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APPLICATION OF ELECTRO OPTICS TO AURORAL STUDIES

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General Electric Company
Advanced Technology Laboratories
Schenectady, New York

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Prepared for

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OFFICE OF AEROSPACE RESEARCH
UNITED STATES AIR FORCE
BEDFORD, MASSACHUSETTS

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TABLE OF CONTENTS

PHOTOGRAPHS AND ILLUSTRATIONS

ABSTRACT

During 1963 an investigation was performed to examine the feasibi-
lity of obtaining information on the changing characteristics of the aurora
and night air glow by low-light-level image orthicons (I.O.) at the Radio-
Optical Observatory of the General Electric Company's Advanced Technology
Laboratories in Schenectady, New York. Although it was a poor year for auroras,
movies and spectral lines were simultaneously photographed of various displays
from the I.O. monitor, and were compared with photographs taken by other
people. The image orthicon is faster by about three orders of magnitude than
photographic film. Night air glow spectra were adequately received with
8 second exposures, with 100 photons sufficient to record a line, even
considering grating loss, etc.

A detailed discussion on image orthicon utilization with weakly
illuminated point, line and extended sources is given, along with the
theoretical and practical limitations on dynamic range, intensity, calibrations,
spectrograph wavelength calibration, and signal-to-noise ratio.

1.0 INTRODUCTION

This document is the final report covering the work done for the Air Force Cambridge Research Laboratories, Electronics Systems Division, by the General Electric Company under Contract AF19(628)-2366. Within the General Electric Company, the work was sponsored by the Heavy Military Electronics Department, Syracuse, New York and was carried out by the Advanced Technology Laboratories, Schenectady, New York.

Four quarterly reports were submitted during the interim period of this contract. This final report describes the Radio-Optical Observatory and cor letely covers the pertinent studies, experiments, and results relating to air glow and aurora that have been conducted throughout the 12 month study period. Included is an analysis of the theory and limitations on the utilization of a low-light-level, closed circuit image orthicon system to obtain real time "movies" and "spectra."

2.0 WORK OBJECTIVES

The objective of the study as outlined in the Statement of Work is as follows:

"The Contractor shall supply the necessary personnel, facilities, services, and materials to accomplish the following:

1) To utilize an image orthicon and auroral spectrograph for studies of aurora and night air glow spectroscopy and attempt to obtain time resolution of changing features.

2) To utilize an image orthicon and filters for real time auroral photography to cover the visual region and near UV and IR in order to obtain information on the faster auroral motions; and also to obtain data as the brightness of the aurora drops below the visual level."

3.0 SUMMARY AND CONCLUSIONS

This study has resulted in a greater understanding of the application of an image orthicon to astronomy; particularly with respect to aurora borealis, night air glow, spectroscopy, and related low-light-level uses.

The signal-to-noise ratio for an extended object varies in an approximately linear fashion with the signal imaged on the image tube; the noise level is determined by the beam current required to discharge the highlights and provide the desired dynamic range. However, if the image is a point source, decreased beam current can lower the noise level, and beam bending can discharge the two dimensional spot, with a resultant increase in signal-to-noise ratio. Included in the beam bending effect is a larger apparent size of the point object, the area of which is a function of the intensity of the source. It has been found that the product of the area and the signal is roughly directly proportional to the light signal. An extended line source produces an effect equivalent to that of the point source. Although beam bending occurs from only two sides of the line, the correlation from scan line to scan line makes up for the dimensional loss.

Presently a dynamic range of approximately 200 is possible in at least 20 resolvable steps, and this range can easily be doubled or possibly tripled by the use of beam feedback or other techniques. Basically the dynamic range is limited by the weak beam current required for low light level detection. Another difficulty arises in detecting two bright, very close lines or a faint one near a bright one. The only method that has appeared fruitful for the solution of this problem is to vary the target voltage with the readout beam. Dynamic range and intensity calibration are intermixed, but if the equipment has reached stable equilibrium and the target and beam voltage are held fixed, intensity calibration can be held for a long time.

3

Wavelength calibration to an accuracy of 0.1%, is simple and is limited by the broadening of bright lines; this broadening is not necessarily symmetrical.

Normally 100 photons are sufficient for the detection of a line or point source. Estimates place our image orthicon photographs at least 1000 times faster than that of any photograph. A good comparison of the picture quality has been impossible because of the weak auroras during 1963 and their changing characteristics with time. Night air glow spectra, for instance, can be obtained with a 16 second integration on the tube. If a peak aurora should have been observed, certainly a continuous scan rate of 1/30 second could have been used to practically stop its time-varying characteristics.

4

The Radio-Optical Observatory

Figure 4.0-1

4.0 DESCRIPTION OF FACILITIES, EQUIPMENT AND PERSONNEL

The Radio-Optical Observatory of the Advanced Technology Laboratories (previously known as the General Engineering Laboratory) is located about seven miles west of the Schenectady General Electric plant, at an elevation of 1320 feet above mean sea level. The geodetic coordinates are 42° 50' 53" north latitude, 74° 04' 15" west longitude. It is one of the highest points in Schenectady County and has an almost unobstructed view of the horizon in all directions. This installation (figure 4.0-1) is a Company-owned facility used for a wide variety of experiments to gain new knowledge of propagation characteristics and to test new equipment, detectors, and techniques for the many aspects of space communications. The combination of radio and electro-optical facilities provides an opportunity for simultaneous radio and optical experimentation and tracking which is believed to be unique.

4.1 Radio Section

The Radio Section operates a 28 foot paraboloidal reflector antenna with a linearly polarized log-periodic feed that is rotatable. The servo mount for the 28 foot dish provides $1/4^\circ$ pointing accuracy in both azimuth and elevation with provision for either manual or programmed tracking of space vehicles. The present receiving equipment covers VLF to 1200 Mc, with a receiver sensitivity of -150 dbm at 960 Mc and as small as 20 cps bandwidth when used in the phase-lock system mode. Presently the radio receiving and measuring system has a resolution of better than 1 part in 10^{10}, or 0.04 cps at 400 Mc.

A few of the past accomplishments in the radio area include:

*The design and development of a parametric amplifier, easily tunable over 350-1200 Mc with a stable gain of 15 db, a bandwidth of 150-700 kc, and a noise figure of less than

6

2 db, which was used in tracking space probe Mariner to a
distance of over 8 million miles.

*The investigation of highly accurate experimental and
mathematical techniques, and methods of instrumentation,
for the position determination of earth satellites and
other space vehicles. Accuracy checks were made to
determine the feasibility of orbit determination by
Doppler means. Included are navigation satellite
studies, and space probe frequency determinations of
high accuracy.

*A lunar reflection study in which signals were analyzed
for spectral content, fluctuations, and coherent band-
width; performed for and in cooperation with AFCRL.

*The measurement of signal strength, Doppler shift,
and distortions introduced by the ionosphere on
signals reflected from the Echo satellite and from
the Shotput series of balloons launched from Wallops
Island.

4.2 Observatory Interests in the Optical Area

From a modest beginning in 1959, the Observatory has grown physically
and the areas in which it works have broadened. The most important factor in
this growth has been the emphasis on correlating the results of direct experi-
ment to theoretical expectations, and the determination of empirical data on
which to base further theoretical analysis and to indicate the direction that
investigation must take. Optical investigations are currently in progress in
the areas of image size and degradation, seeing, and precision position measure-
ment.

7

Extensive tests have been made to determine the limiting magnitude and signal-to-noise ratio of an image orthicon when used with star fields. John Spalding has compared signals from known star fields and determined that our low-level television chain has an NEP of about 1.4×10^{-15} watts (visual). In other words, approximately 20 photons are necessary to produce a noticeable signal (S/N =1) without any special noise rejection circuits. Many of these results have been reported in General Electric Photoelectric Observatory Reports Nos. 1, 4, and 5, and Image Orthicon Signal to Noise Evaluation reports.

A test of our efforts in low level detection came on September 3 and 4, 1962 when we detected asteroid 1627 Ivar with a 12" f/16 Cassegrain reflector and a 500 line scan on a Z5396 image orthicon. Nominally Ivar is 15.5 magnitude at zenith, but detection occurred at a very low elevation where the object was near 18th magnitude under poor seeing conditions, where 10 to 20 second exposures were required with the $1/2^{\circ}$ field of view.

In addition to work with star fields a number of other applications of image orthicons have been experimented with. The Observatory obtained the first photographs showing the development of meteors and meteor trains using an image orthicon, and meteor train spectra have also been obtained. This work, which began in 1960, has since been continued, and has been reported in several papers at meetings of the American Astronomical Society and in the reports of the Smithsonian Astrophysical Observatory. The work has been noted in "Meteor Physics and Engineering" by McKinley and in Vol. IV of "The Solar System" edited by G. Kuiper. A full report on these activities has not been issued, but one is planned in the near future.

In 1960 the Observatory obtained, again using an Image Orthicon, the first real time photographs (moving pictures) of a flaming aurora. This work has been continued to the point where spectra of night air glow and aurora are

8

obtained in one to twenty seconds, and changes are detected that were not previously possible with photographic techniques. The complete report on this topic is discussed in the Results Section of this document. A number of firsts have been established in this area, and work is progressing rapidly.

The Observatory has long been interested in the problem of detecting a dim object that is moving with respect to a highly populated star field. A storage tube with 1000 TV lines of resolution is used to store a number of integrated frames of I.O. video information, and succeeding TV scans are compared so that all stationary objects cancel and moving objects will produce a spot on the monitor. This work has been reported in General Electric internal report TIS 63GL37, "Television Moving Target Indicator," by T. H. Klotz. A cancellation of star field by the use of photographic negatives to reveal moving objects and variable stars has also been successful.

As soon as one approaches the limit of detectors, the topic of "seeing" becomes important. The fundamental limits imposed on an optical system by the atmosphere are of such a nature that a 20" aperture telescope is as precise as a 200" one so far as position determination is concerned; a way in which this limitation might be circumvented is by using the short exposure times possible with a sensitive image orthicon. Movies of the Schlieren patterns that cause stellar scintillation have been made, and much data has been collected on image distortion and dancing. A discussion of the problems involved, and early work in this area included in Photoelectric Observatory Reports #3 and #4. Work in this area has continued and will be explained in other reports now in preparation. Recent work has dealt especially with laser and horizontal path propagation, and with correlation with a parallel ultrasonic beam. Some of this work has been reported in various General Electric laser symposia. With the installation of the new 16" telescope and its mounting, it is hoped that this work can be extended into next year (1964).

9

Another area of experimentation with image orthicons is exemplified by work done with the Meridian Circle at Dudley Observatory. This was reported in Photoelectric Observatory Report 2, and it is hoped that further contributions can be made. Positions of stars have been measured with a precision of 0.1 second of arc.

Image orthicons have played a dominant part in what has been mentioned to this point, except for the seeing experiments where they played a secondary role. Other detectors have not been slighted, however. The Observatory has experimented with image intensifiers, photomultipliers, and photographic plates.

4.3 Facilities and General Equipment

The Observatory now has two moderate aperture telescopes and over 1500 square feet of modern, well-equipped working space which includes a dark room, a central control room, offices, and laboratories. The facilities include such excellent equipment as a densitometer, a film viewer, and earth-sky radiometer, a measuring engine, a gas laser, Textronix oscilloscopes, a tunable microvoltmeter, and other usual instrumentation. Recorders include a 7-track Ampex DC to 100 kc magnetic tape, and DC pen recorders with cut-off responses from 0.1 cps to 100 cps, such as the 4 channel Sanborn. An oscillator gives stable time to 5 parts in 10^{10} per day, in conjunction with VLF receivers. Time is set to approximately 1 millisecond with CHU or WWV.

Types of available amplifiers range from DC amplifiers of high or low input impedance with variable bandwidths as high as 10 Mc, to AC amplifiers with a flat frequency response over the range of 15 cps to 15 Mc. Pulse amplifiers to 100 Mc are also available.

4.4 Telescopes

a) 16" Telescope

Installation of a 16" Boller and Chivens telescope in the new 16 foot Fiberglas dome will soon be completed. This telescope was chosen from

10

the standpoint of operating convenience and stability, rather than aperture, and is similar in design to the smaller telescopes at Kitt Peak Observatory. Provisions are made for both prime and Cassegrain focus of f/4 and f/19 ratios respectively. Slow motions are continuously variable from 3" of arc per second of time to 2' of arc per second of time. Slow motors capable of 6°/second are available for setting. A 4" guide telescope is provided with provisions for offset guiding if necessary.

A control room remote from the dome has a control console with digital setting circles to provide positioning as well as a variable frequency power supply to control the tracking rate.

b) 12" Telescope

A 12' Fiberglas dome houses a 12" Tinsley Cassegrain reflector on an equatorial mount that rests on a concrete pier sunk to bedrock. A 4" guide telescope is also available for setting. All equipment for the 12" telescope may be operated from the control room except for external slewing and setting. Slow motion controls for both hour angle and declination exist, as well as a variable rate clock drive.

c) Other Telescopes

A variety of refractor telescopes are available for use at the Observatory, including:

2.4" f/11 refractor

4" f/5 astrographic camera

4" f/15 refractor (2)

5" f/16 refractor and collimator

6" f/11 refractor and collimator

8" f/5 refractor

9" f/4 refractor with a 14" x 14" image plane.

plus small special purpose telescopes and a variety of other optics.

11

d) Supporting Equipment

Many interchangeable adapters to the 12" and 16" have been made for special purposes such as a star tracker, an image analyzer, many photo-multiplier heads, plate holders, relaying and enlarging optics, etc. Adapters are available to permit use of the telescope as a light collimator, or for projecting a resolution chart for alignment of an image orthicon camera when it is attached to the telescope. The 12" telescope is provided with an optical bench so that a variety of optics can be used on the equatorial mount. Several photoelectric photometers have been made, including an integrating unit with time constants in "excess of three minutes" and pulse counting photometers with counters capable of a 10 Mc rate. Photomultipliers are available, with various types of responses, which can be used in conjunction with the photo-meter integrator, electronic choppers, or synchronous detectors that have been designed for special purpose use.

4.5 Optical Paths

a) External

The Observatory has a 400-meter horizontal light path for testing light propagation through the atmosphere. The base pier is one meter high and 2 feet by 4 feet in size. Down-range piers of similar size are placed at 25, 50, and 400 meters. Additionally, three off-line piers 3 feet by 3 feet are each built overlooking a wide window within the Observatory and are capable of sighting the down-range piers. All of the piers are sunk to bedrock for stability.

b) Internal

Two light optical benches and a dark box approximately 2 meters long are used for checking out optical systems and making measurements. The inside piers make possible a straight path length of 50 feet.

12

4.6 Auroral Spectrograph

On the roof of the Observatory between the two domes is an auroral spectrograph for use in studying night air glow and aurora. The image is now made to focus on the image orthicon photocathode, although a film plate could be used. The large light-tight box which encloses the entire spectrograph may be left on during daylight, with only a small door open to illuminate the spectrograph slit. Thus sunlight spectra may also be taken, or the box may be removed for ease in focusing, and adjustment as is usually done while observing night air glow.

4.7 Image Orthicon

The new General Electric Z-5294 image orthicon offers a sensitivity increase over other types of detectors with an effective ASA rating of over one million. The original electronic equipment consisted of a modified TE-5 television system with a special pulsing unit. Further additions over the past four years to the low light level chain include:

(1) a 36 mm synchronized Beattie data camera

(2) a 16 mm Bolex movie camera -- unsynchronized

(3) a special pulsing unit capable of

(a) an automatic photocathode integration or exposure time, variably set from ten microseconds to 20 seconds or manually pulsed at any desired rate

(b) a variable number of readout scans

(c) a target slicer capable of 5 steps of approximately one volt each during readout

(4) a wide range in control voltages on the various grids.

(5) a moving target indicator (MTI) which uses a memory tube to store and compare successive scans either digitally or in analog. Many possible modes exist.

13

(6) a two-position sweep rate of 1/30 second or 1/15 second non-interlaced.

(7) a variable resolution, either 525 or 1050 lines non-intercaced.

4.8 Cameras

Previously mentioned was a 16 mm Bolex movie camera and a 35 mm Beattie data camera. The Observatory also has a 4 x 5 Speed Graphic and quite versatile interchangeable mounts on the telescopes so that they can be used with the Speed Graphic accessories. The accessories for the Speed Graphic include a camera back to take both 3 x 4 Polaroid rolls or the large 4 x 5 prints, 4 x 5 plates, and film packs. A general purpose Polaroid camera, or a Polaroid camera especially built for oscilloscope use, may be used to take photographs.

4.9 Personnel

The following named personnel actively participate in supporting the optical and electro-optical systems work at the Observatory:

J. F. Spalding

Engineer - Optical Instrumentation
Electrical & Information Engineering Laboratory
ADVANCED TECHNOLOGY LABORATORIES

BS in Physics - Michigan State University - 1951

Mr. Spalding was born in Toledo, Ohio. From 1944 to 1946 he served in the European Theatre in the Infrantry and was discharged a Sergeant. He attended the University of Chicago from 1946 to 1949 majoring in Philosophy and Michigan State University from which he received his degree in physics.

In 1951 Mr. Spalding was employed by Lick Observatory, working first as an optician at Mt. Wilson and Palomar Observatories and then as an astronomer's assistant at Mt. Hamilton. He was Junior Optician on the 120-inch telescope project. From 1953 to 1955 he attended graduate school at the University of California, majoring in astrophysics.

14

In September 1955, Mr. Spalding joined the General Electric Company with the Light Military Electronics Department in Utica, New York as a Product Design engineer. At Utica he worked on both mechanical and electrical problems on the ARR 39 System; mathematical analysis of velocity damped inertial guidance systems and their errors; design of navigational and guidance computers for missiles. In 1958 he became a digital design engineer on the Polaris fire control system. In 1959 Mr. Spalding joined the General Engineering Laboratory (now Advanced Technology Laboratories) as an engineer in optical instrumentation for observing re-entry of ICBM nose cones. He is making significant contributions in the design and operation of the Radio-Optical Observatory; the first optical observatory built by and for private industry.

Mr. Spalding is a member of the American Physical Society, American Astronomical Society, and the Institute of Radio Engineers. He is a member of Sigma Pi Sigma Physics Honorary Society.

Published Material - He has had papers in the Publications of the Astronomical Society of the Pacific, Astrophysical Journal, Proceedings of the IRE Wescon (1957), and Proceedings of the National Electronics Conference (1957). . ."Applications of Image Orthicons to Astronomy," TIS 60GL229 . . . "Seeing Studies," TIS 61GL145 . . . A series of memos on image devices and astronomy . . . "Infrared Horizon Sensor Study," February 1961 . . . Several papers at meetings of the American Astronomical Society and papers on Satellite Tracking at both General Electric Satellite Tracking Symposiums.

J. E. Anderson

Electronics Engineer
Electrical & Information Engineering Laboratory
ADVANCED TECHNOLOGY LABORATORIES

Education: BS in Electrical Engineering - University of Wisconsin - 1960
Experience: 1961 to present - engaged in analytical and experimental investi-
                gations of antennas and microwave circuits including electromagnetic

15

radiation, transmission and propagation with emphasis in micro-
wave circuit theory, wave optics and antenna design with direct
concern on the design and operation of a low light level image
orthicon chain used for observational astronomy at the G.E. Radio-
Optical Observatory.

1960-1961 -- General Electric's Engineering Science Program -
research and development work on high-frequency tunnel diodes,
circuit voltage ratio detectors, saturating core MCT's, strain
gage indicators; flow testing on T64 aircraft engines.

16

5.0 INSTRUMENTATION FOR AIR GLOW AND AURORAL MEASUREMENTS

The instrumentation for night air glow and aurora includes the equipment needed to utilize the image orthicon and spectroscope to obtain spectral lines, and that needed for using the image orthicon to take real time auroral movies.

5.1 Spectrograph

The auroral spectrograph loaned by Dr. Gartlein of Cornell for use with the image orthicon is installed upon the roof of the Observatory along
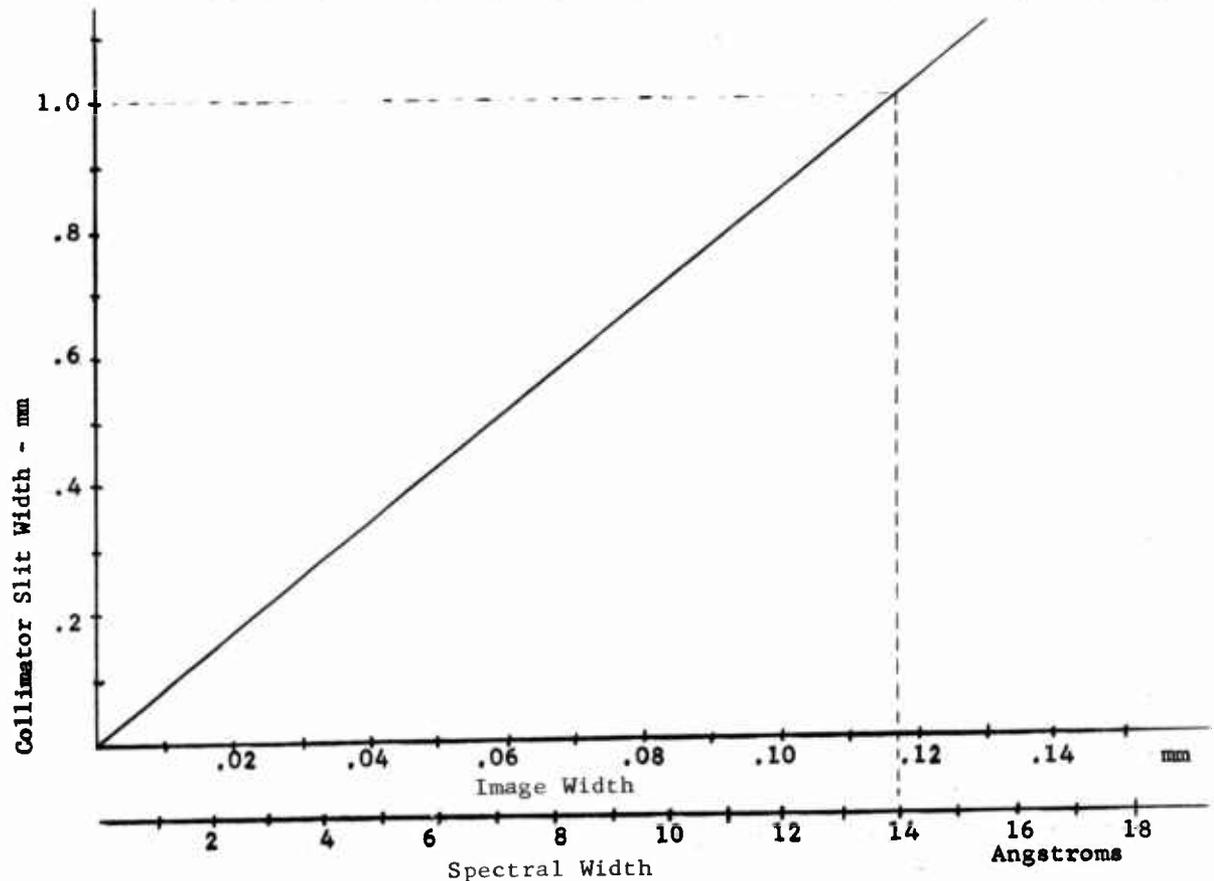
Spectroscope Image Width Resolution

Figure 5.1-1

17

with a protective housing against the weather. The focal length of the slit collimator lens of the spectroscope is 876 mm and that of the camera lens is 101.6 mm. The collimated light which is reflected from the grating with an angular dispersion dependent on wavelength is focused on the photocathode of the Image orthicon. Figure 5.1-1 shows how the image width varies with the spectroscope slit width. A slit of less than 0.2 mm loses intensity rapidly.

Additonally a neon light bulb has been fixed to illuminate the spectrograph slit to allow for focusing, both optically and electronically, before recording data to correct for ambient temperature differences, etc., affecting the image orthicon. The spectrograph can easily be made to scan the entire sky by moving a set of two mirrors that are positioned in front of the slit.

5.2 Image Orthicon

The image orthicon chain is basically a closed-circuit television system that has been specially modified to provide felxibility for astronomical work and associated problems. Instead of being greatly interested in extended objects or gray scale, the operational characteristics of the I.O. are primarily directed towards the detection of point source illumination at very low light level, and secondarily toward resolution and dynamic range. Two image orthicon chains were set up to obtain both spectral and real time movies of the aurora.

5.2.1 Elementary Theory of the Image Orthicon (I.O.)

The image orthicon is a very complex device that is not entirely understood, so that prediction may not be given accurately for all operational circumstances, especially those encountered in very low light level illumination. A general description will be given here, with a more exact analysis given in the Results Section.

18
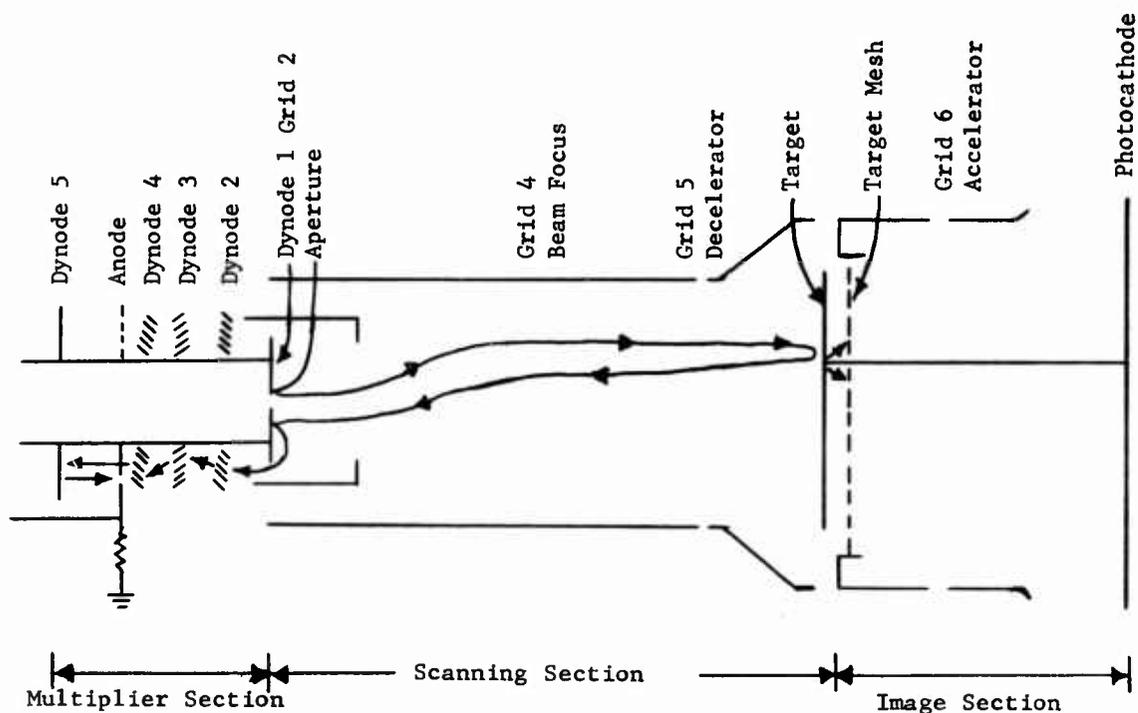
Schematic of an Image Orthicon Camera Tube

Figure 5.2-1

a)   Image Section

Figure 5.2-1 shows a sketch of an image orthicon camera tube.
An optical image is impressed on a semi-transparent photosensitive grid, the
photocathode, which is at about 500-600 volts negative with respect to ground
potential. The photocathode has a quantum efficiency as high as 30% so that
on the average for every three light photons, one photoelectron is released and
accelerated towards the target which is near a positive potential of two volts.
During the photoelectrons' travel a magnetic field in the image section produced
by an external coil focuses it to produce an electron charge image approaching the
target identical to the optical image on the photocathode. When each electron with
500-600 electron-volts of energy strikes the target, approximately 12 secondary

19

electrons are ejected by the target and collected by a collector grid, thereby leaving a net positive charge on the target with a charge gain. Thus the image section of the I.O. basically records the optical image as a positive charge image on the target, where the regions of greater positive charge correspond to the brighter regions of the optical image.

b) Scanning Section

The requirement of the scanning section is to change the two-dimensional charge pattern into one-dimensional information flow with time. A constant current, small diameter, sharply focused beam of low velocity electrons is magnetically deflected to scan across and down the target in synchronism with the scanning beam of the picture tube in the monitor. The positive image charges on the target absorb the readout beam electrons until they are neutralized, and the excess electrons are repelled. Thus the repelled beam decreases when there is a net positive charge on the scanned target, and a destructive readout occurs.

c) Multiplier Section

The returned beam of excess electrons is then amplified about 1000 times in a five-stage electrostatically focused electron multiplier section similar to that of a photomultiplier to provide practically noiseless secondary emission amplification. The multiplier gain is high enough to confine the limiting noise in the use of the tube to the random noise of the electron beam multiplied by the gain of the dynode stages. This noise exceeds the input noise of a good video preamplifier. The signal leaves the anode for further external amplification and processing to correct for shunt anode capacitance, blanking requirements, etc.

This video information is then fed into a monitor and scanned across the monitor face simultaneously as the camera beam scans the

20

target so that the charge image representing the optical image is reproduced on the fluorescent monitor screen for visual observation or for photographic purposes. The image orthicon has thus been used as a light amplifier to produce a sufficient light intensity to meet the desired film speed and exposure requirement.

5.2.2 Modes of Operation

Normally the image orthicon system is operated in the continuous mode of 30 frames per second with 500 non-interlaced scan lines; but for a satisfactory signal at very low light levels some sort of pulsed operation may be desirable.

The common pulse mode is a photocathode integration mode where the imaging and scanning sections of the tube are alternately operated at a slower speed than normal. Basically the photocathode voltage is applied until sufficient charge has accumulated on the target to be at least capable of producing a recognizable signal. Then the beam is turned on for the required time to read out the integrated information. This technique is limited by background noise and the dynamic range of the target. The readout frames are usually few, since the charge concentrations are immediately destroyed and the weak light source does not have time to replenish them until another integration has occurred. However, some latent image effect can exist depending on beam current intensity.

The target pulse mode is used to increase the dynamic range in reading out the stored charge of point or line sources. Optimum target integration for weak illumination occurs when the target potential is approximately two volts positive and if the stored charge is read out with this target potential the beam noise is sufficient to destroy some fine detail and resolution. However, if the beam current is reduced, thereby

21

integration level
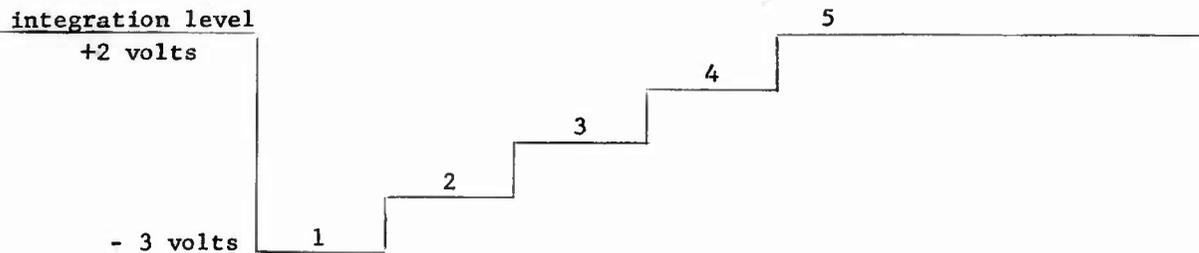
(a) Target Voltage Change with Frame Readout

(b) Beam and Blanking Signals
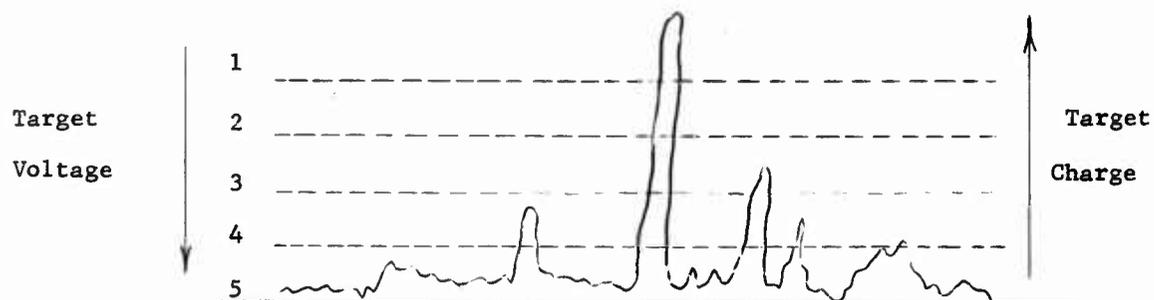
(c) One Horizontal Line Charge

(d) Video Signal on Each Scan

Figure 5.2-2 Target Pulser Operation

22

reducing the beam noise, and about five successive readout frames are integrated on photographic film, an improved dynamic range and resolution will result. This mode is illustrated in Figure 5.2-2 where 'a' shows how the target voltage is varied, 'b' shows when the beam readout current is on. During the integration time, a line charge from the spectrograph may produce a charge profile on the target such as sh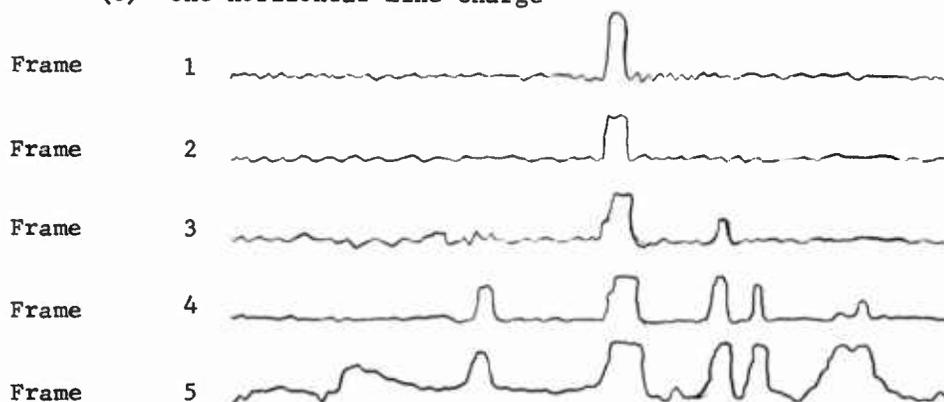own in Figure 5.2-2 'c'. The variation of target voltage with each readout frame basically divides the profile into sections, where each section is read out on successive frames, and the electronic voltage signals for each frame resemble 'd'. They are impressed on the monitor screen and the film photographing the monitor integrates these frames to reproduce an image similar to the original profile, and thus the dynamic range of the optical image has been retained on the photographic film even though one TV frame cannot tolerate much dynamic range in amplitude at low signal-to-noise ratios.

A companion storage tube assembly allows a storage mode in which many frames of TV video may be stored on a storage tube until the integrated signal will produce a high quality read out. The storage tube unit at the Observatory has the advantage that the stored information readout may be non-destructive so that as the successive frames are being integrated a periodic check can be made to determine the quality of the image.

The field mesh image orthicon tube can produce an internal integration effect at low light levels. The use of this mode on aurora is completely discussed in the Results Section of this report.

5.3 Oscilloscope

Beside the normal needs of utilizing an oscilloscope to adjust and line-up the image orthicon, the oscilloscope can be a useful device in

23

analyzing spectral amplitude and line width. This A-scope presentation is a great advantage in providing another means of time correlation of the auroral "scene" films and the spectral films.

5.4 Recording Cameras

The two types of photographic data obtained from the image orthicon are spectral lines and real time movies. All real time auroral films were recorded with a 16 mm Bolex movie camera that was not synchronized with the I.O. chain, but running at 8 frames per second. Since the chain reads 30 frames per second in continuous operation, any bar effect is not noticed on the film.

The spectral lines were recorded with a Speed Graphic on 3 x 4 or 4 x 5 Polaroid prints for rapid inspection and identification of the observed lines, and also by a synchronized 35 mm Beattie data camera for future intensity analysis and for investigation of the spectral time-changing characteristics of the aurora.

5.5 Calibration Light Sources

Two discharge lamps emitting a number of monochromatic spectral lines have been used for spectroscopy calibration of the image orthicon -- spectrograph system. One is a sodium-mercury (NaHg) Osram lamp that also produces many unknown lines because of contamination, and the other is a Spectroline Helium (He) discharge lamp with fewer lines distributed over the entire spectrum for easy identification.

5.6 Microfilm Viewer

A Documat Microfilm Reader is used in the analysis of spectral lines photographed on the 16 mm and 35 mm film. Basically, the instrument expands the image on a 11" x 11" viewing screen where calibration marks may be made for suspected spectral lines so that by positioning the known lines

24

of brighter intensity, the weaker photographed lines may be recognized.

5.7 Densitometer

Measurement of the line intensity is made with a Welch Scientific Company transmission light source combined with a Logarithmic Densichron Photometer to produce an excellent densitometer that can measure the transmission density of either photographic plates or films. The illumination and light collection system are such as to give readings of ASA diffuse density within the tolerances of the Photometer. The aperture may be selected as desired according to the size of the smallest area to be measured. Of course, the smallest aperture limits dynamic range and introduces possible error by ambient side light interference. The instrument is adequate for our measurements since the line widths photographed are relatively wide, and the dynamic range was quite limited.

6.0 <u>RESULTS</u>

6.1 <u>Application of an Image Orthicon</u>

The purpose of this section is to review the theory of operation of an image orthicon in order to evaluate its limitations and the best mode of operation with various types of images. Much of what follows is not original, but to simplify the discussion no distinction is made as to the originality of the explanation. This theory should be regarded as tentative since the image orthicon is a complicated device with a tendency to confound explanations.

Consider the tube itself in general outline. There is first a photocathode, from which the photoelectrons are accelerated through about 600 volts, and imaged on a thin magnesium oxide target. Each photoelectron gives off 12 to 15 secondary electrons which are collected by a target mesh, leaving a net positive charge on the target. The resulting charge distribution is then scanned by a low velocity scanning beam from which it removes electrons when there is a signal. Thus a decrease in the return beam from the target corresponds to a signal. This return beam is multiplied in an electron multiplier, and then amplified external to the image orthicon.

Consider a signal of n photons falling on a spot of the photocathode. These photons arrive at random, following a Poisson distribution, and so to a good approximation we may assume fluctuations in this signal of $n^{1/2}$. If ϵ is the quantum efficiency there will be ϵn photoelectrons given off, with an approximate noise $(\epsilon n)^{1/2}$. Of these ϵn photoelectrons $\alpha \epsilon n$ will reach the target, where α is the transmission of the target mesh, and we may assume that to a good approximation the fluctuations will be $(\alpha \epsilon n)^{1/2}$. If the secondary emission ratio of the target is β there will be

26

$\alpha \epsilon n\beta$ secondary electrons given off leaving a net charge (positive) of $\alpha \epsilon n(\beta-1)$. Since the arriving noise is $(\alpha \epsilon n)^{1/2}$ it will be multiplied by β in the secondaries given off, and assuming fluctuations in β of the order of $\beta^{1/2}$ which will be orthogonal to the incoming fluctuations we have an added noise of $(\alpha \beta \epsilon n)^{1/2}$. We thus have a total fluctuation noise at the target of $(\alpha \epsilon n \beta(\beta+1))^{1/2}$ with a signal $\alpha \epsilon n(\beta-1)$ positive charges. If the capacitance per positive element is C_T, then there will be associated with this positive charge a voltage $V_T = \alpha \epsilon n(\beta-1)/C_T$. This voltage is of course fluctuating as it is read out, but for each read out or scan, it will have a definite value so that if we are considering a single scan, we should not simply add this noise to that occurring later on, as there is a frame-to-frame fluctuation, but no time fluctuation within a frame.

6.1.1 Latent Image

Now consider the incident beam, and assume that in the length of time that it is on the target element it contains m electrons. Under steady state conditions it is obvious that the return beam must consist of $m - \alpha \epsilon n(\beta-1)$ electrons. Investigating this process in more detail, we see that the beam will have some energy distribution $N(V)$ such that $\int_{-\infty}^{+\infty} N(V) \, dV = m$, and depending on V_t a fraction of the beam will be available for discharging the target, say $\int_{-\infty}^{V_t} N(V) \, dV$, and some portion of the beam will not be available for discharge $\int_{V_t}^{+\infty} N(V) \, dV$. Note that $\int_{-\infty}^{V_t} N(V) \, dV$ is not the amount removed from the beam, rather, it is the amount available for discharge. If $N(V)$ is either a Gaussian or a Poisson distribution, we would expect, that for small values of V_t we will have $\int_{-\infty}^{V_t} N(V) \, dV < \alpha \epsilon n(\beta-1)$. Thus a fraction of the original charge, $k \alpha \epsilon n(\beta-1)$, remains on the target and the charge the next time will be $(1+k)\alpha \epsilon n(\beta-1)$ so that the voltage V_t will increase until $\int_{-\infty}^{V_t} N(V) \, dV = \alpha \epsilon n(\beta-1)$ where $V_t > \alpha \epsilon n(\beta-1)/C_T$. This

27

process yields a type of latent image formation that can be of considerable importance in analyzing continuous or steady state conditions versus conditions under single scan situations. Another process that must be noted is that under signal free conditions not all of the beam electrons return, but there exists a V_c such that the fraction of the beam $\int_{V_c}^{+\infty} N(V)\, dV$ always lands on the target. This leads to a gradual shift in bias of the target itself if there is no incoming photoelectron signal, and in some cases this can bias the target off so that it cannot be read out. This fraction is small and does not enter into noise calculations, although it is not a constant. Under continuous operating conditions it will reach a relatively steady state level.

6.1.2 Signal-to-Noise

In scanning out a charge of n_0 the beam must contain a greater charge, say kn_0. Under steady state conditions we have an incident beam containing kn_0 electrons, and a return beam containing $(k-1)n_0$ electrons. Under single scan conditions, this formulation is obviously wrong, since for weaker charges we do not completely cancel out the charge because of lack of availability of the correct energy electrons in the beam. This immediately indicates an apparent reciprocity failure between continuous and single scan conditions. As observed with stars this loss is roughly one stellar magnitude for single scan readout.

There are a number of ways in which the signal to noise ratio may be defined, but the most meaningful would seem to be the ratio of signal plus noise in the signal to noise outside of the signal. First then, let us define what is meant by signal. It is the difference between the average return beam when no signal is present, and the average return beam when a signal is present. If the average beam is m, and n electrons are

28

removed from it, then the signal is m-(m-n) or n. The noise present at
this time will be $(m-n)^{1/2}$, and the noise present outside of a signal will
be $m^{1/2}$. Thus our signal plus noise to noise ratio will be

$$S/N \;=\; \frac{n+(m-n)^{1/2}}{m^{1/2}} \;=\; (n^2/m)^{1/2} + (1-n/m)^{1/2} \qquad\qquad 6\text{-}1$$

6.1.3 Extended Object

Now assume that we are observing an extended object with
a highlight area of charge per element of n_o. To discharge this region the
beam must have kn_o electrons, where k is of the order of 2 (modulation of
the beam is 50%); actually it is possible to go somewhat higher, but not
very much. Another area with a charge of $\ell n_o = n,$ $\ell < 1$, will have a
signal which is less, and we may then compare the loss in signal to noise
of the two cases.

For the first case the signal plus noise to signal is
obviously

$$\frac{S+N}{S} \;=\; \frac{n_o^{1/2} + (k-1)^{1/2}}{k^{1/2}} \qquad\qquad 6\text{-}2$$

and for the second case it is

$$\frac{S+N}{S} \;=\; \frac{\ell n_o^{1/2} + (k-\ell)^{1/2}}{k^{1/2}} \qquad\qquad 6\text{-}3$$

so that the ratio is

$$\frac{n_o^{1/2} + (k-1)^{1/2}}{\ell n_o^{1/2} + (k-\ell)^{1/2}} \qquad\qquad 6\text{-}4$$

For a change in signal of 10, this ratio becomes

$$\frac{n_o^{1/2} + 1}{0.1n_o^{1/2} + 1.4}$$

6-5

assuming $k \sim 2$. Roughly, the signal to noise varies as the signal. This radically limits a system as far as large dynamic ranges are concerned, especially since we usually do not start out with high signal to noise ratios.

6.1.4 Point Source

Consider now a single element, surrounded by a region of no signal. It is now not necessary to set the beam current so that it will discharge the spot, instead we may let beam bending (deflection of the beam by the charge distribution) take care of the overload. Thus, if we are willing to accept a growth of the point source from one element to a width of 10 elements, we may set the beam at 10^{-2} of its previous value. Now the signal to noise ratio for a point will be the same as before, since the maximum value of k will not change much (at an extreme, the greatest possible change would be from 2 to 1), but the signal to noise will remain constant until the intensity (signal) has dropped to 10^{-2} of its previous value, and then it will begin to decrease. This model is of course somewhat over simplified.

To carry this analysis further there are several things which must be investigated. These include the inherent resolution (or image size) on the target, the beam current and modulation, and the effects of velocity dispersion in the beam.

Consider a situation where the charge on the target is large enough to cut off the return beam (100% modulation), or alternatively, the modulation indeed has reached a limiting value which is constant. Then

30

Source Width - k^2 (Scan Line Widths Squared)
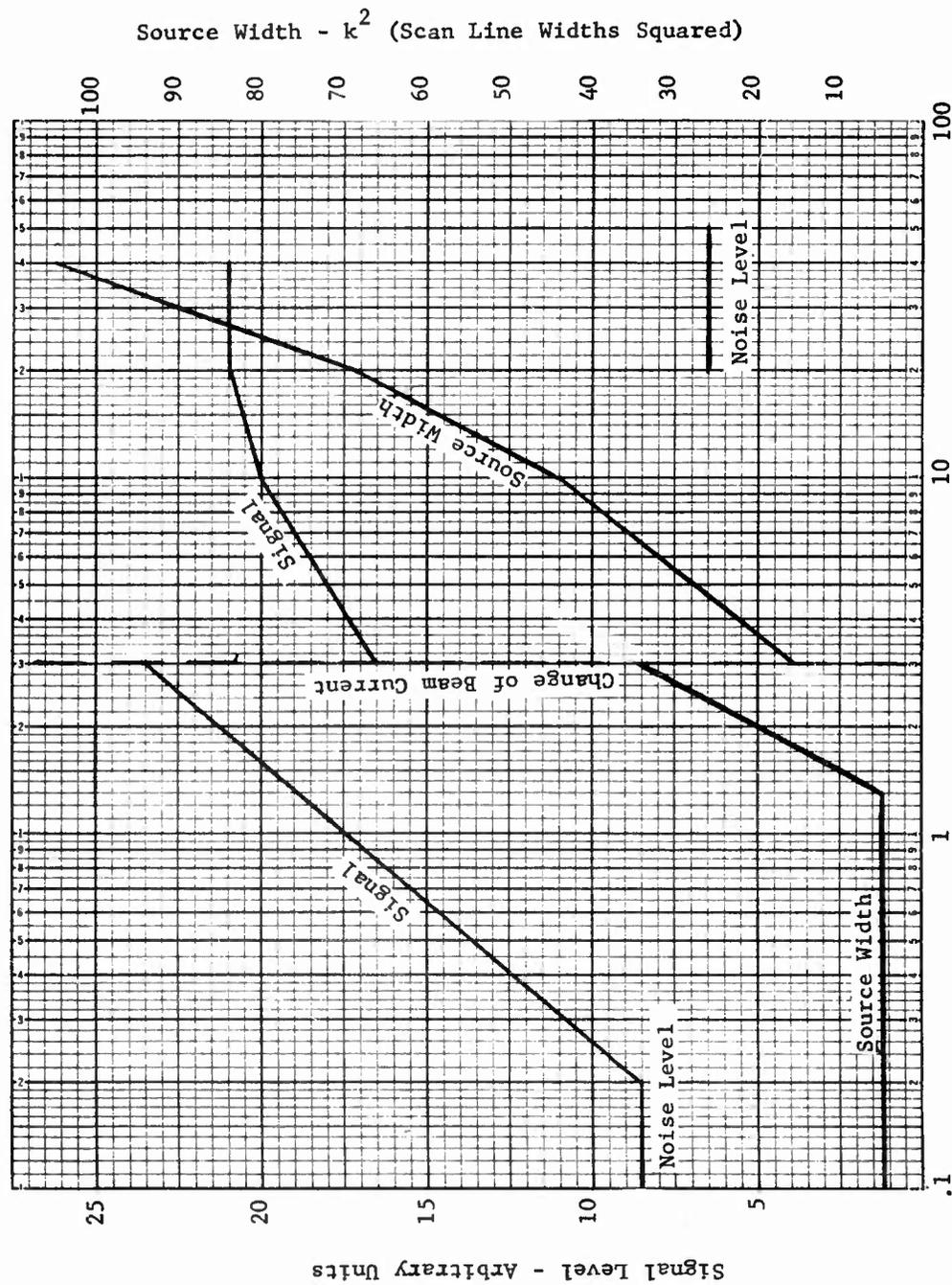
Relative Source Intensity - Arbitrary Units

Source Width and Signal vs Intensity of Source

Figure 6.1-1

Signal Level - Arbitrary Units

Noise Level

Source Width

Signal

Signal

Change of Beam Current

Noise Level

Source Width

31

the apparent size of the image due to charge diffusion, beam bending, or other effects, must be directly proportional to the signal, so that a steady state condition is obtained. This leads to a situation in which the apparent diameter of a point source is a function of its magnitude, as is observed. Figure 6.1-1 plots the square of the width of a point source, measured in scan lines as a function of the relative intensity of a source. Several arguments are indicated here. The first is that the area of the image does not change in proportion to the intensity of the source at low light levels, but that the signal does. However, with increasing intensity, the area begins to become proportional to the signal, but the amplitude remains constant. Note that the horizontal lines in Figs. 6.1-1 do not indicate noise level relative to zero, but are indicative of the beam current level. Units are purely arbitrary.

It should be noted that the product of the area and the amplitude of the video signal is roughly proportional to the optical signal, but that there are a number of other factors involved also, including the errors of measurement.

The actual modulation levels involved here are not known for certain, but it would appear that the signal levels off at approximately 100% modulation. This is not surprising in that beam velocity fluctuations will be .2 ev, while the target voltage can be several volts.

When considering measurements such as these one effect in particular must be considered, that of a strong overload.
A large charge distribution on the target can accelerate the scanning beam so that it strikes the target with enough energy to give off secondary electrons, which then appear as a portion of the return beam. These added electrons wash out the signal, resulting in a decrease in signal amplitude. This effect is illustrated in Figure 6.1-2, in which the minimum and

32
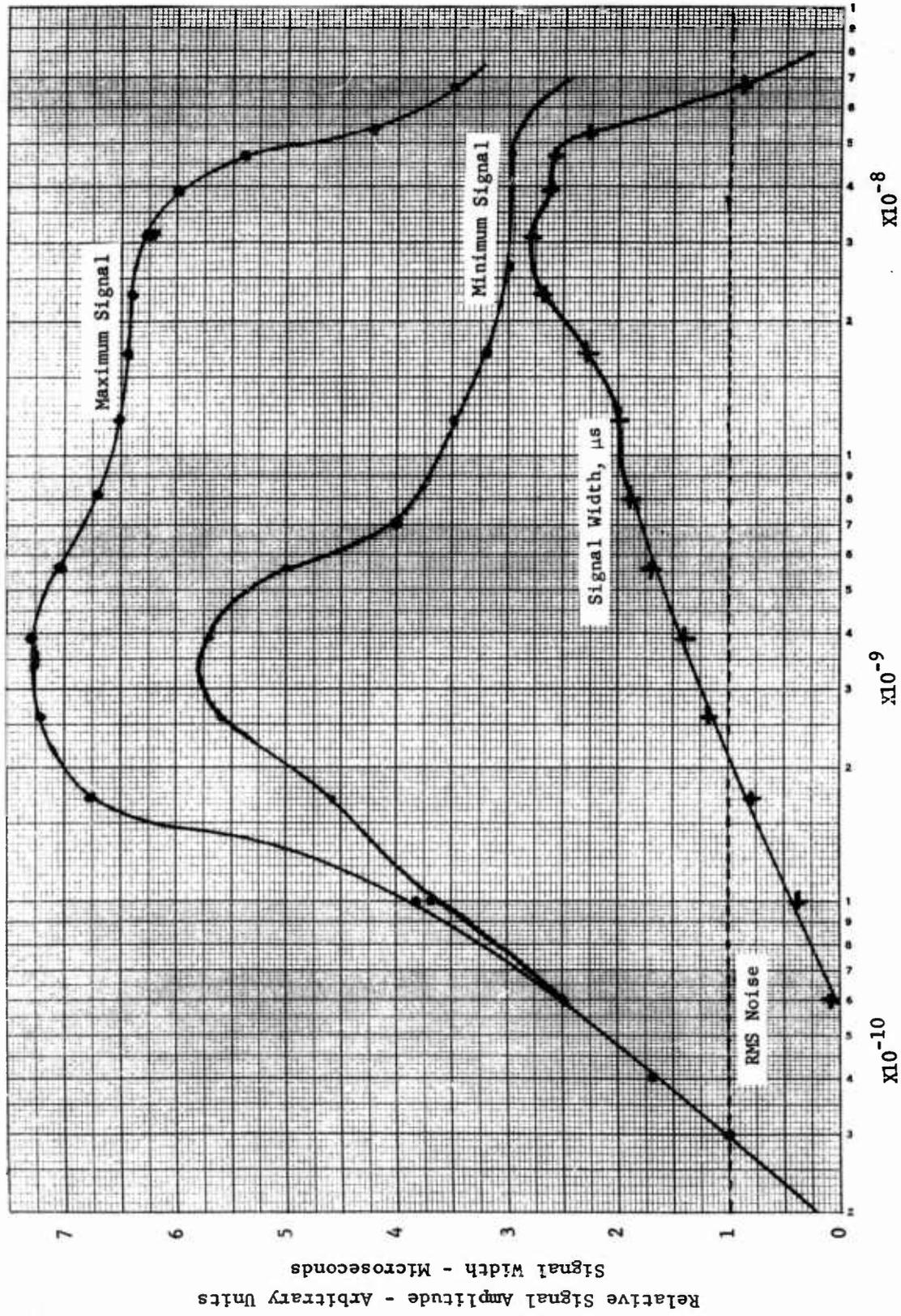
Line Illuminance - Lumens/cm

Figure 6.1-2

33

maximum signal, and signal width, are given as a function of the intensity of a line source. Note that even with the drop in signal at the higher levels, the output is usable. Taking the point at which maximum and minimum signal diverge, we only have a 3:1 increase over the minimum detectable signal, however, there is a usable range of over 200:1.

Although a range of better than 200:1 is useful, a basic question arises as to how this range can be extended. There appear to be two fundamentally different techniques that can be applied. The first is the use of beam feedback controlling the beam current on a point-to-point basis so that the control will be sufficient to discharge the target under any conditions. The primary difficulty here is that at extremely low light levels our problem is not beam current, but rather the acceleration of the beam by a target charge distribution leading to secondary electrons being ejected by the target. Thus although this technique is promising with extended objects at higher light levels it is not as promising for our application.

The second technique is sometimes termed target slicing. It depends on the fact that the overload characteristics at low light levels are caused by the beam, and are not inherent in the target. By this method the target mesh is biased during successive readouts so as first to discharge the high charges, and finally to read out faint signals after the large charge distributions have been partially discharged.

This mode has been investigated with artificial fields in a light tight box using a transmission resolution chart and a series of artificial stars of varying magnitudes. Comparisons were made with different voltages on the target mesh during exposure and read out. It was determined that blooming (overexposure) was a function of the target mesh

34

voltage during exposure of the photocathode. It is to be expected that
this technique will at least double the dynamic range, and in addition
bring much of the overload portion of the tube characteristic into the
linear range, thereby permitting neighboring bright lines to be read and
also allowing a more accurate intensity calibration.

6.1.5 Line Source

A spectral line represents a somewhat different
situation in that it can grow in only one dimension. However, since
in this case a number of elements in a line are being scanned, and
we are making repeated measurements, the signal to noise ratio is
improved by the square root of the number of scan lines that the
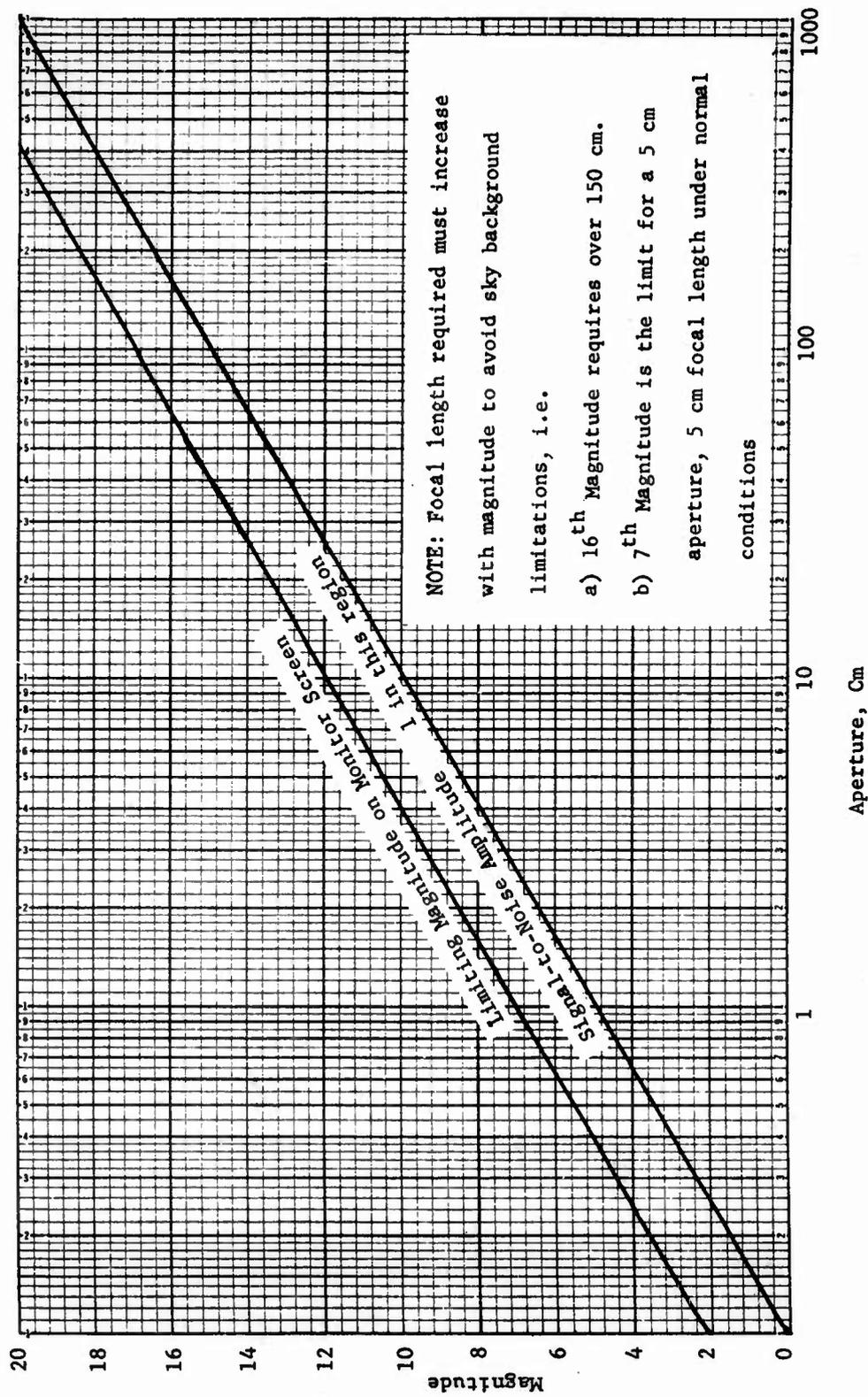spectral line covers.

6.1.6 Sensitivity

A further series of tests was made with regard to sensi-
tivity and reciprocity failure. It can be shown that for a non-saturated
detector the limiting star magnitude, if it is set by background noise
(such as skylight), can be expressed by

$$M_O = M + 0.5M - 2.5 \log k - 2.5 \log \delta + 1.25 \log D^2 qt$$

$$- 1.25 \ (1+R) \qquad\qquad 6-6$$

where M_O is the threshold magnitude, M the magnitude of the sky background,
δ the diameter of the seeing image, k the coefficient of recognition, D
the aperture, q the quantum efficiency, t the time, and R the ratio of
instrument background to sky background. For a discussion of this see
Baum, "The Detection and Measurement of Faint Astronomical Sources",
page 1 et. seq., Astronomical Techniques, edited by Hiltner, University of
Chicago Press, 1962.

The interesting point here is that the limiting magnitude

35

NOTE: Focal length required must increase with magnitude to avoid sky background limitations, i.e.

a) 16th Magnitude requires over 150 cm.

b) 7th Magnitude is the limit for a 5 cm aperture, 5 cm focal length under normal conditions

Limiting Magnitude on Monitor Screen

Signal-to-Noise Amplitude = 1 in this region

Limiting Magnitude

Aperture, Cm

Magnitude

Limiting Magnitude vs. Aperture for a Z5396,
500 Line Non-Interlaced Scan, 1/30 Second Continuous Frame Rate

Figure 6.1-3

as set by background noise should be proportional to $t^{1/2}$, not to t. A

series of measurements was made using various apertures and target voltages.

When the tube was operated in a normal manner, the $t^{1/2}$ relationship was met fairly

well, and data similar to the usual curves for resolution vs. exposure

time was obtained. However, when the tube was operated as one does for

point or line sources, this relation was not met, except partially when the

target voltage was decreased to reduce sensitivity. Thus it appears that

under these conditions the tube is not background limited but gain limited. This

result raised serious questions about the video amplifiers used, but exam-

ination showed that these had more gain than needed. The source of the

discrepancy appears to lie in operating procedures and the noise character-

istics. The video gain is normally increased until the noise peaks over-

load the amplifiers, and then decreased somewhat. This limits the gain

used and is the apparent source of difficulty. Two procedures are immedi-

ately apparent to avoid this difficulty. The first is to use a logarithmic

amplifier to avoid overloading on noise peaks. The second and simpler is

to precede the video amplifier with a clipper that eliminates the noise

peaks that cause the gain limitation. It appears that the sensitivity of

the image orthicon may be roughly doubled using this procedure for point

or line sources. This approach must of course be thoroughly checked out, but it

appears to be a very useful technique. It is especially interesting in

that it provides a potential real gain in sensitivity.

A series of measurements was also made of sensitivity

against stars, using various apertures and integration times. These have

been combined and extrapolated in the accompanying Figure 6.1-3, giving

limiting magnitude vs. aperture. For continuous operation, 30 frames per

second, non-interlaced, we obtain

$$M = 7 + 5 \log D \qquad\qquad 6\text{-}7$$

where D is the aperture in cm, and for pulsed operation we obtain

$$M = 6 + 5 \log D + 2.5 \log 30t \text{ (t in seconds)} \qquad 6\text{-}8$$

which with the assumption that a 0 magnitude star has a flux of 10^6 photons/cm^2/sec in the visible, indicates that under these conditions a flux of 1200 photons/cm^2/sec is required. Under pulsed conditions this gives a flux of 100 photons as that necessary for detection of a point source or star. This value also corresponds approximately to the estimated fluxes required to detect a line, made from measurements on night air glow. Although the signal is spread over a line, we gain in recognition because of the repetition from scan line to scan line. If a line covers 10 scan lines we would have 1/10 of the signal per line, but 10 measurements improve the situation by $\sqrt{10}$, so that on the order of 300 photons should be expected for line detection. These figures are, of course, those of an almost ideal circumstance.

6.1.7 Hypersensitization

It should also be noted that some mention of hypersensitization of image orthicons has appeared in the literature, and so some comment on this will be made here. Under some conditions the shining of a faint light on the photocathode will give an apparent increase in sensitivity. This is caused by the weaker charges being brought up to readability. This corresponds to the previous discussion of the appearance of a longer integration time when using continuous operation. With the long exposures used in spectroscopy we have a faint background that effectively gives the same effect as hypersensitization, so no increase in sensitivity is to be expected using these techniques. With the high efficiencies quoted here it is not surprising that none is found.

38

6.1.8 Intensity Calibration

A critical question with respect to an actual instrument is the accuracy with which the device can be calibrated, both in intensity and wavelength.

We may give approximate characteristic curves, but it is readily apparent that the curve depends radically on the actual target and beam current settings used, so that it is not possible to maintain calibration from one period of operation to another. However, over a period of a few hours, once the equipment has warmed up to a stable temperature, calibration before and after operation seems to be quite feasible. The simplest means of doing this is to use a spectral line source, and a series of neutral density filters. A series of exposures are made of some of the lines, and a characteristic curve is constructed for the period of operation. The difficulty that has appeared with this technique is that it requires that the controls be untouched for the entire period of operation. A better technique would be to project a series of lines on the photocathode above or below the actual spectra, so that each photograph of the monitor will have an intensity comparison on it.

Changing the beam current of course modifies the characteristic curve. An increase in beam current will decrease sensitivity by eliminating the faintest lines, but it will extend the region without overload. Similarly, a decrease in target voltage will permit the brighter lines to not be overloaded. Two techniques assist in obtaining good intensity calibration. The first uses varying periods of integration so that the strongest lines are picked up and measured on short exposures, and the fainter lines on longer exposures. This permits measuring both intensities on efficient portions of the characteristic curve. The second technique is target slicing, where the strongest lines are read on the first readout,

39

and the weaker on the last

At present a dynamic range of perhaps 200 is possible, and this can be broken up into at least 20 resolvable steps. It appears that these values can be extended to give a dynamic range of 500 in more than 50 resolvable steps. Present techniques have the disadvantage of not being able to resolve two bright, close lines, or a faint line near a bright one. This disadvantage can probably be overcome with target slicing. Another disadvantage is that information about line profiles is not obtainable, as the decrease in beam current compared to normal operation that gives us sensitivity reduces dynamic range. There seems to be no way of getting around this problem. However, it has been noted on auroral spectra that the H_α and H_β lines do show a fuzziness - so that some information on extreme broadening is possible.

6.1.9 Wavelength Calibration

Wavelength calibration, or equivalently, position calibration leads to certain problems. If the equipment has attained a steady state temperature, and power supplies are well regulated, calibration to a higher resolution than the 500 line scan used to date can be maintained for hours. Non-linearities in the scan exist, but these are constant in time, usually slowly changing in space, and exist primarily at the edges of the field. Thus there seems to be no problem in calibration. Moderately weak signals to average signals give no problem in measuring, and an accuracy to 0.1% is easily achieved. Weak signals can be measured with almost as great a resolution, especially if the entire length of the line is present. The primary measurement problem lies with strong lines since the apparent profile is a function of the extent of overloading and is not necessarily symmetrical. Measurements of these badly overloaded lines can

40

be made to at least one percent, but a familiarity with the image orthicon is required since, for example, a strong line may appear as a doublet under certain conditions of overloading. This problem area will probably be solved by the use of target slicing.

6.1.10 Memorization Mode

The field mesh image orthicon tubes are known to produce an integration effect at low light levels. This mode can be initiated by increasing the beam current and defocusing the beam slightly. The output then appears to be integrated over several seconds, and a readout frequently negative with respect to the normal positive output will frequently continue for several seconds after the lens is shuttered, implying a partially non-destructive readout. The mode exists in many forms and frequently has poor resolution. It cannot be obrained consistently, is difficult to maximize, is not uniform across the field of view, and does not consistently give a sufficiently long integration. The mechanism of this effect is not understood, and its application has been completely unsuccessful on night air glow even though black box experiments produce partial success. Perhaps the scattered background light from the spectroscope nullifies the integration readout effect.

Two field mesh image orthicons, one with an S-10 and another with an S-20 photocathode, were investigated with respect to operation in a memorization mode. All attempts made with auroral lines have been unsuccessful because the memorization mode is difficult to induce and also the action is not understood theoretically.

6.2 Auroral Data

Late in December 1962, Messrs. John Spalding and John Eric Anderson met with Dr. Gartlein, the Head of the IGY Data Center which is located at Cornell University, to investigate auroral activity and to review

41

plans for an effective method of investigating auroral displays with respect

to spectral emission, brightness, and time rate of change of certain features

such as rays and flames.   Since 1963 was a "quiet year" with respect to

sunspot activity and aurora, we wished to establish a channel for notifi-

cation of probable aurora during the year. Dr. Gartlein also mentioned

the extended fan shaped infrared phenomenon at low latitudes which simul-

taneously had been detected along with aurora borealis by various observors.

This fan shaped phenomenon was not noticed during the few aurorals that

were observable at the Observatory, although emphasis was not put on their

 detection. Presently an all sky lens and red filter combination is being constructed

to detect any red areas that may exist.

The primary limitation on obtaining data at the Observatory

has been the weak strength and low occurrence of auroras due to the present

portion of the sunspot cycle.

6.2.1 Photons Required for Detection

Close calibration is not possible as yet, but it would

appear that 100-200 Rayleighs/second is adequate with present equipment to

yield good lines. The equipment had a slit area of roughly 2mm when these

measurements were made, and a field of view of roughly 10^{-3} steradians.

Assuming that I, where $4\pi I$ = Rayleighs, is of the order of 10, we find that

approximately 2×10^3 photons were accepted by the spectroscope for the

detection of a line. This is pessimistic since the line was much longer

than required for detection, but yields as a first approximation something

over a thousand photons necessary for detection of a line. This may seem

large, but the spectroscope could easily be not too much more than 10%

efficient, and the photocathode is of the order of 10% efficient, so that as

of this writing lines are being detected with possibly as few as 10

42

photoelectrons. This last figure is probably a minimum, but apparently there is sufficient sensitivity so that less than 100 photoelectrons are required.

6.2.2 A Good Aurora in 1963

Of all the auroras during 1963, one of the finest was captured on 24 September with over 300 feet of 16 mm real time movies taken from one I.O. monitor operating at 60 interlaced frames per second, with an accompanying reel of 35 mm photographs simultaneously showing the spectral characteristics from another I.O. using 8 or 16 second integrations. Many Polaroid pictures were taken in addition.

Although the auroral display was bright enough to produce high dispersion spectra, it was devoid of identifying structure such as brillant regions or rays, and no dramatic pattern changes were noted to which the spectrograph could be directed. The main effect observed appeared to be one of intensity changes. Comparison of the spectral movies with the real time movies taken simultaneously show that

> a) No observable change in the relative intensity of the spectral lines could be noted in the entire sequence of spectral pictures. Therefore no correlation between the spectral response and the charging characteristic of the auroral pattern could be detected. This was probably due to the subdued intensity variations over the entire aurora and the wide field of view of the spectrograph - - over 12°.

> b) Intensity variations of the spectral pictures (intensity of all lines remaining in a constant ratio) as well as intensity variations in the auroral scene

43

films were observed and could be correlated to a
limited degree.

c) Temporal cycles of intensity variations could be detected
on the auroral scene films but not on the spectral films.
Periodicity of this intensity showed fluctuations ranging
from 8 to 40 + seconds.

d) The first film sequence showed a much brighter aurora.
A second film showed a reduced auroral intensity having
less time variation.

6.2.3 Time Sequence

None of the auroras observed during 1963 produced dramatic
ray structure, but the one on 24 September 1963 had a sharp horizontal line
of demarcation as illustrated in Figure 6.2.1. Let us briefly summarize the
frame orientation: The very dark region at the bottom of the frame is the
tree line and horizon; a grey clear sky region exists as we scan up on a
frame until we reach a bright line. Particularly notice the bright spots that
move along this line and their intensity changes in each succeeding frame.
This is the north base of the aurora and it extends to the top of the picture.
Disregard a random dark horizontal line that moves through the frames, as this
is caused by the photographic camera and the I.O. chain not being synchronized.

These photographs were taken at 8 frames per second from an
image orthicon chain operating at 30 frames per second and with an f/2.5 lens
on the I.O. camera. Although the aurora was bright, contrast was lacking
except for this very narrow, bright region.

Along with these "scene" photographs, a 35 mm data camera
recorded spectral lines from another I.O. An indication of how the lines
varied with time is shown in Figure 6.2-2 where a short dash denotes that

44
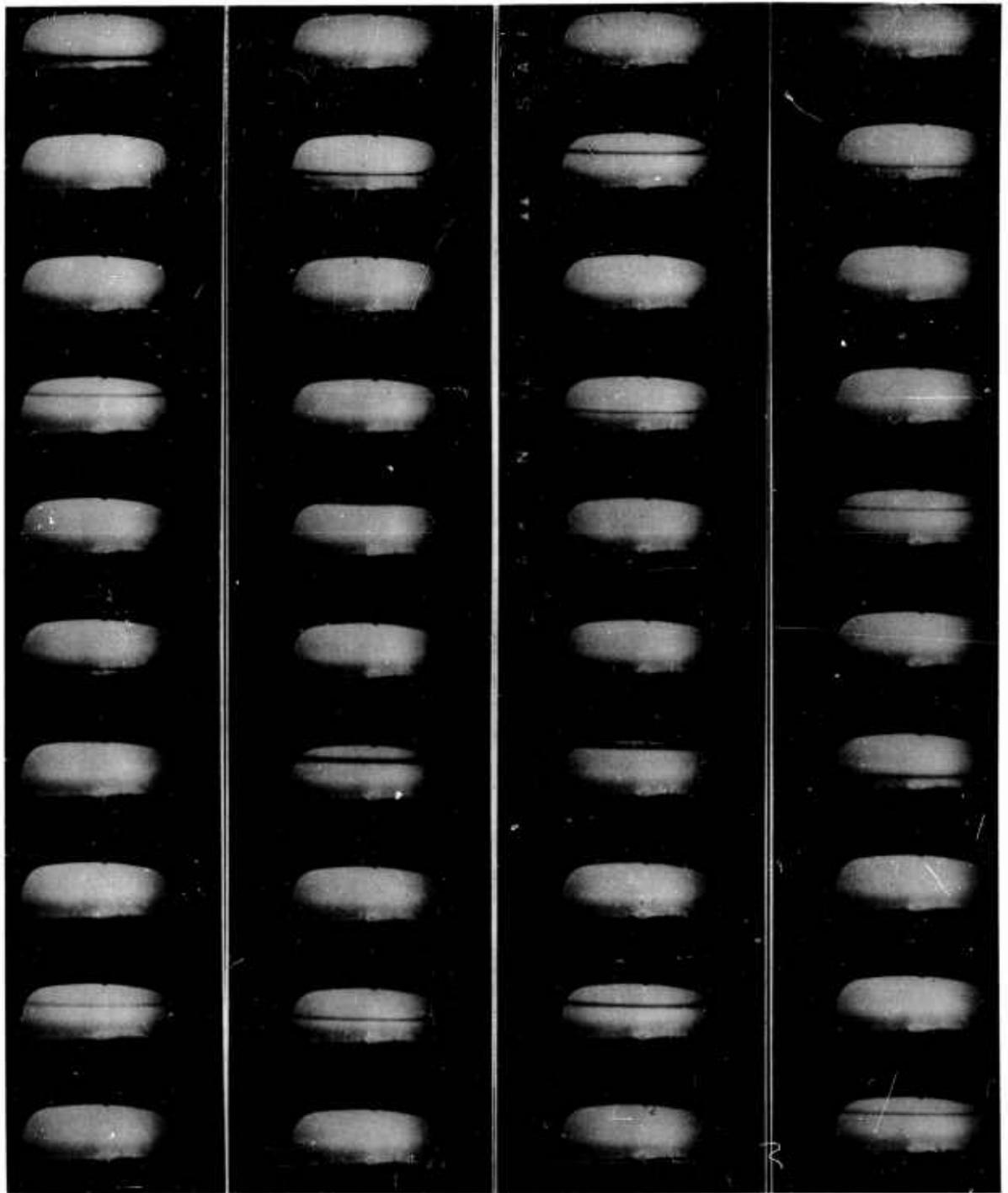
An Aurora on 24 September 1963

Figure 6.2-1

45

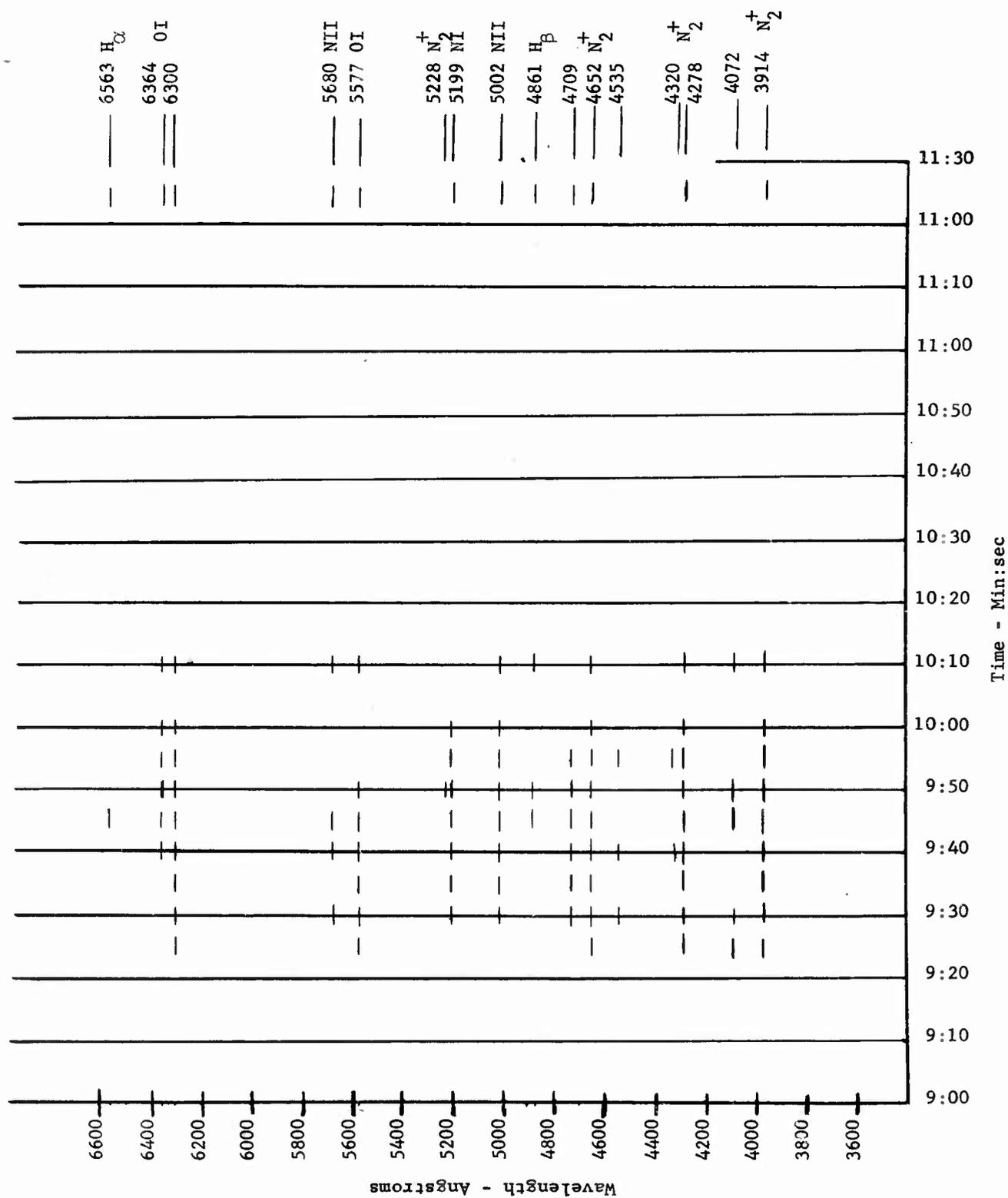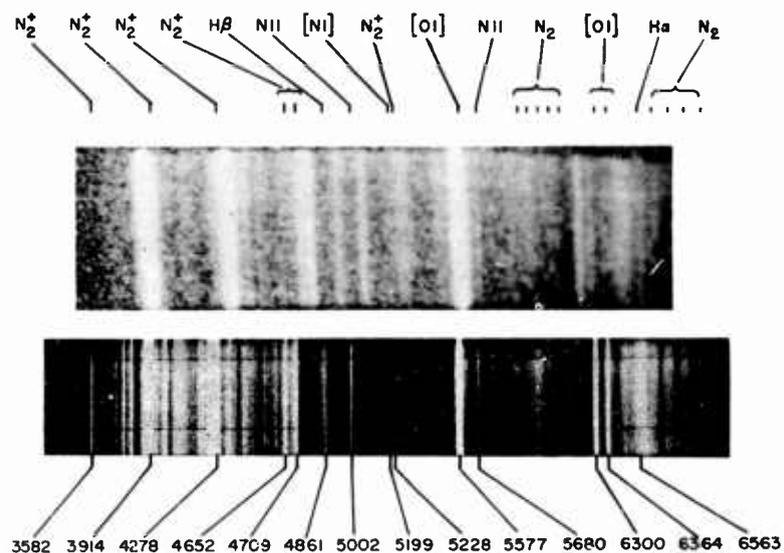Figure 6.2-2 Spectral Change With Time

a) Spectrum of an aurora observed the 24th of September 1963 at the
General Electric Radio Optical Observatory, Schenectady, New York.
This reproduction is of a Polaroid print of one frame of an Image
Orthicon Camera after a 16 second exposure and a camera speed of
f/1.6.

b) A low-dispersion spectrum of a green aurora, obtained with a patrol
spectrograph of the type used in the United States and Canada in the
IGY. The horizontal dark lines are at zenith angles of 45°. This is
a 27 minute exposure, with a geometrical camera speed of f/0.625, on
the great aurora of 2 March 1957. (From Chamberlain, "Physics of the
Aurora and Airglow", Academic Press, p. 152; 1961)

Comparison of Spectral Lines

Figure 6.2-2

a particular wavelength line had been observed in a 16 second exposure.

6.2.4 Typical Spectra and Comparison

The detection capabilities and possibilities of an image orthicon system on auroral spectra use is indicated by Figure 6.2-3 where two photographic reproductions are shown. Figure 6.2-3a is a Polaroid print of one frame from an image orthicon camera that had a 16 second exposure of an aurora occurring on 24 September 1963. The slit width was about 2mm and the lens speed was f/1.6.

Figure 6.2-3b is a copy of a 27 minute photographic exposure of a great aurora of 2 March 1957, from the book by Joseph W. Chamberlain, "Physics of the Aurora and Airglow", Academic Press, 1961. The geometrical camera speed was f/0.625 and the transmission grating produced a dispersion of about 350 A/mm.

Although our slit width on the spectroscope was probably much wider, the aurora was much weaker, the camera lens slower, and the exposure shorter by a factor of 100. However, the number of lines detected were practically identical, although the wider slit and the limited dynamic range did not allow as good a quality picture.

6.3 Night Air Glow

Night air glow spectra have been recorded with integration periods varying from 1/2 second to 1 minute. Four to sixteen second exposures appear to be adequate for most purposes. Comparison of night air glow spectra with those in the files of the IGY World Data Center at Cornell show that 4 to 8 second I.O. exposures compare quite favorably with exposures with film of 1 to 2 hours or longer. Dr. Sprague at the Center stated that in his opinion our spectra are faster by a factor of at least a thousand over normal film techniques.

48

Typical lines received on a clear night are:

Hg	4047 - 4078	
Hg	4358	
Hg	5460	
Hg	5780	
NaD	5893	Twilight
N_2^+	4652	
N_2^+	4709	
N_2^+	5228	
OI	5577	
OI	6300 - 6364	

Mercury lines caused by scattered city lights are detected over the entire sky, even in the darkest region away from any city. Their intensity is of course a strong function of atmospheric scattering.

Forbidden lines of oxygen, the twilight NaD line, and N_2^+ bands are normally detected in air glow. Many absorption lines have been observed during early sunset, along with emission lines which gradually predominated.

Relatively fast fluctuation in the intensity of the OI 6300 line has been noted and has been found to vary over the sky. The reason is not clear although a weak auora may be causing these fluctuations. On the 24th of May the spectroscope was pointing west with an elevation of 10 - 20 degrees. After twilight, roughly 10:00 P.M. EDT, the 6300 line varied from quite strong to very faint when using an 8 second integration. It would appear and disappear; sometimes covering the entire slit, or only the top or bottom. This pulsation was such that if it appeared strong on one frame, it usually was extremely faint on the next frame 8 seconds later. Further visual investigation showed that the time constant appeared to be about 10 seconds although on a particular night the time constant may change or the line may even disappear.

49

7.0   POSSIBLE FUTURE INVESTIGATION AREAS

7.1   Correlating M Arc with Path Length Fluctuations

Transit Navigation Satellite Studies at the General Electric
Radio-Optical Observatory on 400 Mc during 1962-63 showed that at certain
times very erratic fluctuations occurred in the received Doppler frequency
that could not be explained. Recently a correlation has been found between
the line of sight flux from an M arc and the index of amplitude scintillation
power of UHF satellite signal. The results are reported by F. E. and
J. R. Roach, "Stable 6300 $\overset{o}{A}$ Auroral Arcs in Mid-Latitudes", Planetary and
Space Science, Vol. 11, pp. 523-545, Pergamon Press Ltd., 1963. An inter-
esting experiment would be to simultaneously track a satellite by radio and
optical means and to determine further correlation between auroral arcs and
electrical path length. The radio receiving equipment could receive one or
more transmitted signals from the satellite while a tracking telescope with
a narrow field of view, fitted with a spectrograph and a photomultiplier
could simultaneously record the intensity of the 6300 $\overset{o}{A}$ line. A method of
measuring the RF phase jitter with a phase-lock receiving system that exceeds
one part in 10^9 short term stability would be to tape record the VCO output,
then play it back through two heads with variable spacing and apply the outputs
to a phase detector. The Doppler shift will tend to be cancelled out and the
phase fluctuation characteristics or changes in electrical path length will
be measured.

7.2   Altitude Variations

Reliable quantitative information on elevation variation is
scarce as most data has been recorded photographically with long exposures
which average out the auroral time fluctuations. Pure altitude variation
could probably best be studied with an all-sky lens, assorted filters, a

grating, and the image orthicon to produce a fast spectrograph or "photograph" with time as a parameter. Investigation of the variation of hydrogen emission lines will possibly be the most fruitful since observers have noted that the hydrogen-line character of an auroral display may change significantly with time.

7.3 Various I.O. Modes

Although the memorization mode was found to be impractical because of a lack of understanding of its operation, proven techniques such as beam feedback may be incorporated to extend the dynamic range of the I.O. and to reduce any shading problems.

Also the target slicing equipment recently developed to read out the stored charge image on the target in five or so sections was not used as no auroras could be observed because of a) moonlight, b) weather limitations or, c) none existed.

The storage tube integration mode in which many frames are stored on a storage tube and then read out can also be tried.

51

8.0 GLOSSARY OF SYMBOLS

α -   Transmission of the I.O. target mesh

β -   Secondary emission ratio of the target

δ -   Diameter of the seeing image

ϵ -   Quantum efficiency of the I.O. photocathode

C_T -   Capacitance per positive element of the target

D   -   The aperture diameter

I.O. -   Image orthicon

k   - $\begin{cases} \text{a) ratio of } m/n_o \\ \text{b) percentage of the original target charge not readout} \\ \text{c) the coefficient of recognition} \end{cases}$

ℓ -   Percentage charge at a spot as compared to a spot with charge n_o

m   -   Number of beam electrons approaching a target spot

M   -   The magnitude of the sky background

M_O -   A threshold magnitude

n   -   Number of photons landing on a spot of the photocathode

n_o -   electron charge on a target spot

P.E.O -   Photoelectric Observatory (now Radio-Optical Observatory)

q   -   The quantum efficiency of any detector

R   -   The ratio of instrument to sky background

V_T -   Voltage associated with a positive charge spot on the target

t   -   Time

52

AFCRL
Office of Aerospace Research, L. G.
Hanscom Field, Mass.
Rpt. No. AFCRL-64-209. APPLICATION OF
ELECTRO OPTICS TO AURORAL STUDIES.
Final Report, December 1963, 52p.
incl. illus.   Unclassified Report

During 1963 an investigation was per-
formed to examine the feasibility of
obtaining information on the changing
characteristics of the aurora and night
air glow by low-light-level image
orthicons (I.O.) at the Radio-Optical

1. Auroras
2. Night Sky
3. Sky Brightness
4. Spectra
5. Line Spectrum
I. AFSC Project
   8653
II. Contract AF 19
    (628)-2366
III. General Elec-
     tric Co.,
     Schenectady, NY
IV. J.E. Anderson,
    J.F. Spalding

Front of Card

Observatory of the General Electric
Company's Advanced Technology Labora-
tories in Schenectady, New York. Al-
though it was a poor year for auroras,
scene movies and spectral lines were
simultaneously photographed of various
displays from the I.O. monitor and
compared with photographs taken by
other people. The image orthicon is
faster by about three orders of magni-
tude over film. Night air glow spectra
was adequately received with 8 second
exposures, and 100 photons are suffi-
cient to record a line, even consider-
ing grating loss, etc.

Back of Card