AD 653416

The Limitations for Night-time Detection of Celestial Bodies Employing the Intensifier-storage-image Orthicon

By

RADAMES K. H. GEBEL

JUN 26 1967

Reprinted from
THE OHIO JOURNAL SCIENCE
Vol. 61 No. 3, May, 1961

ARCHIVE COPY

20

THE LIMITATIONS FOR NIGHT-TIME DETECTION OF CELESTIAL BODIES EMPLOYING THE INTENSIFIER-STORAGE-IMAGE ORTHICON

RADAMES K. H. GEBEL

Aeronautical Research Laboratory, Wright-Patterson Air Force Base, Ohio

INTRODUCTION

The purpose of this paper is to calculate the results one may expect by using the image orthicon and intensifier image orthicon for detection of celestial bodies during night time hours. The paper treats, in Part I, the image orthicon without intensifiers and calculates the limit in detection determined by the scanning beam noise. In the Part II, the preamplification necessary for the intensifier section to overcome this scanning beam noise is calculated. The intensifier image orthicon is not necessarily the only arrangement for overcoming this beam noise. Intensifier image converter tubes effectively placed between the telescope and an image orthicon could produce the same results; however, such a solution is not suitable for use in flight vehicles because it results in a heavy bulky arrangement.

PART I

Image Orthicon without Intensifiers with Negligible Noise due to Sky Radiation and Dark Current Emission of the Photocathode

In deriving the following equations, it has been taken into consideration that the mechanisms of the operation of the image orthicon are of a complex nature, and not too easily understood. Therefore, to render the mathematical derivations simple and clear, factors of minor importance were deliberately neglected and the relationships were expressed by the most elementary functions.

The image orthicon, well-known from television techniques, constitutes one of the most suitable tools for light amplification. It is the most advanced workable pickup device for short exposure time star photography, but may be superseded by another transducer now in the development stage, the new image isocon.* For proper understanding of this paper a superficial familiarity with the image orthicon's structural and operational features is necessary. The image orthicon consists of several sections: the image section, storage section, scanning section, and multiplier section (fig. 1). First, the image of the scene is projected by a telescope onto the photocathode of the image section which emits primary electrons as a result of the absorbed energy of the quanta of light (hereafter called simply "photons"), thus changing the optical image into an electronic one. The primary electrons are magnetically focused and accellerated by an electrostatic field and hit the target plate of the storage section, where each primary electron causes the emission of S secondary electrons, producing S positive charges. One of these unit charges is neutralized by the primary electron; the rest, (S-1) unit charges, are "stored" as a positive charge on the target plate, forming an amplified electronic image of the scene.

*Research Contract No. AF 33(616)-5728 initiated 4 February 1958 by the Aeronautical Research Laboratories.

The next operation is the removal and "count" of the integrated stored positive charges by a beam of electrons scanning the target plate and being reflected backwards. The reflected or "return" beam contains a lesser number of electrons than the scanning beam, since some of the electrons land on the target plate corresponding to the charge pattern in order to neutralize the charge. The difference in the number of electrons contained in the scanning and return beams is practically equal to the integrated number of charge units stored on the target between two consecutive sweepings with the scanning beam. This is true independently of the time elapsed between the subsequent sweepings, if allowance is made for the loss of charge units due to a slow, but unavoidable, leakage. As a result of this leakage, and other factors, the image produced by such a sensor has a limited resolution and, therefore, may be considered composed of small defined elements of resolution. Other factors contributing to loss of resolution are: the light focused on and absorbed by the photocathode contains a distribution in wavelength causing a distribution of velocity in the electrons released, insufficient electron-optics, finite diameter of the scanning beam, and finite band-width of the video amplifying system. However, at very low light levels, because of the quantum nature of light, the smallest area such an instrumentation is capable of resolving may not collect a detectable number of photons and, therefore, may

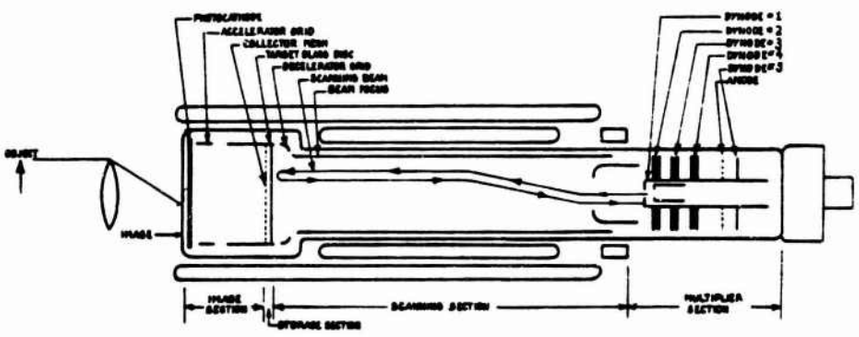

FIGURE 1. Conventional image orthicon.

have to be increased in order that, for the unit of time available, a sufficient number of quanta of light for detection are received. The conversion factor of photons into electrons of a photocathode is independent of the local density of the quanta flux; and since storage of the collected charges at the target plate over an arbitrary unit of time integration can be achieved, the function of such a device depends on the total number of photoelectrons released at the photocathode for each resolution element during the exposure time, rather than on the local density of the quanta flux. However, in the photographic plate and similar processes if the local density of the quanta flux is very low, then the failure of the photographic reciprocity law requires that the flux density also be considered.

Therefore, in the derivations to follow, if not otherwise stated, the term "total number" of photons or electrons means that number within each element of resolution which have occurred during the selected time interval.

If the detection of fast moving celestial objects is achieved by using an image orthicon system, the read-out of information from the target plate can be done by scanning the target plate in the conventional manner, by using a continuous frame rate of 20 to 60 frames per sec. In addition to using a continuous frame rate, the first photocathode may also have to be pulsed, if the object moves very rapidly, or if movement of the image due to air scintillations has to be stopped,

because conventional sweep rates might not be fast enough to stop the motion. This would apply only to objects bright enough to supply sufficient quanta of light for detection during the short exposure time. However, for the observation and recording of faint, non- or slow-moving celestial bodies, the exposure time may have to be extended to such a time interval that continuous read-out becomes impractical. For this type of arrangement, the scanning beam is not operating during the exposure time, thereby allowing the target plate to collect a sufficient charge that can be detected later by the scanning beam. After completion of the exposure time, this information is then removed from the target plate and transferred to the reproducer screen by one single sweep of the scanning beam. The correct time duration of the read-out sweep is determined by the band-width of the video amplifier and other circuitry factors. Since the information read-out is not continuous, and one single frame with a time duration of a fraction of a second is used which cannot be visually observed on a conventional reproducer, it is quite convenient to use a storage reproducer in connection with such an image orthicon system. The resulting visual observations on the storage reproducer which can be over several minutes then allow the determination of the optimum adjustments for photographic recording.

Beginning with the operation of the target section of an image orthicon, we compute the number, e_t, of positive unit charges owing to the star radiation, stored on the target plate in any one element of resolution. The number e_t is, evidently, equal to the number of the photons, Q_s, arriving from the star onto any equivalent resolution element of the photocathode, multiplied by the photon to electron conversion yield of the photocathode, η_P, which is usually called the quantum efficiency of the photocathode, and the effective secondary emission yield multiple (S–1) of the target. (*See appendix, p. 145, for symbols.*)

$$e_t = Q_s \cdot \eta_P (S-1) \tag{1a}$$

And since $Q_s \cdot \eta_P$ is the number of electrons, e_s, emitted from the photocathode owing to the star radiation in any one element of resolution during the chosen unit of time

$$e_t = e_s (S-1). \tag{1b}$$

Now, Q_s is equal to the photon flux, Q_M, to which the lens area, $D^2\frac{\pi}{4}$, is exposed and which is concentrated upon the image area, $D_i^2\frac{\pi}{4}$, multiplied by the lens transmission coefficient, η_T, the area of a resolution element, $D_r^2\frac{\pi}{4}$, and the exposure time, t_e. Thus, the number of photons collected by each resolution element in the focal plane in the time t_e; i.e.,

$$Q_s = Q_M \cdot D^2\frac{\pi}{4}\eta_T \frac{D_r^2 \frac{\pi}{4}}{D_i^2 \frac{\pi}{4}} \cdot t_e. \tag{2a}$$

However, this equation is valid only if D_r is substantially smaller than the image diameter, D_i. If the resolution element were substantially larger than the star image, all of the photons collected by the photocathode would land inside the resolution element, and the equation would read:

$$Q_s = Q_M \cdot \eta_T \cdot D^2 \frac{\pi}{4}. \tag{2b}$$

To obtain an expression for Q_s, covering the entire range, we set,

$$Q_s = Q_M \cdot \eta_T \cdot t_e \cdot D^2 \frac{\pi}{4} \cdot \frac{1}{K} \tag{3}$$

where the "coverage factor," K, is included between 1 (unity) and

$$K = \frac{D_i^2}{D_r^2} \geqq 1 \tag{4}$$

the value of K for $D_r \approx D_i$ depends on the focal length of the employed optical system, effective angular resolution, angular size of the celestial body in case it

is a planet, etc., scintillations of the star image during the exposure time, and haze, as well as design limitation of the sensor. However, this equation is of particular practical interest, e.g., for matching the optical resolution of a telescope with the resolution of the sensor.

The number of positive charges stored on the target becomes, according to Eqs. (1) and (2)

$$e_t = Q_s \cdot \eta_P \cdot (S-1) = e_s(S-1) = Q_M \cdot D^2 \frac{\pi}{4} \eta_T \cdot \eta_P \frac{t_e}{K} (S-1) \tag{5}$$

where

$$Q_M = Q_o \cdot 2.512^{-M}, \tag{6}$$

and Q_o is the number of photons received on the telescope lens per unit area and time from a star of apparent magnitude number $M = \text{zero}$. Q_o depends upon the spectral composition of the star radiation For a radiation with a spectral distribution similar to the sun the number of photons per square meter second within the wavelength range between $0.29\ \mu$ and $1.45\ \mu$ is (Gebel, 1958)

$$Q_o = 8.7 \cdot 10^{10}. \tag{7}$$

According to elementary geometric optics, the star image diameter is zero, if the distance of the star can be considered infinite (point source), which is always the case with fixed stars. Actually, however, the image at the focal plane has a finite diameter, D_i, which is determined by one of the following phenomena, whichever yields larger values:

(*a*) *Diffraction effect:* According to a well known formula the diameter, D_i, in meters of the star image at the focal plane is

$$D_i = 1.22 \cdot 10^{-6} \cdot \lambda_{max} \cdot \frac{f_T}{D} \tag{8}$$

if the wave length, λ_{max}, is in μ (micron), f_T is the focal length of the telescope objective and f_T and D are in the same dimensions.

(*b*) *Atmospheric effect:* Owing to rapid fluctuations of the density gradiant of the atmosphere, the instantaneous star image rapidly oscillates about its average position, or due to scattering of the star light caused by haze, the average image of the star appears larger. According to Eq. (8), the apparent diameter, D_i, in meters of the star image is

$$D_i = \alpha \cdot f_T \tag{9}$$

where α is the apparent oscillation angle (in radians) of the light beam arriving from the star, or the increase of the stars angular size caused by scattering of the light due to haze, or the true angular size of the celestial object (planet, satellite, missile, etc.) and f_T is the focal length of the telescope objective in meters.

Obviously, Eq. (5) is valid only up to a certain apparent star magnitude, which may cause saturation in the device However, this is not important here because we shall consider only lower values of e_s since this paper is concerned principally with the value of the threshold magnitude which is possible to be detected.

According to the quantum theory, the scanning beam does not consist in a regular, homogeneous, flow of electrons, but of an irregular motion of individual electrons, each of which has a velocity more or less deviating from the average velocity. It is generally assumed and accepted as a rule, in accordance with statistical methods, that the root mean square of the electron current density fluctuations is, in the average, numerically equal to the square root of the mean electron current density. The same is usually assumed for the photon flux distribution.

Because of the velocity distribution in the scanning beam and the low velocity scan operation of an image orthicon only a fraction of the electrons in the scanning

beam fulfill the requirement necessary to land on the target plate and to discharge it. Also the percentage of electrons available in a beam for discharge is not a constant percentage but a direct function of the target charge. Hence, the return beam differs very little from the scanning beam and has, for operations with sufficient illumination available for optimum performance, an approximate value of 90% of the scanning beam, and at light levels below threshold of the image orthicon it becomes nearly 100% of the scanning beam.

Now, the number of electrons in the return beam, e_r, for the time duration the scanning beam is remaining on one resolution element may be assumed to be practically equal to the difference of the number of electrons in the scanning beam, e_{sc}, and the number of the stored positive charges, e_t, thus, the difference of two fluctuating quantities. This difference is a fluctuating quantity, too.

$$e_r = e_{sc} - e_t. \tag{10}$$

The ratio of the difference between the scanning beam, e_{sc}, and the return beam, e_r, to the scanning beam is usually called the orthicon beam modulation factor, m, where

$$m = \frac{e_{sc} - e_r}{e_{sc}}. \tag{11}$$

The usual value of this beam modulation factor under light conditions above threshold and a possible arrangement for determining it is treated in a supplement to this paper.

Since the scanning beam contains a much larger number of electrons than the number of stored positive charges existing on the target plate we will neglect, in the further calculations of Part I the fluctuations of the target plate charge and consider only the fluctuations of the scanning beam as the limiting factor of detection.

Now, it is evident that a small quantity, x, locally superimposed upon a fluctuating large quantity, $y \pm \Delta y$, will be easily confused with one of the fluctuation peaks, Δy, of the latter, if x is not substantially larger than the effective mean value, Δy_m, of the fluctuation. The latter was formerly shown under the used assumption, to be numerically equal to $y^{1/2}$. Thus, a necessary, but not necessarily sufficient, condition of detectability and assumed arbitrarily as threshold in this paper is

$$x = y^{1/2} \tag{12}$$

which, for our case, will require for the above assumed condition the expression

$$e_t = e_s(S-1) = e_{sc}^{1/2}, \tag{13}$$

where e_{sc} is the number of scanning beam electrons for each resolution element of the photocathode, and e_t the number of positive unit charges at the target plate. Obviously, the threshold or minimum detectable number of target charges will be smaller when fewer electrons are present in the scanning beam. However, the number of scanning beam electrons can only be reduced to a certain amount, because experience in operating image orthicons shows that there is a definite critical lower limit of the scanning beam current where, with a further reduction of beam intensity, regardless of the target charge, no modulated return beam seems to be produced, thereby establishing an operational threshold condition for the image orthicon. Above this threshold condition the minimum number of scanning beam electrons, e_{sc}, necessary to neutralize each specific target plate charge, e_t, is not obtained by multiplying e_t by a constant factor. This factor decreases as e_t increases.

$$e_{sc} = f(e_t). \tag{14}$$

By substituting Eq. (10) into Eq. (11) we obtain

$$m = \frac{e_t}{e_{sc}}. \tag{15a}$$

And in accordance with (14) and (15a)

$$m_{(e_t)} = \frac{e_t}{e_{sc}}. \tag{15b}$$

Since m is a function of e_t, and e_{sc} cannot be below a certain value or the image orthicon would not work at all, we are mostly interested in the smallest value of m, which we shall call the threshold modulation factor, m_{tr}, where we are still able to obtain usable information in the return beam with a signal to noise ratio in accordance with Eq. (12).

Now, we set as a criteria for further analysation for the threshold condition characterized by the mechanism by which the image orthicon operates in accordance to Eqs. (13) and (15).

$$e_t = e_{sc}^{1/2} = \left(\frac{e_{ttr}}{m_{tr}}\right)^{1/2} \tag{16}$$

where e_{ttr} is the smallest detectable number of charges at the target plate. Hence, the numerical value of m_{tr}.

$$m_{tr} = \frac{e_{ttr}}{e^2_{ttr}} = \frac{1}{e_{ttr}}. \tag{17}$$

This equation determines the threshold modulation factor, m_{tr}, for a signal to noise ratio in accordance to Eq. (12).

The time, t_e, necessary to collect a detectable target plate charge, e_{ttr}, may be calculated in accordance to Eqs. (5) and (17) for threshold conditions

$$m_{tr} = \frac{1}{e_{ttr}} = \frac{K}{Q_m \cdot D^2 \frac{\pi}{4} \cdot \eta_T \cdot \eta_P \cdot (S-1) \cdot t_e} = \frac{1}{Q_s \cdot \eta_P (S-1)} \tag{18}$$

From this equation we yield for the exposure time using a radiation similar to sunlight with Eqs. (6) and (7)

$$t_e = \frac{2.512^M \cdot K}{m_{tr} \cdot 8.7 \cdot 10 \cdot \frac{\pi}{4} \cdot D^2 \cdot \eta_T \cdot \eta_P (S-1)} \tag{19}$$

where t_e denotes the minimum exposure time necessary to collect on any resolution element of the target plate, a charge arbitrarily assumed detectable in accordance with Eq. (12).

To determine the threshold modulation factor of image orthicons used for this type of work the following calibration test may be made. The star is replaced by a light source of known intensity, thus replacing the star image on the photocathode with a spot of light. The spot size is controlled by masking the photocathode front glass with a diaphragm containing a very small aperture.

The illumination, I, of the photocathode by a light source of the intensity, C candles, at a distance of l feet from the diaphragm is

$$I = \frac{C}{l^2} \text{ft-c}. \tag{20}$$

According to accepted measurements, one foot candle radiating from a glowing body at 2870°K corresponds to 1.7×10^{18} photons per square meter second, for the spectral range between the wave lengths 0.29 μ and 1.45 μ

$$1\text{ft-c}_{2870°K} = 1.7 \cdot 10^{18} \frac{\text{photons}}{\text{m}^2 \text{ sec}}. \tag{21}$$

To approximately match the intensity of the illumination of the photocathode at the calibration to that produced by the star, a gray filter with constant attenuation factor of W is used. To establish the threshold condition, the distance between light source and diaphragm, and the scanning beam current is adjusted so that the average signal from the image of the diaphragm hole on the television screen is just detectable with a signal to scanning beam noise ratio as given by Eq. (12); at the same time, the scanning current must be kept on the verge of workability.

Under these conditions of the calibration test, the total number of photons, Q_e, absorbed by a resolution element of the photocathode becomes, according to Eqs. (2) and (21)

$$Q_e = 1.7 \cdot 10^{15} \cdot \frac{I}{W} \cdot D_r^2 \frac{\pi}{4} \cdot t_e \tag{22}$$

and using Eq. (4)

$$Q_e = 1.7 \cdot 10^{18} \frac{I \cdot D_r^2 \cdot \pi \cdot t_e}{W \cdot K \cdot 4}. \tag{23}$$

Hence, using Q_e from Eq. (22) in Eq. (18) we may compute

$$m_{tr} = \frac{4W}{1.7 \cdot 10^{15} I \pi D_r^2 \cdot \eta_P (S-1) \cdot t_e} \tag{24}$$

$$= \frac{7.5 \cdot 10^{-19} \cdot W}{I \cdot D_r^2 \cdot \eta_P \cdot (S-1) \cdot t_e}.$$

The easiest way to perform the callibration test is to scan the target plate continuously, therefore, in such a case t_e becomes the reciprocal value of the frame scanning rate, f_r, used for operating the image orthicon.

It must be kept in mind, however, that the threshold modulation factor m_{tr} found in Eq. (23) is valid only for the same conditions under which it was measured. A change in the frame scanning rate, bandwidth of the video amplifier, scanning beam width, etc. will effect the value of m_{tr}. The result is important because it serves later for determining the necessary preamplification in intensifier image orthicons. Further it is an important test result in itself, because the reciprocal value of m_{tr} represents the number of electrons in the scanning beam necessary to neutralize one positive charge at the target plate under assumed threshold conditions.

Numerical example I. Experimental determination of the threshold modulation factor:

A standard point light source (2870°K) with 8.7 candle power was placed at a distance of one foot before a wide spaced image orthicon RCA 73469, with a multialkali photocathode operated with a 2 Mcycles/sec bandwidth video chain. An aperture with a diameter of 0.155 mm was used. Threshold as defined in this paper was reached by placing a filter with an attenuation factor of 10^5 before the aperture.

The quantum efficiency of the photocathode was previously determined to be 0.006 for a color temperature of 2870°K by counting all the photons between λ min. 0.290 μ and λ max. 1.45 μ.

The secondary yield of the target plate was assumed to be 4. The area of the photocathode, 25 x 25 mm, was scanned continuously with 250 lines per frame with a non-interlaced frame rate of 40 per second.

$$D_r = \frac{25.10^{-3}}{250} = 10^{-4} \text{ m}.$$

Using Eq. (24) we find

$$m_{tr} = \frac{7.5 \cdot 10^{-19} \cdot 10^5}{8.5 \cdot (10^{-4})^2 \cdot 0.006 \cdot (4-1) \cdot \frac{1}{40}} = 2 \cdot 10^{-3}$$

which means the scanning beam has to have, for each charge to be neutralized at the target plate, 500 electrons to fulfill the above condition.

Since m_{tr} may be determined experimentally it is useful to rewrite Eq. (19) in order that, from this equation, we may determine the apparent star magnitude, M_{tr}, which may be sensed by the image orthicon under the threshold definition assumed by Eq. (12)

$$M_{tr} = 2.5 \log \frac{6.8 \cdot 10^{10} \cdot m_{tr} \cdot D^2 \cdot \eta_T \cdot \eta_P (S-1) \cdot t_e}{K} \tag{25}$$

However, it must be noted that this equation is not valid if the exposure time, t_e, is extended so far that the dark current emission and the emission caused by the sky background are not of a negligible order in comparison to the scanning beam noise. An equation treating the latter situation will be derived in Part II.

Numerical example II.

A telescope with a 10-in. aperture is used in connection with an image orthicon closed circuit television chain. m_{tr} was determined to be 0.002 for a sweep frequency of 40 frames, for the tube employed and the chosen arrangement. The target plate employed permits an effective storage of the charge for 1 second with an efficiency, η_{te}, of 50 percent. The transmission efficiency of the refractor telescope is 0.7. The photocathode efficiency is 0.04 for a spectral distribution similar to sunlight (λ 0.29 μ to 1.45 μ). The spectral distribution of the star to be recorded has a radiation similar to that of the sun. As a result of seeing conditions, the star image covers 10 resolution points of the photocathode. The secondary emission yield of the target plate is assumed to be 4. Then, from Eq. (25)

$$M_{tr} = 2.5 \log \frac{6.8 \cdot 10^{10} \cdot 0.002 \cdot 0.25^2 \cdot 0.7 \cdot 0.04 (4-1)(1 \cdot 0.5)}{10}$$

$$= 11.4$$

PART II

Image Orthicon with Intensifiers

In astronomical photography the primary reason for amplification is to increase sensitivity, so as to obtain a reduction of exposure time. If part of the amplification is ahead of the scanning process, it is called preamplification. In this case, the fluctuations (noise) of the photo-electron emission from the photocathode, plus the statistical and spontaneous fluctuation of the photocathode dark current, are amplified as well as the electron current due to the signal portion of the star radiation. To this preamplified primary noise is added the noise in the scanning beam. Then, the relative dominance of these two noises in the return beam determines which one is the limiting factor for detection. Which noise is dominant is affected by the amount of preamplification used.

Preamplification with intensifiers improves the detectability because very weak signals from the photocathode, provided they are stronger than the primary noise, can be amplified to such an extent that they are stronger than the scanning beam noise and, hence, can be detected. In pickup tubes without sufficient preamplification such weak signals would be weaker than the scanning beam noise and, therefore, unrecognizable. However, an unfavorable effect of preamplifier stages consists, usually, in an impairment of resolution. This raises objections to the use of too many cascaded preamplifier stages. This section of the report shows how to find a reasonable preamplification factor.

The secondary emission of the target plate is a kind of preamplification; however, in most cases it is insufficient. In the intensifier image orthicon (fig. 2) the photo-electrons impinge on one or more intensifier screens placed between the photocathode and the target plate. Each of these intensifier screens consists of several layers, including an aluminized phosphor layer and a contiguous photocathode. The phosphor layer reconverts the electronic image emitted by the

primary photocathode into an optical one, and the contiguous photocathode produces an amplified electronic image which is projected either upon the target plate or upon the next intensifier screen. In the present state of the art, the rate of preamplification of each intensifier screen may exceed 10; thus, a rate of 100 may be exceeded with two intensifier stages.

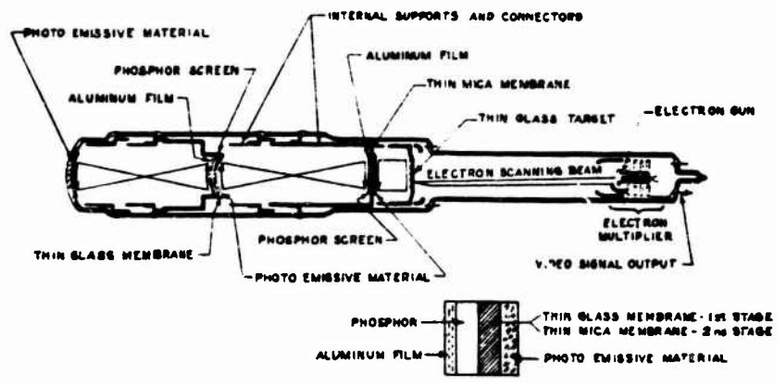

FIGURE 2. RCA two-stage intensifier image orthicon.

If, in Eq. (25), which computes the detectable star magnitude, M_{tr}, the preamplification factor, V, is incorporated, we obtain M'_{tr}.

$$M'_{tr} = 2.5 \log \frac{6.8 \cdot 10^{10} \cdot m_{tr} \cdot D^2 \cdot \eta_T \cdot \eta_P \cdot V(S-1)t_e}{K}. \tag{26}$$

This equation is valid as long as the emission caused by the sky background, e_B, plus the photocathode dark current emission, e_D, may be neglected because it is sufficiently smaller than the emission caused by the starlight, e_s. The fluctuations of e_s are also neglected in this equation.

The smallest detectable number of target plate charges, e_{ttr}, in accordance with Eq. (17), is the reciprocal value of the threshold modulation factor. Then, V has an upper limit, V_{lim}, because if one electron during the selected exposure time is released by the chosen area of resolution of the photocathode

$$V_{lim} \cdot (S-1) = \frac{1}{m_{tr}} = e_{ttr}, \tag{27}$$

then, by neglecting the fluctuations in the photocathode emission, this one electron would produce the necessary target charge to be detected in accordance with Part I.

Hence,

$$V_{lim} = \frac{1}{m_{tr} \cdot (S-1)}. \tag{28}$$

Since the validity of Eq. (26) is limited, it is of interest to find the preamplification factor, V_{max}, where the emission, e_n, which is the summation of the dark current emission, e_D, plus the emission, e_B, caused by the sky background radiation, Q_B, at the photocathode will be detected by selected exposure times by the threshold condition assumed in Part I. We may write for this condition the following equation:

$$e_n \cdot V_{max}(S-1) = e_{ttr} = \frac{1}{m_{tr}}, \tag{29}$$

where

$$e_n = e_D + e_B. \tag{30}$$

The number of electrons, e_B, caused by the sky background for the total exposure time occurring at any element of resolution may be derived as follows: If the brightness of the sky background, B_B, is known in foot-Lamberts, the illumination, E_B, at the photocathode is expressed by the following equation in foot-candles:

$$E_B = 0.25 \cdot B_B \cdot \frac{D^2}{f_T^2} \cdot \eta_T. \tag{31}$$

Since 1 ft-c from a source with a color temperature of the sun is equal to approximately $3 \cdot 10^{17} \frac{\text{Quanta}}{\text{m}^2\,\text{sec}}$, counting the photons for a range from $0.29\,\mu$ to $1.45\,\mu$, we may rewrite the equation for obtaining the flux of photons, Q_F, per m^2 sec at the focal plane as follows:

$$Q_F = 7.5 \cdot 10^{16} \cdot B_B \cdot \frac{D}{f_T^2} \cdot \eta_T; \tag{32}$$

and if e_B' is the number of electrons caused by the sky background emitted by the photocathode per mm^2 sec, we may write

$$e_B' = 7.5 \cdot 10^{10} \cdot B_B \cdot \frac{D^2}{f_T^2} \cdot \eta_T \cdot \eta_P. \tag{33}$$

Further, if A is the number of resolution elements per mm^2, the number of electrons, e_B, caused by the sky background and released by the photocathode at any element of resolution during the selected exposure time are

$$e_B = \frac{10^{-6} \cdot Q_F \cdot \eta_P \cdot t_e}{A}. \tag{34}$$

Eqs. (32) and (33) used in Eq. (34) yield

$$e_B = \frac{7.5 \cdot 10^{10} \cdot B_B \cdot D^2 \cdot \eta_T \cdot \eta_P \cdot t_e}{A \cdot f_T^2} = \frac{t_e}{A} \cdot e_B'. \tag{35}$$

If e_D' is the dark current of the photocathode per mm^2 sec (usually 2000 electrons per mm^2 sec for multialkali photocathodes at 300°K), we derive for the dark current emission component, e_D, released by any element of resolution during the chosen exposure time

$$e_D = \frac{e_D' \cdot t_e}{A}. \tag{36}$$

Eq. (30), by using Eqs. (33), (35), and (36), may then be rewritten

$$e_n = \frac{t_e}{A}\left(e_D' + 7.5 \cdot 10^{10} \cdot B_B \cdot \frac{D^2}{f_T^2} \cdot \eta_T \cdot \eta_P\right) \tag{37}$$

$$= \frac{t_e}{A}(e_D' + e_B').$$

If we designate with e_n' the emission per mm^2 sec from the photocathode not caused by the stars radiation, we may write for our assumption from Eq. (37)

$$e_n' = e_n \cdot \frac{A}{t_e} = e_D' + 7.5 \cdot 10^{10} \cdot B_B \cdot \frac{D^2}{f_T^2} \cdot \eta_T \cdot \eta_P. \tag{38}$$

Eq. (36) substituted in Eq. (29) yields, for the defined maximum preamplification factor, V_{max},

$$V_{max} = \frac{A}{t_e\, m_{tr}(S-1)\left(e_D' + 7.5 \cdot 10^{10} \cdot B_B \cdot \frac{D^2}{f_T^2}\eta_T \cdot \eta_P\right)} = \frac{A}{t_e \cdot m_{tr}(S-1)e_n'} \leqq V_{lim}. \tag{39a}$$

V_{max} of Eq. (39a) just permits detection of the photocathods emission, e_n, and shows that the maximum preamplification factor, V_{max}, decreases with an increase

of exposure time, an increase of photocathode dark current, and an increase of the telescope aperture.

In other words, small telescopes and cooled photocathodes will require a tube with a higher preamplification factor to reach the arbitrarily assumed threshold of Eq. (26) than larger telescopes such as the 200-in. reflector at Mount Palomer.

If, in Eq. (39) V_{max} becomes larger than V_{lim}, the exposure time, t_e, would be too short for the average emission, e_n, of the photocathode to produce one electron. However, a V larger than V_{lim}, by employing short exposure times, can be useful as long as the source to be detected causes a few electrons to be emitted for each area of resolution of the photocathode during the chosen exposure time.

Numerical example III.

A telescope with an aperture of 500 cm is used, and the original f/15 m is extended to an effective f/50 m. The pick-up tube is a two-stage intensifier image orthicon with a preamplification gain, V, of 100; the target mesh assembly is wide-spaced and a multi-alkali photocathode is used.

$$A = 100,\ \eta_T = 0.05,\ \eta_P = 2000 \text{ electrons/mm}^2 \text{ sec.}$$

$$m_{tr} = 0.002,\ S = 4,\ B_B = 10^{-4} \text{ ft-L.}$$

To determine the shortest exposure time just permitting detection of e_n in accordance with the definition of m_{tr} by rewriting Eq. (39) and $V = V_{max}$,

$$t_e = \frac{A}{V_{max} \cdot m_{tr}(S-1)(e_D' + 7.5 \cdot 10^{10} B_B \frac{D^2}{f_T^2} \cdot \eta_T \cdot \eta_P)} = \frac{A}{V_{max} \cdot m_{tr}(S-1)e_n'} \tag{39b}$$

$$= \frac{100}{100 \cdot 0.002 \cdot (4-1)(2000 + 7.5 \cdot 10^{10} \cdot 10^{-4} \cdot \frac{5^2}{50^2} \cdot 0.5 \cdot 0.05)} = 0.043 \text{ sec.}$$

Detection of Faint Stars in the Presence of a Sky Background Brighter than the Stars

In the situation expressed by Eq. (26), using V as expressed by Eq. (39), it was arbitrarily assumed that a limit in detection exists when the average photocathode current from the sky background and the average dark current just produces a detectable target charge, e_{ttr}.

As already explained in Part I, Eq. (12), the probability to detect a signal, x, superimposed over a fluctuating value, $y \pm \Delta y$, depends on the ratio $\delta = \frac{x}{\Delta y_{max}}$; and since we assumed a Poisson distribution for $y \pm \Delta y$, we must have $\delta = \frac{x}{y^{1/2}}$. It was assumed further that the "threshold" value of ratio δ is 1; i.e., the signal becomes detectable as soon as δ becomes 1, which is, of course, a rather favorable assumption. In reality, the probability of detecting a signal is a function of and increases asymptotically with δ.

The recording of celestial pictures using a telescope followed by a light amplifying system consists of a sequence of steps. The characteristic ratio, δ, may decrease after each step because of the possibility that fluctuations are introduced during such steps.

The ratio, δ, is a maximum for the number of photons from star radiations, Q_s, to the fluctuations in the number of photons from the sky background radiation, Q_B

$$\delta_{max} = \delta_{LF} = \frac{Q_s}{Q_B^{1/2}}, \tag{40}$$

where

$$Q_B = \frac{Q_F \cdot t_e}{A}. \tag{41}$$

After conversion of the light into electrons, δ is decreased because the conversion factor is smaller than 1 and the statistical fluctuations have to be calculated from the smallest number involved.

δ may be further decreased because of the possibility that noise is added in the amplifying system.

The first part dealt with a ratio of the target plate charge to statistical fluctuations in the scanning beam, δ_{sc}, neglecting all other noise sources and noted that

$$\delta_{sc} = \frac{e_t}{e_{sc}^{1/2}}. \tag{42}$$

Let us now assume the task of detecting a faint star against a much brighter, but homogeneous, sky background. It is possible, with an assumed ideal electronic device, to suppress the portion of the signal which corresponds to the average value of the sky background; but the statistical fluctuations in the signal from the background will determine the limit in detection. The probability, then, to detect the star radiation, with such an ideal arrangement, is a function of the ratio of the photocathode emission caused by the star to the statistical fluctuations in the emission caused by the sky background plus the photocathode dark current emission.

Consider the simplified condition

$$\delta_P = \frac{e_s}{e_n^{1/2}} \tag{43}$$

and neglect other noise sources. The signal, e_s, is constituted by the number of electrons produced by the radiation of the star for each resolution element during the chosen exposure time, t_e, while the fluctuations of e_n will be represented by the square root of the summation of the number of electrons caused by the radiation from the sky background plus the photocathode dark current emission. Evidently δ increases if e_s and e_n are multiplied by the same factor. This may be done by increasing the telescope aperture, by increasing the conversion yield of the photocathode, and also by extending the time duration of collecting photons. The latter is very important if stars with a radiation weaker than the background radiation of the universe have to be detected.

The fluctuation, $e_n^{1/2}$, in the photocathode emission, e_n, cannot be detected and, therefore, becomes the limiting factor, unless by employing preamplification the corresponding target charge fluctuations can be made sufficiently larger than the fluctuations in the scanning beam.

However, in view of the loss of resolution caused by the preamplifier stages, it is advisable to exceed only slightly that degree of preamplification at which the threshold of detectability due to scanning beam noise becomes equal to the fluctuations in the conversion at the photocathode of the sky background radiation plus the fluctuations of the dark current. Thus, the "critical" preamplification factor, V_{crit}, recommended is that for which the bottleneck for detectability changes over from the limitations determined by the scanning beam fluctuations to that of the photoelectron transformation plus dark current fluctuations, if the noise sources after the scanning process may be neglected.

Therefore, we may write the following equations in accordance with Eq. (13).

$$e_n^{1/2} \cdot V_{crit} = e_{sc}^{1/2} = \left(\frac{e_t}{m}\right)^{1/2} \tag{44}$$

$$V_{crit} = V'_{crit}(S-1). \tag{45}$$

Furthermore, since

$$e_n \cdot V_{crit} = e_t, \tag{46}$$

we may rewrite Eq. (44)

$$e_n^{1/2} \cdot V_{crit} = \left(\frac{e_n \cdot V_{crit}}{m}\right)^{1/2}.$$

Hence,

$$V'_{crit} = \frac{1}{m(S-1)}. \tag{47}$$

But since m is a function of e_t, V'_{crit} becomes a function of e_n. Also, the smallest possible value by definition for m was m_{tr} and, hence,

$$V'_{crit\ max} = \frac{1}{m_{tr}(S-1)}. \tag{48}$$

This equation corresponds to Eq. (28) and is logical because the smallest detectable number of charges at the target plate is $\frac{1}{m_{tr}}$, and if $V_{crit} = \frac{1}{m_{tr}}$, this charge would be caused by one electron, and the fluctuation would be $1^{1/2} = 1$, which is 100 percent, thereby making the fluctuations of e_n at the target plate equal to the fluctuations of e_{sc}.

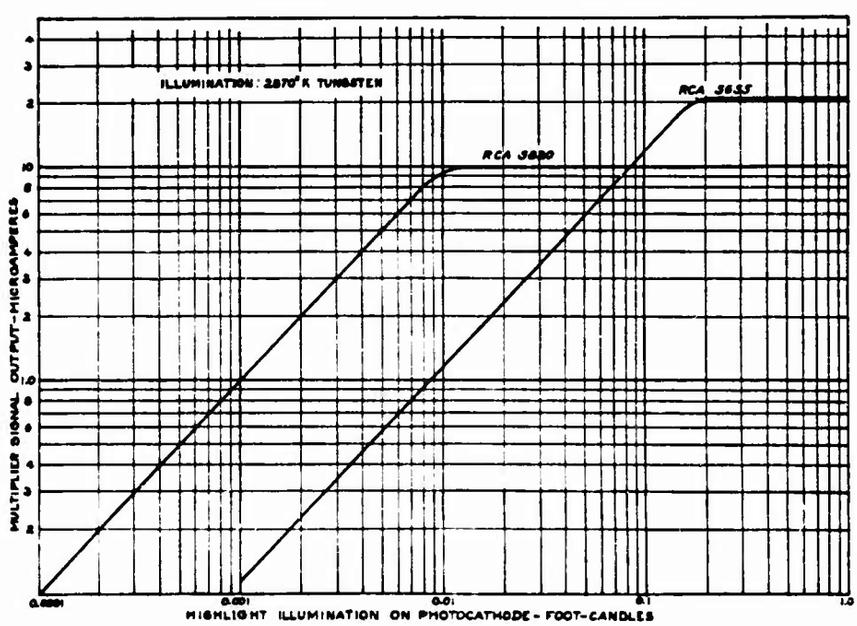

FIGURE 3. Typical signal output characteristics for image orthicon RCA 5655 and 5820.

Since, in accordance with statistics, the detectable percentage change in the average number of charges between the different resolution elements of the target plate depends on the total average number of charges involved, the target plate should have a storage capacity as large as possible. However, since the statistical fluctuations that occur are determined by the smallest number of particles involved, which is expressed in our case by the ratio, δ_P, for the condition of the emission at the photocathode, preamplification should be used only in as far as it increases the target charge sufficiently to overcome the scanning beam noise. Use of a

higher preamplification factor will not produce a gain in detection; on the contrary, the target plate will become saturated unnecessarily fast, which means that the otherwise permissible longer exposure time is shortened. However, for a given astronomical instrumentation and for a given δ_P in Eq. (41), e_s has to be increased only by the half power of e_t, or, if the exposure time is extended by a factor one hundred, a star ten times fainter can be detected (a gain of 2.5 magnitudes).

In reference to the foregoing it is, therefore, necessary to investigate, for the present state of the art, the maximum number of charges, $e_{t\ max}$, that can be stored on an image orthicon target plate.

The RCA image orthicon 5655 has a very close-spaced target plate where the meshwire is nearly in contact with the target plate. Charge saturation of the target plate of an image orthicon is indicated by the knee of the light transfer characteristic curve. The knee of the 5655 characteristic is at a highlight illumination, E_K, of 0.2 ft-c ($\lambda = 290 m\mu$ to 1.45 μ; sunlight) (fig. 3) on the photocathode. Hence, the following number of charges, $e'_{t\ max}$, during each frame of scanning which may be stored at the target plate for each mm² photocathode area exposed, just reaching saturation is

$$e'_{t\ max} = \frac{E_K \cdot 3 \cdot 10^{11} \cdot \eta_P \cdot (S-1)}{f_r}, \tag{49}$$

and in the case for the 5655 image orthicon target plate, the maximum number of stored charges per mm² area of the photocathode during the exposure time would be

$$e'_{t\ max} = \frac{0.2 \cdot 3 \cdot 10^{11} \cdot 0.03 \cdot (4-1)}{30} = 1.8 \cdot 10^8. \tag{49a}$$

The 5655 orthicon has a beam modulation factor, m_{max}, of 10% if operated at the knee. The secondary emission yield is 4.

Therefore, in accordance with Eq. (47), the critical preamplification factor for making the background noise equal to the beam noise for a target plate as the 5655, if operated at the knee, is

$$V'_{crit(5655)} = \frac{1}{m(S-1)} = \frac{1}{0.1(4-1)} = 3.3, \tag{49b}$$

which can easily be achieved with the present state of the art in making intensifier stages.

The maximum permissible photocathode emission, e'_n, per mm² sec caused by the stray light and the dark current, which will just start to saturate the target plate of a tube using preamplification for overcoming the scanning beam noise, will in accordance with Eq. (46) and Eq. (48) be

$$e'_n = \frac{e'_{t\ max}}{V'_{crit}(S-1)t_e}; \tag{50}$$

and by using Eqs (45), (42) and (50), assuming perfect storage, we may equate for the maximum exposure time, $t_{e\ max}$, in seconds that produces a target plate charge just leading to saturation

$$t_{e\ max} = \frac{e'_{t\ max}}{V'_{crit}(S-1) \cdot e'_n} = \frac{e'_{t\ max} \cdot m}{e'_n}. \tag{51}$$

Numerical example IV.

An intensifier image orthicon is used with a telescope having a 500-cm aperture and a 50-m effective focal length. The target plate-meshwire arrangement is similar to that in the 5655 orthicon with an $e'_{t\ max}$ of $1.8 \cdot 10^8$; and it is assumed that the target plate can store and integrate over several hours without loss of resolution, that the beam modulation factor at the knee is 10%, and that the

secondary emission yield is 4. Then, from Eq. (47) for numerical values of e'_D, B_B, η_T, η_P, as in example III

$$V'_{crit}=\frac{1}{m(S-1)}=\frac{1}{0.1(4-1)}=3.3.$$

Then, according to Eq. (38)

$$e'_n=(2000+7.5\cdot 10^{10}\cdot 10^{-4}\frac{5^2}{50^2}\cdot 0.5\cdot 0.05)=3875,$$

and from Eq. (51)

$$t_{e\ max}=\frac{1.8\cdot 10^8\cdot 0.1}{3875}=4650\text{ sec.}$$

The star magnitude which can be recorded under the previous assumptions by the present state of the art with an intensifier image orthicon in the presence of the sky background and the photocathode dark current for a chosen δ_P may be derived by rewriting Eq. (43)

$$e_s=\delta_P\cdot e_n^{1/2}.$$

Using Eq. (5) for e_s in the above

$$Q_m\cdot D^2\cdot\frac{\pi}{4}\cdot\eta_T\cdot\eta_P\cdot\frac{t_e}{K}=\delta_P\cdot e_n^{1/2}. \tag{52}$$

In accordance with Eq. (46) we may write

$$e_n=\frac{e_{t\ max}}{V'_{crit}(S-1)}=\frac{e'_{t\ max}}{A\,V_{crit}}. \tag{53}$$

Substituting for e_n in Eq. (52) with Eq. (53), by neglecting the much smaller additional charge caused by the star radiation which is also stored on the target plate, we find for Eq. (52)

$$Q_M\cdot D^2\cdot\frac{\pi}{4}\cdot\eta_T\cdot\eta_P\cdot\frac{t_e}{K}=\delta_P\left(\frac{e'_{t\ max}}{A\cdot V'_{crit}(S-1)}\right)^{1/2}. \tag{54}$$

Substituting t_e with Eq. (51) gives

$$\frac{Q_M\cdot D^2\cdot\frac{\pi}{4}\cdot\eta_T\cdot\eta_P\cdot e'_{t\ max}}{K\,V'_{crit}(S-1)e'_n}=\delta_P\left(\frac{e'_{t\ max}}{A\cdot V'_{crit}(S-1)}\right)^{1/2},$$

and rewriting this yields

$$Q_M\cdot D^2\cdot\frac{\pi}{4}\cdot\eta_T\cdot\eta_P\cdot\frac{e'^{\,1/2}_{t\ max}\cdot A^{1/2}}{K\,[V'_{crit}\cdot(S-1)]^{1/2}\cdot e'_n}=\delta_P. \tag{55}$$

Assuming radiation similar to sunlight and $\lambda=0.29\ \mu$ to $1.45\ \mu$, we may substitute Q_M in Eq. (55) in accordance with Eqs. (6) and (7) with

$$Q_M=\frac{8.7\cdot 10^{10}}{2.512^M}.$$

Then, we find for the faintest magnitude which can be detected using an intensifier image orthicon with the assumptions previously made,

$$M_{limit}=2.5\log\frac{6.8\cdot 10^{10}\cdot D^2\cdot\eta_T\cdot\eta_P\cdot e'^{\,1/2}_{t\ max}\cdot A^{1/2}}{\delta_P\cdot K\,[V'_{crit}(S-1)]^{1/2}e'_n}. \tag{56}$$

This equation contains no factor for the exposure time, because the exposure time cannot be extended beyond the storage capability of the target plate; however, it is assumed that the correct exposure time is available for just collecting the necessary maximum charge, $e'_{t\ max}$. The value for this exposure time may be

calculated by using Eq. (51), and exposure beyond this value will not detect a fainter magnitude star, due to saturation of the target plate.

Numerical example V.

In numerical example IV the theoretical maximum exposure time was calculated to be 4650 sec. The faintest apparent star magnitude may then be calculated with Eq. (56), assuming $\delta_P = 2$ and a coverage factor of 5 resulting from air scintillations. Hence,

$$M_{limit} = 2.5 \log \frac{6.8 \cdot 10^{10} \cdot 5^2 \cdot 0.5 \cdot 0.05 \cdot (1.8 \cdot 10^8 \cdot 100)^{1/2}}{2 \cdot 5\,[3.3 \cdot (4-1)]^{1/2} \cdot 3875} \approx 27.$$

It may be of interest to determine as a figure of merit, the theoretical magnitude, M_{FM}, which could be achieved if there were no sky background radiation. If one assumes sufficient storage of the charge image, the determining factor for the limiting magnitude would then be the photocathode dark current emission, e_D', which may be assumed to be reduced by cooling to 35 electrons/mm² sec. Then, if

$$e_r' = e_D' = 35;\ \delta_P = 1;\ K = 1;\ D = 5;\ \eta_T = 0.5;\ \eta_P = 0.05;$$
$$A = 100;\ V_{crit} = 10;$$
$$M_{FM} = \frac{6.8 \cdot 10^{10} \cdot 5^2 \cdot 0.5 \cdot 0.05 \cdot (1.8 \cdot 10^8 \cdot 100)^{1/2}}{1 \cdot 1 \cdot 10^{1/2} \cdot 35} \approx 34.$$

The previous calculations were made assuming maximum performance, where the tube is operated at the knee of the light transfer characteristic, which means that the target plate is just approaching saturation. It is now of interest to calculate for a more practical situation the apparent star magnitude M_{pract}. This is the situation where the amount of star light available and the chosen exposure time will determine a point of operation below the knee of the charge transfer characteristic; i.e., below saturation of the target plate. From Eqs. (38) and (52) we may write (for radiation similar to sunlight),

$$\frac{8.7 \cdot 10^{10}}{2.512^M} \cdot D^2 \cdot \frac{\pi}{4} \cdot \eta_T \cdot \eta_P \cdot \frac{t_e}{K} = \delta_P \cdot e_n^{1/2} = \delta_P \left(\frac{e_n' \cdot t_e}{A}\right)^{1/2}$$

and from this the apparent star magnitude

$$M_{pract} = 2.5 \log \frac{6.8 \cdot 10^{10} \cdot D^2 \cdot \eta_T \cdot \eta_P \cdot t_e^{1/2} \cdot A^{1/2}}{\delta_P \cdot K \cdot e_n'^{1/2}}. \tag{57}$$

Numerical example VI.

A telescope with a 10-in. aperture and a f/15 m is used with an intensifier image orthicon system. Perfect storage and tracking is assumed for an exposure time of 30 min. $e_D' = 2000$ electrons/mm² sec.

$$B_B = 10^{-4}\ \text{ft-c};\ \eta_T = 0.5;\ \eta_P = 0.05;\ m = 0.05.$$
$$A = 100;\ K = 5;\ \delta_P = 2;\ S = 4.$$

Hence, from Eq. (38)

$$e_n' = 2000 + 7.5 \cdot 10^{10} \cdot 10^{-4} \cdot \frac{0.25^2}{15^2} \cdot 0.5 \cdot 0.05 = 2052;$$

and the maximum charge at the target plate from the dark current plus the background, from Eq. (51) is

$$e_{t\,max}' = \frac{e_n' \cdot t_e}{m} = \frac{2052 \cdot 1800}{0.05} = 7.4 \cdot 10^7 \frac{\text{charges}}{\text{mm}^2}.$$

This value is possible with a target plate mesh assembly like that in the 5655, and the star magnitude calculated as in Eq. (57).

$$M_{pract} = 2.5 \log \frac{6.8 \cdot 10^{10} \cdot 0.25^2 \cdot 0.5 \cdot 0.05 \cdot (1800 \cdot 100)^{1/2}}{2 \cdot 5 \cdot 2052^{1/2}} \approx 20.$$

The preamplification necessary is in accordance with Eq. (47)

$$V'_{crit} = \frac{1}{m \cdot (S-1)} = \frac{1}{0.05 \cdot (4-1)} = 6.6,$$

which is easily achieved by the present state of the art, with a single stage intensifier image orthicon.

CONCLUSIONS

The previous calculations demonstrate the theoretical possibility to photograph faint celestial bodies of 34th magnitude. The faintest star ever recorded with an image device was of 24th magnitude and this was achieved with the 200-in. Mount Palomar reflector. The necessary specifications of the intensifier image orthicon are feasible with our present technological knowledge. However, different telescope arrangements, tasks, and exposure times require different tube specifications. The most important feature of the pick-up tube, for such an endeavor, is the storage target plate. The target plate must have the same, or higher, capacity as the target plate of the R.C.A. 5655 image orthicon, and permit effective storage and integration of the charge image over at least 80 minutes with a negligible loss of resolution or charge. Such a target plate is possible with the present technological knowledge; and further directed research should lead to the desired results, thereby permitting mankind the efficient detection of artificial earth satellites and the penetration deeper into the mysteries of space.

ACKNOWLEDGMENT

This paper was accomplished under Project 7072, Task 70827, "Light Amplification," at the Aeronautical Research Laboratory, Wright Air Development Division, Dayton, Ohio. I wish to express my sincere thanks to Mr. Philip von Doepp for helpful criticism and discussions, and to Mr. Roy Hayslett for helpful suggestions and performing the threshold measurements of the image orticon on which the calculations in this paper are based. To Dr. Max Scherberg gratitude is expressed for technical review and helpful criticism.

APPENDIX—LIST OF SYMBOLS

- A Number of resolution elements per square millimeter at photocathode.
- B_B Brightness of sky background in foot-Lamberts.
- C Candle power of light source used for calibration test.
- D Diameter of telescope lens in meters.
- D_i Diameter of star image at focal plane (photocathode) in meters.
- D_r Diameter of one resolution element at focal plane in meters.
- E_B Illumination of photocathode in foot-candles caused by sky background.
- E_K Illumination of photocathode in foot-candles resulting in an operation of the image orthicon at the knee of the light transfer characteristic.
- I Illumination of photocathode in foot-candles for calibration test.
- K Coverage factor, indicating the number of resolution elements the star image occupies.
- M Apparent magnitude number of celestial body involved.
- M_{limit} Faintest apparent star magnitude detectable with the intensifier image orthicon depending on storage capability of target plate assuming optimum exposure time.
- M_{pract} Apparent star magnitude detectable with intensifier image orthicon using selected exposure time that operates image orthicon below knee of light transfer characteristic.
- M_{FM} Faintest apparent star magnitude theoretically detectable with the intensifier image orthicon by assuming ideal conditions, cooling the photocathode, and neglecting sky background radiation.

M_{tr} Apparent star magnitude by neglecting background and dark current emission just producing detectable charge at target plate with image orthicon.

M'_{tr} Same as M_{tr}, but for intensifier image orthicon under defined conditions.

Q_B Number of photons arriving from sky background onto any resolution element of the photocathode during selected exposure time.

Q_F Photon flux at focal plane per square meter·second.

Q_M Photon flux of star radiation per square meter·second for apparent star magnitude M.

Q_o Number of photon per square meter·second for apparent star magnitude O.

Q_s Number of photons from star radiation onto any resolution element occuring during selected exposure time.

S Secondary emission factor of target plate.

S−1 Effective secondary emission yield multiple of target plate.

V Preamplification factor of intensifier stages.

V_{crit} Critical preamplification factor of intensifier stages including gain by secondary emission at target mesh wire assembly, where fluctuations of e_n are equal to fluctuations of e_{sc}.

V'_{crit} Critical preamplification factor of intensifier stages.

V_{lim} Preamplification factor before target meshwire structure to produce at target plate a detectable charge caused by one electron emitted by the photocathode.

W Attenuation factor of gray filter used for calibration test.

e_B Number of electrons emitted by the photocathode caused by sky background radiation occurring for any element of resolution during selected exposure time.

e'_B Number of lectrons of photocathode emission per square millimeter per second exposure time caused by sky background radiation.

e_D Number of electrons of dark current emission from photocathode occuring at any element of resolution during selected exposure time.

e'_D Number of electrons of dark current emission from photocathode per square millimeter area per second exposure time.

e_n Number of electrons emitted by the photocathode that are not due to star radiation, but caused by sky background plus dark current emission occurring for any element of resolution during selected exposure time.

e'_n Number of electrons of photocathode emission per square millimeter per second exposure time caused by sky background radiation plus dark current emission.

e_r Number of electrons in image orthicon return-beam during selected time the scanning beams remains on one element of resolution.

e_s Number of electrons emitted by the photocathode owing to star radiation for any one element of resolution during selected exposure time.

e_{sc} Number of electrons of the scanning beam during the selected time the scanning beam remains on one element of resolution. The time the scanning beam remains on one resolution element is not identical with the exposure time.

e_t Number of positive unit charges on the target plate in any one element of resolution during selected exposure time.

$e'_{t\,max}$ Number of positive unit charges at target plate per equivalent square millimeter area of photocathode operating the image orthicon at knee of light transfer characteristic.

e_{ttr} Smallest detectable number of positive unit charges on the target plate.

f_T Focal length of telescope in meters.

f_r Frame scanning rate of image orthicon.

l Distance of light source in feet; used in calibration test.
m Orthicon beam modulation factor.
m_{tr} Threshold beam modulation factor as defined in paper.
t_e Selected time duration photons are collected, (exposure time) in seconds.
$t_{e\,max}$ Exposure time that causes a charge at target plate which operates image orthicon at knee of light transfer characteristic.
α Apparent angle of oscillation of the light beam arriving from the star, or increase in the stars angular size caused by scattering of the light due to haze or true angular size of the celestial objects (e.g., planets satellite, missile etc. in radians.
δ Ratio of signal caused by star radiation to root mean square value (fluctuation) of signal portion not due to star radiation.
δ_{LF} Ratio of number of photons from star radiation to root mean square value of number of photons from sky background.
δ_P Ratio of number of electrons emitted by the photocathode owing to star radiation to root mean square value of number of electrons emitted by the photocathode that are not due to star radiation.
δ_{sc} Ratio of number of charges at the target plate to root mean square value of number of electrons of the scanning beam which occur during the time the scanning beam rests on one element of resolution.
η_P Photocathode quantum efficiency = average photon to electron conversion yield of photocathode.
η_T Transmission factor of the telescope lens.
η_{te} Efficiency factor for storage capability of target plate.
λ Wavelength of light sensed in μ.

LITERATURE CITED

Gebel, R. K. H. 1958. Daytime detection of celestial bodies using the intensifier image orthicon. WADC TN 58-324. OTS release.