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AIR FORCE APPROACHES TO NIGHT GATED PHOTOGRAPHY

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Systems Research Laboratories

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Performance of present non-gated active night photographic systems is severely constrained by the effects of atmospheric backscatter. The use of a gated image intensifier camera in conjunction with a pulsed illuminator to eliminate backscattered energy offers significant potential for improvement over non-gated night photographic systems.

This paper presents an analytical approach to the problem and experimental data to verify the analytical approach.

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This technical report has been reviewed and is approved for publication.

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FOREWORD

The information presented in this report is the result of joint research performed by the Air Force Avionics Laboratory (AFAL) and Systems Research Laboratories, Inc. (SRL), 2800 Indian Ripple Rd., Dayton, Ohio 45440. The work was performed under Project 2004, Task 0503. The SRL contract number was F33615-73-C-1135.

Mr. James C. Rachal, Jr. (AFAL/RSP) of the Air Force Avionics Laboratory, Reconnaissance and Surveillance Division, Reconnaissance Sensor Development Branch, was the Air Force Project Engineer. The SRL project engineer was Mr. Ronald N. Hubbard. The electronics were designed by Mr. Herbert Hirsch. Mr. Charles Bond designed and fabricated the experimental apparatus. Technical assistance was also provided by Mr. John Weinhold.

This report was submitted by the authors in May 1974.

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LIST OF ABBREVIATIONS

C	=	Contrast Ratio
Co	=	Contrast Ratio Inherent
Cr	=	Contrast Ratio Received
D	=	Separation Distance Between Sensor and Illuminator (Ft)
Rb	=	Reflectance of Background
Rt	=	Reflectance of Target
r	=	Altitude (Ft)
s	=	Range (Ft)
Ta	=	Transmission of Atmosphere
β'	=	Volume Scattering Coefficient (Ft^{-1})
θ	=	The Illuminator Beam Half-Angle (Radians)
σ	=	Attentuation Coefficient (Ft^{-1})
ϕ	=	Angle Between Axis of Lens and Point of Interest in Scene

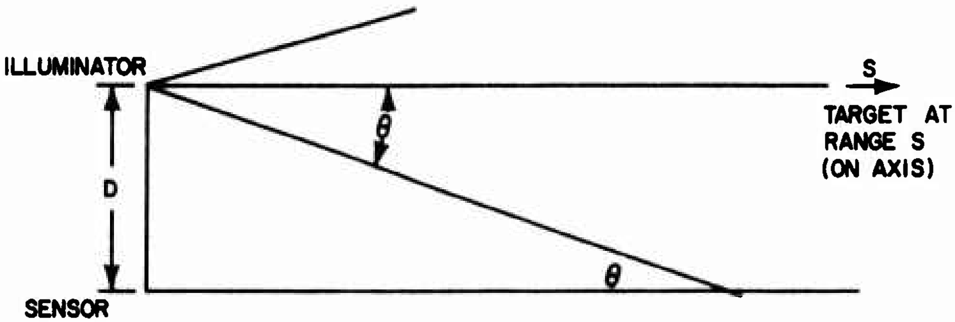
SECTION I
INTRODUCTION: THE PROBLEM OF BACKSCATTER

The need for application of photographic reconnaissance techniques to nighttime operations is apparent. In many situations, troop movements occur primarily at night and weapons installations and equipment may be camouflaged against daylight detection. The weather during daytime hours in many geographic locations makes daytime photographic reconnaissance difficult because of heavy cloud cover.

Night aerial photography presents a number of problems which are more severe than those oridinarily encountered in daylight operations. Since the available natural illumination is generally inadequate for conventional photography, an additional source of illumination must be provided. One approach is to carry an artificial illuminator on board the reconnaissance aircraft. Use of this technique can make implementation of conventional photography at night possible, but introduces some additional problems.

Target contrast is of prime interest in aerial reconnaissance. The scene information is due to brightness differences proportional to reflectance differences between scene elements. If contrast is defined as the brightness ratio of a scene element to its background (which is proportional to the reflectance ratio of the same two elements), then the contrast is a measure of the information.

When an artificial illuminator is used in an atmosphere with significant scattering, a loss in contrast between scene elements is observed at the reconnaissance sensor. The reason for this reduced contrast is that the signal from the target elements is attenuated by the scattering. Additionally, a portion of the scattered radiation is returned to the sensor as noise or backscatter. The backscattered radiation provided an undesired background signal level which reduced the effective contrast that may be obtained. When this background radiance approaches or exceeds the radiance of the illuminated scene, it becomes increasingly difficult to extract useful information (i.e., the contrast falls below a useful level). Since atmospheric scattering effects reduce the apparent scene contrast, this factor limits the operational envelope in which useful information can be obtained using an artificial illumination source onboard the reconnaissance vehicle. Additionally, within the envelope of acceptable results, the quality of the photography varies widely, depending on the atmospheric conditions, the altitude, and even the location of the targets within the format. The reason for this wide variability in results can be seen from an analytical description of an active reconnaissance system. If we assume the following geometrical configuration,



it can be shown that the contrast at the sensor image plane is:

$$C = \frac{\frac{TaRt}{S^2} + \frac{\pi\beta'}{D}\left(\sin\theta - \frac{D}{S}\right)}{\frac{TaRb}{S^2} + \frac{\pi\beta'}{D}\left(\sin\theta - \frac{D}{S}\right)} \tag{1}$$

where

C = Contrast Ratio

S = Range (ft)

β' = The volume scattering coefficient at the illuminator (F^{-1})

D = Separation distance between sensor and illuminator (Ft)

θ = The illuminator beam half-angle with constant angular source intensity (radians)

Ta = Atmospheric transmission

The derivation of this equation is given in AFAL-TR-70-47.

The value for β' as a function of altitude is taken from Figure 1, which was obtained using data in The RCA Electro-Optics Handbook.

It can be seen from this expression that the contrast in the sensor image plane varies as a function of the target and background reflectance, the target range, the volume scattering coefficient, the illuminator beam angle, and the sensor-illuminator separation distance.

The following figures show the dependence of contrast on each parameter for a typical system configuration. The first two parameters are controllable by the system design engineer. If there were no other constraints, the preference would be to minimize the illuminator coverage angle and maximize the illuminator-sensor separation distance. However, aircraft packaging and mission requirements usually demand that the illuminator be packaged with the sensor, and wide angular coverage be provided. The other two parameters, backscatter coefficient and target range, are not controllable by the system designer and, in fact, usually vary during a given reconnaissance mission due to atmospheric variability and altitude changes.

The aforementioned equation computes the contrast between two points in the image plane of the sensor on the axis of the lens. It is easily observed that the backscatter changes across the format of the image plane. The contrast at any point in the image plane may be computed by changing the limits of integration from $D\cot\theta$ & S to $\frac{D\cos\theta}{\sin\theta\cos\phi+\cos\phi\sin\theta}$ & $S/\cos\phi$ where ϕ is the angle between the axis of the lens and the point in question. For simplicity, this is omitted in Equation 1. A graph of the change for one set of parameters is given in Figure 6.

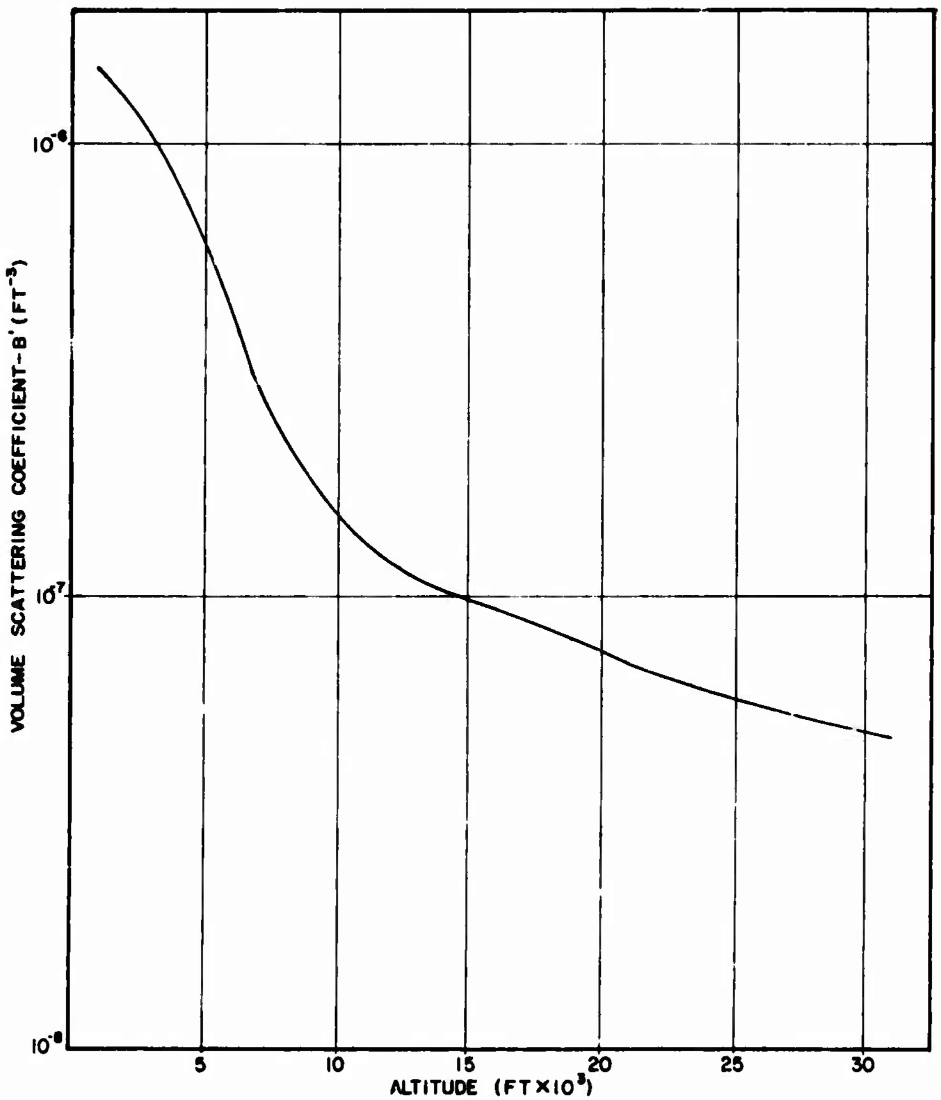


Figure 1. Volume Scattering Coefficient vs. Altitude

As the previous figures show, backscatter limits night photographic reconnaissance due to both the reduction of contrast and also to the large variability in results due to the variation in backscatter. This variability makes optimum system design impossible and result either in overdesign or inadequate performance.

SECTION II
A SOLUTION: GATED PHOTOGRAPHY

The ideal solution to the problem of backscatter is to eliminate the backscatter. With the total elimination of backscatter being almost impossible, there are two feasible alternatives to reduce the majority of the backscatter: (1) design system geometry for minimum backscatter; (2) electronically eliminate the backscatter (gating). The first approach is not likely to completely solve the problem because it requires narrowing the angular coverage, providing wide separation between illuminator and camera, and/or limiting operation to lower altitudes. The second approach (gating) is attractive and has been successfully employed for night vision applications.

Gating to eliminate the backscatter requires a short pulsed illuminator and a camera that can be accurately shuttered in the microsecond time domain. The camera shuttering is achievable with image amplifier tubes incorporating a cut-off electrode. The timing relationships of an ideal gated system are shown in Figure 7 for a target at a 4000 feet range. The transit time for a light pulse for this range is 8 microseconds. Waveform #1 indicates the illuminator output. Waveform #2 shows the backscattered energy seen by the camera which increases to a peak value and then decreases due to illumination fall-off with increasing range. The third and fourth waveforms are identical and show the target reflected energy at the camera and the camera shutter time achieved by electronic pulsing of the image tube electrode to an "on" condition. As can be seen from the figure, the backscatter has decreased to nearly zero by the time the camera is turned on. If the camera were "on" the whole time, it would integrate all the backscatter shown and reduce the observed contrast. Thus, gating can electronically "eliminate" the majority of the backscatter by waiting for it to decrease to a low value before turning on the camera.

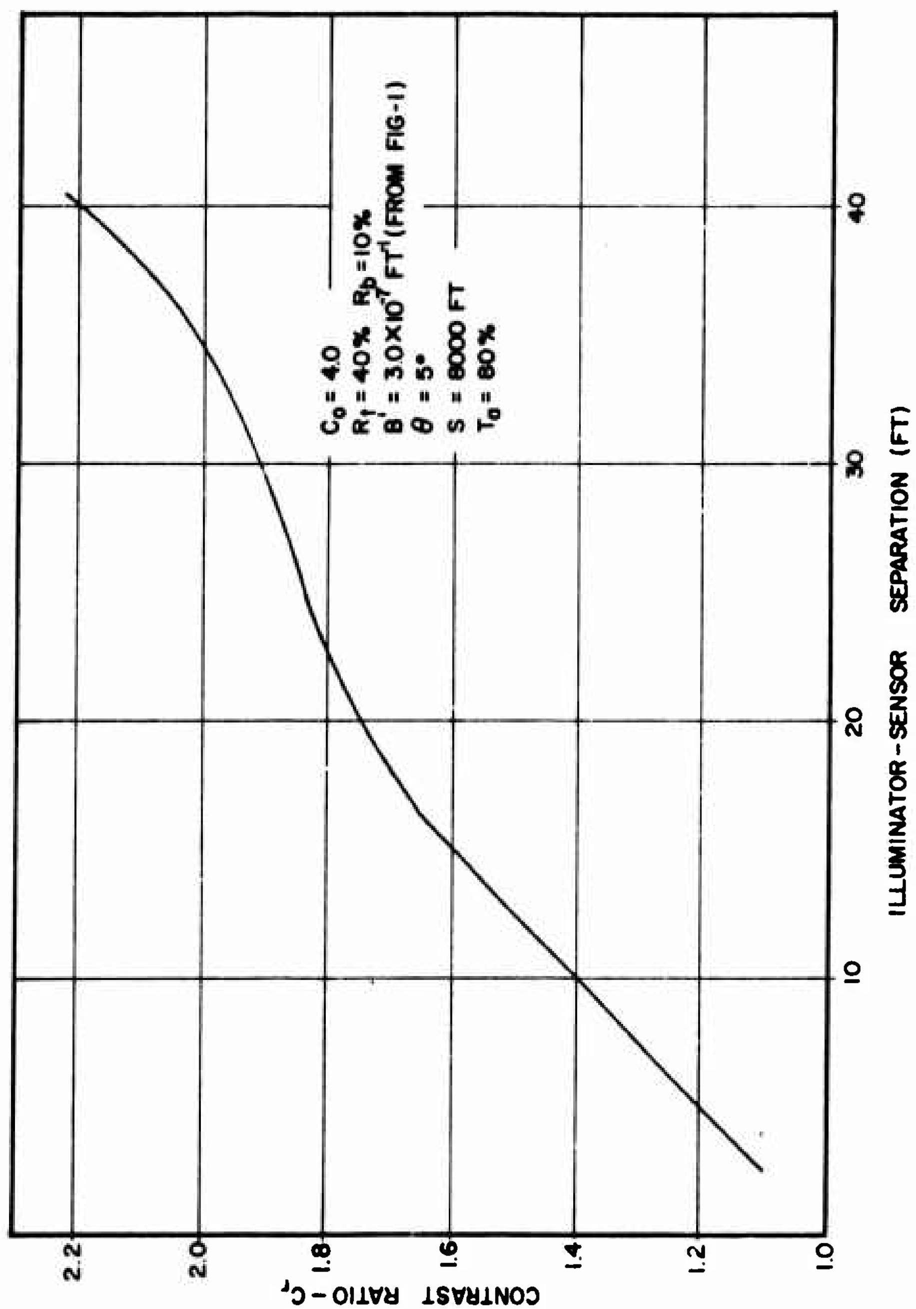


Figure 2. Dependence of Contrast on Illuminator-Sensor Separation

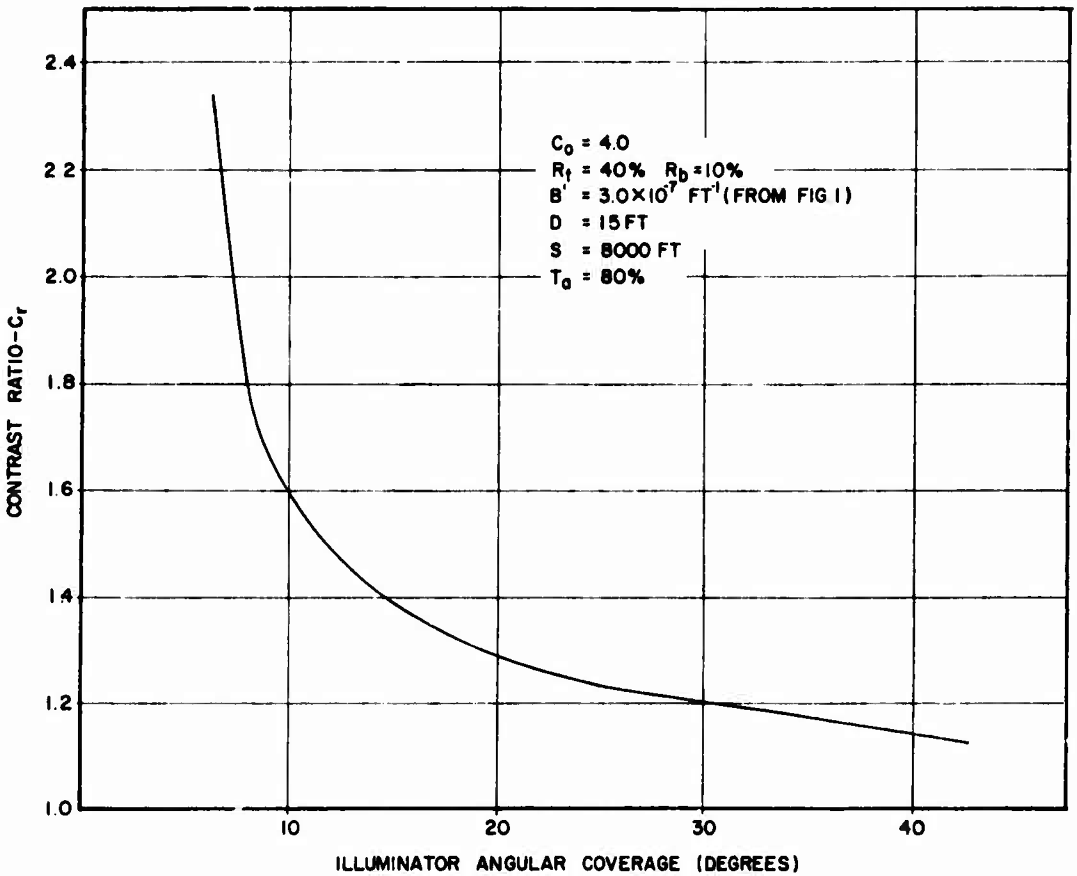


Figure 3. Dependence of Contrast on Illuminator Angular Coverage

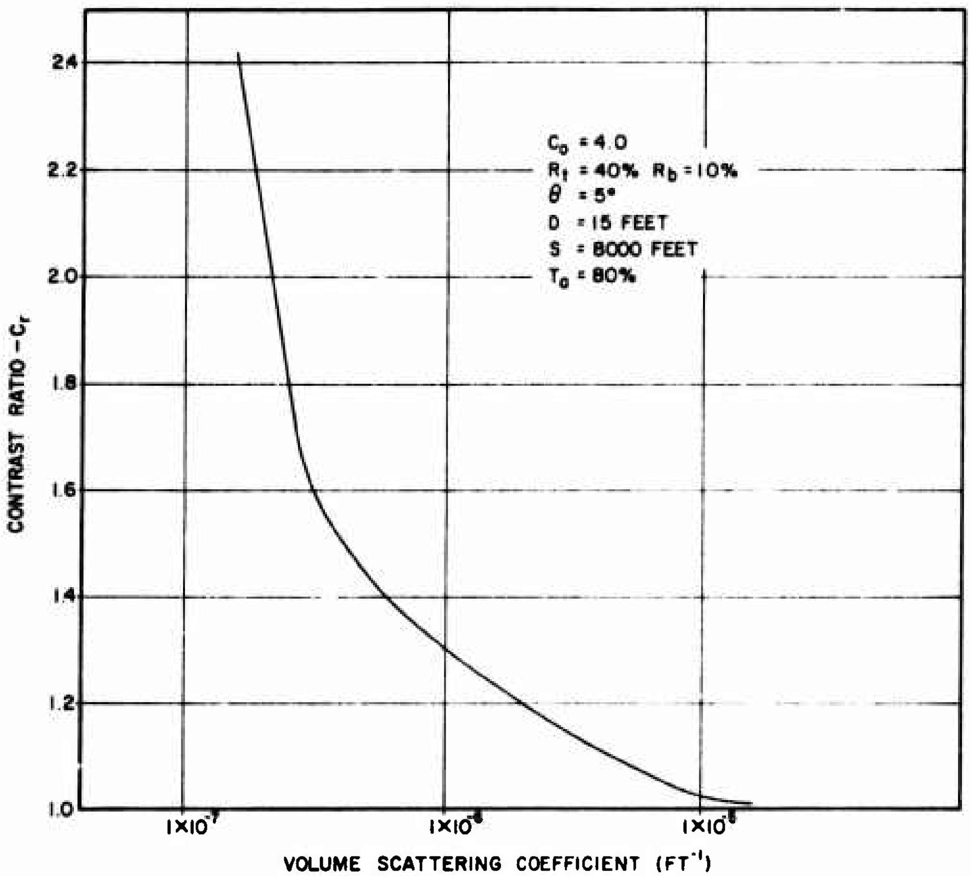


Figure 4 Dependence of Contrast on Volume Scattering Coefficient β'

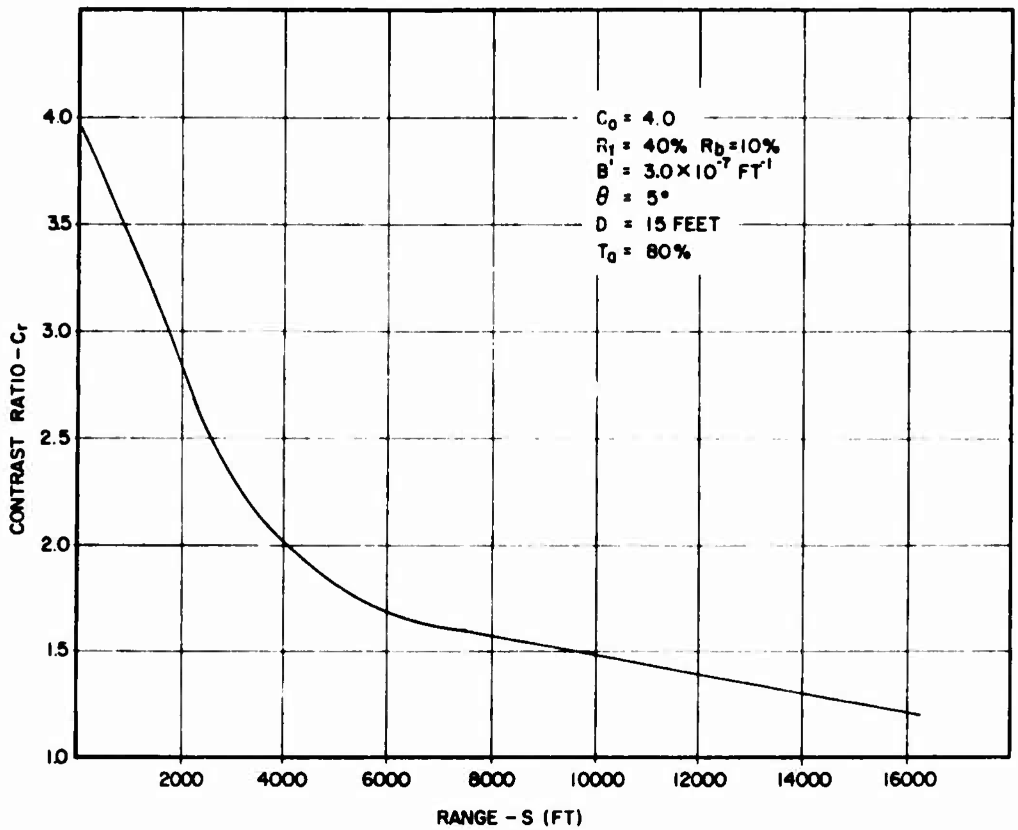


Figure 5. Dependence of Contrast on Target Range

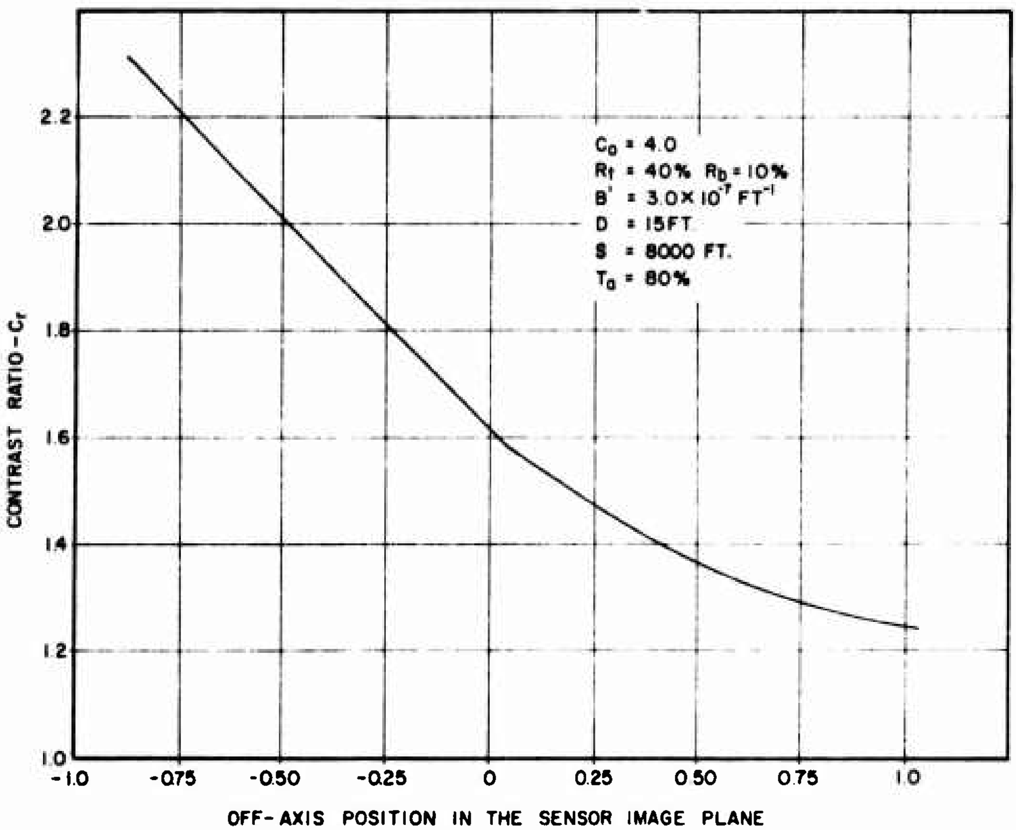


Figure 6. Dependence of Contrast on Format Position

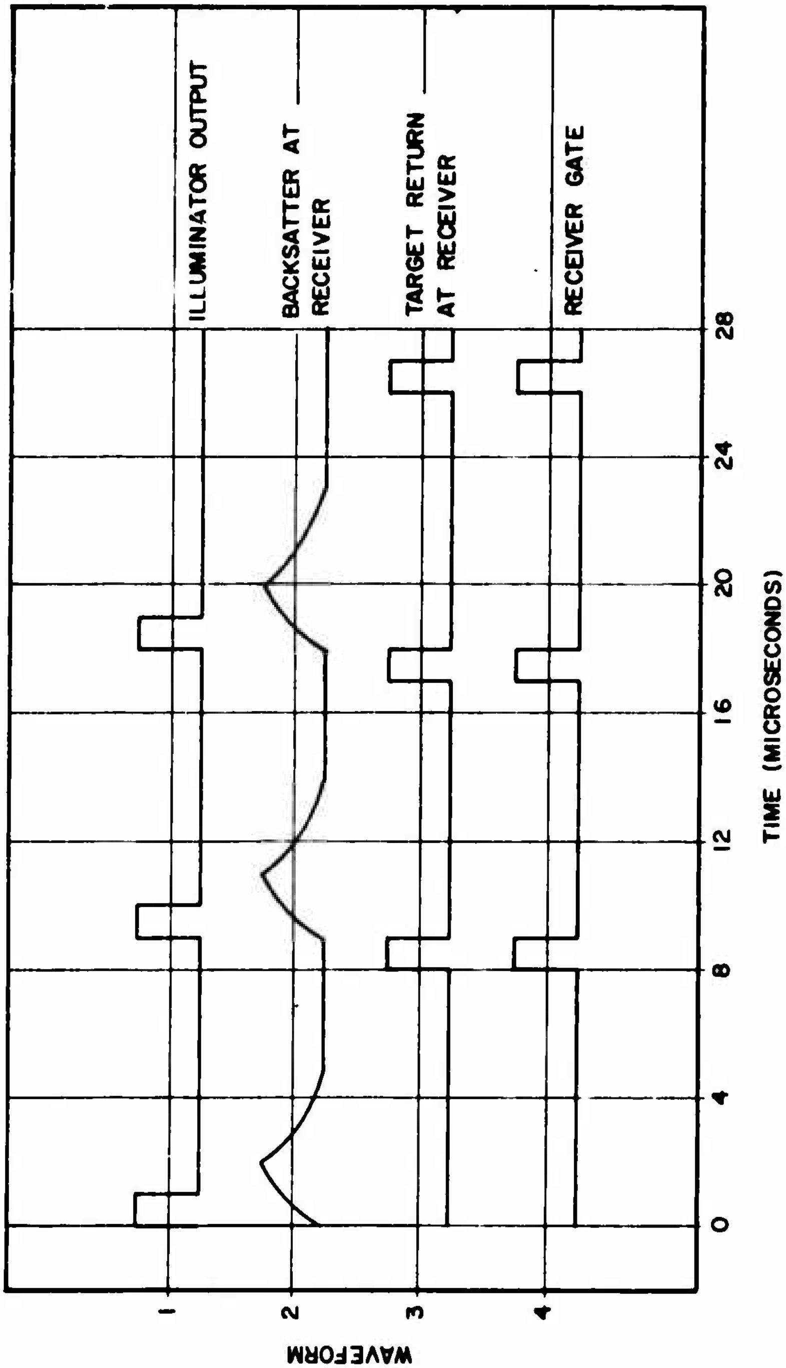


Figure 7. Ideal Gated System for Target Range of 4000 Feet

1. GATED SYSTEMS

a. Night Vision Equipment

Many gated systems composed of a gated image intensifier or TV camera and pulse illuminator are currently in use for night vision applications. However, these systems are unsatisfactory for high quality photographic reconnaissance applications.

The two primary limitations of previously existing tubes designed for night vision applications are the small diameter and the nonuniformity of performance across the diameter. The fact that the resolution and gain decreases by approximately a factor of two from center to edge is not a serious limitation for the night vision application since the operator simply centers anything that he is interested in examining carefully. The photo interpreter, however, does not have this freedom. The photograph must have reasonably consistent performance over the format.

The small diameter (40mm or less for available tubes) means that for a given ground resolution requirement, the instantaneous angular coverage is small. For example, if the system requires 6-inch ground resolution at 10,000 feet altitude and the camera has a 20 lp/mm capability on film, then a 500 mm focal length lens is required. A 40 mm tube would only cover 4-1/2 degrees, which is too narrow for most mission requirements.

Virtually all gated night vision systems use GaAs laser arrays for the illuminator. GaAs lasers are ideal for this application with respect to pulse shape and duration, being capable of submicrosecond pulsewidths with fast rise and fall times. Additionally, it is possible to obtain controlled narrow illumination beam patterns to match the sensor field of view.

The night photographic reconnaissance situation, however, has requirements that cannot be met by GaAs laser arrays without further development. A typical requirement is for approximately 100 joules from 250 (maximum) pulses in 10 milliseconds. The maximum number of pulses is due to the transit time required for a pulse from a range of 20,000 feet (transit time is 40 microseconds). This is equal to a requirement of 0.4 joules per pulse, which would require thousands of GaAs lasers of presently available types. Further development for these requirements would probably result in a practical system, but the feasibility, reliability, and maintainability of such a system has not been demonstrated.

b. Air Force Gated Photographic System

The Air Force is presently procuring equipment to meet the particular requirements of a gated photographic reconnaissance system. The primary developments required were for a large diameter high resolution gated image amplifier tube and a pulsed illuminator. System constraints required development of an illumination source with sufficient energy within the established time envelope and beam configuration.

(1) Large Diameter Gated Tube

A large diameter (162mm aperature) gated electromagnetic tube is being developed by ITT. The present procurement is for a one stage tube, although a second stage could be easily added. This tube combines for the first time into one tube several performance features obtained previously only with separate tubes:

(a) Full coverage of the standard 4-1/2" x 4-1/2" film format.

(b) Uniform high resolution over the format (30 lp/mm on film with 1×10^{-2} erg/cm^2 faceplate irradiant energy in the 700-900 nm spectral band; 50 lp/mm visual resolution with high contrast target).

(c) High efficiency ERMA photocathode with average cathode conversion efficiency greater than 2.7% in the 700-900 nm spectral band.

(d) Gatable with pulses of 10 microseconds or longer with a voltage swing of less than 300 volts.

(2) Gated Illuminator

The Air Force is presently procuring a flyable "breadboard" Gated Light to be flight tested in the Fall of 1974. The flight test will supply a quantitative comparison of gated and non-gated photography for a range of altitudes from 3000 to 30,000 feet. Meterological data will be taken to allow a comparison of actual and predicted performance.

This illuminator utilizes a partial gating technique which is designed to optimize the trade-off between illuminator output energy and pulse length. Only the most intense portion of the backscatter is gated out, which allows the use of a relatively long pulse length and thus a high output energy from the illuminator. The basis for this approach can be seen from Figure 8 showing the relative amount of backscatter contributed by each distance increment. The cumulative backscatter is also shown. It is clear that eliminating the first few thousand feet of backscatter eliminates the majority. For example, the first 1000 feet of atmosphere contributes 80% of the total backscatter.

Figure 9 shows the timing characteristics of a partially gated system for a single pulse from the illuminator. The shaded areas represent the returns seen by the sensor, which includes the target reflected energy and the backscatter from the atmosphere. As shown by the figure, almost all of the backscatter is eliminated even though the illuminator pulse if of relatively long duration.

The breadboard gated illuminator system will consist of three 10° reflectors, each containing two xenon flash lamps with required power supplies and logic circuitry. For a single frame of photography, each pair of lamps in a reflector will be pulsed 30 times simultaneously. Thus, the total frame will consist of 90 pulses integrated for a total exposure time of 0.01 seconds. The light pulses are intended to trigger the delay timer on a gated image tube. The timer will be set to minimize backscatter and still collect nearly 100% of the target reflected energy when operating at 20,000 feet.

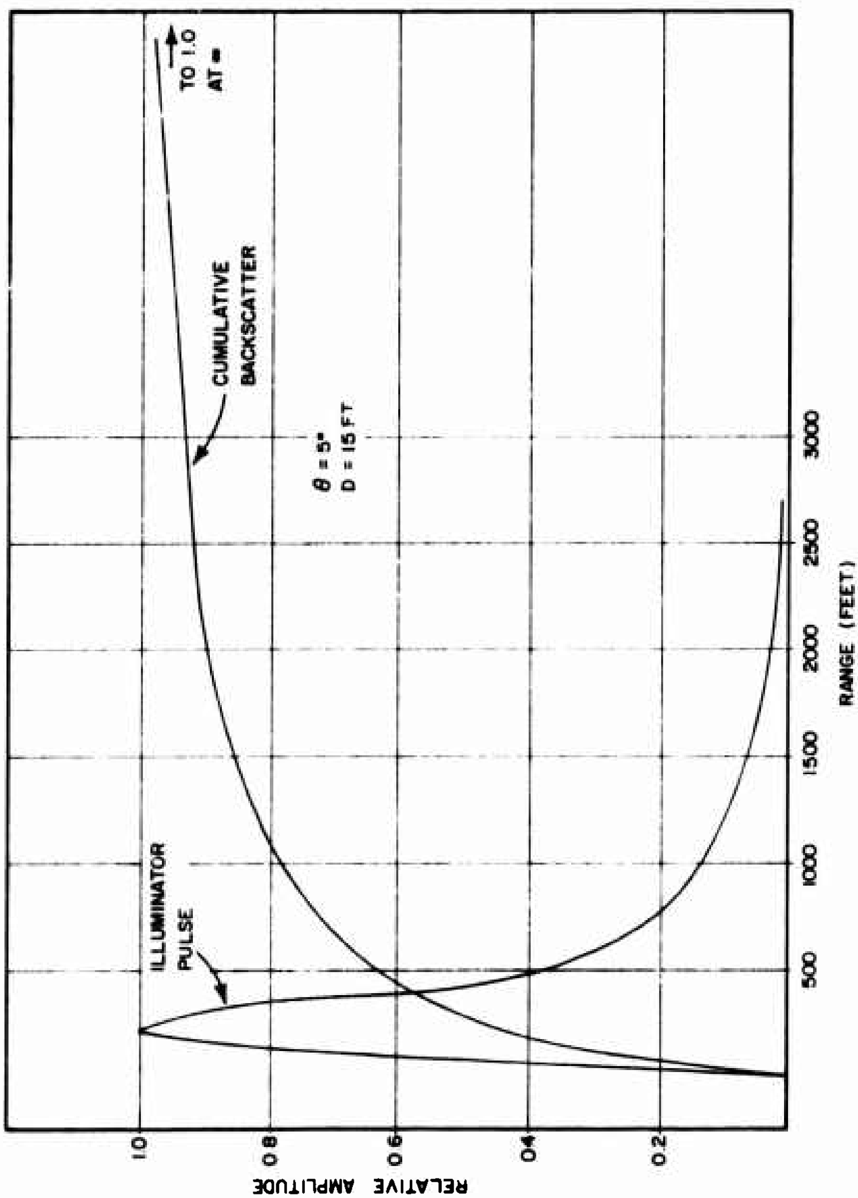


Figure 8. Backscatter as a Function of Distance Below Aircraft

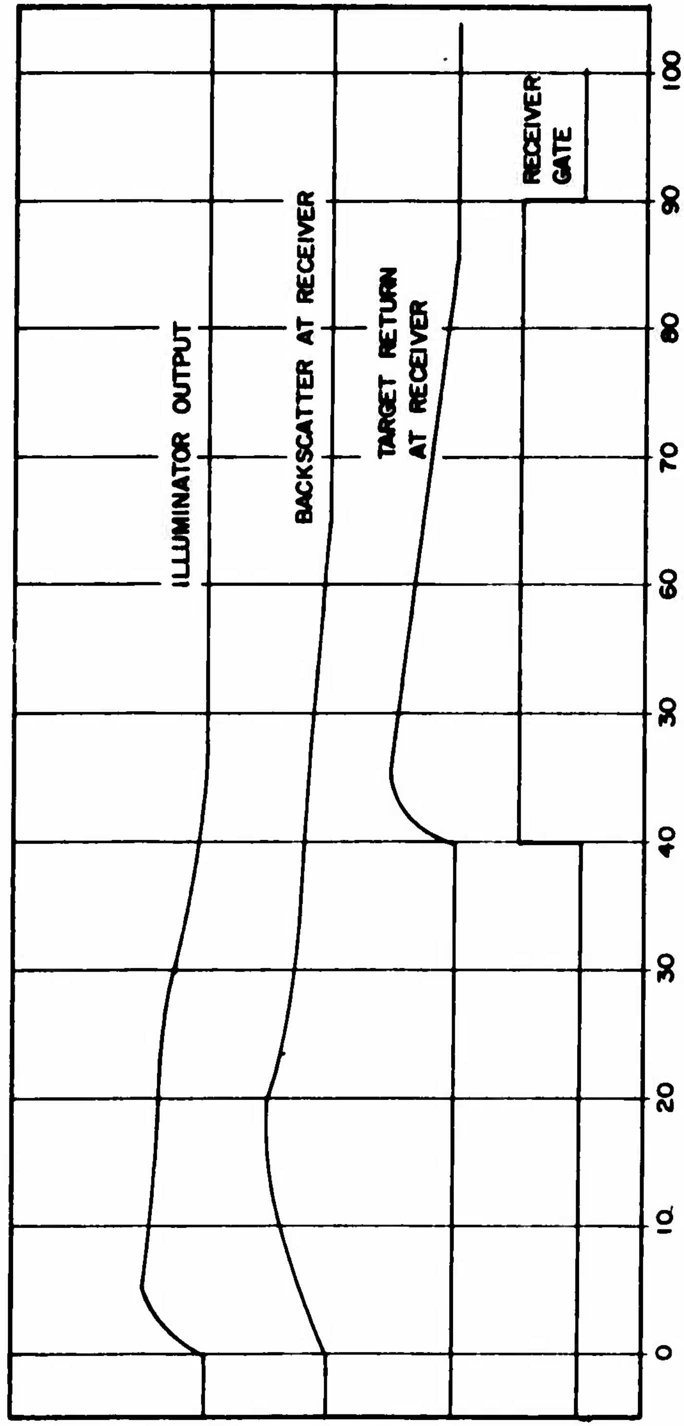


Figure 9. Partially Gated System Timing Relationships for Flashtube Illuminator Range of 20,000 Feet

The light pulse is shown in Figure 10; the intensity is reduced to 20% of the peak by 35 μ seconds. The total lamp electrical and radiant conversion efficiency in the spectrum from 700 nm to 900 nm is 10.2%. This value appears higher than would have been expected. A partial explanation appears in Figure 11, which shows that the first light pulse has an output of approximately 0.75 joules; and after that, each succeeding pulse has an output of approximately 1.2 joules. The increase in output is theorized to be caused by the heating of the lamp with the first pulse. The input energy into each lamp is 12 joules per pulse, which is approximately 15% of the explosion energy. Exceeding values of 10%-20% of the classical explosion energy predictions tends to be associated with catastrophic failure.

The total integrated energy thus becomes:

(30 pulses/lamp) (6 lamps) (12 joules/pulse/lamp)
(0.102 conversion) = 220.32 joules

Using a 55% collection efficiency into a 10° beam reflector yields 121.2 joules on the ground in a 10° circular pattern.

If the illuminator were to be used in a system with an f/2.0 lens flying at 20,000 feet, the energy in the image plane would be 5.5×10^{-4} erg/cm^2. This energy level, incorporated with a two stage image tube, should yield a resolution on film on the order of 20 lp/mm.

A successful completion of the image tube and gated light source will make a gatable system for night photography available within current manufacturing capability.

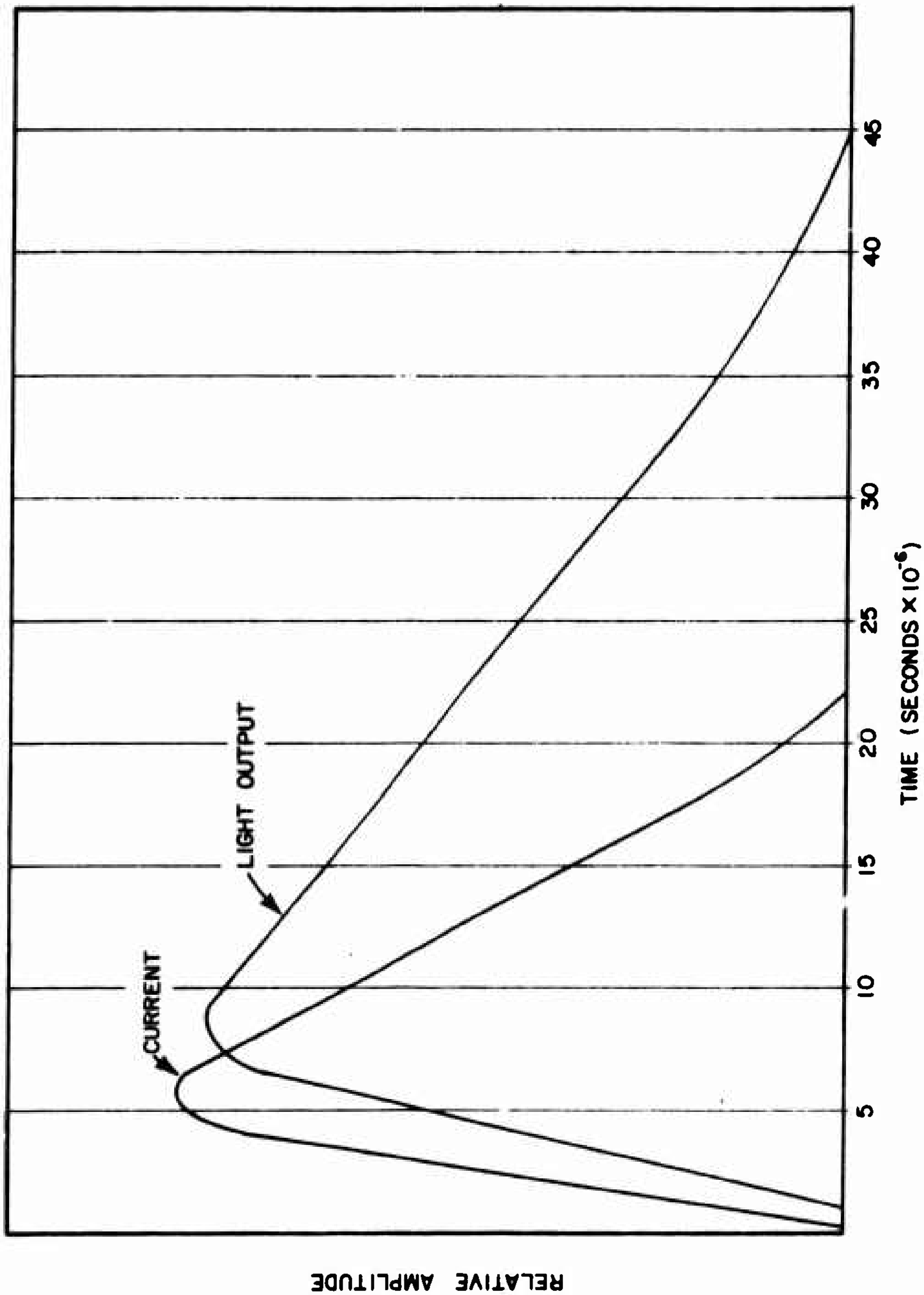


Figure 10. Single Pulse Shape for CAI Gated Illuminator

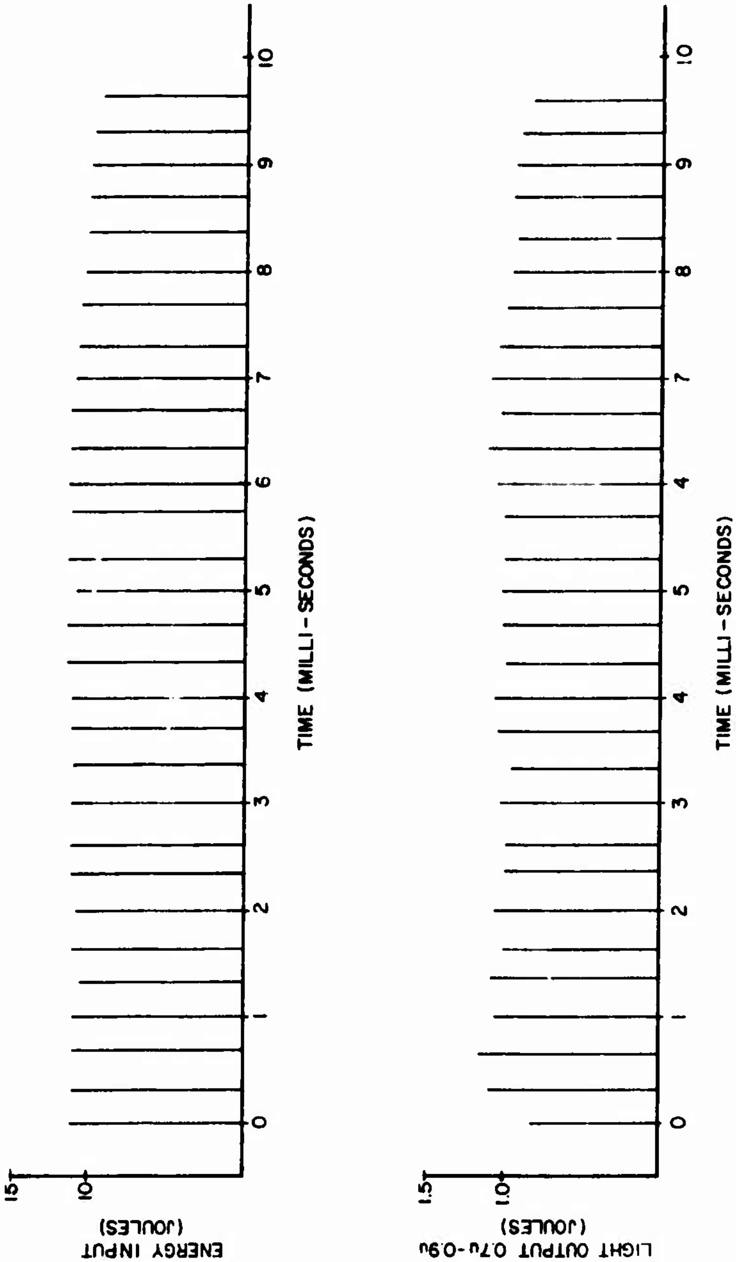


Figure 11. Gated Illuminator Pulse Burst Characteristics

SECTION III
GATED PHOTOGRAPHY EXPERIMENTS

Ground experiments were conducted to compare the results obtained with partially gated and non-gated photography. The experiments were designed solely to show the degree of improvement that could be obtained with partial gating for a given amount of backscatter. The results should not be used as a measure of the absolute scattering that would be obtained from an optimized non-gated airborne system.

The experiments consisted of utilizing a laboratory breadboard pulsed xenon illuminator in conjunction with a breadboard gated image amplifier camera to obtain photographs of contrast and resolution targets at a range of 4250 feet. The conditions were varied to provide data on the effects of illuminator-sensor separation. Three separations of 3, 6, and 9 feet were used. The delay between illuminator pulse and camera gate and the camera "on" time were both varied to test the ability to predict the results for varying degrees of partial gating.

Controlled photographic sensitometry allowed quantitative measurements to be made of the input contrast to the film for the various experimental conditions.

1. EXPERIMENTAL APPARATUS

a. Gated Image Amplifier Camera

The camera was specially fabricated for these experiments. The lens employed was a 410 mm T/2.0 Zenith catadioptric lens. The field coverage was listed by the manufacturer as 40 mm.

The image tube employed was a two-stage 40 mm electrostatic tube. The first stage was an ITT F4081 gated tube with P20 output phosphor. The second stage was a Varo 40 mm diode with P-11 output phosphor. The tubes were joined with optical cement and potted in a Plexiglas housing. Since the tube was operated with the anode (output phosphor) at ground, an insulating glass plate was cemented to the cathode (input) fiber optic plate to prevent arcing. This insulating plate had transparent conductive coatings on both sides. The outside coating was grounded and the inside coating was connected to cathode potential (-25kV) to eliminate the possibility of arcing through the input fiber optic plate.

The gain and resolution of the two-stage module was measured with the insulating glass plate in place. The axial limiting resolution was 35 lp/mm operating at a pulsewidth of 10 μ sec and a 1000 Hz repetition rate. The radiant power gain at 850 nm was measured to be 350 watt/watt at 12.5 kV per stage. The cathode sensitivity was measured to be 12.20 ma/watt at 850 nm and 220 μa/lumen at 2854° (with the insulating glass plate).

A Graflex 70 mm roll film back was modified to place the film in direct contact with the output fiber optic plate with mild pressure.

The lens, tube assembly, and film back were packaged into camera form using a Plexiglas housing.

b. Film

The film used in these experiments was Eastman Kodak Type 3400 Panatomic-X Aerographic. The film was processed in D-19 at 68°F on Nikor reels which resulted in a gamma of 2.50.

c. Electronics

The power supply used for the dc high voltage was manufactured by Walden Electronics, Model CRN 20/20. This supply has two series outputs of 0 to -20 kV each. The regulation and ripple are both less than 0.01%.

Exposure control was obtained by varying the number of pulses from the illuminator integrated by the camera. A preset counter was designed and fabricated to allow predetermining the number of desired pulses from 1 to 1000 pulses. The preset counter included an oscillator operating at 100 Hz which was used to trigger both the illuminator and the gate generator.

The gate generator power supply was a Venus Scientific RS-03FL. This supply was triggered externally at a 100 Hz rate. A focus voltage of approximately +220 volts was used, with a cut-off voltage of -1500 volts with respect to the cathode voltage (-25 kV). Pulse-widths between 3 and 12 μsec were used with delays ranging from 0 to 9 μsec.

A standard oscilloscope was used to monitor the pulse timing and to adjust the pulsewidth and delay to the desired values.

d. Illuminator

The illuminator employed for the experiments consisted of a Xenon Corp. Novatron 725 xenon flashtube, a Model 457 micropulser (power supply) and a 22-inch diameter, 7-inch focal length spherical metal reflector. The micropulser provides 5 joule input energy per pulse to the flashtube and was operated at a 100 Hz rate. The flashtube has a linear arc of 2-inch length and with the reflector employed produced a beam of 9 degree angular width at the 1/2 peak-power points across the horizontal dimension.

Since the source was not inside a deep reflector, the near-field illumination pattern approximates a bare-bulb source. Thus, a larger amount of backscatter was obtained from this illuminator than would be obtained from a deep relfector illuminator of the same far-field angular intensity distribution.

The normalized pulse duration distribution is shown in Figure 12. The integrated energy curve shows that 0.80 of total energy in the pulse is obtained during the time interval $0.5 \leq t \leq 3.5$ μsec. This is the portion of the pulse used for the gated photographs.

e. Target Materials

Two 10 ft by 10 ft cloth targets were hung on a 20 ft long truck at a range of 4250 ft. One was a 0.60 reflectance white cotton cloth; the other was a 0.10 reflectance gray denim material. The contrast ratio between these materials was approximately 6:1 throughout

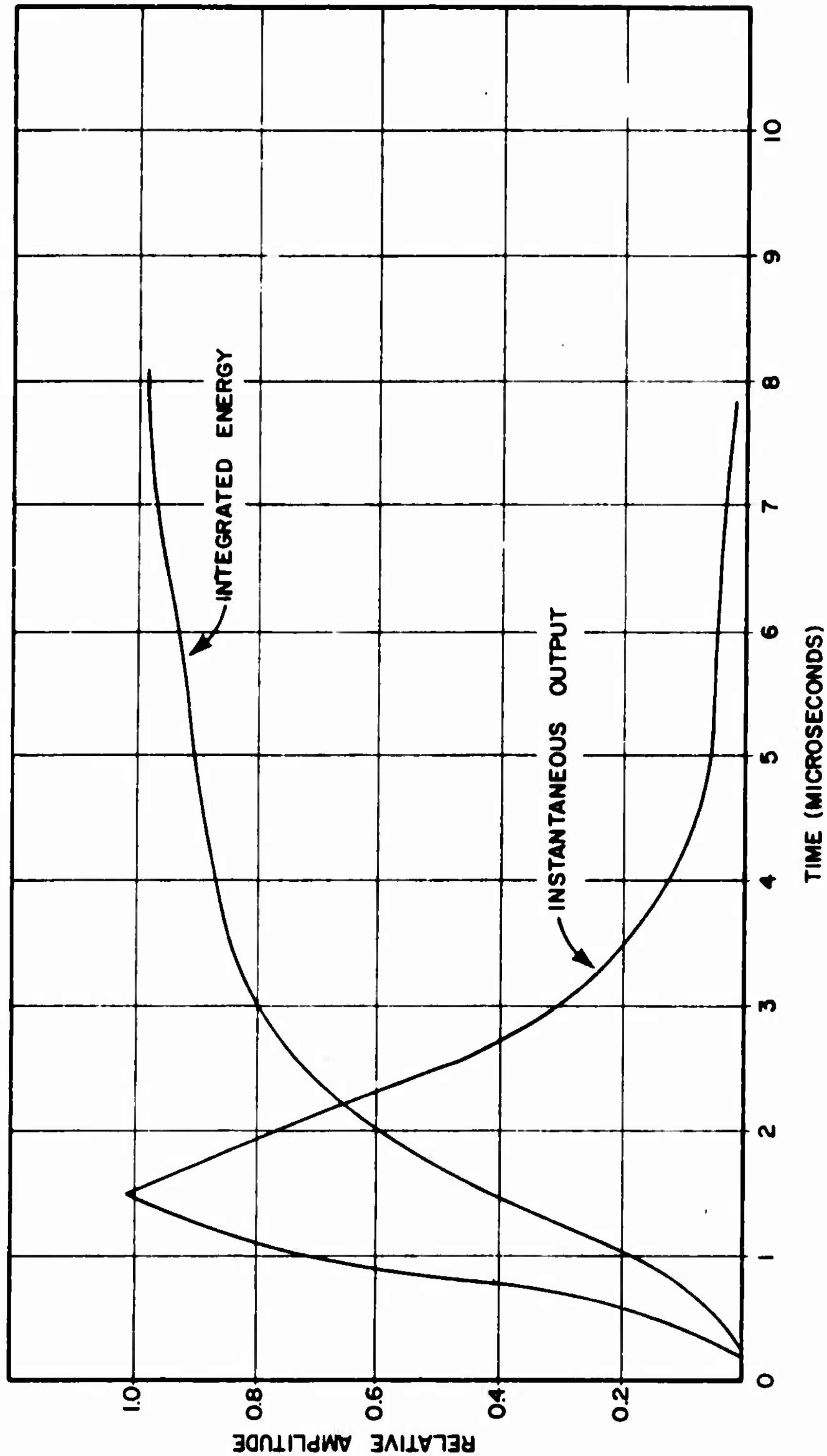


Figure 12. Xenon Corporation Novatron 725 Gated Lamp Characteristics

the visible and near infrared spectral region. The targets enabled density measurements to be made on the photographs to obtain a quantitative measure of the contrast obtained with various experimental conditions.

f. Densitometric equipment

A Macbeth TD-100 diffuse transmission densitometer was used to read the step tablets processed with each roll of film to establish the sensitometric properties.

The film image densities corresponding to the reflectance targets were measured using a Gamma Scientific microphotometric eyepiece on a standard microscope. The eyepiece sampling aperture was 0.450 mm and the microscope objective used was 3X magnification, resulting in a 0.150 mm sampling aperature. The target images were approximately 1 mm square. The transmitted light from the eyepiece was measured with a photomultiplier by means of a fiber optic coupler. A digital voltmeter was used to measure the photomultiplier signal. The whole system was calibrated using the step tablets calibrated by the Macbeth densitometer.

2. EXPERIMENTAL RESULTS

The photographs obtained show clearly the value of gating for conditions of high backscatter. Figures 13 and 14 show two photographs obtained with identical geometry with only the gating conditions varied. The photographs in Figure 13 is gated as efficiently as possible within the limitations of the illuminator pulse waveform. This was obtained with a delay of 9 μsec and an "ON" time of 3 μsec.

The photograph in Figure 14 was obtained with no delay and an "ON" time of 12 μsec, which corresponds to a conventional non-gated system. The comparison is dramatic and shows that an effective gated system can be achieved without "square pluses" and also with moderately long ones. The difference in resolution is significant also; the gated photograph has 28 lp/mm, the non-gated one 10 lp/mm.

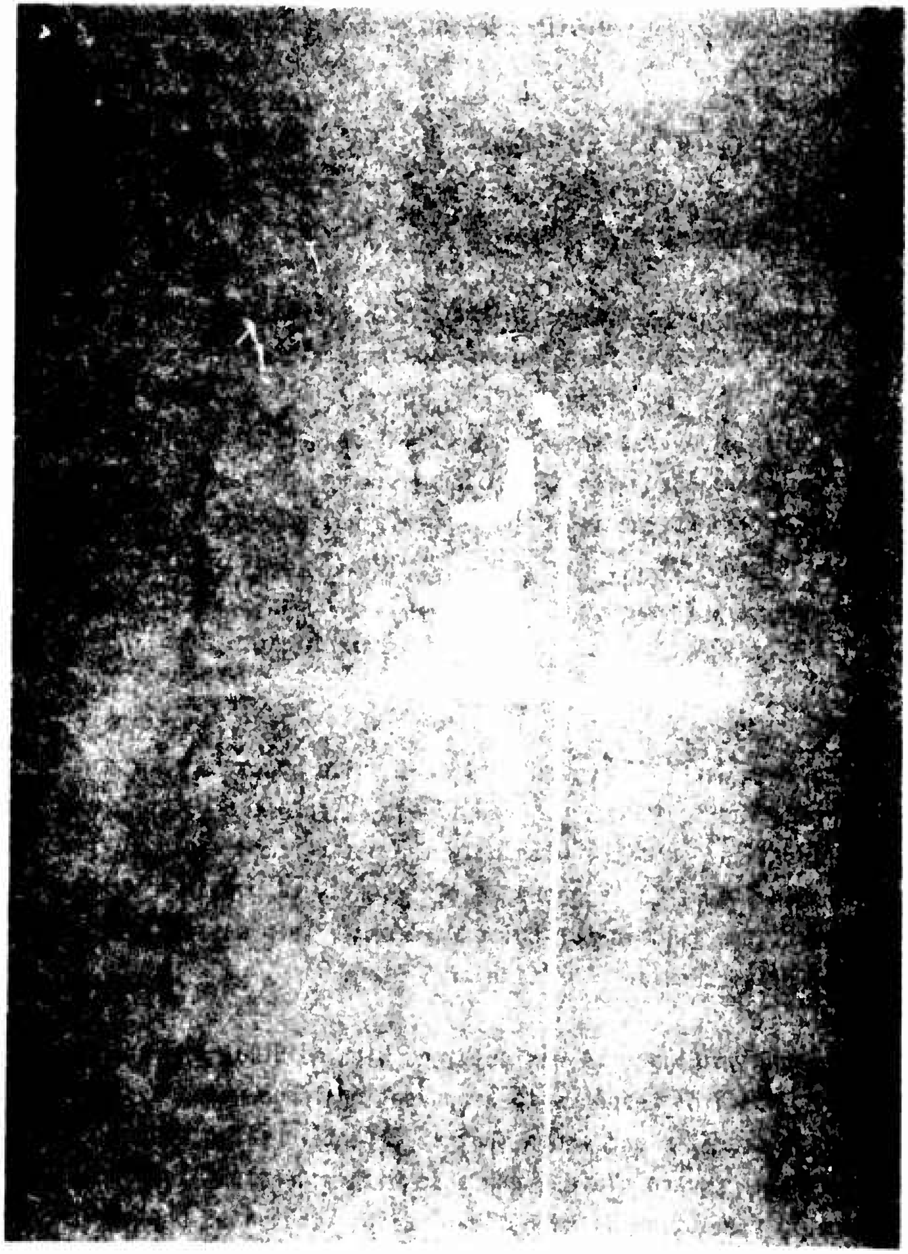


Figure 13. Gated Photograph

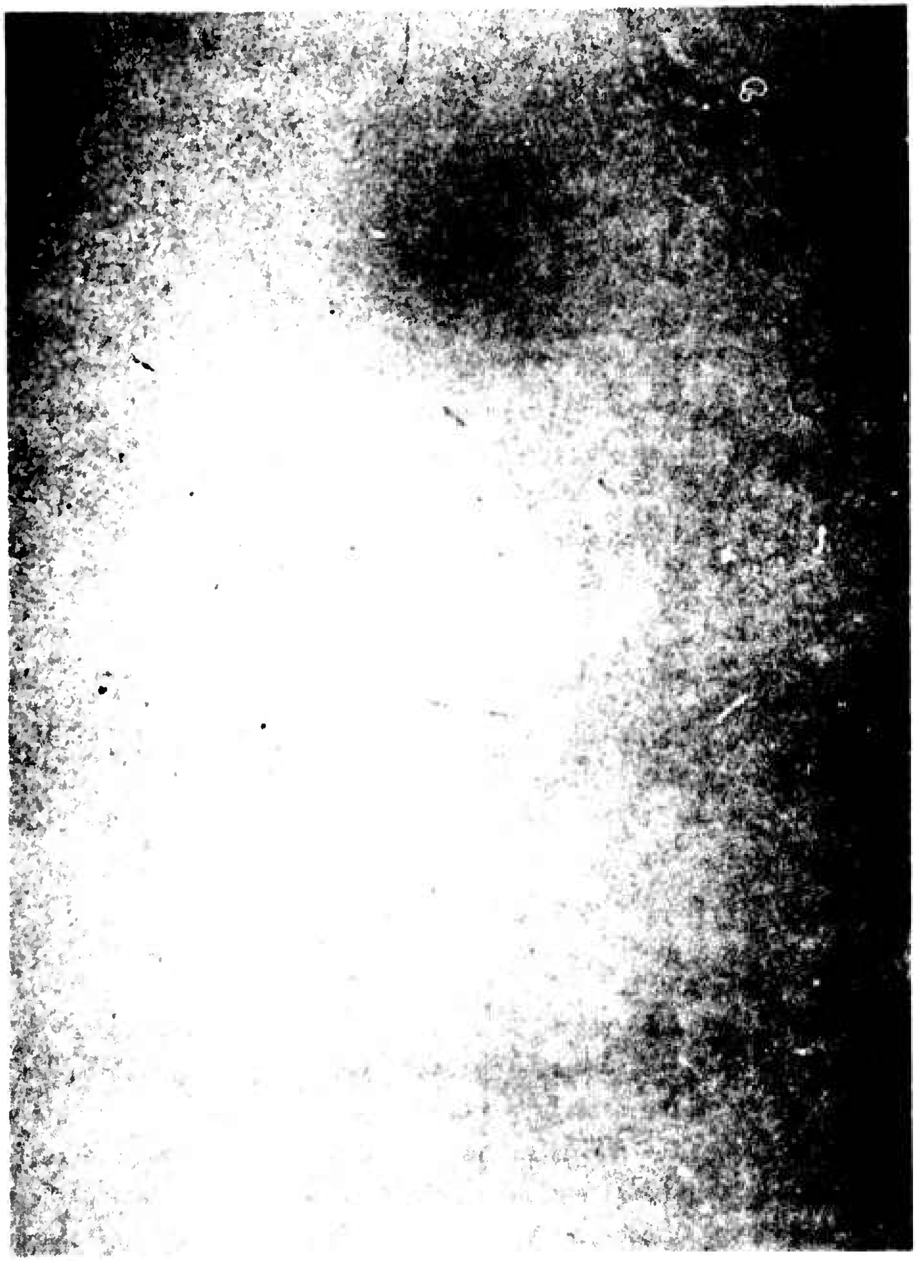


Figure 14. Non-Gated Photograph

Daytime photographs were obtained of the targets at the same range on a clear day (visibility of 6 miles) and the results showed significantly less contrast than the night gated photograph (2.10:1 gated vs 1.85:1 non-gated day).

The prime purpose of these experiments was not just to obtain proof of the effectiveness of gating, but to test a mathematical model describing a gated system. If the model can be verified, it can be used to predict the performance of any gated system for any combination of system parameters.

3. GATED SYSTEM MATHEMATICAL MODEL

The analytical description of a gated system is very similar to the expressions derived to calculate backscatter shown previously except that the illuminator output as a function of time must be included in the integration, and the sensor gate timing is used to define the limits of integration (overtime). The following expression shows this time dependence:

$$H_i = \frac{\pi B'}{4(f/)^2} \int_{D\cot\theta}^{S} \int_{t_1}^{t_2} Jo \left[\frac{t-2(X^2+D^2)^{1/2}}{c} \right] \frac{X\, e^{-\sigma(X^2+D^2)^{1/2}}}{(X^2+D^2)^{3/2}}\, dt\, dx \qquad (2)$$

where c = velocity of light, and all other variables are as shown in Eq (1). A computer program was written to evaluate this expression for various values of the system parameters.

4. VALIDITY OF THE MODEL

The model cannot be tested fully due to the very limited data available from the experiments. Also, the lack of instrumentation for the measurement of the backscatter coefficient β' prevents calculation of the contrast for the non-gated results. However, a reasonable test of the gating portion of the model can be obtained by calculating the expected reduction in backscatter and consequent improvement in contrast obtained by varying the delay between the non-gated case (t_1 = 0) and the gated case (t_1 = 9 μsec for these experiments). For the non-gated case, (t_1 = 0) this expression reduces to the previous expression for backscatter. The model can be used to calculate the relative amounts of backscatter observed as a function of the delay time (t_1). The irradiance due to backscatter can be calculated from the non-gated photograph according to Eq (2). The reduction of backscatter due to gating as predicted by the model can then be used with the calculated backscatter value from the photography to calculate a predicted contrast for each value of t_1. These calculations were performed for delays (t_1) of 1, 2, 3, 4, and 9 μsec for the experimental setup previously described with a 3 feet illuminator-sensor separation. The actual contrast vs predicted contrast is plotted in Figure 15.

The line of perfect prediction and the least squares fit line to the data are shown. The standard deviation of the data fit is 0.11. Thus, within the variability of the data, the model gives perfect prediction. This good agreement between the predicted and actual contrast indicates the utility of the model for calculating the contrast improvement obtained with various degrees of partial gating for a given backscatter condition. If β' is known, the amount of backscatter can be calculated for any system, and thus the model can predict gated system performance. The next section will examine the performance of gated and non-gated systems.

5. COMPARISON OF GATED AND NON-GATED CONTRAST

The effects of backscatter were shown previously in Section 1.0. Eq (1) can be simplified by the following approximation:

$$\sin\theta - \frac{D}{S} \cong \theta \tag{3}$$

This is accurate within 3% for the systems of interest. Thus,

$$\text{Contrast to Sensor} = \frac{T_a \dfrac{Rt}{S^2} + \dfrac{\pi\beta'\theta}{D}}{T_a \dfrac{Rb}{S^2} + \dfrac{\pi\beta'\theta}{D}} \tag{4}$$

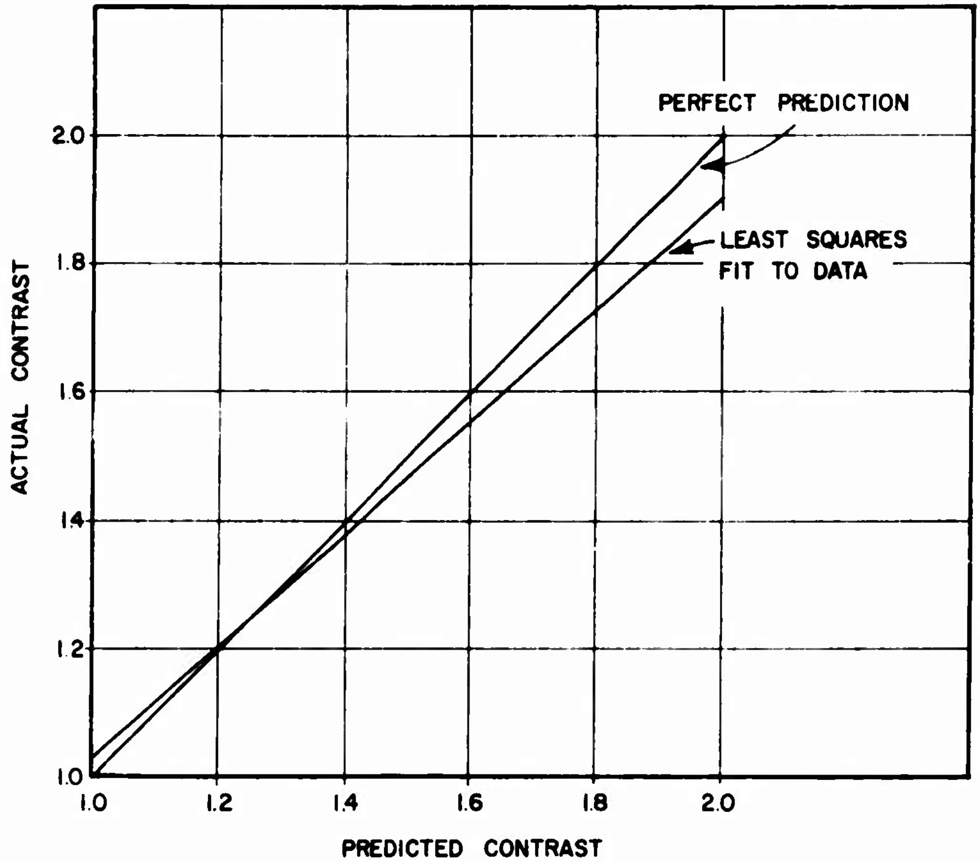


Figure 15. Prediction Accuracy of Gated System Model

This equation yields a very good approximation of the backscatter and the contrast for a non-gated system.

For a non-gated system typical values are tabulated below:

Rt = 0.4 Rb = 0.1 D = 15 feet θ = 5°

Cr	Altitude	β' ft^{-1}	$\frac{\pi\beta'\theta}{D}$ ft^{-2}
1.85	5×10^3	7.5×10^{-7}	1.37×10^{-8}
1.78	10^4	1.5×10^{-7}	2.74×10^{-9}
1.57	1.5×10^4	10^{-7}	1.83×10^{-9} (5)
1.45	2.0×10^4	7.5×10^{-8}	1.37×10^{-9}
1.38	2.5×10^4	6×10^{-8}	1.097×10^{-9}
1.32	3.0×10^4	5×10^{-8}	9.14×10^{-10}

For a perfectly gated system, the majority of the backscatter is eliminated. However, atmospheric scattering still reduces contrast. The contrast at the sensor for this case is $Cr = Co\ e^{-\sigma r}$

where

Cr = contrast received

Co = contrast original

σ = attenuation coefficient

r = altitude

The value of σ requires correction for altitude and spectral region (700-900 nm). These correction factors were obtained from the Electro-Optics Handbook, RCA, 1968, pp. 7-8 and 7-9.

The following table shows the contrast received (Cr) for a perfect gated system, for a standard clear atmosphere with a ground visibility of 16 miles, which corresponds to a σ(700-900 nm) = 3.3×10^{-5} ft ^{1}.

Cr	Altitude	σ ft^{-1}	
3.64	5×10^3	1.9×10^{-5}	
3.54	10^4	1.2×10^{-5}	
3.51	1.5×10^4	8.9×10^{-5}	(6)
3.50	2.0×10^4	6.6×10^{-6}	
3.48	2.5×10^4	5.6×10^{-6}	
3.45	3.0×10^4	4.9×10^{-6}	

As noted previously in the section on partial gating, the majority of the backscatter is contributed by the region closest to the aircraft. To a first approximation then, the backscatter irradiance for a partially gated system can be calculated by reducing the backscatter by the fraction of light emitted prior to the sensor being activated. The use of this approximation to the model developed in Section 3.3 allows rapid calculation of the performance of a partially gated system without the need for a computer. The accuracy of this approximation in calculating the backscatter irradiance is within 10% for altitudes of 5000 feet or greater.

The above approximation technique was used to calculate the system performance for a partially gated system with a pulse width equal to the one-way propagation time of light and also for a fixed 35 microsecond pulse width.

Figure 16 shows the results of these calculations with a perfect gated system and a non-gated system for comparison. As shown in the figure, partial gating can provide for superior performance to non-gated systems at high altitudes (> 10,000 feet).

It is also apparent that a successfully gated aerial photographic system only needs to allow a few microseconds separation between the source "on" time and the sensor "on" time to produce high contract photography.

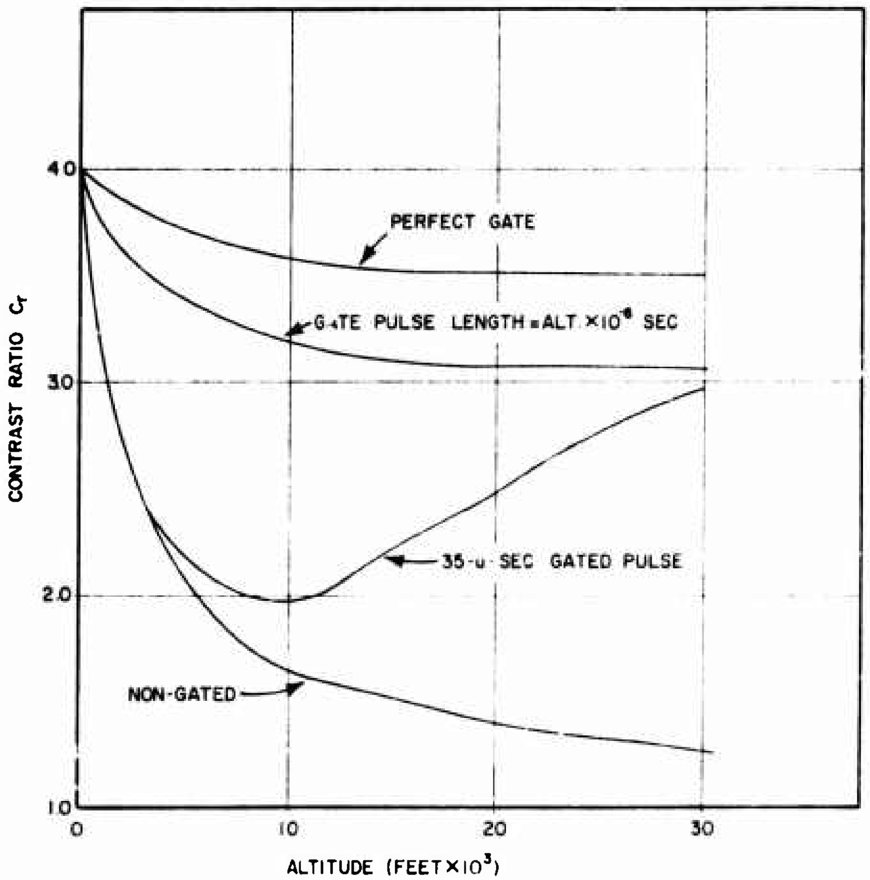


Figure 16. Contrast as a Function of Gated Pulse Characteristics

SECTION IV
CONCLUSIONS

The variability of performance from night photographic reconnaissance systems is due primarily to backscatter, which can be eliminated by gating. An Air Force approach to gated photography is described, which includes the development of large aperture high resolution gated image amplifier tubes and the use of partial gating to eliminate the majority of the backscatter while allowing use of available high energy flashtube illuminators. Experimentally obtained photographs are shown which prove that partial gating techniques can greatly reduce backscatter and provide high contrast high resolution performance. A mathematical model describing gated system performance accurately predicts experimental results. This model is used to show the improved performance that would be obtained from operational partially gated systems.

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1. Electro-Optics Handbook, RCA, Commercial Engineering.

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