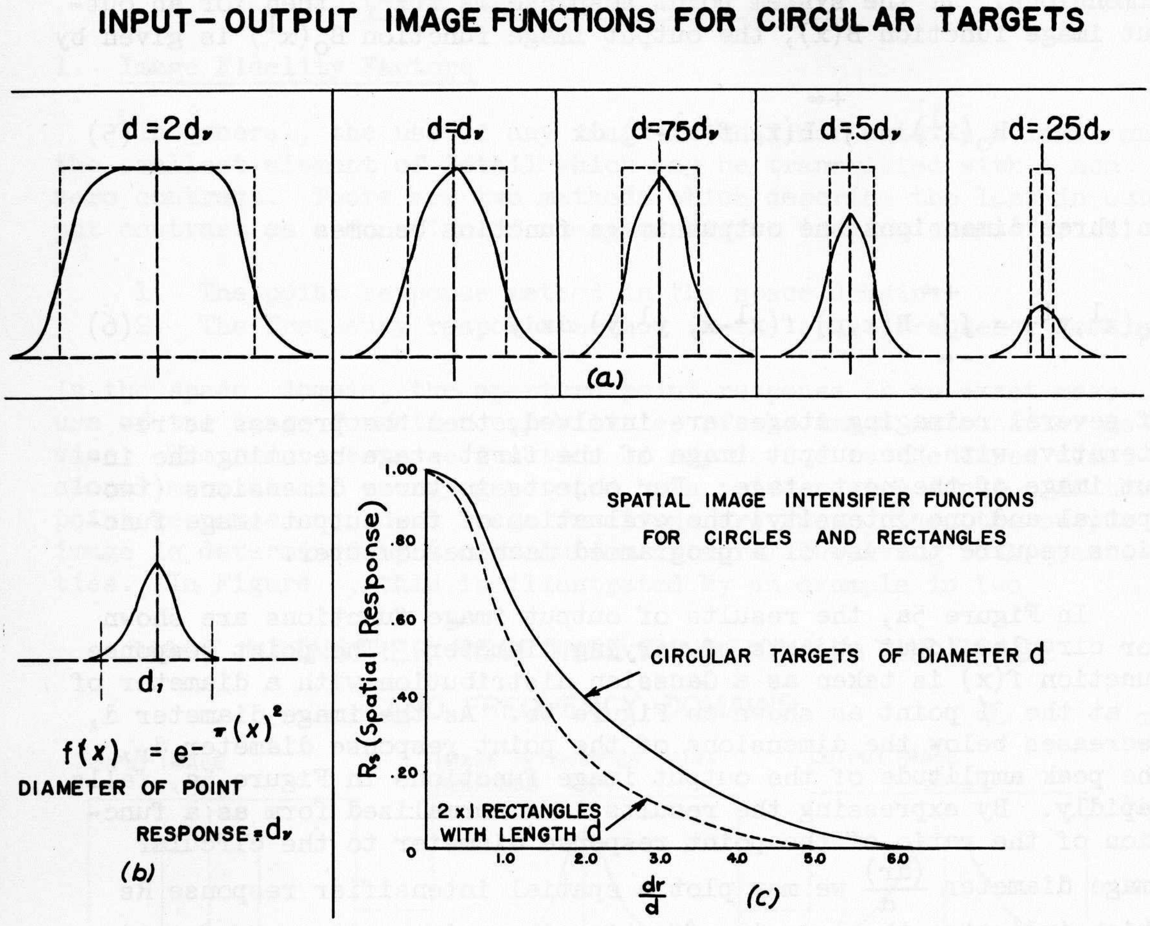


Figure 5

then it may be shown that the output image contrast C_o^S is given by Equation 7.

$$C_o^S = \frac{Rs\ (B_o^T - B_o^B)}{\frac{B_o^T - B_o^B}{C} + K\ (B_o^T + B_o^B) + B_o^N} \qquad (7)$$

while the output image brightness is given by

$$B_o^T = \frac{B_1^T\ T\ G}{4F^2M^2} + B_o^N - Rs\ \frac{(B_1^T - B_1^B)}{4F^2M^2} \qquad (8)$$

$$\text{for } B_1^T > B_1^B$$

and $$B_O^T = \frac{B_1^T \; T \; G}{4F^2M^2} + B_O^N + Rs \; \frac{(B_1^T - B_1^B)}{4F^2M^2} \qquad (9)$$

$$\text{for } B_1^B > B_1^T$$

where F = objective aperture ratio
M = tube magnification
G = tube light gain
T = optical transmission

Knowledge of the spatial response function of a system allows the direct determination of the output image contrast and brightness factors.

2. Effect of Shot Noise

If the image is appreciably shot noise limited, then the expression for output contrast (equation 7) must be modified to allow for the additional image degradation. Rose has derived expressions for the minimum detectable contrast threshold which may be discriminated as a function of image signal to noise ratio. These expressions apply only to threshold events and do not describe the decrease in image contrast as the threshold is approached. Let us consider an image sample with an average signal lever σ over which is superimposed an a.c. r.m.s. noise component Ω. The signal to noise ratio in the image sample is $\frac{\sigma}{\Omega}$.

Then when

$$\frac{\sigma}{\Omega} \rightarrow \infty, \text{ output image contrast = input contrast}$$

also when

$$\frac{\sigma}{\Omega} \rightarrow 1 \text{ output image contrast} \rightarrow 0$$

Also from Rose's theory, the contrast threshold is a linear function of image signal to noise ratio. From this we may infer that the contrast decreases linearly with image sample signal to noise ratio. Equation 10 is the simplest expression which approximately satisfies these conditions

$$C_{out} = C_{in} \; [1 - (\frac{\Omega}{\sigma})^{\frac{1}{2}}] \qquad (10)$$

where C_{out} = output contrast

C_{in} = input contrast

Ω = r.m.s. noise level

σ = average signal level

It should be understood that the output image contrast C_o^S defined by equation 7 may be used as the input contrast in equation 10. Equations 7 and 10 then, indicate the manner in which image contrast is degraded by the point response factor, the degree of macroscopic light scatter, the internal noise level and the signal to noise ratio in the target image.

E. CONTRAST REQUIREMENTS IN SPACE DOMAIN

We may now direct our attention to the denominator of the information flow equation (1). C_e was defined there as the visual contrast threshold required for each specific decision level activity. Generally speaking, contrast thresholds for the higher visual decisions functions are not yet available for specific military type targets. To obtain the necessary information for the sideview display of an M-48 Tank some 20,000 observations were taken in a semi-statistical manner on the contrast requirements for target detection, orientation and shape discrimination. The results are on figures 6 and 7 plotted on log - log scale with target brightness as abscissa and contrast ratio as ordinate. The detection thresholds were found relatable to equivalent circular objects of the Tiffany detection set by about a factor of 3 on the high side.

The most significant feature of the data is the non linear increase in the contrast jumps separating the decision levels as the target distance is increased. This is prominently evident if the target threshold data at 500° (Fig. 6a) is compared with the target data for 3200 feet (Fig. 7b). Magnification or scale in a viewing system becomes increasingly important as the visual activity becomes more highly differentiated.

F. INTENSIFIER DECISION DIAGRAMS IN THE SPACE DOMAIN

We are now in a position to combine the factor variables into information flow diagrams. Five image intensifier systems were selected for performance evaluation. All utilized a 5" diameter f/2.0 objective lens. The system characteristics of the various viewing devices were as follows:

DETECTION & SHAPE DISCRIMINATION THRESHOLDS of a MILITARY TARGET

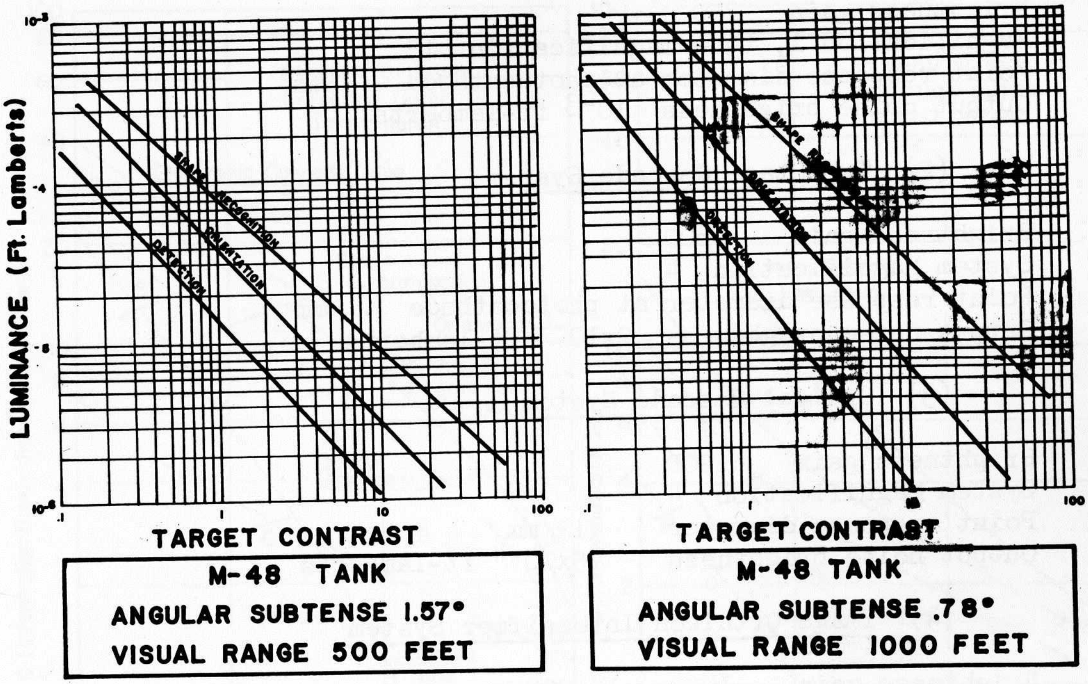


Figure 6

DETECTION & SHAPE DISCRIMINATION THRESHOLDS of a MILITARY TARGET

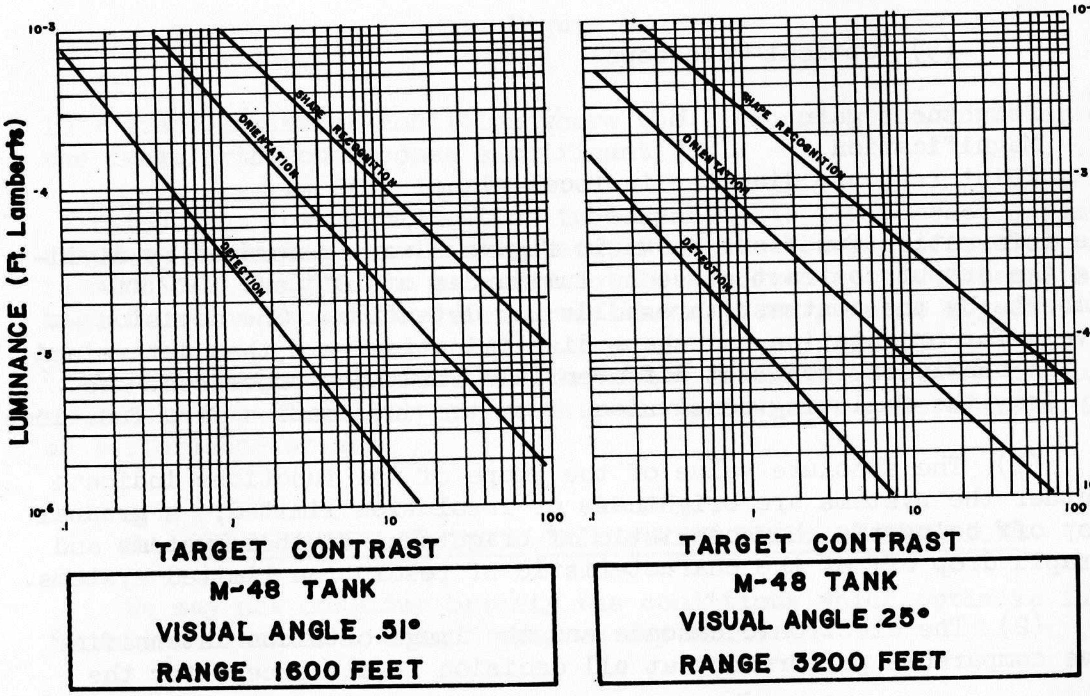


Figure 7

(1) Low Magnification Viewer

Brightness gain 250
Magnification 1, tube magnification .15
Point response diameter at photocathode .35mm
Output noise brightness 10^{-3} ft-lamberts

(2) Two Stage Cascade System

Brightness gain 600
System Magnification 4
Point response diameter at photocathode .14mm
Output noise brightness 2×10^{-4} ft-lamberts

(3) Optical Cascade System

Brightness gain 200
System Magnification 4
Point response diameter .12 mm
Output noise brightness $.5 \times 10^{-4}$ ft-lamberts

(4) Image Orthicon Intensifier System

Brightness gain 1000 - 10,000
Magnification 3
Point response diameter .6 mm
Noise equivalent input 4×10^{-7} ft-lamberts
Storage time 1 second

(5) Optical Telescope

Brightness gain .8
Magnification 15
Point response diameter in focal plane .05 mm

The information functions shown in figure 8 were generated by dividing the output contrast at scene luminances of 10^{-4} and 10^{-5} ft-lamberts by the contrast thresholds for detection. The decision levels for orientation and shape discrimination were then determined by the non-linear contrast differentials for these processes. We may draw the following conclusions from the information flow functions:

(1) The absolute value of the slope of the functions indicate whether the systems are brightness or resolution limited; a gradual drop off being the characteristic of brightness limited systems and a rapid drop off of the characteristic of resolution limited systems.

(2) The electronic cascade and the image orthicon intensifier have comparable performance at all decision levels except for the

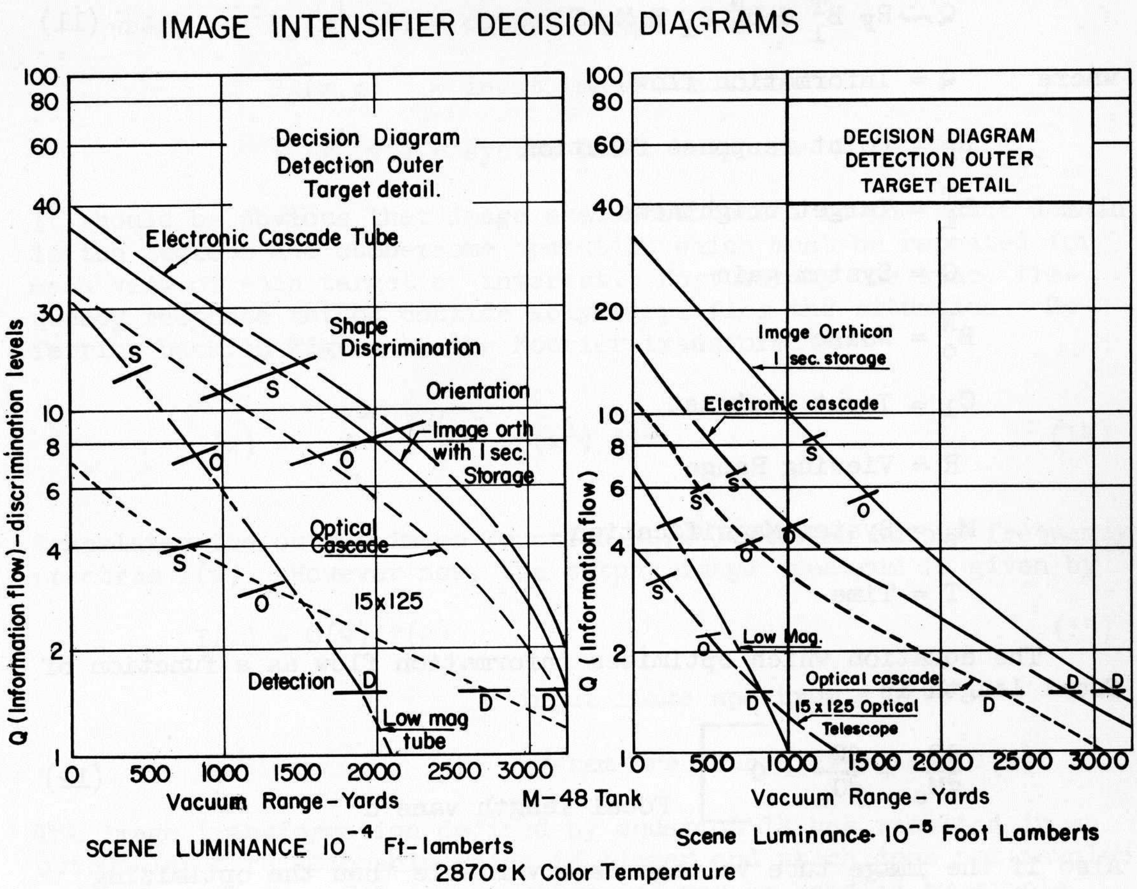


Figure 8

10^{-5} scene luminance condition where the 1 second storage factor of the image orthicon becomes significant.

(3) The low magnification tube system has the poorest decision response performance primarily because of its low magnification and resolution. Brightness gain may not be achieved at the expense of magnification except for the surveillance of very large objects.

It is rather obvious that the image intensifier system is an extremely non-linear device which permits few wide generalizations on performance or use.

G. OPTIMIZATION OF IMAGE INTENSIFIER RESPONSE FUNCTIONS

We may now consider briefly the conditions which optimize information transfer. Out of hand we may write

$$Q \sim R_F\, B_1^T\, G\, B_o^N\, C_1\, R\, M_s\, T \tag{11}$$

where Q = Information flow

R_F = Point response function

B_1^T = Target brightness

G = System gain

B_o^N = Noise

C_1 = Input contrast

R = Viewing Range

M_s = System Magnification

T = Time

The equation which optimizes information flow as a function of focal length is

$$\left.\frac{\partial Q}{\partial M_s} + \frac{\partial Q}{\partial G_s} = 0 \right] \text{ Focal length vane d} \tag{12}$$

Also if the image tube voltage is a variable then the optimizing condition is

$$\left.\frac{\partial Q}{\partial G} + \frac{\partial Q}{\partial B_o^N} = 0 \right] \text{ Voltage variable} \tag{13}$$

It should be obvious that a large number of optimizing conditions exist and these cannot all apply simultaneously over a large domain. Only over a restricted region of interest made the performance of an intensifier device be optimized. A device intended for use under starlight illumination levels would not be very effective under daylight conditions.

H. IMAGE ANALYSIS IN THE SPACE FREQUENCY DOMAIN

In the space domain image analysis and evaluation is based on the output-input relationship indicated by

$$B_o(x^1,y^1) = \int\int_{-\infty}^{+\infty} B\ (x,y)\ f\ (x^1-x,\ y^1-y)\ dx\ dy$$

where $B_o(x^1,y^1)$ = output image function

$B_o(x,y)$ = input image function

$f\ (x^1,y^1)$ = system point response

It should be obvious that image evaluation based in the space domain is the tedious and cumbersome operation which must be repeated for each view of each target of interest. Fortunately the space frequency response method considerably simplifies the situation. Referring back to Figure 4, the Fourier transformation

$$I(w) = \int_{\infty}^{+\infty} e^{-Jw(x)}\ B_o(x^1)\ dx^1 \qquad (14)$$

translates the output image function $B_o(x^1)$ into an output frequency spectrum $I(w)$. However now, the output image spectrum is given by

$$I(w) = O(w)\ f(w) \qquad (15)$$

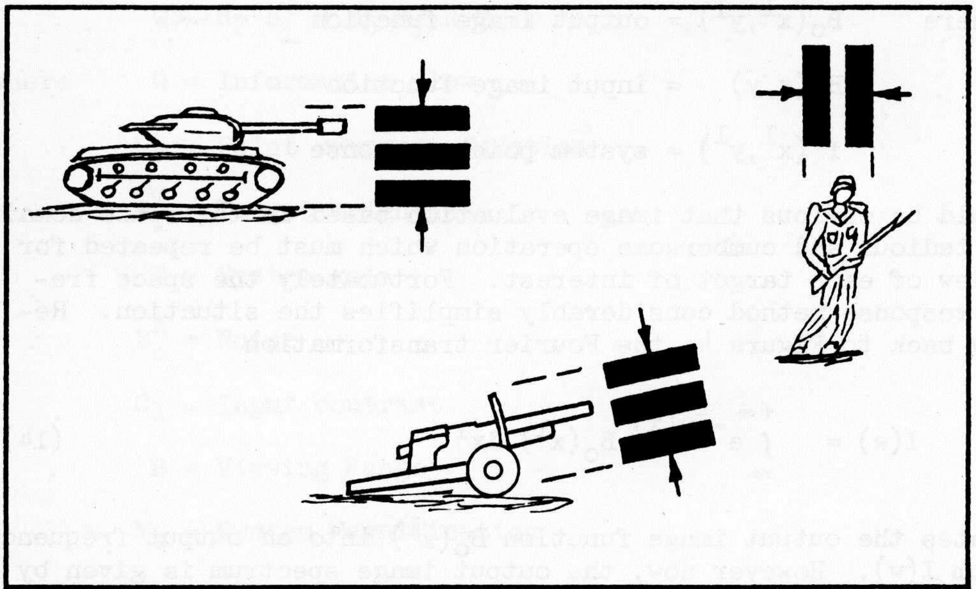
input image spectrum = $O(w)$

system frequency response = $f(w)$

The image transformation defined by equation 14 has resulted in an output-input relationship which is linear and which does not involve any integrations. Subsequent reimaging may be handled by simple multiplication by the frequency response function of that particular reimaging process. Image analysis in the frequency domain is much simpler than the corresponding operations in the space domain. However in the frequency domain, the image functions are abstract spectra which must be related in some fashion to real target.

(1) OPTICAL IMAGE TRANSFORMATIONS

Intuitively, it would seem that there must be some relationship between the number of lines resolved at the target and the corresponding decisions of detection, recognition and identification. By normalizing the resolved line pairs for a critical target dimension as shown in Figure 9 it was found that minimum resolution required for a particular decision activity was a constant for nine military targets within a maximum error excursion of 25%. The results are shown tabulated in Table I.



Method of Optical Image Transformation

Figure 9

Table I - Optical Image Transformations

TARGET	RESOLUTION PER MINIMUM DIMENSION			
Broadside View	Detection	Orientation	Recognition	Identification
Truck	.90	1.25	4.5	8.0
M-48 Tank	.75	1.2	3.5	7.0
Stalin Tank	.75	1.2	3.3	6.0
Centurion Tank	.75	1.2	3.5	6.0
Half-track	1.0	1.50	4.0	5.0
Jeep	1.2	1.50	4.5	5.5
Command Car	1.2	1.5	4.3	5.5
Soldier (Standing)	1.5	1.8	3.8	8.0
105 Howitzer	1.0	1.5	4.8	6.0
Average	1.0 ± .25	1.4 ± .35	4.0 ± .8	6.4 ± 1.5

These target transformations were found to be independent of contrast and scene signal to noise ratio as long as the contrast in the resolution chart was the same as the contrast in the complex target. These results indicate that complex military targets may be considered equivalent in a visual sense to repetitive resolution patterns of appropriate spatial frequencies for each decision level. The results are general, at least for the limited group considered, and are independent of distance. They simplify considerably the determinations of decision level activity in any imaging system since it is only necessary to determine the angular resolution characteristic as a function of a few parameters.

(2) THRESHOLD RESOLUTION AND SIGNAL TO NOISE RATIO

One of the parameters which is fundamental to the angular resolution characteristic is the signal to noise ratio in the image sample. In Figure 10(a), the signal to noise ratio in the image sample

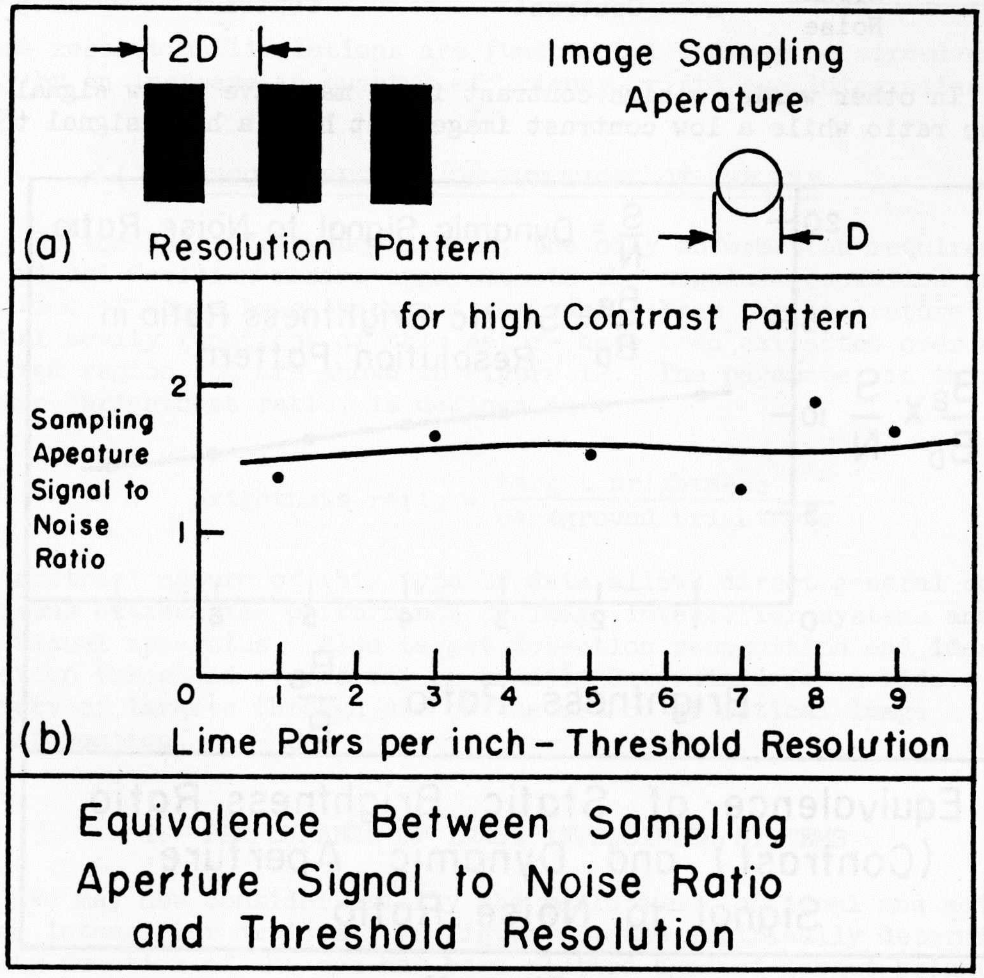


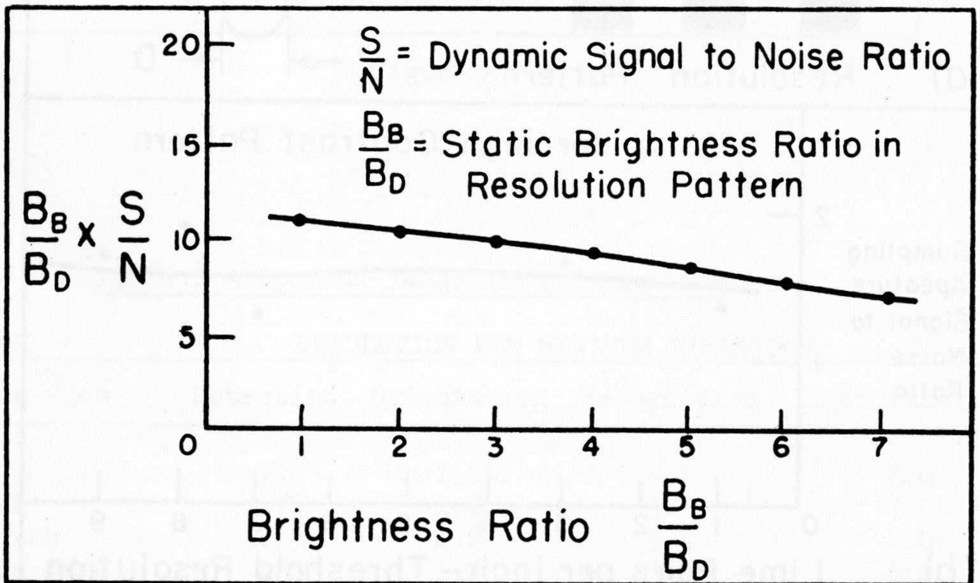
Figure 10

of diameter D may be readily determined from the conventional theory of the statistical fluctuations of quantum samples. The relationship between the signal to noise ratio in the image sample and the corresponding threshold resolution in a frequency pattern is not obvious and must be determined by empirical studies. The empirical relationship shown in Figure 10(b) indicates that for a contrast ratio of seven, a signal to noise ratio in the image sample of about 1.5, is equivalent to a threshold resolution of 1/25 line pairs per unit length.

This result allows the determination of the effect of signal quantum fluctuations on image resolution for this particular contrast value. In order to generalize this result to all contrast values, it is necessary to determine the relationship between signal to noise ratio and contrast ratio. As indicated in figure 11, over a contrast ratio of 1 to 10, it was found that:

$$\frac{\text{Signal}}{\text{Noise}} \times \text{Contrast} \qquad \text{Contrast} \sim 10.5$$

In other words, a high contrast image may have a low signal to noise ratio while a low contrast image must have a high signal to



Equivalence of Static Brightness Ratio (Contrast) and Dynamic Aperture Signal to Noise Ratio

Figure 11

noise ratio for the same threshold resolution condition. In Table II, these results have been used to compute the quantum signal limitations to resolution for a photocathode with an efficiency of 100 microamperes per lumen and a frame time of .2 seconds.

Table II - Quantum Fluctuation Limitations to Resolution

Photocathode Illumination ft - candles	Resolution - line pairs per millimeter, Contrast Ratio 1.3	2.0	5.0	10.0
10^{-3}	60	90	225	450
10^{-4}	18.5	28	69	138
10^{-5}	5.5	8	21	42
10^{-6}	1.6	2.6	6.5	13
10^{-7}	.5	.8	2.1	4.2

These resolution limitations are fundamental and may be circumvented only by an increase in quantum efficiency or storage integration time.

(3) ANGULAR RESOLUTION FUNCTIONS OF THE EYE

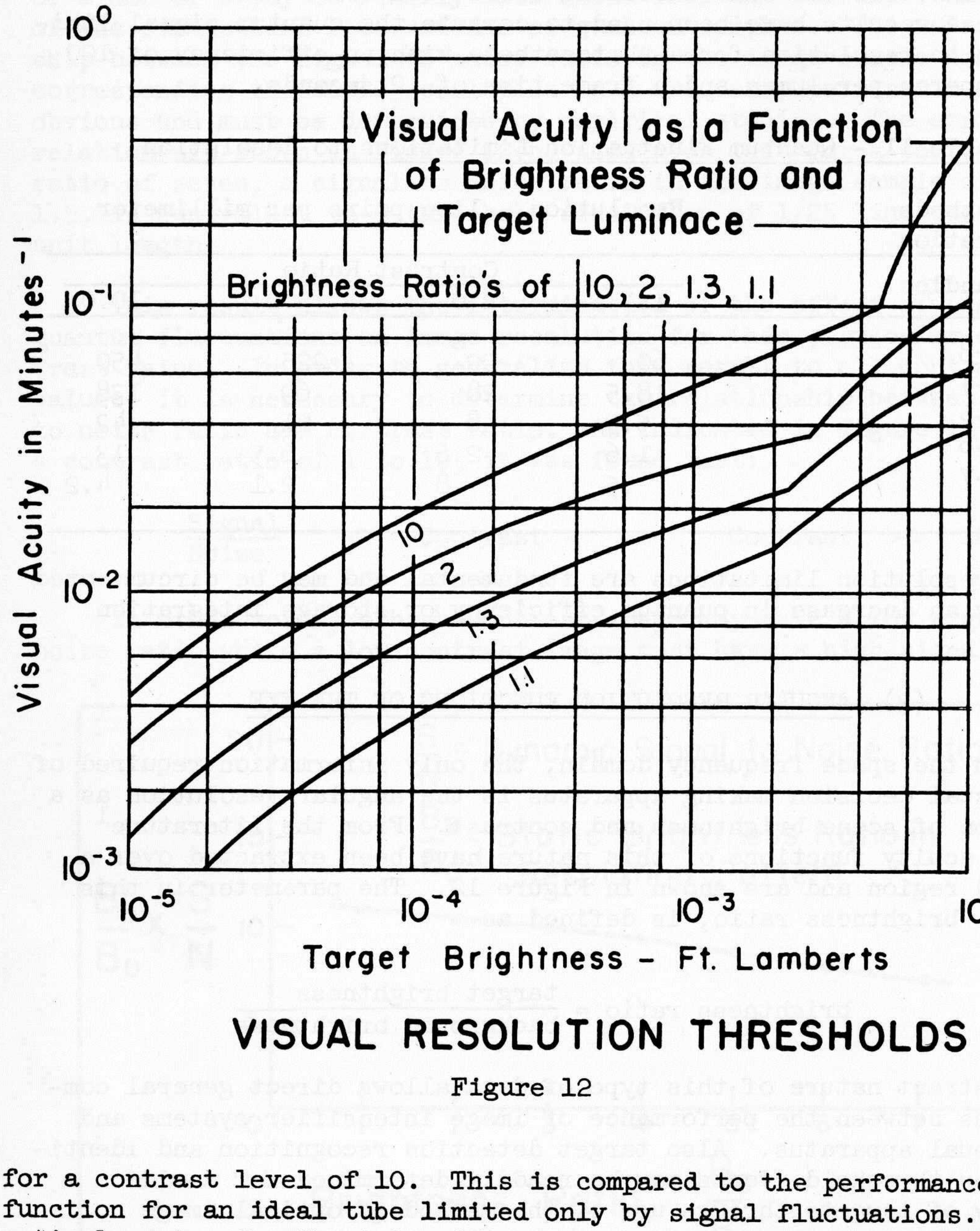
In the space frequency domain, the only information required of the visual decision making apparatus is the angular resolution as a function of scene brightness and contrast. From the literature[1] visual acuity functions of this nature have been extracted over a limited region and are shown in Figure 12. The parameter in this figure, brightness ratio, is defined as

$$\text{brightness ratio} = \frac{\text{target brightness}}{\text{background brightness}}$$

The abstract nature of this type of data allows direct general comparisons between the performance of image intensifier systems and the visual apparatus. Also target detection recognition and identification threshold events may be readily determined for a wide variety of targets through use of the method of optical image transformation.

I. PERFORMANCE OF IMAGE INTENSIFIER SYSTEMS

We may now consider briefly the performance of ideal and actual image intensifier devices. In Figure 13, the empirically determined acuity function of the eye has been plotted against target brightness



VISUAL RESOLUTION THRESHOLDS

Figure 12

for a contrast level of 10. This is compared to the performance function for an ideal tube limited only by signal fluctuations. The optical system for the intensifier is equivalent to the lens characteristic of the dark adapted eye. The illumination on the photocathode is

$$E = \frac{B\ t}{4F^2} \quad \text{ft candles} \qquad (16)$$

where B = scene brightness (ft lamberts)

F = optical aperture ratio = 2.0

t = transmission = .7

By using the threshold data for a contrast of 10 in Table II, the resolution corresponding to various target luminance levels is readily determined. Let this be L_p line pairs per millimeter. Since the focal length is 16 mm, the angular resolution corresponding to this threshold is:

$$R_p = \frac{L_p \times 16}{3450} \quad (\text{minutes}^{-1}) \qquad (17)$$

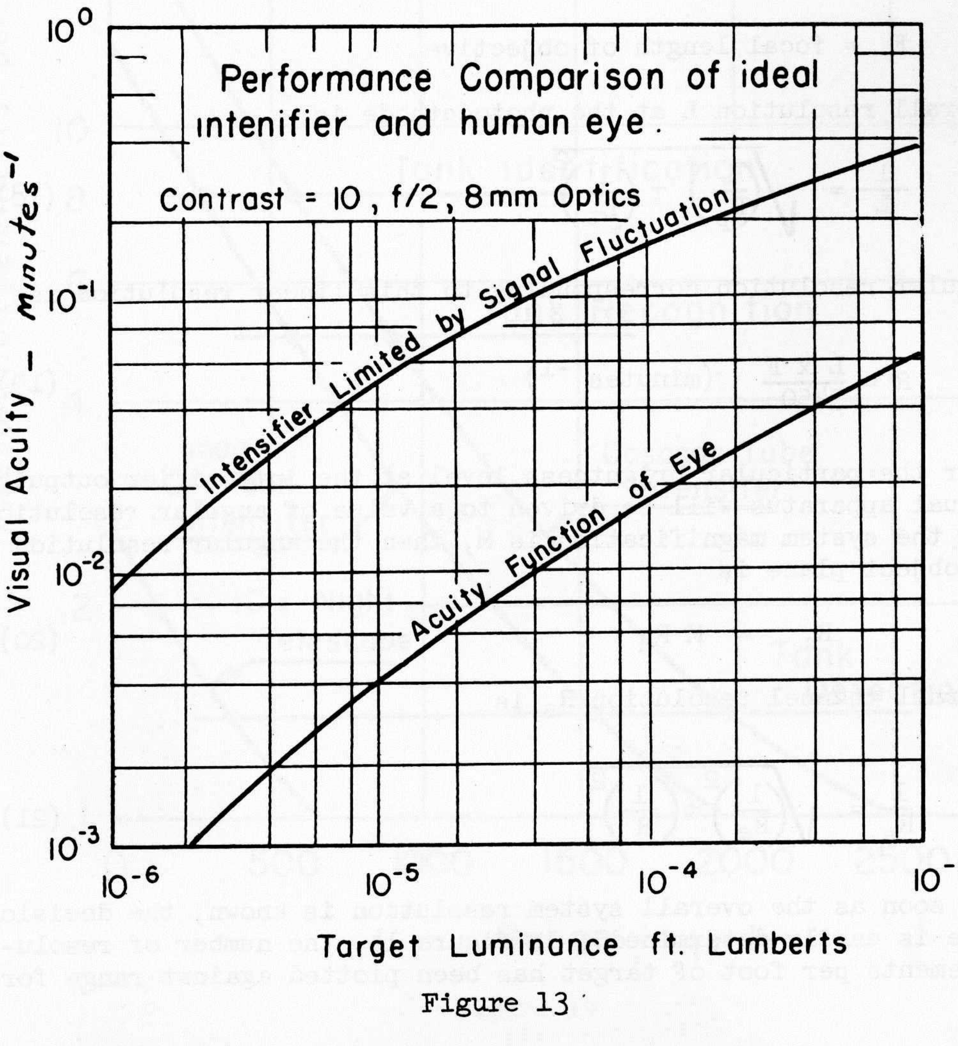


Figure 13

The ideal performance of the intensifier exceeds the performance of the unaided eye by a factor of 10 over a wide range of target luminance. Actually the difference is even greater since the information leaving the intensifier may be used almost immediately irrespective of signal level. The unaided eye requires considerable time for adaptation and interpretation.

The field performance of non-ideal intensifiers may be determined in similar fashion but with several important differences. In the non-ideal case, the device may be limited both by technological deficiencies such as poor high light resolution and by low visual resolution caused by inadequate brightness gain in the intensifier. Let

L_p = signal fluctuation resolution threshold

L_t = high light threshold resolution of tube

F = focal length of objective

The overall resolution L at the photocathode is

$$\frac{1}{L} = \sqrt{\left(\frac{1}{L_p}\right)^2 + \left(\frac{1}{L_t}\right)^2} \qquad (18)$$

The angular resolution corresponding to this linear resolution is

$$R = \frac{L \times F}{3450} \quad (\text{minutes}^{-1}) \qquad (19)$$

For the particular brightness level at the intensifier output, the visual apparatus will be driven to a value of angular resolution R_e. If the system magnification is M, then the angular resolution R_a in the object plane is

$$R_a = M R_e \qquad (20)$$

The overall channel resolution R_s is

$$\frac{1}{R_s} = \sqrt{\left(\frac{1}{R_a}\right)^2 + \left(\frac{1}{R}\right)^2} \qquad (21)$$

As soon as the overall system resolution is known, the decision response is easily determined. In figure 14, the number of resolution elements per foot of target has been plotted against range for

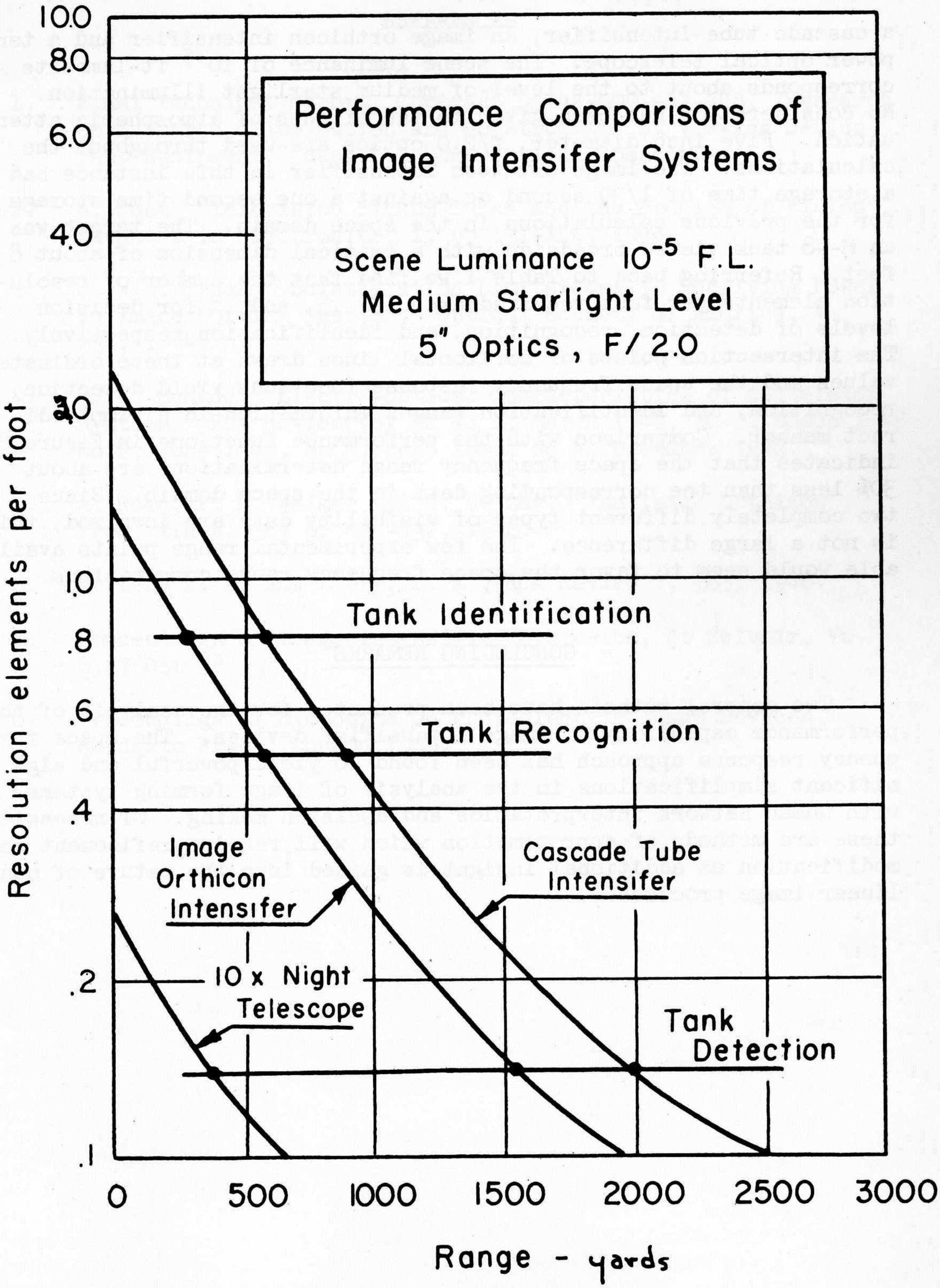

Performance Comparisons of
Image Intensifer Systems
Scene Luminance 10^-5 F.L.
Medium Starlight Level
5" Optics , F/2.0
Tank Identification
Tank Recognition
Tank Detection
Image Orthicon Intensifer
Cascade Tube Intensifer
10 x Night Telescope
Resolution elements per foot
Range - yards
10.0
8.0
6.0
4.0
3.0
1.0
.8
.6
.4
.2
.1
0
500
1000
1500
2000
2500
3000

Figure 14

a cascade tube intensifier, an image orthicon intensifier and a ten power optical telescope. The scene luminance of 10^{-5} ft-lamberts corresponds about to the level of medium starlight illumination. No consideration has been given to the effects of atmospheric attenuation. Five inch diameter, f/2.0 optics are used throughout the calculations. The image orthicon intensifier in this instance had a storage time of 1/30 second as against a one second time storage for the previous calculations in the space domain. The target was an M-48 tank viewed broadside with a critical dimension of about 8 feet. Referring back to Table I we find that the number of resolution elements per foot required are .15, .5, and .8 for decision levels of detection, recognition, and identification respectively. The intersection points of horizontal lines drawn at these ordinate values and the space frequency response functions yield detection, recognition, and identification ranges information in a simple direct manner. Comparison with the performance functions in Figure 8 indicates that the space frequency range determinations are about 30% less than the corresponding data in the space domain. Since two completely different types of visibility data are involved, this is not a large difference. The few experimental range points available would seem to favor the space frequency range computations.

CONCLUDING REMARKS

Two general methods have been presented for the analysis of the performance capability of image intensifier devices. The space frequency response approach has been found to yield powerful and significant simplifications in the analysis of image forming systems with human network interpretation and decision making. Of necessity, these are methods of approximation which will require refinement and modification as additional insight is gained into the nature of nonlinear image processes.

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