General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.

- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.

- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.

- This document is paginated as submitted by the original source.

- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

Produced by the NASA Center for Aerospace Information (CASI)

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

EARTH RESOURCES SURVEY PROGRAM

INTERAGENCY REPORT NASA-97

COMPARISON OF A UV SCANNER/PHOTOMULTIPLIER WITH AN IMAGE ORTHICON

By

Howard Goldman

and

Robert Marshall

IIT Research Institute
Chicago, Illinois

October 1967

Prepared by the Geological Survey for the
National Aeronautics and Space Administration (NASA)
under NASA Contract No. R-146 (09-020-006)
ORDER #

FACILITY FORM 602

N69-28376 (ACCESSION NUMBER) | (THRU)

48 (PAGES) | 1 (CODE)

TMX-61710 (NASA CR OR TMX OR AD NUMBER) | 14 (CATEGORY)

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WASHINGTON, D.C. 20242

Interagency Report
NASA-97
October 1967

Dr. Peter C. Badgley
Program Chief,
Earth Resources Survey
Code SAR - NASA Headquarters
Washington, D.C. 20546

Dear Peter:

Transmitted herewith is one copy of:

INTERAGENCY REPORT NASA-97

COMPARISON OF A UV SCANNER/PHOTOMULTIPLIER
WITH AN IMAGE ORTHICON*

by

Howard Goldman**

Robert Marshall**

Sincerely yours,

William A. Fischer
Research Coordinator
Earth Orbiter Program

*Work performed under NASA Contract No. R-146-09-020-006
**IIT Research Institute, Chicago, Illinois

UNITED STATES

DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

INTERAGENCY REPORT NASA-97

COMPARISON OF A UV SCANNER/PHOTOMULTIPLIER WITH AN IMAGE ORTHICON*

by

Howard Goldman**

Robert Marshall**

October 1967

Prepared by the Geological Survey
for the National Aeronautics and
Space Administration (NASA)

*Work performed under NASA Contract No. R-146-09-020-006
**IIT Research Institute, Chicago, Illinois

CONTENTS

Page

INTRODUCTION..... 1

IMAGE ORTHICON..... 2

COMPARISON WITH ROTATING MIRROR CAMERA..... 5

SUMMARY.....12

BIBLIOGRAPHY ON IMAGE ORTHICONS.....14

ILLUSTRATIONS

Figure 1 - Assumed Frame Formation by Line Scan..... 7

Table 1 - Input Values for S/N Calculations.....10

1. INTRODUCTION

The spectral region 3000-4000Å is of current interest to the U. S. Geological Survey in its delineation of techniques useful for remote sensing of surface properties. Imaging in this spectral region is currently performed by a rotating mirror camera using a photomultiplier detector to modulate a light source and record a line-scan image on film. The effective color temperature of the Sun gives a Planckian distribution function peaking in the mid-visible region (~5550Å) and thus with an S-13 photocathode, rejection of energy for wavelength > 4000Å poses a real difficulty. Some preferential discrimination can be achieved through the use of filters such as Corning 7-54. However, far better rejection of red response should be possible through use of "solar-blind" cathodes. This laboratory has recently shown this to be the case for CsTe photomultipliers.[1] This detector when used in conjunction with coarse Corning filters and possibly transition metal oxide and sulphide filters, should provide optimum detector-spectral discrimination for use in the general rotating mirror camera (RMC). The cut-off filter characteristics of the CsTe photocathode coupled with the additional fore-filter is believed to be sufficiently effective in removing any "red" response. Theoretical calculations beyond 4000Å (Table I) indicate negligible response assuming that filter luminescence and photocathode impurity response will be small.

The RMC system suffers the disadvantage of forming a frame element by element. Hence, for relatively low intensity

---

1. Letter Report by H. Goldman to USGS (W. Hemphill) March 9, 1967

objects, a severe signal to noise problem may arise because of the small allowable dwell time. Obviously, since the imaging is performed from a moving platform, the dwell time per element ultimately limits the system resolution. In the current system there must be trade-offs between detectivity and resolution. Picture tubes, and, in particular, image orthicon tubes have a very definite advantage in this respect. Such tubes have inherent integration capability and thus use each element forthe whole frame time; in a typical orthicon tube 50,000 such elements accumulate image information simultaneously. The purpose of this study is to give consideration to the following:

(1) Is the application of orthicon feasible?

(2) How would it compare with a line-scan imager using an equivalent PM detector?

(3) Obtain approximate figures of signal to noise ratio and red rejection capability.

2. IMAGE ORTHICONS

The image orthicon tube is in itself a relatively complex system and the level of understanding and development is still at a cursory stage. It is only during this last year that even a detectivity (D*) has been defined for orthicon tubes. Nevertheless, such systems have found immediate application in low intensity reconnaisance systems and in astronomical observations. The application considered here has aspects common to both of those areas and hence there is some precedence for applying orthicons to imaging in the 3000-40000 spectral channel.

It must be noted, however, the specific tubes for this spectral range have not been developed and an optimum orthicon

would not be an off-the-shelf item. Emphasis in the past has been to develop truly solar blind tubes such as the CsI cathode (responds to wavelengths < 3000A) for astronomical purposes, approximate eye response tubes as with the S-10 photocathodes and tubes with long wavelength sensitivity with the trialkali cathode S-20 for near infrared reconnaisance purposes. None of these tubes is well suited for use in the 3000-4000 spectral channel. During the course of this study we obtained a fairly recent bibliography on orthicon topics and have attached a separate list of these for reference.

This problem has been discussed at length with Professor Sol Nudelman of the Electrical Engineering Department, University of Rhode Island, who is a leading authority on photoelectric tubes. His general comments were:

(a) At the available power inputs ($200\mu w/cm^2$ ster.) imaging should be no real problem. Infrared reconnaisance groups have to cope with power inputs of the order $2\mu w/cm^2$/ster. with less efficient photocathodes.

(b) The near red rejection is a problem but either RCA or General Electric would possibly manufacture an orthicon tube with a CsTe photocathode. (We have previously discussed this with Frederick Sachs at General Electric -- see later notes). Deliberate contamination of the CsTe cathode can possibly improve the sensitivity over the channel of interest.

(c) Although he has recently derived a detectivity (D*) for orthicons he strongly advised that we confine our thinking to comparison of signal/noise ratios--many experimental parameters required for calculation of true (D*) are not immediately available.

(d) Do not underestimate the difficulties of using orthicon tubes in an airborne environment. Such tubes are, of course, fragile, sensitive to environmental changes, expensive and need relatively sophisticated support equipment. In this respect he suggested that consideration should be given to an S.E.C. Vidicon being developed at Westinghouse Laboratories. They have made significant progress in photocathode sensitivity and target materials to the extent where for many applications no multiplier is required. This work is being directed by

Dr. Arthus S. Jensen, Senior Advisory Physicist
Westinghouse Advanced Development Laboratories
Friendship International Airport
Post Office Box 746
Baltimore, Maryland 21203
Telephone 301/765-2078

To date we have had no success in contacting Dr. Jensen.

We also contacted Frederick Sachs of the Photoelectric Tube Development Group of the General Electric Company in Schenectady. His thinking was closely aligned with that of Professor Nudelman. Also, G.E. can manufacture a special CsTe orthicon tube should this eventually be required; S-10 and S-20 tubrs are standard. Mr. Sachs is arranging for his sales engineer to forward a formal quotation for such a tube.

At this time he was only able to supply the following approximate characteristics:

Cathode: CsTe on Corning 9741 glass

9741 Glass: Transmission down 50% at 2200A
Above 90% over range 3000-6000A.

Cathode Sensitivity: Peaking at about 3000A of 4.10^{-3} A/w.

Device Diameter: 3 inches

Effective Cathode Area: 1.6" - 1.8"

Target: Magnesium oxide or photoelectric glass

Cost: About $5,000.00 (This is to be compared to $2,500 - $2,600 cost of a standard S-10 or S-20 tube.)

He emphasized that the $2,000 additional cost is not that significant in terms of the cost of a complete imaging system/

These general arguments and impressions then seem to indicate that application of an orthicon tube is certainly within the realm of practicality.

3. COMPARISON WITH ROTATING MIRROR CAMERA

3.1 General Discussion

Our original intention was to compare the performance of the present camera with an S-13 photomultiplier with that of an off-the-shelf orthicon tube--i.e., having an S-10 or S-20 cathode. In the light of recent calculations on the CsTe cathode and subsequent developments as noted above, we have compared the rotating mirror camera using a CsTe cathode with an orthicon system using a CsTe cathode since CsTe will probably be used to avoid the effects of the undesired "red" response.

Before making this comparison in detail, some definition of assumed functional parameters are presented as the basis for comparison. Some actual operating characteristics for the line-scan/PM imager (RMC) are known, but these have been modified somewhat to make a comparison with the image orthicon more realistic. The RMC system has been listed as having an instantaneous field of view of about 4×10^{-3} radians (0.23°). This corresponds roughly to an element of resolution of 8 meters on a side for an aircraft at a kilometer altitude; this 8 meter ground resolution is retained for both systems being compared.

While the scan angle of the RMC, transverse to the ground track, has been listed at 90°, the scan angle assumed is 45° which is more closely allied to the optics and total field of view (FOV) for image orthicons; both systems will exhibit a degradation in spatial resolution along the edges as the total object field is increased. It is also noted that the assumed FOV reduction to 45° is more consistent with that of the metric camera (FOV of about 41°) that may be onboard and which could be used for correlating locations and features with the near UV imagery.

For the listed value of 4 milliradians as the resolved instantaneous FOV for the RMC, a single transverse scan line of the RMC over a 45° angle would sweep out about 200 elements on the ground. Although the RMC generates a continuous strip along the ground track as it scans, for comparison purposes the strip is assumed to be composed of contiguous frames, each of which is made up of 200 scan-lines. Thus a single frame is visualized as a 200 x 200 element picture; this 4×10^4 element frame is entirely consistent with current orthicon capability.

A comparison based on both systems imaging a 200 x 200 element field, can now be made with regard to the dwell time spent by each in collecting reflected/luminescent energy from each surface element. The line scans for the RMC have been ideally assumed to be non-overlapping to avoid the distinct line structure that appears in image printouts when such overlap occurs; if the mirror rotations rate is not closely controlled with the V/h ratio, the line scans may not only avoid overlap but actually underlap, leaving gaps in coverage with an attendant loss of information. Figure 1 illustrates the assumed ideal-scan formation of a single frame, (200 scan lines) as the aircraft moves forward.

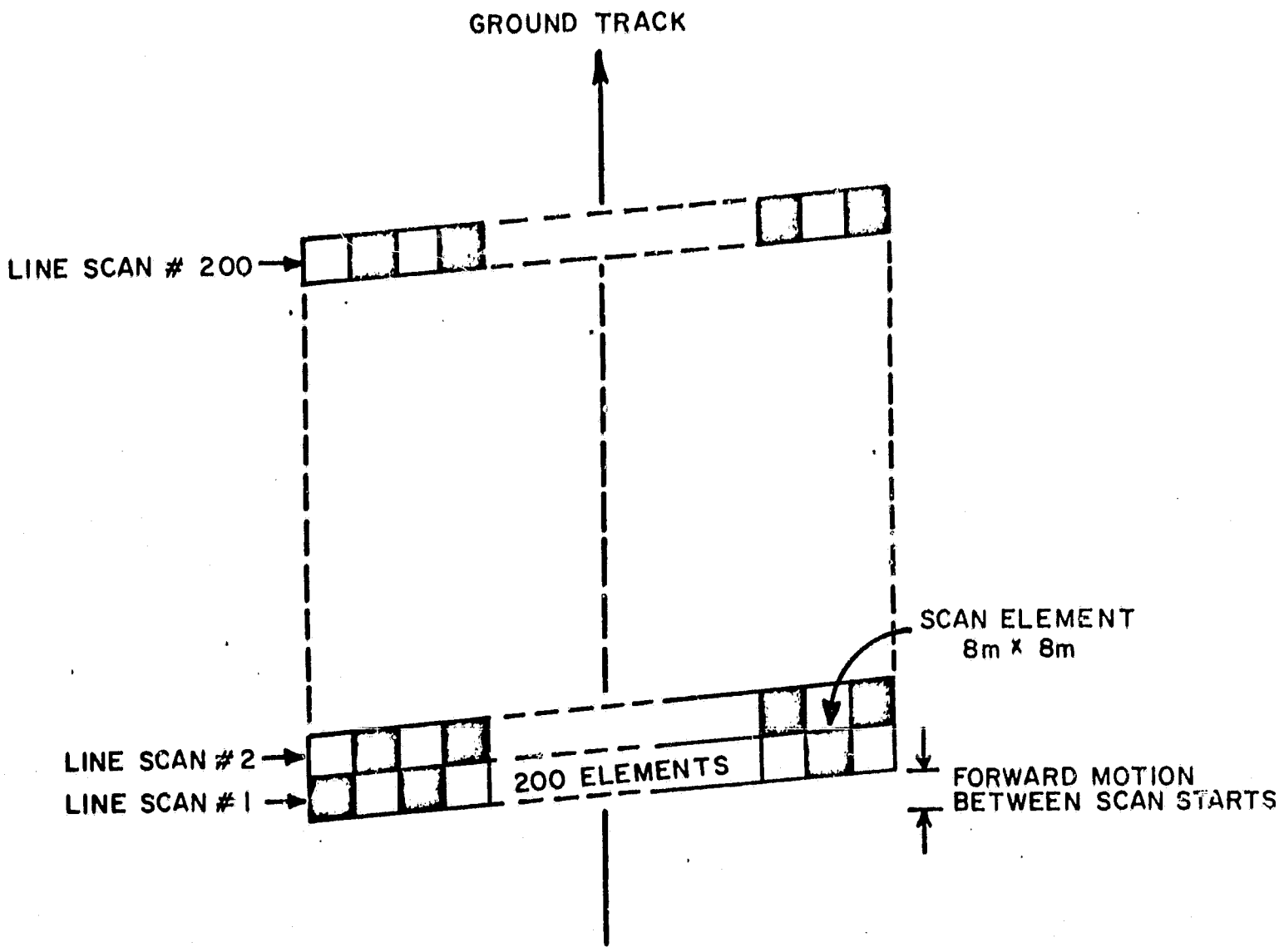

FIGURE I.

ASSUMED FRAME FORMATION BY LINE SCAN

The simplest mirror scan system assumed for the RMC is that of the single mirror (tilted at 45° to the axis of rotation) and rotating at a constant speed for a given V/h ratio; this avoids any reciprocating mechanism which provides a side-to-side scan but with a non-uniform rate of angular motion. Under such assumption, an active line scan will occupy 45/360 of the period for a complete mirror rotation. However, as shown in Figure 1, overlap is avoided when the interval between scan starts is equal to that corresponding to the time taken by the aircraft to move forward a distance of an element dimension, or about 0.1 seconds. In this 0.1 second, the mirror completes an entire revolution (at a 10 rps rate) so that the actual active period for a single line scan becomes 45/360 x 0.1, or 0.0125 seconds. Since some 200 elements are swept out during this active scan period, the dwell time/element becomes approximately 60μsec; the forward a/c motion on a given element in this interval is negligible in comparison to the element size. The maximum signal variation (bandwidth controlling photocathode shot-noise contributions) can now be resolved. Maximum variation will occur when adjacent elements exhibit bright to dark contrasts in radiance. Thus, in one single line scan of 200 elements, one can expect 100 complete periods of signal variation (at most) in 0.0125 seconds, or a bandwidth of 8000 cycles/sec.

The exposure or shutter time for the image orthicon will be limited primarily by the smearing of an element's image due to aircraft motion (image-motion compensation will probably not be available under the current a/c test site program). Allowing

a smear area of only 25% of the elemental area (2 meter forward motion), the exposure must be completed within 2m/76m/sec or about 1/38 second. During this exposure interval, all elements are being exposed simultaneously so that the dwell time/element equals the exposure time, or about 26,000 microseconds in contrast to the 60 microseconds for the RMC; the dwell time ratio favoring the image orthicon over the RMC is thereby in excess of 400:1 and which plays an important role in S/N calculations as discussed below.

3.2 S/N Calculations

Subsequent discussion is directed towards estimating the signal-to-noise ratios of the two imaging systems being compared; identical filtering has been included to ensure removal of any undesired "red" response. Table I lists the assumed input values and computed photocathode currents used in deriving these S/N ratios. The listed values were based on the following assumptions:

1. Surface Illumination: Mid-day (clear) over Cleveland (Koller, 1965).
2. Surface Reflectance: Based on laboratory measurements (IITRI Technical Memorandum W6137-1).
3. Atmospheric Transmission: Based on reported values (Elterman 1964).
4. CsTe Photocathode Quantum Efficiency (A/W): Based on values reported by a manufacturer (Ascop, Division of EMR) out to 3500 A; longer wavelength values were extrapolations of the reported curve.
5. Optical transmission, excluding filter, was assumed close to 100%.
6. The effective collecting aperture for both systems was assumed to be a 25 mm diameter, which removes this as a factor in the comparison.

Table 1 - INPUT VALUES FOR S/N CALCULATIONS

(Column No. Definitions Listed Below)

$\Delta\lambda$ Å	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
2950-3050	5.2	5.2	10	.15	.48	.55	.86	.473	.23	$1 \cdot 5.10^{-5}$	$6 \cdot 3.10^{-3}$	$9 \cdot 5.10^{-14}$
3050-3150	48	47	95	.15	4.6	.59	.87	.514	2.4	15	2·8	42
3150-3250	130	120	250	.16	13	.63	.89	.561	13	46	1·4	64
3250-3350	216	192	408	.17	22	.64	.89	.570	12	78	$6 \cdot 5.10^{-3}$	51
3350-3450	252	214	466	.17	25	.66	.88	.582	14	91	3·3	30
3450-3550	272	224	496	.18	29	.68	.87	.592	17	107	1·5	16
3550-3650	316	246	562	.19	34	.69	.84	.580	20	123	$8 \cdot 0.10^{-5}$	9·8
3650-3750	360	270	630	.20	40	.71	.79	.561	22	140	4·5	6·3
3750-3850	380	274	654	.21	44	.72	.66	.575	25	157	2·7	4·2
3850-3950	434	292	726	.22	51	.73	.44	.321	16	102	1·8	1.9
3950-4050	536	330	866	.23	63	.74	.14	.107	6.7	42	1·4	·6
4050-4150	678	418	1096	.23	77	.75	.05	.037	2.8			
4150-4250	754	446	1200	.23	88	.76	.01	.008	.07		$\sum P_{\Delta\lambda}\bar{n}_{\Delta\lambda} = 235 \cdot 10^{-14}$ A	
4250-4350	808	426	1234	.23	90	.77	~0	~0	~0			

(1) Direct sunlight, $\mu W/cm^2$
(2) Skylight, $\mu W/cm^2$
(3) Total incidence, Io, $\mu W/cm^2$
} Solar incidence

(4) Reflectance, ρ, dimensionless
(5) Radiance, $\frac{\rho Io}{\pi}$, $\mu W/cm^2/ster$.
(6) Atmospheric transmission, one-way (2 km), dimensionless
(7) Filter transmission, Corning 7-54, dimensionless
(8) Combined transmission, (6) x (7), dimensionless
(9) Effective radiance, (5) x (8), $\mu W/cm^2/ster$.
(10) Power incident on photocathode from ground element, $P_{\Delta\lambda}$, μW
(11) CsTe photocathode sensitivity, $\bar{n}_{\Delta\lambda}$, $\mu A/\mu W$
(12) Photocathode emission per ground element, $P_{\Delta\lambda}\bar{n}_{\Delta\lambda}$, amps

Since the manner in which signals are generated differ between the two imagers, different expressions are used for computation of their S/N ratios. In both cases, however, signal detection is fundamentally a counting of random independent events (charge arrivals) such that the average deviation or rms noise component in a single sample count equals the square root of the mean value obtained by averaging such counts over a large number of samples. On this basis, the S/N ratio for the RMC is defined as the ratio of signal current emitted from the photocathode of the PM tube to the shot-noise current in the photocathode emission (Garbuny 1965) or

$$S/N = \sqrt{\frac{1}{2e(\Delta f)} \sum_{\lambda = 300\ \mathring{A}}^{\lambda = 400\ \mathring{A}} P_{\Delta\lambda}\ \bar{n}_{\Delta\lambda}} \qquad (1)$$

where

$P_{\Delta\lambda}$ = Power/100 Å interval incident on the total active photocathode area from a ground resolved element, watts (Table I)

$\bar{n}_{\Delta\lambda}$ = Averaged quantum efficiency for the 100 Å interval being summed, amp/watt (Table I)

e = Electronic charge, 16×10^{-20} coulombs

Δf = Signal bandwidth dictated by line scan rate, 8×10^{3} cps.

The computed S/N ratio for the RMC system is 30:1.

The S/N ratio for the image orthicon is defined as the ratio of signal charge on the target to the noise charge in the read beam (Powers and Aikens 1963), or

$$S/N = \sqrt{\frac{p\tau mk}{e} \sum_{\lambda = 3000\,\mathring{A}}^{\lambda = 4000\,\mathring{A}} P_{\Delta\lambda}\, \bar{n}_{\Delta\lambda}} \qquad (2)$$

where

- p = Fraction of the total number of available electrons leaving the beam to neutralize the target image element, dimensionless. Value assumed was 0.3 (based on a readout time of about one second with a beam current of 10^{-8} amps.)
- τ = Frame exposure time, 1/38 sec.
- m = Mesh transmission factor, dimensionless, 0.8 assumed.
- k = Secondary emission factor, dimensionless, value of 6 assumed (generally between 5-7).
- e = Electronic charge, 16×10^{-20} coulombs
- $P_{\Delta\lambda}$ = Identical to that defined in the RMC expression except that this power is now focused on a small elemental-image area as part of the total active photocathode area, watts (Table I).
- $\bar{n}_{\Delta\lambda}$ = Identical to that defined in the RMC expression.

The computed S/N ratio for the image orthicon is 780:1. In view of this extremely high value (ratios of 10 are highly satisfactory in terms of contrast degradation), calculation was repeated for the narrower wavelength band from 3000Å - 3200Å which provides a reduction by a factor of about $1/\sqrt{2}$ or an S/N of about 550:1.

4. SUMMARY

The rotating camera system offers a highly satisfactory S/N ratio when using a CsTe photocathode (plus filter) at

aircraft altitudes of about 2 km under clear, mid-day illumination conditions. The image orthicon appears to offer S/N ratios that are about 25 times better than those of a rotating mirror camera or line scanner using a PM tube. The advantage comes about from the signal integration capability that image orthicons possess. This may be somewhat tempered by the noted fragile character of such tubes plus the additional complexity of equipment, for aircraft use and further investigation of these factors is suggested.

BIBLIOGRAPHY ON IMAGE ORTHICONS

1. D. L. Fried et al., "A Theoretical Analysis of Image Orthicon Performance," Appl. Optics 4, 785 (July 1965).

2. G. T. Hicks and T. N. Davis, "Cinematography of Spatial and Temporal Variations in Auroral Forms with an Image Orthicon TV System," Appl. Optics 4, 187 (February 1965).

3. E. Luedicke et al., "Astronomical Image Integration System Using a Television Camera Tube," Appl. Optics 3, 677 (June 1964).

4. W. T. Powers, "Non-Destructive Readout with a Field-Mesh Image Orthicon," Appl. Optics 3, 673 (June 1964).

5. C. B. Murray, Jr. and A. van der Ziel, "Measurements of Noise in Image Orthicons," I.E.E.E. Trans. Electron Devices Vol. E.D. II, No. 8, 365 (August 1964).

6. K. R. Coleman, "Ultrahigh Speed Photography," Rep. Progr. Phys. 26, 269 (1963). NOTE - Considers comparison of rotating mirror cameras with image tubes.

7. W. T. Powers and R. S. Aikens, "Image Orthicon Astronomy at the Dearborn Astronomy," Appl. Optics 2, 157 (February 1963).

8. E. F. DeHaan, "Signal to Noise Ratio of Image Devices," Advances in Electronics and Electron Physics, p. 291, Academic Press, New York (1960).

9. R. Theile, "On the Signal to Noise Ratio in Television Storage Tubes," Ibid, p. 277.

10. Edwin W. Dennision, "An Isophote Converter for Use with Signal Generating Image Tubes," Ibid, P. 307.

11. Max Garbuny, "Optical Physics," p. 414 (Academic Press).