<table>
<thead>
<tr>
<th>UNCLASSIFIED</th>
</tr>
</thead>
<tbody>
<tr>
<td>AD NUMBER</td>
</tr>
<tr>
<td>AD519010</td>
</tr>
<tr>
<td>CLASSIFICATION CHANGES</td>
</tr>
<tr>
<td>TO: UNCLASSIFIED</td>
</tr>
<tr>
<td>FROM: SECRET</td>
</tr>
<tr>
<td>LIMITATION CHANGES</td>
</tr>
<tr>
<td>TO: Approved for public release; distribution is unlimited.</td>
</tr>
<tr>
<td>FROM: Distribution authorized to U.S. Gov't. agencies only; Test and Evaluation; 13 JAN 1972. Other requests shall be referred to Electronic Systems Division, ATTN: ESD-TR-2, Hanscom AFB, MA 01731-5000.</td>
</tr>
</tbody>
</table>

**AUTHORITY**

DARPA ltr dtd 26 Oct 1983; DARPA ltr dtd 26 Oct 1983
AD- 515010
SECURITY REMARKING REQUIREMENTS
DOD 5200.1-R, DEC 78
REVIEW ON 01 JAN 92
SECURITY MARKING

The classified or limited status of this report applies to each page, unless otherwise marked. Separate page printouts MUST be marked accordingly.

THIS DOCUMENT CONTAINS INFORMATION AFFECTING THE NATIONAL DEFENSE OF THE UNITED STATES WITHIN THE MEANING OF THE ESPIONAGE LAWS, TITLE 18, U.S.C., SECTIONS 793 AND 794. THE TRANSMISSION OR THE REVELATION OF ITS CONTENTS IN ANY MANNER TO AN UNAUTHORIZED PERSON IS PROHIBITED BY LAW.

NOTICE: When government or other drawings, specifications or other data are used for any purpose other than in connection with a definitely related government procurement operation, the U. S. Government thereby incurs no responsibility, nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use or sell any patented invention that may in any way be related thereto.
Range Capability
of an Infrared Vidicon Sensor
(Title UNCLASSIFIED)

Prepared for the Advanced Research Projects Agency
under Electronic Systems Division Contract F19628-70-C-0230 by

Lincoln Laboratory
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Lexington, Massachusetts

11 January 1972
Distribution limited to U.S. Government agencies only; test and evaluation; 13 January 1972. Other requests for this document must be referred to ESD-TR-2.
RANGE CAPABILITY OF AN INFRARED VIDICON SENSOR

(TITLE UNCLASSIFIED)

GROUP 3

10. DIMMOCK

M. JOQUIST

Group 52

DOWNGRADED AT 12 YEAR INTERVALS; NOT AUTOMATICALLY DECLASSIFIED

TECHNICAL NOTE 1972-3

11 JANUARY 1972

12. 25 P.

14. TN-1972-3

This document contains information affecting the national defense of the United States within the meaning of the Espionage Laws, Title 18, U.S.C. Sections 793 and 794. The transmission or the revelation of its contents in any manner to an unauthorized person is prohibited by law.

GROUP 1

Downgraded at 12-year intervals; not automatically declassified.

Distribution limited to U.S. Government agencies only; test and evaluation: 13 January 1972. Other requests for this document must be referred to ESD-TR-2.

LEXINGTON

L.G. HANSCOM FIELD

BEDFORD, MASS. 01730

MASSACHUSETTS
The work reported in this document was performed at Lincoln Laboratory, a center for research operated by Massachusetts Institute of Technology. This work was sponsored by the Advanced Research Projects Agency of the Department of Defense under Air Force Contract F19628-70-C-0230 (ARPA Order 600).
ABSTRACT

The range capability of an infrared photoconductive vidicon is calculated as a function of background photon flux density. Range is maximized by adjusting a quantity which involves the target photoconductive gain, the quantum efficiency and the spectral bandwidth. The optimum value of the product of these three factors is obtained as a function of background flux. A limiting factor is the amount of charge that can be stored on the vidicon retina for the frame time. This is determined by the maximum breakdown field of retina material and the retina capacitance or dielectric constant. The resultant equations are evaluated for several practical situations. In the case of high backgrounds, range capability can be increased by enhancing the capacitance of the vidicon retina or alternatively by employing frame-to-frame signal integration.

Accepted for the Air Force
Joseph R. Waterman, Lt. Col., USAF
Chief, Lincoln Laboratory Project Office
RANGE CAPABILITY OF AN INFRARED VIDICON SENSOR (U)

I. INTRODUCTION

(U) In this note we calculate the range capability of an infrared photore conductive vidicon as a function of background photon flux density. It is assumed that the vidicon is operating in the return beam mode and that the dominant noise is beam shot noise. Range is maximized by adjusting a quantity which involves the target photoconductive gain, the quantum efficiency, and the spectral bandwidth. The optimum value of the product of these three factors is obtained as a function of background flux. A limiting factor is the amount of charge that can be stored on the vidicon retina for the frame time. This is determined by the maximum breakdown field of the retina material and the retina capacitance or dielectric constant.

II. ANALYSIS

(U) The electron beam current required to replace the charge lost during the discharge or frame time, \( t_f \), is given by

\[
\frac{Q}{t_d} = \frac{C_e (V_o - V_c)}{t_d},
\]

where \( t_d \) is the dwell time of the electron beam on an elemental area \( A_e \) of capacitance \( C_e \), and

\[
V_o - V_c = V_o(1 - e^{-t_f/RC}),
\]

where \( V_o \) is the initial and \( V_c \) the final voltage across the retina. The

1

Unclassified
discharge RC time constant is given by

\[ RC = \rho \epsilon = \varepsilon / \sigma \]  

(3)

where \( \rho \), \( \varepsilon \), and \( \sigma \) are the resistivity, dielectric constant, and conductivity, respectively, of the retina target material. The conductivity is assumed to be determined by the background photon flux density at the retina and is given by the current density \( j \) divided by the applied electric field \( E \):

\[ \sigma = j / E \]  

(4)

The current density in the photoconductor is given by

\[ j = \frac{q}{h\nu} H'_b \eta G \]  

(5)

where \( q \) is the electronic charge, \( h\nu \) is the photon energy, \( H'_b \) is the background flux density at the retina, \( \eta \) is the quantum efficiency, and \( G \) is the photoconductive gain given by

\[ G = \frac{\mu E}{d} \]  

(6)

where \( \mu \) is the carrier mobility, \( \tau \) is the carrier lifetime, and \( d \) is the target thickness. The conductivity is thus given by

\[ \sigma = \frac{q}{h\nu} H'_b \eta \frac{\mu t}{d} \]  

(7)

and is a constant throughout the discharge time, although \( E \) is changing.

The RC discharge time is given by
The electron beam current required is given by

\[ i_b = \frac{eA V}{e_o \sigma} \left(1 - e^{-K t_f H'_b} \right) \]  

(9)

\[ = \frac{eA V}{e_o \sigma} \left(1 - e^{-K t_f H'_b} \right) \]  

(10)

\[ = \frac{eA E}{e_0} \left(1 - e^{-K t_f H'_b} \right) \]  

(11)

where \( E_o \) is the initial field across the retina and \( K \) is a factor given by

\[ K = \frac{q \nu}{h \varepsilon_d} \frac{\nu}{h \varepsilon E} \]  

(12)

We can consider that the signal current is the change in \( i_b \) brought about by a small change in \( H'_b \). Thus,

\[ i_s = \Delta i_b = i_b \Delta t = \frac{eA E K t_f}{e_o} \frac{e^{-K t_f H'_b}}{t_d} \Delta H'_b \]  

(13)

where \( \Delta H'_b \) like \( H'_b \) is in watts/cm². If we assume that this is focussed on a single element of area \( A_e \), then \( \Delta H'_b = h_s/A_e \) where \( h_s \) is the signal flux on the retina in watts.

The shot noise in a return beam vidicon is given by

\[ \overline{1_n} = (2q i_b B/m)^{1/2} \]  

(14)
where \( B = \frac{1}{2} t_d \) is the bandwidth and

\[
m = \frac{i_b}{I_b} \quad (15)
\]
is the ratio of target discharge current to total read beam current \( I_b \). For optimum sensitivity, \( m \) will typically take on values between 0.15 and 0.2. For the present, we will assume a value of 0.2. Substituting Eq. (11) in Eq. (14) and solving for the signal-to-noise ratio using Eq. (13), we obtain after rearranging terms

\[
\frac{S}{N} = \frac{i_s}{I_n} = \frac{h_s}{H_b} \left( \frac{mcE_o}{qA_e} \right)^{1/2} \frac{xe^{-x}}{(1 - e^{-x})^{1/2}} \quad (16)
\]

where

\[
x = Kt_f H_b' = \frac{t_f}{R} \quad (17)
\]

\[
x = \frac{q_{\nu \nu}}{hv c_d} t_f H_b' = \frac{q_{\nu \nu}}{hv c_d} t_f H_b' \quad (18)
\]

(U) The signal flux \( h_s \) and background flux \( H_b' \) at the retina can be referred back to the target signal and background flux density incident on the optical system

\[
h_s = \frac{H_s A_s A_0}{\pi R^2 T_o} \quad (19)
\]

where \( H_s \) is the source radiance in watts/cm\(^2\), \( A_s \) is the source area, \( A_0 \) is the optics area, \( R \) is the range, and \( T_o \) is the total transmission efficiency of the optical system.
\[ H' = \frac{b}{4F^2} \cdot T_0 \quad , \]  

(20)

where \( H_b \) is the background flux density at the entrance aperture, and \( F \) is the f-number of the optical system. Substituting in Eq. (16) using 

\[ n_o = \left( D^2 / 4 \right) \]  

where \( D \) is the optics diameter we obtain

\[ S/N = \frac{H_s \cdot F \cdot D \cdot n_s}{R \cdot H_b} \left( \frac{mcE}{qA_e} \right)^{1/2} \cdot \frac{xe^{-x}}{(1 - e^{-x})^{1/2}} \quad , \]  

(21)

where \( n_s \) is the fraction of the signal flux falling on the elemental area \( A_e \).

Using \( f = FD \) where \( f \) is the focal length, \( A_e = A_r / n \) where \( A_r \) is the active area of the retina, \( n \) is the number of resolution elements, and \( \Omega_{FOV} = A_r / f^2 \) where \( \Omega_{FOV} \) is the total angular field of view, Eq. (21) becomes

\[ S/N = \frac{H_s \cdot A \cdot n_s}{R \cdot H_b \cdot \Omega_{FOV}} \left( \frac{mcE}{q \cdot nA_r} \right)^{1/2} \cdot \frac{xe^{-x}}{(1 - e^{-x})^{1/2}} \quad . \]  

(22)

(!) The signal-to-noise ratio or alternatively, the range given by Eq. (22) can be maximized with respect to the parameter \( x \). For example, we can write

\[ H_s \]  

and \( H_b \) in terms of the spectral radiance in watts/cm² micron, \( H_s = W_s \Delta \lambda \), and \( H_b = W_b \Delta \lambda \), where \( \Delta \lambda \) is the spectral bandwidth of the sensor. Equation (18) then becomes

\[ x = \frac{q}{h \nu} \cdot W_b \cdot \frac{n \Delta \lambda}{\epsilon E} \cdot T \cdot \frac{T_0}{4F^2} \quad . \]  

(23)
so that Eq. (22) can be optimized by adjusting the product \( nGAGt_f \) or alternatively \( nGAlt_f \). Taking the derivative of Eq. (22) with respect to \( x \) or effectively with respect to these parameters (since \( W_s/W_b = W_s/W_b \) is assumed independent of \( x \)), we obtain a maximum at \( x = x_0 = 0.6438 \), for which

\[
Y_0 = \frac{x_0 e^{-x_0}}{(1 - e^{-x_0})^{1/2}} = 0.4908
\]

The maximum range obtainable through adjustment is given, from Eq. (22), by

\[
R^2 = \frac{W_b A_n A_o Y_o}{W_s P_{0V}/S/N} \left( \frac{mc}{q} n A_r \right)^{1/2}
\]

under the condition that \( x \) given by Eq. (23) equals \( x_0 \).

There is an additional condition which must be considered. The minimum amount of target beam current which can be supplied by an oxide-coated thermionic cathode is approximately \( 10^{-6} \) A, although this might be increased to \( 10^{-5} \) A by using a higher-power electron gun. Under high background operating conditions, this is given by \( I_b \), where

\[
I_b = \frac{eA e_o}{t_d} (1 - e^{-x_0}) \quad (25)
\]

However, \( A_e/t_d = A_r/t_f \) so that this becomes

\[
I_b = \frac{eA e_o}{t_f} (1 - e^{-x_0}) \quad (26)
\]

In the case where the minimum elemental area \( A_e \) is limited by the diffraction of the optics, \( A_e \) is given by
Secret

\[ A_e = (2.44F\lambda)^2 \quad (27) \]

where \( \lambda \) is the wavelength of the signal radiation. Therefore, the effective number of resolution elements is

\[ n = \frac{A_r}{(2.44F\lambda)^2} \quad (28) \]

Substituting this into Eq. (24), we obtain

\[ R^2 = \frac{W_A \eta Y_s s b_o}{W_b \eta_{FOV} S/N} \frac{A_r}{(2.44F\lambda)} \left( \frac{mcE_o}{q} \right)^{1/2} \quad (29) \]

However, using \( \eta_{FOV} = A_r/f^2 \) and \( f = FD \), this can be rewritten as

\[ R^2 = \frac{W_A \eta Y_s s b_c}{W_b S/N} \frac{FD}{(2.44\lambda)} \left( \frac{mcE_o}{q} \right)^{1/2} \quad (30) \]

This can be rewritten in one additional useful form using Eq. (26) as

\[ R^2 = \frac{W_A \eta Y_s s b_o}{W_b S/N} \frac{D}{(2.44\lambda)} \left( \frac{m c \xi_f i_b}{q \eta_{FOV}} \right)^{1/2} \quad (31) \]

Since the electron beam current is effectively limited to between \( 10^{-5} \) and \( 10^{-6} \) A, this indicates that one cannot gain indefinitely by increasing \( \varepsilon \) and \( E_o \) without increasing \( t_f \) as is also shown by Eq. (26).
III. EVALUATION

We can evaluate these range equations for various values of the relevant parameters. For a 1-m², 300°K unit emissivity standard target in the 7.5 µm region, W_s A_s = 26 W/µm. We assume a minimum signal-to-noise ratio of S/N = 6.5 and a fraction of the signal power in a minimum resolution element n_s = 0.84. For the optical system, we assume

\[
\begin{align*}
D &= 25.4 \text{ cm} \\
F &= 1.5 \\
f &= 38.1 \text{ cm} \\
A_r &= 2.7 \times 2.7 \text{ cm} = 7.29 \text{ cm}^2 \\
\phi_{\text{FOV}} &= 0.071 \times 0.071 \text{ rad} = 5 \times 10^{-3} \text{ sr} (4° \times 4°)
\end{align*}
\]

For a 7.5 µm system, this gives for A_e from Eq. (27)

\[
A_e = 27.5 \times 27.5 \text{ µm} = 7.56 \times 10^{-6} \text{ cm}^2 \\
n = 984 \times 984 = 9.68 \times 10^5
\]

For an Al-doped Si retina, we estimate a maximum bias field of E_o = 1000 V/cm and the dielectric constant is \(\varepsilon = 11.5 \varepsilon_o = 1.02 \times 10^{-12}\) F/cm. Using these parameter values, the range obtained vs background flux density is plotted in Fig. 1 (curve labeled \(\varepsilon = 11.5 \varepsilon_o\)). We have also plotted in Fig. 1 a curve corresponding to a retina with a hundredfold enhanced capacitance (curve labeled \(\varepsilon = 1150 \varepsilon_o\)). For the parameters assumed above, (\(\varepsilon = 11.5 \varepsilon_o\), A_r = 7.29 cm², E_o = 1000 V/cm), and a 1/30 sec frame time, Eq. (26) gives a beam current of 10⁻⁷ A, well within the present
Fig. 1. Range vs background radiation density for an infrared vidicon sensor with and without capacitive enhancement. (U)
electron gun capabilities. It has been suggested by H. Sippach and R. Reddington of General Electric that it may be possible to enhance the capacitance of the retina by as much as a factor of 100 by employing special structures. The present electron gun could handle a factor of 10 increase in capacitance at the same 1/30 sec frame time. A factor of 100 could only be accommodated through the incorporation of the higher-power electron gun, which is a major modification, or through an increase in frame time to 1/3 sec.

In Fig. 2 we plot the optimum values of $nG$, $\Delta \lambda$, and $t_f$ as a function of $W_b$ from Eq. (23) setting $x = x_0$. As Eq. (23) only establishes the product of these quantities, their values can be traded off against each other. In Fig. 2 we have assumed a maximum value for $nG$ of 0.05, $0.1 \mu m \leq \Delta \lambda \leq 2 \mu m$ and a minimum value for $t_f$ of 1/30 sec. For a specific system, different values for $t_f$, $nG$, and $\Delta \lambda$ than those shown in Fig. 2 may be desirable, but it appears that an optimum condition can be reached for the background shown provided one is willing to use long frame times in low backgrounds. This is not a serious problem as the system is very sensitive in these backgrounds and a departure from optimization will not seriously degrade the range capability.

A similar plot for the capacitively enhanced system is given in Fig. 3. This indicates that the capacitively enhanced system cannot be optimized much below $W_b = 10^{-6} \text{W/cm}^2 \mu m$. Again, this is not much of a problem as the system is very sensitive and one would probably prefer to employ a nonenhanced system with a faster frame rate in these backgrounds.
Fig. 2. Optimum values of frame time, spectral bandwidth and gain-efficiency product as a function of background radiation density for the vidicon sensor without capacitive enhancement. (U)
Fig. 3. Optimum values of frame time, spectral bandwidth and gain-efficiency product as a function of background radiation density for the vidicon sensor with capacitive enhancement. (U)
IV. CALCULATION FOR AN AIRCRAFT SYSTEM

The background encountered by an aircraft-borne sensor system arises principally from two sources: the atmospheric background radiance at the altitude and look angle of the aircraft, and the radiance from any warm elements in the optical system. The ambient temperature outside an aircraft at altitudes between 40 and 100 kft is approximately 220°K so that optical elements at ambient should attain this temperature. The present refractive telescope is designed to operate with a 1-1/4" thick Ge objective, which will be at or near ambient temperature. The possibility of reducing the thickness of this by a factor of 2 is under study. The expected radiance of these two Ge objectives at 220°K is plotted in Fig. 4. Also plotted is the spectral radiance for a 220°K grey body with an emissivity of 1.5 percent, which is about the best one can hope to do using a reflective optical system, and that of a 300°K black body. Also shown in the figure is the atmospheric background radiance obtained from balloon measurements at 40 and 65 kft, adjusted for a look angle of 15° above the horizon. The optimum operating wavelength for each situation is that at which \( W_{\text{b}}(300^\circ \text{K})/W_{\lambda} \) is a maximum. This is given in Table I, along with the background flux density \( W_b \), the signal flux density \( W_s \), the optimum spectral bandwidth \( \Delta \lambda \), and the expected system range. The values of \( \eta G \) assumed are those given in Fig. 2 and \( t_f = 1/30 \text{ sec} \). The rest of the parameters are those assumed above for the noncapacitively enhanced retina.

The results for a hundredfold capacitively enhanced system are given in Table II, where \( \eta G \) is assumed fixed at 0.05 and \( \Delta \lambda \) at 1.0 \( \mu \text{m} \) and the
Fig. 4. Background and signal radiation density vs wavelength for a 300°K black body and various background conditions corresponding to aircraft altitudes of 40 and 66 kft and various optical systems. (U)
<table>
<thead>
<tr>
<th>ALTITUDE</th>
<th>TELESCOPE</th>
<th>$\lambda_o (\mu m)$</th>
<th>$W_b (W \text{ cm}^{-2} \mu^{-1})$</th>
<th>$W_b (W \text{ cm}^{-2} \mu^{-1})$</th>
<th>$\lambda (\mu m)$</th>
<th>$t_f (sec)$</th>
<th>Range(Km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 Kft</td>
<td>Ge Refractor Ambient element</td>
<td>7.0</td>
<td>$1.5 \times 10^{-5}$</td>
<td>$2.4 \times 10^{-3}$</td>
<td>0.1</td>
<td>$\frac{1}{30}$</td>
<td>450</td>
</tr>
<tr>
<td></td>
<td>3.18cm thick</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ge Refractor Ambient element</td>
<td>8.3</td>
<td>$1.4 \times 10^{-5}$</td>
<td>$3 \times 10^{-3}$</td>
<td>0.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.59cm thick</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reflective $\epsilon = 1.5%$</td>
<td>8.3</td>
<td>$9 \times 10^{-6}$</td>
<td>$3 \times 10^{-3}$</td>
<td>0.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>66 Kft</td>
<td>Ge Refractor Ambient element</td>
<td>6.5</td>
<td>$5 \times 10^{-6}$</td>
<td>$2 \times 10^{-3}$</td>
<td>0.27</td>
<td>$\frac{1}{30}$</td>
<td>750</td>
</tr>
<tr>
<td></td>
<td>3.18cm thick</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ge Refractor Ambient element</td>
<td>6.5</td>
<td>$3 \times 10^{-6}$</td>
<td></td>
<td>0.45</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.59cm thick</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reflective $\epsilon = 1.5%$</td>
<td>6.5</td>
<td>$3 \times 10^{-6}$</td>
<td></td>
<td>0.45</td>
<td></td>
<td>950</td>
</tr>
<tr>
<td>ALTITUDE</td>
<td>TELESCOPE</td>
<td>$\lambda_o$ ((\mu m))</td>
<td>$W_b$ (W cm(^{-2}) (\mu m^{-1}))</td>
<td>$W_s$ (W cm(^{-2}) (\mu m^{-1}))</td>
<td>$\Delta \lambda$ ((\mu m))</td>
<td>$t_I$ (sec)</td>
<td>Range (Km)</td>
</tr>
<tr>
<td>----------</td>
<td>--------------------------------</td>
<td>--------------------------</td>
<td>----------------------------------------</td>
<td>----------------------------------------</td>
<td>-------------------------------</td>
<td>-------------</td>
<td>------------</td>
</tr>
<tr>
<td>40 Kf.</td>
<td>Ge refractor</td>
<td>7</td>
<td>1.8 x 10(^{-5})</td>
<td>2.4 x 10(^{-3})</td>
<td>1</td>
<td>0.23</td>
<td>1300</td>
</tr>
<tr>
<td></td>
<td>Ambient element</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.18 cm thick</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ge refractor</td>
<td></td>
<td>1.4 x 10(^{-5})</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ambient element</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.5% cm thick</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reflective</td>
<td></td>
<td>1.3 x 10(^{-5})</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\varepsilon = 1.5%$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>66 Kf.</td>
<td>Ge refractor</td>
<td></td>
<td>1.0 x 10(^{-5})</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ambient element</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.18 cm thick</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ge refractor</td>
<td></td>
<td>5 x 10(^{-6})</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ambient element</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.5% cm thick</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reflective</td>
<td></td>
<td>4.5 x 10(^{-6})</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\varepsilon = 1.5%$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
optimum values of \( t_e \) are given in the table. As indicated, the frame times get rather long for the lower backgrounds. Some departure from the optimum condition, along with a reduction in range, may be necessary if long frame times are not tolerable.

V. CONCLUSIONS

(S) An LWIR photoconductive vidicon is, in principle, a very sensitive device when operated under low background conditions. For optimum operating conditions the background at the retina should be less than approximately \( 10^{-7} \text{W/cm}^2 \) for a standard vidicon. If the charge storage capability of the retina can be increased by increasing its effective capacitance then the vidicon can be operated at higher background levels. For example, a 100 fold increase in capacitance would allow a 10 fold increase in background power without loss of sensitivity. However, a 100 fold increased retina capacitance and the higher background power requires a larger electron beam current than the presently available \( 10^{-6} \text{A} \) or an increase in frame time. A comparison of Table I and Table II shows that on the average a 100 fold increase in capacitance gives a factor of about 2.7 increase in range.

(S) All range calculations have been done for S/N = 6.5 which is considered necessary for a tracking instrument. However, if the sensor is required only to view and obtain radiometric data on the target then the S/N can be reduced by about a factor of 3. A 3 to 1 reduction in the S/N requirement gives a 3 \( 1/2 \) increase in range. This means that for the nonenhanced vidicon sensor the range would become 1650 km. In addition it may be possible to employ frame-to-frame integration to increase the S/N at a given range, or
alternatively to increase the range. If this integration can be accomplished over \( p \) frames then the S/N at a given range can be increased by \( p^{1/2} \) or the range at a given S/N can be increased by \( p^{1/4} \). For example a 16 frame integration gives a 2 fold increase in range for the same S/N, or a range of 1900 km = 1000 nmi for the 66 kft, 1.59 cm Ge refractor or \( e = 1.5\% \) reflective telescopes. At this range the target can be expected to remain within a single resolution element for about 0.6 sec so that a 30 frame/sec system could integrate for 18 frames and a 100 frame/sec system could integrate for 60 frames giving almost 2650 km = 1400 nmi range. In practice these numbers will probably be somewhat less but it does appear that a range of 1000 nmi could be achieved at 66 kft using frame-to-frame integration and 100 frames/sec. Note that at 100 frames/sec the optimum spectral bandwidth for these systems is increased to about 1.5 \( \mu \)m and the performance is quite comparable to that of a capacitively enhanced system. Note also that the information rate is about the same since the frame time is increased for the capacitively enhanced system.

(S) However, the frame-to-frame integration scheme has the potential advantage of a larger dynamic range since the minimum single frame S/N can be close to unity in the integration mode at long range whereas at short range where the signal is larger the integration can be reduced or eliminated and information can be obtained from each frame. A reduction in the frame-to-frame integration will in fact be necessary at shorter ranges as the target moves more rapidly through the field-of-view.
There are, of course, a number of questions which need answers such as:

1. Can a vidicon with the specified resolution and sensitivity performance be obtained?
2. Can the telescope be constructed maintaining diffraction limited optics?
3. Can the frame-to-frame integration be accomplished without loss in signal-to-noise ratio?
4. Can all of this be incorporated into an aircraft capable of flying at 66 kft?
5. Can the telescope pointing be maintained to 70 μrad over 1/2 sec?

We intend to obtain answers to as many of these questions as possible over the next 6 months. If these answers are affirmative then a range of 1000 nmi for a 1 m², 300°K target appears feasible from an aircraft at 66 kft. The situation at 40 kft appears quite marginal unless the vidicon instantaneous field of view is reduced to allow the frame rate to be increased to at least 200 frames/sec, since a factor of (100)¹/⁴ at least is required in range. If this could be accomplished then the vidicon could be scanned to recover the full field of view in 1 to 2 sec. However we are clearly significantly better off at the higher altitude.
REFERENCES


The range capability of an infrared photoconductive vidicon is calculated as a function of background photon flux density. Range is maximized by adjusting a quantity which involves the target photoconductive gain, the quantum efficiency and the spectral bandwidth. The optimum value of the product of these three factors is obtained as a function of background flux. A limiting factor is the amount of charge that can be stored on the vidicon retina for the frame time. This is determined by the maximum breakdown field of retina material and the retina capacitance or dielectric constant. The resultant equations are evaluated for several practical situations. In the case of high backgrounds, range capability can be increased by enhancing the capacitance of the vidicon retina or alternatively by employing frame-to-frame signal integration.