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SPACE OBJECT SEARCH AND DETECTION STUDIES WITH A GROUND-BASED TELEVISION SENSOR

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Surveillance Branch
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A test facility was constructed for the purpose of evaluating the sensitivity of modern television camera tubes for detection of moving point sources under operating conditions approximating those to be encountered by ground- or space-based optical surveillance sensors in the ADC SPACETRACK Augmentation role. This test facility was very similar to the GEODSS prototype concept later evolved by the MIT Lincoln Laboratory for installation at the Lincoln Laboratory Stallion Test Site,

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ABSTRACT (Continued)

White Sands Missile Range. Results are given for use of the test-bed system, for a period of 50 days, as a quasi-operational sensor patrolling the geosynchronous traffic belt where some 70 spacecraft and their rocket stages are known to be orbiting. Four hundred thirty-seven satellite detections were made, 175 being of near geosynchronous objects. Positional data were taken of 74 of these satellites and reported to the Space Defense Center for comparison with Baker-Nunn photographic data.

A simple photometric SOI subsystem was devised to use the EBSICON camera tube as the detector, and signatures of more than 20 satellites recorded. Some of these are reported here. The test-bed system was also used to evaluate several concepts for the suppression of background clutter to enhance the detection of faint moving space targets, and conclusions are given on this work.

FOREWORD

This report presents experience gained at the USAF Avionics Laboratory OPOS Observatory during the conduct of exploratory development on the use of intensified vidicon camera systems for the detection of distant space objects. This effort was carried out under Work Units 03-18, 03-20, and 03-31 of Project 7660. These work units comprised a direct support effort, TV camera and MTI Evaluation, for the Directorate of Technology, Space and Missile Systems Organization (SAMSO/DYB). The work was funded primarily by SAMSO from Program Elements 64406F and 63424F. AFAL funding was provided under P.E. 62204F.

The results reported here are the culmination of efforts by several organizations, including work by Systems Research Laboratories, Inc., RCA Aerospace Systems Division, AFAL Technical Services Division, and a number of personnel formerly assigned to the Surveillance Branch, Reconnaissance and Weapon Delivery Division of AFAL. Special note must go to Mr. Don Pedrick of SRL and to Mr. Ron Wiensch of AFAL/RWI. Dr. Kenneth E. Kissell, AFAL/RW, Autovon Number 785-6502, was the Project Manager for this effort and may be contacted for further information. The camera tube test facility itself has been moved to the MIT Lincoln Laboratory Stallion Test Site, White Sands Missile Range, for further use in development of the GEODSS system.

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INTRODUCTION

In the mid-1960's an attempt was made to utilize electro-optical technology to provide a near real-time satellite detection and cataloging capability to complement the Baker-Nunn photographic camera system. For a variety of reasons this effort was abortive: the state-of-the-art in camera tubes would not support the requirements imposed by point-source detection against the celestial background and scattered light of the foreground sky. The FSR-2 or POSS (Passive Optical Surveillance Sensor) was designed to use multiple image orthicon cameras behind a single large optical system. The I/O cameras were coupled by coherent fiber optics to the curved focal plane of the large Baker-Schmidt optical system. Losses in the Schmidt optics and the coupling optical fibers, when combined with the unexpectedly low performance of the image orthicon cameras against point sources, prevented the system from reaching its specified sensitivity and the effort was abandoned in the late 1960's until better detectors were available.

In 1972 two promising new detectors were available--the double-intensified vidicon and the silicon intensified-target or SIT or EBS camera tubes (also known as the EBSICON). In a coordinated effort to validate the actual performance of these candidate camera tubes under a range of target brightnesses and background brightnesses, the Surveillance Branch (AF Avionics Laboratory), the Directorate of Technology (SAMSO), and the Directorate of Planning and Technology, ESD, agreed to establish a test-bed camera system to evaluate several tubes. This was carried out under a Memorandum of Understanding, dated 15 October 1973. Tests were carried out at the AFAL Cloudcroft Electro-Optical Facility in 1973 and at the AFAL OPOS (Optical Properties of Orbiting Spacecraft) Observatory in 1973-1975. This latter facility was provided with a special 25-inch aperture, wide-field telescope for this testing as well as with a versatile TV camera chain capable of operation over a wide range of frame rates and scan-line densities. This report summarizes use of these two systems in evaluation of some operational concepts after the camera tube evaluation was completed. The tube evaluation is reported in another companion technical report. Preliminary camera results appear in an earlier publication. A technical description of the test-bed is included here.

BASIS FOR THE SEARCH AND DETECTION EXPERIMENTS

During the final weeks of operations at the AFAL OPOS Observatory at John Bryan State Park, Ohio, the 25" telescope and associated camera system were operated on a nightly basis (when clear). There were four main objectives to the operations. First, it had been theorized that there was a single optimum scan rate for the system operation in all phases of the Moon and sky conditions. Second, AFAL had been asked by ESD to look at some suggestions for search patterns for particular satellite search scenarios. These were investigated, and several other search patterns were also investigated. Third, an understanding was desired of the interaction between an observatory and SDC in the nightly operations including the predictions from ADC and the transmission of observations from the observatory. Finally, an understanding was desired of the human factors involved in nightly operations including not only the actual search and acquisition of satellites, but also the daily mission planning and reporting of data.

The 25" telescope and associated camera system were operated on a quasi-operational basis, observing on every clear night (including weekends). The configuration of the systems was unchanged during the entire series of tests in order to evaluate the first objective listed above and to enable comparison of data from different nights. During the 19 nights of operation out of the 50-day period, 437 satellites were detected, not counting multiple observations of the same satellite in a single night. Of these, 262 had an apparent angular velocity greater than 75 arc-sec/sec, the maximum tracking velocity of the telescope, and were not pursued. Of the remaining 175 detections, 101 were not pursued after detection since the operator was busy with some other activity or test. Observations on the remaining 74 objects were transmitted to SDC by TWX on a daily basis using the standard SDC format. A total of 550 individual positions with time were transmitted. In addition, 70 aircraft were observed within the field of view. They were generally so bright that excessive blooming on the image and storage tubes would destroy 10-20 seconds of stored data. Local airports routinely directed large numbers of aircraft over the observatory and hundreds were seen on the wide-field TV system. Finally, 29 objects were detected with a high velocity (usually hundreds to thousands of arc sec/sec) moving generally from East to West. It is probable that these were meteors.*

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*For a complete discussion of this subject, see Reference 1

SYSTEM CONFIGURATION

Optical System and Mount

The optical system consisted of a 25"-aperture f/3 telescope, shown in Figure 1a. The sensor is mounted at prime focus behind a three-element Wynne-type corrector for field flattening. The observed spot size on-axis is 20 microns.*

The telescope was on an equatorial mount. Both axes had identical drive motors and encoders, consisting of a DC slew motor operating a fixed speed of 2°/sec and a stepping motor continuously variable between 0 and 75 sec/sec. The encoders were 15-bit absolute encoders interfaced with the SRL Special Display Package that converted Declination from 15-bit binary to decimal degrees (+1/100 of a degree) and local hour Angle from 16-bit binary to hours, minutes and seconds of local hour angle. In addition, this package had a siderial clock and computing circuitry to calculate hours, minutes and seconds of Right Ascension. The telescope could be controlled manually with a joystick control, or it could be controlled by a Data General Model 1200 Nova Computer. For the bulk of the tests described here, the telescope was controlled manually in order to avoid the problem and costs of special programming. The control and test console were located in a room below the dome, thermally isolated from the telescope area. The camera test console is shown in Figure 1b.

Video System

The video system consisted of a Westinghouse WX32432 Ebsicon tube (deep-etched metal-capped SIT) mounted in an SRL Variable Rate Camera System. The camera system was operated at 650 lines per frame with a 1:1 interlace and scanned at 8 frames per second. When conditions permitted, the beam was blanked for an integral number of frames to increase the integration time up to 1/2 second. Other scan rates were available.

The selection of 8 frames per second and 650 lines per frame was based on prior tube tests and observations which will be discussed in depth in other reports presently being prepared at AFAL. Basically, there was a practical requirement to select a single scan rate for all operations. This is because, when the system is used operationally, a wide variety of scan rates would increase the complexity, and therefore the costs, of the system. The selection of 650 lines per raster height

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*80% of the energy was judged to be contained in a 20-micron spot by visual microscopic inspection. Total energy spot size was 60 microns. At the edge of the scanned area (16mm off axis) 80% of the optical energy was in a 20-micron spot and the total energy spot size was 80 microns. The corrector was a variation of the Wynne design in Ref. 2.

was based on the observation that the dancing limit of stars caused by atmospheric effects is about 5 $\widehat{\text{sec}}$ at its greatest.* A 650-line raster on a 3:4 aspect ratio on a 32mm diameter photocathode with the 75" focal length, yields a resolution-element size of 4.3 sec. More lines per frame would also have resulted in an increased bandwidth with a consequent increase in the noise without gain in resolution or sensitivity. Further, the spot size on the telescope closely matches the resolution element size (20 microns = 2.1 $\widehat{\text{sec}}$) for 650 lines per frame. It should be noted that in an operational system the tube would normally be scanned with a 1:1 aspect ratio (square format) making the maximum use of the photocathode area. The tubes we were supplied had a 3:4 aspect ratio (standard TV size) mask in front of the target; therefore, the 3:4 aspect ratio scan was employed.

A 1:1 interlace was employed in the raster scan since this eliminates the sequential field problems. For analog storage-tube MTI it makes little difference whether 1:1 or 2:1 interlace is used, but if digital MTI techniques are ever used, a 1:1 interlace is mandatory since otherwise the computer must reconstruct the adjacent lines in sequential fields in order to perform MTI. We have therefore generally used 1:1 interlace.

Video Chain Operation

The choice in scan rate was based on experience with camera tube testing over a period of several months. It is generally recognized that scanning at standard rates is not the most efficient method of satellite observation. First, standard-rate TV allows only 1/30 second of integration time. Unless a large amount of gain is used in front of the target (usually with an intensifier), the full storage capacity of the target will not be utilized, and operation is less than the maximum attainable. This can be overcome with the technique of beam blanking for an integral number of frames, thereby increasing the integration time. It should be noted that integration times in excess of 1 second are not useful for this program, since the satellite will move out of the resolution element in that time. Integration times greater than 1 second will result in the energy of the satellite image being spread over the target, resulting in no greater sensitivity to the satellite, while the star images will integrate resulting in greater system sensitivity to the stars which clutter the field.

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*AFAL Interim Technical Report #4, Contract AF33(615)5307 "Research and Experimentation on Space Object Identification Using Ground-Based Electro-Optical Techniques", Peter A. Button, Juan C. Busti. Institute of Atmospheric Science, University of Miami, Coral Gables, Florida.

The use of an intensifier is recommended for sensors not provided with pre-scanning gain. Running an intensifier or image section at full gain, however, degrades the system effectiveness for this mission by producing excessive internal ion scintillations, making the MTI process difficult. In practice, the image section of the WX 32432 performed best at 70% to 80% of its maximum recommended operating voltage. For this application, 7Kv was used.

The use of slower scan rates than those normally employed for standard rate TV is desirable for several reasons. First, the slower scan allows the use of narrower bandwidths. The noise of the system should decrease with the three-halves power of the decrease in bandwidth.* Since the scanning beam is moving more slowly over the charge image on the target, the signal current will decrease linearly with the decrease in scan rate. The net result is that the SNR increases with the square root of the decrease in scan rate.

In addition to the increase in SNR with decreased scan rate, the slower beam velocity has more time to discharge the target fully. Therefore, the apparent lag of the system is less. This will become important later when the number of different scenes viewed per hour increases. It also means that areas of the target saturated by bright stars or satellites will be more completely discharged and therefore show less blooming. This increase in the reading efficiency of the beam also allows a decrease in the beam current without a great penalty in sensitivity. This implies that, since the beam current is less, higher resolutions are possible without exotic techniques to make a smaller beam.

In summary, it seems best to operate the system at the slowest practical scan rate above the 100-KHz bandwidth region. The scan time should not exceed 1 second and should not be so long that the target saturates due to background. Since the camera was generally run in continuous scan (integrate while scanning), the integration time equaled the scan time except when beam blanking was used. In choosing a scan rate for our system (with its relatively fast f/3 optics) the saturation condition was the limiting factor. Since the system must operate during all phases of the Moon, it must be able to handle the brightest case, namely full Moon. At full Moon the longest integration time

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*This holds true only for those noise phenomena that are functions of bandwidth, and these are generally the predominant noise mechanisms. This technique will not work for non-random noises generated in the ramp drivers or sync system. The technique does not work well below about 100 KHz, where 1/f noise is the dominant factor.

useable without background saturation when observing 10° from the Moon was 1/8 second.* This scan rate was then chosen for these tests. For darker ambient conditions, multiple frame integration was used, increasing the integration time to as much as 3/4 second on one occasion but usually to 1/2 second for no-Moon conditions. The concept was to operate in a background-limited condition at all times.**

The total system sensitivity is a function of both the background and temperature in practice and this averaged m_V 13 (apparent brightness of a star of solar color expressed in visual stellar magnitudes). During full Moon it was m_V 11.3. The most sensitive observations, at m_V 14, were during the dark of the Moon on a cold night with exceptionally good seeing and low atmospheric extinction. This figure should not be regarded as typical. The typical sensitivity limit was at about m_V 13 for most conditions.***

The video bandwidth used was narrower than would be used for conventional TV. Normally, a scanning system with 650 lines at 8 frames per second would imply a required bandwidth of 1.7 MHz. It was found,

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* The background saturation limit is a strong function of the f/number of the optical system. For a constant sky brightness, the background at the photocathode is proportional to $(1/\text{f-number})^2$. The present system operates at f/3 which is relatively low for an astronomical telescope.

** Usually background limits are reached when the integration time is increased. The dark current of the tube will also add to the background. This is a function of the target and photocathode temperature. Best results are obtained when the target is cold. There is a measurable increase in apparent dark current when the tube is warm to the extent that on warm dark nights the thermally induced charge is the limiting mechanism rather than background photons. It is therefore highly desirable to have camera cooling installed.

***The system sensitivity is determined by measuring the signal and noise of a calibrated star and calculating the brightness of a star that would have a SNR of 6. Care is taken to avoid non-linear extrapolations in sensitivity. The signal is the mean peak star signal above the mean background noise level. The noise is the RMS noise as measured by the two-channel tangential method. While an object with SNR of 1 or 2 can be seen on the monitors, the MTI device to be used requires a SNR of about 6 for detection. This is therefore the limit of detection of the entire system including MTI. All magnitudes given are corrected to the top of the atmosphere, i.e., the star and satellite images are actually fainter at the telescope aperture.

when observing point sources, that a slightly narrower bandwidth can be used, thereby decreasing the system noise without significantly decreasing the signal. This is similar to "peaking" the preamp. It should be noted that with decreased bandwidth the system does not perform well on extended area sources and performs poorly against standard TV test pattern charts. It also introduces a "tail" on the brighter stars which can at first be confusing and mistaken for a streaking satellite, as shown in Figure 2. The bandwidth used for all tests in this series was 1.0 MHz. This bandwidth was chosen empirically from prior observations. This subject will be discussed fully in final reports now being prepared.

Displays

In addition to the line-selecting oscilloscopes used for monitoring the video, a large monitor with a long persistence P-7 phosphor was used. The longer persistence phosphor is needed to minimize the flicker of the 8-Hz raster scan. A second monitor was used to expand a portion of the raster for closer examination. Finally, a scan converter was used as an MTI device. All video to the three units was amplified, clipped to remove the highlights on bright stars and summed with video cursors indicating the position in the ramps of gates for the expanded display and video sampling circuits. In addition, the video was at times AC coupled and high-pass filtered to eliminate EMI at 60 Hz. At times, a 2:1 interlace was used, when fully manual MTI was required, in order to further alleviate the monitor flicker.

The MTI device was a Tektronix model 4501 scan converter. It is essentially a storage tube that sums all video and simultaneously displays the summation, since the storage medium is on a CRT faceplate. This has the advantage over both single and double-ended scan converters in that it can display while writing and does not require a separate display. It has the disadvantage that it has only two shades of gray, black and white. The display does not show satellites that are marginally detectable. In general, about 1/2 m_v of sensitivity is lost between the monitor and the MTI device. This device does not, however, suffer from the eventual saturation of background exhibited by most storage tubes. This is a useful property since most storage tubes must be preprogrammed to write a certain number of frames before the background comes up to a detectable level. Further, any additional writing can saturate conventional storage tubes. This prevents the operator from extending the search time, should he desire to, without erasing and starting a whole new search cycle. A Hughes model MSC-1 scan converter was also tried during the tests and eventually removed from the system for this fault. Although the 4501 is capable of reading the summed video and displaying the result on another monitor in standard rate TV, this feature was not used since the summed video is always displayed on the storage tube CRT face.

Gateable Peak-Reading Voltmeter

The final element in the test set-up was the satellite photometer circuitry. Gates were developed in the vertical and horizontal ramps, as mentioned on the previous page. This is equivalent to forming a small box around part of the picture. The size and position were variable both vertically and horizontally. For photometry the vertical gate usually was set in the center of the display and about ten to fifteen lines high. The horizontal gate was also set in the center of the display and of a roughly equal width as measured on the display. Video was fed into the SRL Gateable Peak-Reading Voltmeter along with the gate signals. The gateable voltmeter sampled video only during the gates and retained the maximum video voltage obtained during the gates. At the end of each frame, the accumulator in the voltmeter was zeroed. The value of the peak voltage was displayed on a digital voltmeter. The BCD voltage (sampled and held) was then put through a D/A converter into a stripchart recorder. This recorded the frame-to-frame variation of the peak voltage within the sampling gates. The sampling gates are roughly analogous to defining the size of the field stop in conventional photometric systems, eliminating video signals in the remainder of the field of view. Unlike a conventional photometer, the system does not average all of the signals within the gates, but responds only to the peak value of the brightest point within the gates, normally the object of interest. In principle, this allows measurement of the brightness of the target to the limit of resolution, rather than to the limit of tracking. In practice it only allows measurement of the peak signal produced in the image spot, from which the brightness must be inferred since the relationship between peak signal level and input intensity is very nonlinear over certain ranges of brightness.

It should be noted that the incorporation of this photometric system was not expected to replace any conventional photometric systems, since there are serious objections and limitations to the use of TV photometric systems. First, this system of photometry is based on detecting the peak video level within the raster of the gates, i.e., the maximum signal in the target image. The relationship between the actual brightness of the target satellite and the peak video level is extremely nonlinear at brighter magnitudes. For this system, it was very nonlinear above m_v 10. Images brighter than m_v 10 tended to spread out (bloom) rather than increase in video level. A better measure of the brightness of the satellite would be an integral over the several lines in the satellite image rather than a measure of the peak video, as is presently being developed by RML. This is analogous to classical astronomical photographic photometry or a measure of the area of blooming which can infer the brightness, as is being developed by the Corralities Observatory of Northwestern University (Ref. 3). Secondly, the peak reading video level is much more susceptible to noise spikes within the video system than an integrating system.

While the nonlinearity of response of the system can be determined and an apparent brightness of the satellite calculated, this is an extremely tedious job. The nonlinearity of response to brighter satellites also causes the errors and uncertainty in the data to increase with increasing brightness. Since it is the brighter measurements that are nonlinear, the targets with the best SNR are those of lowest accuracy. Frequent calibration (several times a night) is required to maintain system accuracy. For synchronous satellites it is not difficult to calibrate since the Landolt calibrated star fields are nearby, and the extinction caused by the atmosphere can be considered to be equal for the satellite and for the calibration stars. For other satellites, however, the calculation becomes almost too involved for any data reduction except by machine methods*.

The photometry system is limited in time resolution by the frame rate of the TV system, 8 Hz in this case. There exists the possibility that two separate events in the photometric signature that are within one or two frames of each other will not be resolved. Typically analog photometry systems can resolve events separated in time by a millisecond. The 8-Hz sample rate also can be misleading if the object under observation has a period at or near 8 Hz or is a multiple of 8 Hz. This situation happened only once during the 19 nights of observation and was ameliorated by changing the scan rate of the video system slightly to eliminate the beat effects.

In spite of the above limitations, the video sampling photometry system was invaluable to the operator in identifying objects in near real time. This enabled the operator to disregard uninteresting objects and spend more time on unknown objects. After a very few nights a library of objects was available with many familiar signatures. The system is advantageous in that it provides simultaneous photometry and tracking data at a limiting sensitivity that is comparable with photon-counting photometry systems of the same aperture. This is possible

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*An additional problem that is also present in conventional photometric systems is the variation of response over the photocathode. This is usually solved by imaging the telescope aperture over the whole face of the photomultiplier in order to average the signal. This is not possible for an imaging system since positional information is desired. It is therefore necessary for the operator to insure that all measurements are taken at the same place on the photocathode. This is only a minor inconvenience to the operator for synchronous or deep space objects, but demands constant fine tracking in other satellite cases.

since the effective field of view of the photometry system is the resolution element as determined by the atmosphere, optics and TV system resolution. Typically, this is about 5 $\widehat{\text{sec}}$. In most conventional photometric systems either (1) the field of view must be small, which requires great accuracy in tracking lest the satellite drift out of the field of view or (2) the tracking is allowed to be less accurate requiring the field of view to be made larger with a loss of sensitivity at faint magnitudes. The former alternative demands expensive tracking systems and the latter has a sensitivity penalty. In the TV system the video gate can be relatively large (typically 10 TV lines or 42 $\widehat{\text{sec}}$) while the effective field of view for the photometry subsystem remains the size of the resolution element. As with any photometric system, stars often fall within the field of view of the video gate and introduce false data. It is left up to the operator to note the event on the chart recorder. It seems quite feasible to automate this function. As discussed above, there remains a difference in the nature of the peak video signatures and the photometric signatures, a difference which can be explored and understood after the GEODSS test site is in operation.

EVALUATION OF A SINGLE SCAN RATE FOR SYSTEM OPERATION

The scan rate of 650 lines per frame at 8 frames per second was used throughout the entire 19 nights of observation. One exception to this standardized rate was discussed earlier. At that time the scan rate was changed to about 10 frames per second for several minutes during which the total system sensitivity was uncalibrated.

The rationale for the selection of this rate is discussed under the system configuration. Validation of the selection consists of the fact that at no time during all lunar phases was the system saturated. Observations were made as close as 7° from the Moon on a m_V 10 synchronous satellite*. Satellites of the same brightness were tracked into the dawn twilight up to 40 minutes before sunrise**.

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* Observations were not made closer to the Moon since this would have let the Moon's image fall within the field-of-view of the wide-field boresight camera. Light levels that high could permanently damage the intensified SEC vidicon sensor in that camera.

**This was generally at reduced HV and with a great deal of operator attention to the monitors. It is not recommended that this be done except in unusual circumstances since it fatigues the operator quickly due to the decreasing SNR on the monitor.

Comparison of measured system sensitivity at 8 Hz with prior observations at other scan rates indicated no significant loss in sensitivity when the system was operated at this single scan rate.

Multiple frame integration was employed extensively under moonless conditions or when observations were made far from the Moon. The maximum integration used was 3/4 second but usually the longest integration was 1/2 second.

The high-voltage control was maintained at 7 Kv with two exceptions. First, in the dawn and dusk periods, the HV was occasionally reduced to prevent saturation. Second, the HV was increased on one night to 8.5 Kv in order to acquire a satellite of special interest that was predicted to be very faint. Scintillations caused by this higher voltage played havoc with the MTI process and the operator had to rely on fully manual MTI using the monitors. This is extremely fatiguing and the operator's effectiveness deteriorates rapidly although it is a useable technique for special cases*. A 2:1 interlace was used during this search which minimized the monitor flicker and seemed to ease the fatigue. At all other times a 1:1 interlace was used since the timing circuitry for the gateable peak reading photometry system was not set up for 2:1 interlace, although it could be with little effort.

EVALUATION OF SEARCH PATTERNS

AFAL was asked by ESD to look at several search patterns for satellite detection. The candidate patterns were the Cross-Search, the Spiral-Scan and the Horizon-Scan as shown in Figures 3, 4, and 5. The Cross-Search pattern is used to set up a fence in the sky. It consists of a sweep from zenith to horizon along the meridian both North and South of the zenith. In addition, similar sweeps are made from the zenith to both the East and West horizons. The telescope slews along the search pattern track to the star scene to be searched, comes to a halt, switches to siderial drive to fix the stars in the field of view and searches for ten to thirty seconds. Assuming no satellite is found, the telescope then slews along the Cross-Search track to the next scene to be searched, halts, switches to siderial drive, etc. Since the AFAL 25-inch telescope was on an equatorial mount, it was difficult to generate the East-West arms of the Cross-Search pattern.

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*A study is presently in progress into these problems by AMRL. Personnel from AMRL have participated in observations at JBSP. A separate report will be issued by AMRL.

The search pattern was discontinued below 30° from the horizon since the extinction in Ohio normally becomes too great for effective search below that elevation. In order to save the costs of special computer programming, all search pattern generation, slewing, and evaluation was carried out with manual control of the telescope. This required about half the search time be spent in slewing the telescope to the proper position. In order to evaluate the effectiveness of all search patterns in terms of the number of square degrees search per hour, each search scene was examined for 20 seconds and the number of square degrees which could be searched per hour with an automated system was computed on the basis of a 20-second search plus 5 seconds for telescope motion*.

The second search pattern to be evaluated is the Spiral-Scan, as shown in Figure 4. It consists of a spiral starting at the zenith and expanding downward to within 30° of the horizon. As with the Cross-Search pattern, the telescope halts at each scene to be searched along the search track, switches to siderial drive to fix the stars in the field of view and remains on the scene for 20 seconds. This pattern proved very difficult to generate manually, although it would be no problem for a computer-controlled telescope.

The third scan to be evaluated is the Horizon-Scan shown in Figure 5. This is similar to the technique used in the AN/FSR-2 Satellite Detector. Little time was devoted to this pattern since it has been shown that it is entirely possible for many satellites of interest to remain undetected with this scan. The Cross-Scan can also miss many satellites of interest. The Horizon-Scan would be superior if carried out long enough in conjunction with a spiral scan.

In addition to the three scan patterns which are oriented toward the problem of autonomous search, as suggested by ESD, three search patterns concerned with the tip-off type search were used. They are the Declination Swath, the Right Ascension Swath and the expanding square as shown in Figures 6, 8, and 9. The Declination Swath is a fence-type search in which the telescope searches a set of field of views with changing declination. It is most useful when the inclination of a satellite orbit is known, but the argument of perigee or the mean motion is not well known. In the simplest version of this search, the siderial drive is not used. The telescope is moved in declination slowly (usually at about 15 sec/sec). On the MTI storage tube the

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*It is assumed that a telescope under the control of a computer generating the search pattern would be able to slew to the next scene in at least five seconds, probably in less time. For this part of the evaluation a straight calculation with no experimentaton is used.

stars will appear to move to the right and upward (or downward depending on whether the declination motion of the telescope is Southward or Northward). In the specific case of quasi-synchronous objects, the satellite will move upward (or downward) vertically. It is very easy for the eye to pick out a vertical line in the midst of many slanted lines, facilitating satellite detection as shown in Figure 7. This method does not work in dense star fields since the display soon becomes too cluttered. In this case, a second version can be used in which each declination position must be searched in siderial drive. This requires, however, that the telescope be slewed East to the base line of declination between scene searches. The resulting zig-zag motion of the telescope is time consuming to control without a computer, but is a trivial problem for automated control.

The second tip-off type search evaluated is the Right-Ascension Swath, shown in Figure 8. It is like the Declination Swath but the search is conducted along lines of Right Ascension. The width of the search depends on the uncertainty in satellite position. This search is most useful for objects whose suborbital longitude point is not known but whose inclination is well known. In addition, the Right-Ascension Swath is also used as an area search by "stacking" several swaths in declination. It is a much simpler search pattern to generate manually since the direction of search is parallel to the stellar motion. The final tip-off search pattern used is the Expanding Square Search shown in Figure 9. In this search, the telescope performs a spiral search about a point which is generally the predicted position of an object whose position is uncertain. This search pattern gives quickest results with more searching done in the area of greatest confidence of the predicted look angle. Usually, the center of the pattern is a moving point as defined by the object's predicted motion. In the case of a synchronous object, the pattern is a simple expanding square with the central point fixed in topocentric coordinates. In all other cases, the pattern is a complex series of motions best generated by a computer. For special cases, Molniya-type objects have been acquired with uncertainties in positions of up to 5° by plotting the object's predicted position on graph paper and letting the operator compare predicted object position with telescope position and "generate" the search pattern in his head. It is hard, fatiguing work, requiring much pre-mission planning, but it is usually effective.

In all cases, the size of the search pattern and the dwell time per search scene are a function of the field of view and the type of satellite sought, especially its apparent angular velocity. The determination of what search pattern to use for what satellite has largely been a matter of intuition and experience on the part of the operator. The object is to generate a "leak-proof" search fence for a given satellite. If the velocity of the satellite is known, then the usual method is to center the fence on the predicted track and make the width of the fence as wide as possible so long as the telescope can repeat the fence search pattern in less time than the satellite can traverse the thickness of the fence. The major problem here is the lack of flexibility imposed by a search time-line. Time must be allowed for occasional delays caused by false alarms which necessitate re-examination of some search scenes and handling other resident space objects which may appear in the fence. A critical analysis of these strategies is needed in an operational configuration with several telescopes.

Search-Pattern Effectiveness

Results of evaluating the search patterns are given below. Results for the expanding square are not given since this pattern was used often and discontinued when the satellite was acquired. So far, the use of this pattern was mainly for reacquisition of previously observed objects for track maintenance. Therefore, it has the unusually high effectiveness of 100%

Type of Pattern	Total deg^2 Searched	Satellite Acquisitions
Horizon Ring	470	17
Cross	277	29
Zenith Spiral	114	0
Declination Swath	50	3
Right Ascension Swath	114	40

One of the satellites acquired and tracked from the Horizon Ring search was object 6932 (25th Molniya 1) which had a very high apparent velocity of 114 $\widehat{sec}$/sec at acquisition. The probability of catching this type object with this search pattern is small due to its high velocity orthogonal to the search ring.

The lack of acquisitions in the Zenith Spiral Search is not understood. By probability alone, there should have at least been an aircraft or meteor acquired. Further, the satellite population per unit time at the declinations covered should be high enough to allow several acquisitions, especially since the search was performed during the early evening when low-altitude satellites would have been illuminated. This subject should be explored more fully at the GEODSS ETS.

The Declination Swath was not pursued fully when it was seen that the Right Ascension Swath was much more effective, especially when considering the fact that without a computer the Right Ascension Swath could cover many more times the number of deg^2 per hour and was also useful as an area search. The high number of acquisitions from Right Ascension Swath searches results from the fact that this search pattern was often used with SDC predictions and almost always used in the Celestial Equator region where the satellite population is especially dense.

The total field of view of the system is $0.58^{\circ} \times 0.77^{\circ}$. For all searches, the search box size was taken to be $0.4^{\circ} \times 0.625^{\circ}$ (2.5 minutes of hour angle). This was to insure some overlap in search scenes.

EVALUATION OF INTERACTION WITH SDC

Coordination with SDC started after observation on 17 January 1975 of a quasi-synchronous satellite having a fairly fast drift. Telephone conversations with SDC indicated there was an interest in this type of object. Initially, the observations were phoned into SDC but at that time the only way of getting observations into the SDC computer was via TWX, which required SDC personnel to generate a TWX to themselves!

Captain Boucher supplied AFAL with the format required for transmitting observations (type B format) and thereafter AFAL generated all observational TWX's. Due to the fact that the format for reporting observations is a field of numbers designed for direct entry to the computers, it was decided not to use the common method of TWX generation on a DD Form 173 since this would require the TWX operator to retype the data, allowing the possibility of uncheckable errors in typing. Instead, an arrangement was worked out with 2046th Communications Group, W-PAFB, whereby the data would be punched on paper tape at JBSP and submitted to the 2046th detachment located in the FTD complex on base. That detachment was selected since they had the proper data tape handling equipment and messages could be delivered to them 24 hours a day. After each night's observations the data would be punched manually and delivered to the FTD building for transmission.

After several conversations with SDC, data formats were worked out for predictions from SDC and observations from JBSP. SDC transmitted element sets on objects of interest to the receive-only TWX terminal at JBSP. Also included were Baker-Nunn type predictions and 3-part bulletins. Since the bulletins dealt mainly with low-altitude objects, they were not used for this series of observations (although the colocated 24" telescope did use them). The Baker-Nunn predictions contain quite a bit of extraneous data for this mission, but the basic information is useful. Due to the large amount of data, and a lack of data-processing capability on-site, only information on the 83XXX series, quasi-synchronous equatorial objects, was requested for this study.

Frequent telephone conversations with SDC revealed special interest in certain objects, especially the super-synchronous objects that had recently been discovered. It would be helpful in future dealings from SDC to have a look-angle prediction format specified for use by E-O sites. This format would include, as a minimum, the raw elements and should include look-angle predictions in the mount coordinates used by the site. This mission planner should have available data on the Solar phase angle, the target's angular distance from the moon, and intersections with the Earth's shadow; these may be done at either the site or at SDC. Predictions of brightness should also be provided from SDC based on inputs from other sites along with information on the target signature. It would also be useful to have an indicator as to whether the object is to be observed for maintenance of orbit (including perhaps elapsed time since last observation and maximum allowable time to next observation) or to be observed regularly for a suspected change in orbit that may occur. Since the SOI function is included in the mission, an indicator of required SOI information would be necessary. In addition, the type of SOI and desired duration of tracking for SOI would be helpful. The nightly mission planning during the recent observations was done on-site with an eye to satisfying all four objectives. It would seem that operational mission planning might be tasked directly from SDC on a nightly basis.

Since the look-angle predictions from SDC arrived out of order and mixed for several days, there was a good deal of sorting required before the data were in a readily-accessible format for the operator. This duty would be eliminated with the incorporation of an on-site computer for daily mission planning, or if such planning is done by SDC. Similarly, the preparation of observations will be greatly aided by an on-site computer. This will also eliminate the human element from typing TWX's. At least one typographical error has been discovered in the data sent to SDC. Errors of this type were enhanced by the fact that the operator typed the observation reporting TWX at the end of a duty day that was at least ten hours and at times as much as thirty hours long.

The most useful information from SDC was the weekly feedback TWX. These TWX's were extremely helpful in mission planning. In the SDC observation reporting system an unknown satellite is given an object number indicating it is not identifiable at the site. Initially, all observations were unknowns. The feedback TWX assigned identifying numbers to the targets based on correlation with expected orbital positions. On subsequent nights these targets could be recognized by positions and/or signatures and correctly numbered; fewer unknowns were reported. This also eased the workload at SDC where unknowns must be processed separately. These feedback reports also gave an idea of which satellites were well known and therefore uninteresting for further extensive observation, freeing valuable time to concentrate on other predicted objects. In future operations, the feedback TWX should probably be a daily message along with the tasking for the next night.

The accuracies of observation were limited by the present system configuration. All positional data were taken by reading the encoder displays and writing down the data for later formatting and transmission to SDC. Obviously, a computer would significantly speed the process and eliminate copying errors. Observations of time were to the nearest second, as determined by the operator. Observations of declination were read from the encoder display. The display indicates to the nearest hundredth of a degree. Observations of right ascension are correct to the nearest 5 seconds of hour angle. The large uncertainty is due to conversion of the 15-bit binary to BCD and of the BCD local hour angle to BCD Right Ascension with associated round-offs. In addition, on any given night there exists the possibility of a systematic error caused by improper daily setting of the Siderial Time Accumulator from which the RA is computed. In practice this accumulator was checked several times a night. There is also the possibility of a constant systematic error caused by misalignment of the polar axis, non-orthogonality of the polar and declination axes, improper zero setting of the RA and Dec encoders and mount droop. Extensive mount calibrations should be performed at the future operating site to identify and account for these systematic errors. The methodology is well known and should be part of the initial operation of the site. Systematic errors may occur in the video system due to ramp generator instabilities and monitor problems. This can be eliminated by placing a reticle at the image plane of the telescope and referencing all measurements to the reticle.

The possibility of handoffs from site to site was discussed with SDC, but the opportunity never presented itself. Due to the nature of real-time observations, this could provide a significant improvement to SDC operations, especially in the case of a maneuvering object, and should be pursued.

As an exercise, and in order to aid the refurbishment and check-out of the 24" telescope system colocated at JBSP, handoffs were given to that system on two nights. This included one object that was far below the acquisition telescope threshold except for two momentary flashes separated by 18 and 23 seconds. Several other handoffs were also given to that system. In addition, several handoffs were given to the Cloudcroft E/O Facility of satellites that had been observed regularly at JBSP. In all probability, Cloudcroft could have found the satellites unassisted, but the handoff was used to speed the process and to see if the technique was feasible. In one case Cloudcroft had a requirement to observe a satellite shortly after it emerged from shadow. A handoff was successfully given which reduced the required search time for Cloudcroft, allowing a successful observation of the required event for SOI work.

For a complete description of SOI data taken at JBSP on the 25" telescope, see the Appendix.

EVALUATION OF THE HUMAN FACTORS OF SITE OPERATION

As a result of the AFAL phase-out of manpower, all but portions of three nights of observations were performed with only one operator. It is recommended that at least two people operate this type of installation since with one operator there is a good deal of telescope dead time while the operator takes data and does real-time mission planning. Ideally, three people should be present to allow the operators to take breaks. It is realized that during the recent observations, there were many objectives to be met due to the multiple goals of the experiment. In the operational site, however, there are several different activities that are to take place. These are: 1--autonomous search; 2--tip-off search for selected special interest objects; 3--maintenance of catalog observations and 4--SOI. In addition to the daily mission planning, there are real-time mission decisions to be made by the operator, since daily mission planning may be changed by contingencies of hand-offs or weather changes*. For instance, at times part of the sky may be obscured, precluding planned first priority observations such as SOI but allowing other secondary observations such as catalog maintenance.

Adequate mission planning during the recent test observations was possible only when cloudy nights allowed the operator to work during the preceding day. When successive clear nights occurred, the data remained unreduced, and the nightly observations were less than adequately organized due to lack of planning. Clearly, additional personnel are required to survey each night's planned operations and identify which observations are to be made mandatory and which are "nice-to-have". This demands a constant interaction with SDC personnel at Cheyenne Mountain.

No maintenance was performed on the system during observations. Clearly, any operational site must have a maintenance schedule and calibration schedule. It is assumed that nearly all normal maintenance can be performed during the daylight hours and calibration will have to be inserted into the observation schedule.

The reduction of position observations will be essentially automatic with the introduction of computers, so this will not require a

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*Invaluable aid was given to mission planning by Det. 15, Air Weather Service, in the form of nightly and, at times, hourly weather information. Personnel at Det. 15, especially Lt Maglassang, took active interest in the prediction of optical atmospheric conditions. This is very useful and should be continued at the Rimfire Site.

great amount of time. SOI data, however, will require data reduction and interpretation manually*. The reduction, formatting and transmission of these data to SDC will require further personnel since it should be done on a daily basis in order to aid real-time mission control on the following night, especially if there are several sites participating.

Comments on MTI Devices

The MTI devices tried at JBSP over the last two years indicated that there were two off-the-shelf possibilities available in the Tektronix 4501 and the Hughes MSC-1. The Tektronix unit was judged to be the most useable and was therefore employed during the recent tests. The use of fully manual MTI consisting of a P-7 phosphor monitor and the operator's ability to discriminate stars from satellites has been used at times when no better MTI was available or useable. Fully manual MTI with a simple monitor has been shown to be extremely fatiguing to the operator**. It is mandatory that some form of semi-automatic MTI be employed in which the operator is not required to look at the display constantly. An MTI that is semi-automatic (operator checks display every 30 seconds or so) is acceptable, although probably not as effective as a "bell-ringer" MTI. Keeping to a search time-line, however, is difficult. The operator feels alternatively pressed for time to examine the MTI display every 30 seconds and bored waiting for the next display to be examined. There is not enough time between examinations of the MTI display to really do anything but wait. Human factor problems of this nature have probably been studied for assembly line workers who have the same cyclic "hurry-up and wait" pressures. This area could best be approached by AMRL.

The idea proposed by MIT/LL of scheduling alternating periods of search and track maintenance is excellent. It was tried during the recent observations and found to be very good. It intersperses the boring task of autonomous search with the relatively rewarding task of track maintenance. This should be expanded to include the tasks of SOI and special object tip-off search.

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* Research on the automatic digital reduction of SOI data is now going on at the Cloudcroft E/O Facility and at various contractors. This function is at present not fully automatic but may be by the time the system is operational. It is a laborious process at present.

**AMRL estimates that the effectiveness of the operator decreases sharply after only one hour of this type of search and, depending on the star-field cluttering, may be effective for only about 15 minutes. Operator effectiveness is strongly dependent on operator fatigue, experience, and motivation.

It would be helpful to the operator to have an interactive display with the site computer showing satellites above the horizon, those satellites above the horizon that are objects of interest, satellites being worked for track maintenance (including the most recent offsets observed from the predicted track), objects of special interest with time-to-go before satellite drops below the operational elevation limit or enters shadow, and a comparison of real-time activity with prior daily mission planning (score board). These are the elements of the nightly operation that the system operator must constantly be aware of in order to follow or modify the daily mission. All interaction should be in real time. In addition, it would be helpful for tracking of new acquisitions to know when sufficient track data have been taken to assure knowledge of position to within a certain error for a given time period. This allows the track telescope to shift to other tasks and begin the new search sooner.

The above considerations of site operation do not include the maintenance or administrative workloads inherent in any military operation of a remote detachment. These workloads should be studied at Rimfire.

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1. K. Stuart Clifton, "Television Studies of Faint Meteors," J. Geophysical Res., Vol 78, No. 28, Oct 1, 1973.

2. C.G. Wynne, "A New Wide-Field Triple Lens Paraboloid Field Corrector," Monthly Notices of the Royal Astron. Soc., Vol 167, No. 1, April 1974.

3. J.R. Dunlap, E.J. Weiler, and J.A. Hynek, "Development of Techniques for Extension of the Magnitude Scale in Selected Equatorial Kapteyn Areas with an Image Orthicon System." AFAL-TR-75-26, March 1975.

Figure 1a. AFAL 25-inch Telescope for Camera Testing

Figure 1b. Camera Test Console

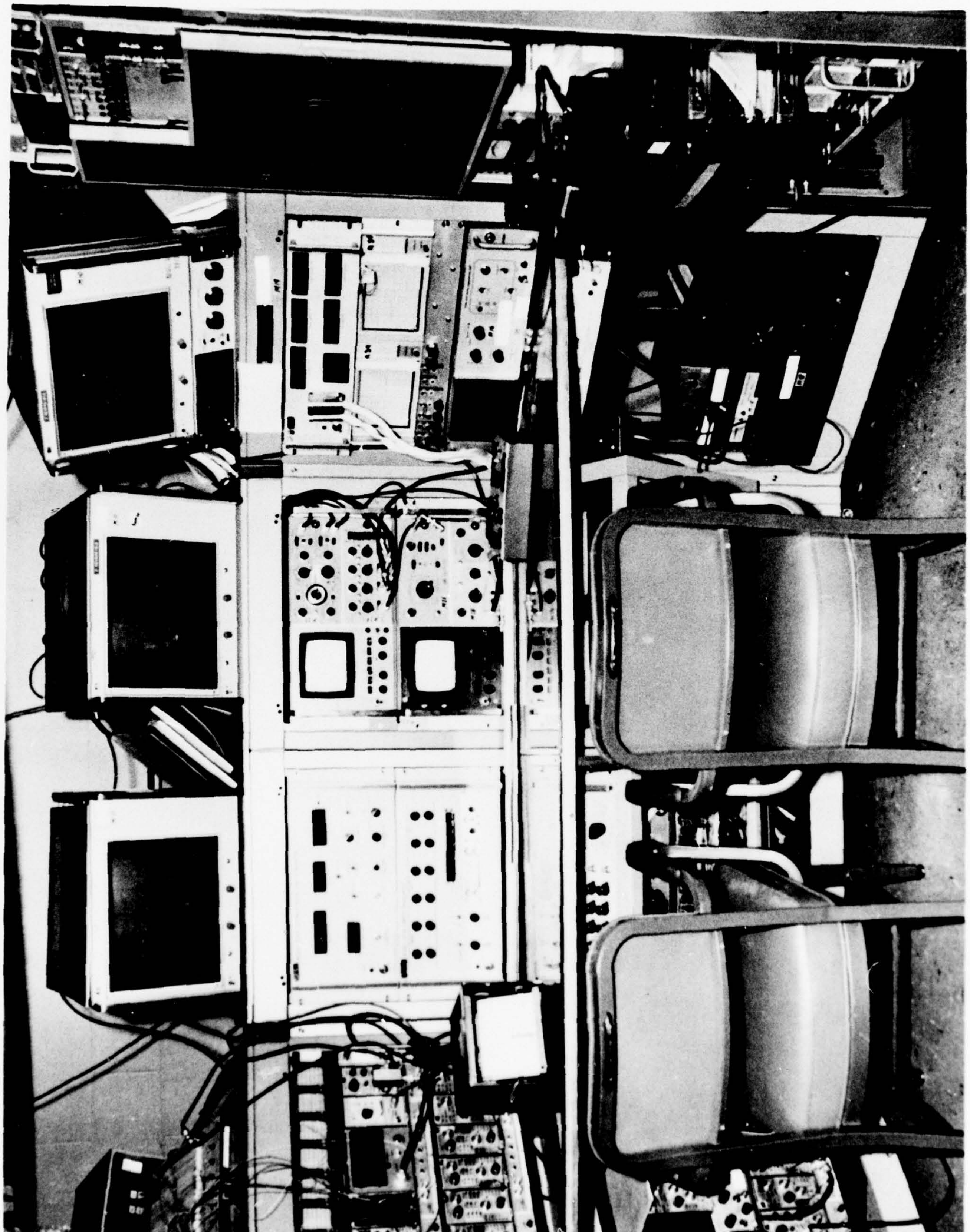

Figure 2. Representation Data Frame showing Apparent "Streak" Produced in the Video System. Brighter stars in field exhibit a tail as if they were moving with respect to the fainter star field. This effect is produced by ringing effect in the video caused by peaking of the video chain to maximize point-source signal-to-noise ratio (Note: the object centered in the field is Pluto as seen on 21 Feb 75 at 10:54 UT, RA $12^h59^m50^s$, Ded +12°21', M_v approx +13)

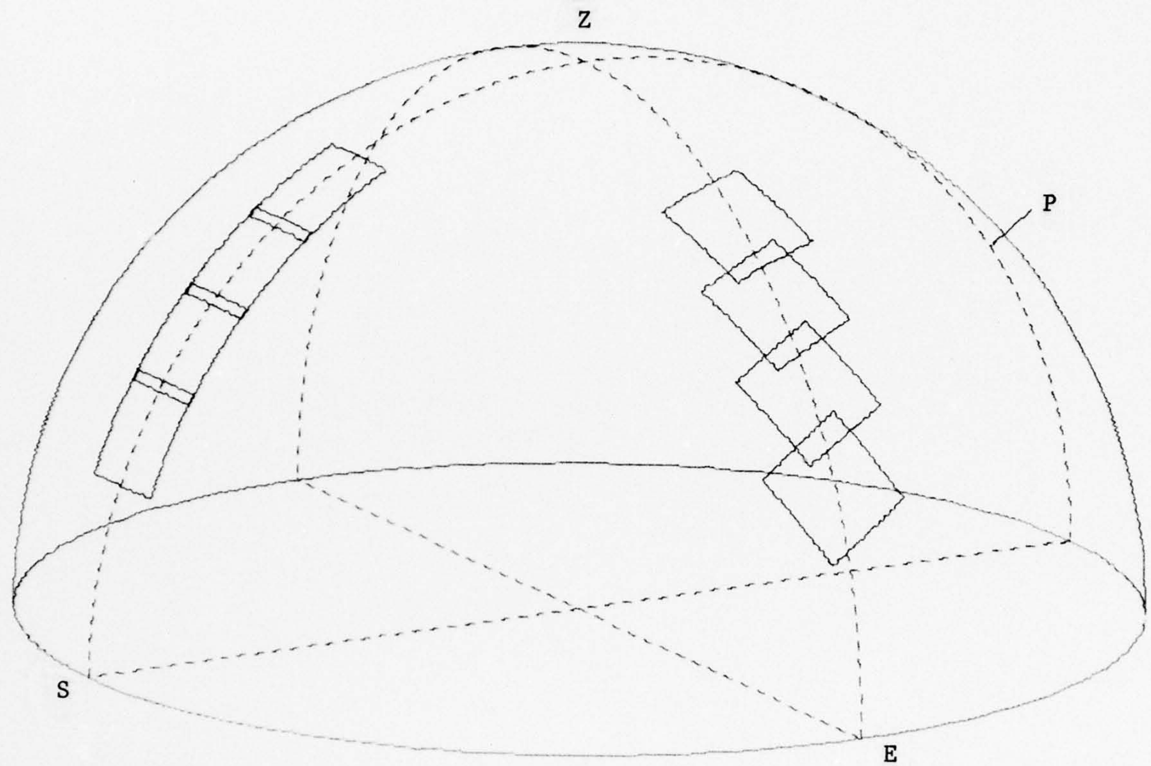

Figure 3. Cross-Search N-S/E-W Pattern Approximated with an Equatorial Mount at 34.5° No Latitude. Fields of view shown are 11.4° (0.2 radians) square, for clarity of overlap and perspective.

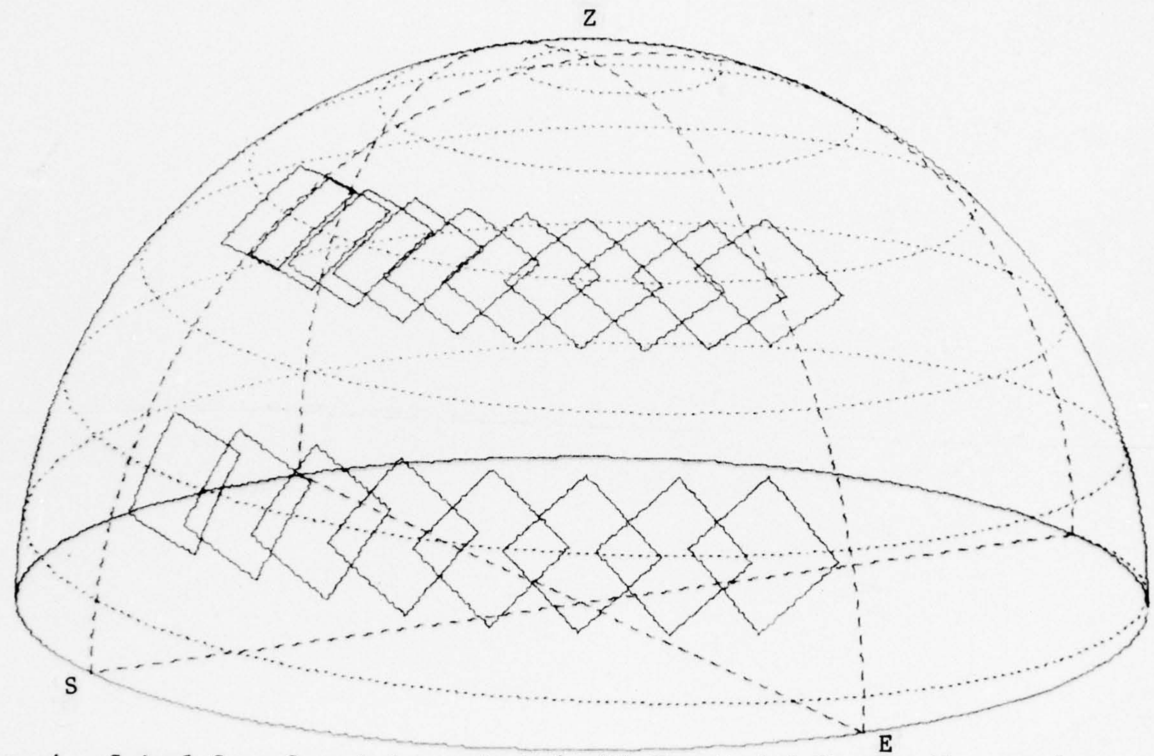

Figure 4. Spiral Scan Search Approximated with Equatorial Mount. Two sections of spiral are depicted with 11.4° fields of view at 10° azimuthal steps and 15° spiral pitch.

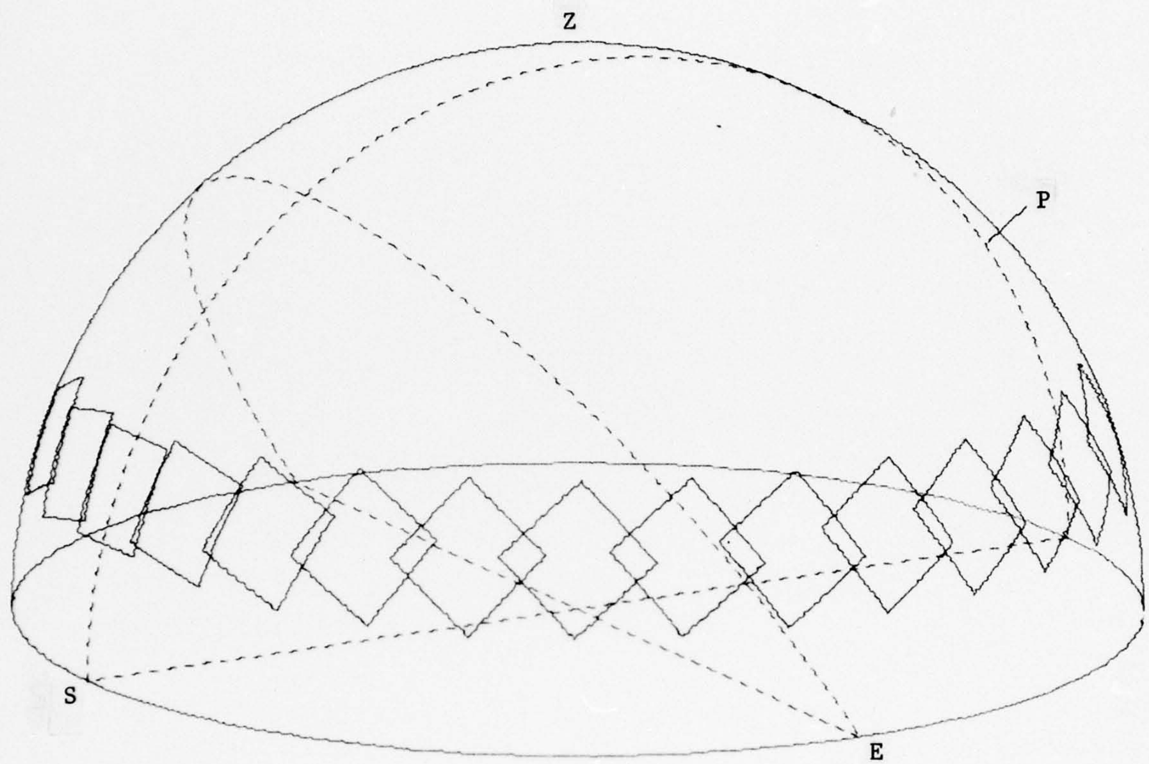

Figure 5. Horizon Ring Search Pattern Approximated with Equatorial Mount. Individual fields-of-view are 11.4x11.4 degrees with 12-degree azimuthal steps.

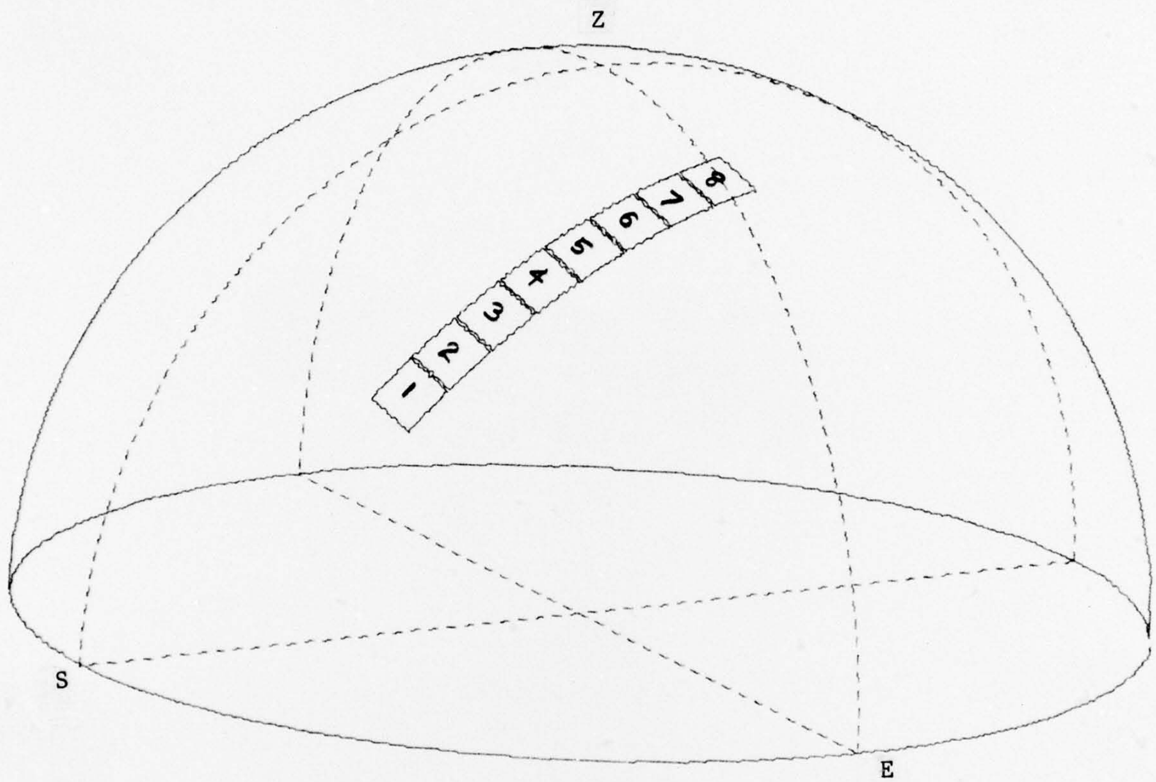

Figure 6. DECLINATION SWATH Search Pattern

FIGURE 7

Scan Converter Display of Summed Video C shows synchronous satellite detected during declination-swath type search.

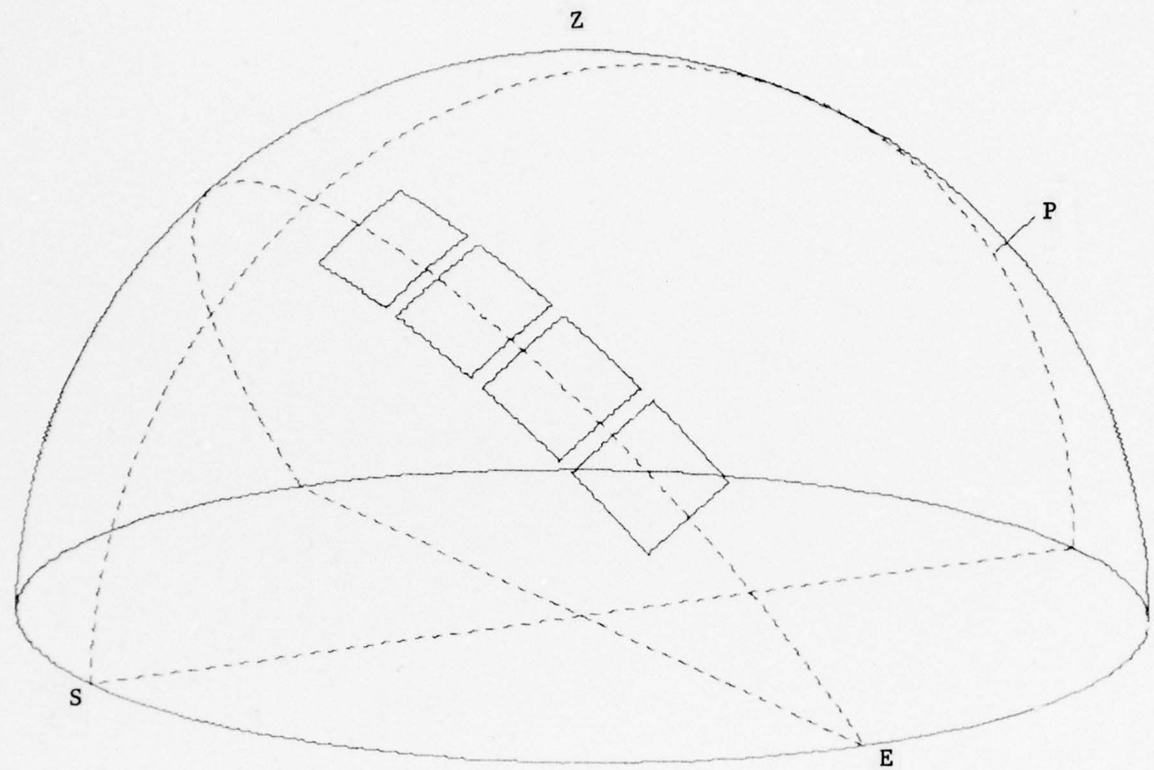

Figure 8. Right Ascension Swath Search, projected on the Celestial Sphere. Several right ascension swaths would be stacked to form an area search. Fields-of-view shown are 11.4x11.4 degrees, with 15-degree spacing for clarity, centered on celestial equator.

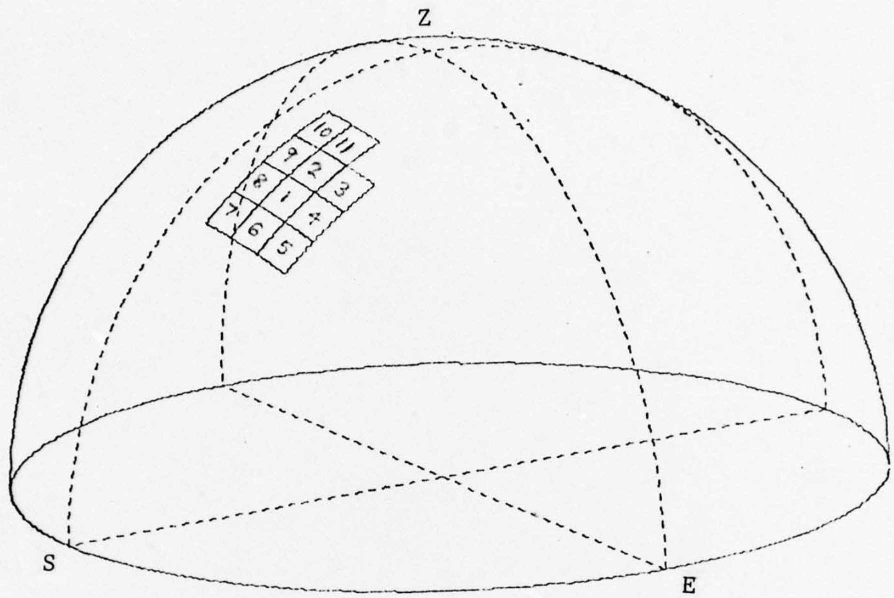

Figure 9a. Expanding Square about a Geostationary Point for Synchronous Objects

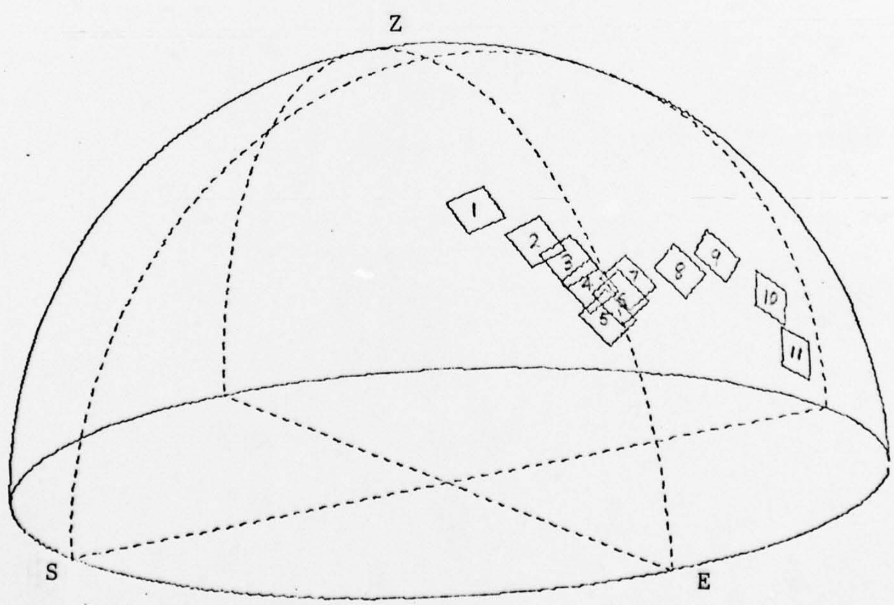

Figure 9b. Expanding Square about a Moving Point.

APPENDIX

Satellite Photometry

The apparatus used for taking satellite photometry, as described in the main body of the report, is diagrammed in Figure 1A. Initial observations were done at point (1) between the peak detector and hold and the A/D converter. This produced uncertain data since the sampled video is zeroed after each frame of video, causing the chart recorder to "chatter" at the video frame rate. This was solved by incorporating a D/A converter with appropriate timing signals. System timing signals are shown in Figure 2A. Only the relative timing signals are shown since the system is designed to operate at any TV rate generated by the SRL Variable-Rate Camera Tube Test Set. For simplicity, only seven lines are shown in the frame and only three lines are gated vertically in the diagram, although in practice the vertical gate was usually about ten lines and 650 lines are used per frame. The D/A data-ready signal timing was perfected only during the last few nights of observation. The D/A converter held the analog output constant until the next data ready signal was given and the output was then changed to the new value without going to zero.

Typical data are shown in Figure 3A, as recorded on the stripchart. It is object 5851 as recorded on 9 March 1975 at 03:24 UT. The diffuse signature of the object is at or below the sky-noise level but the specular flashes are plainly visible. It can be seen from the scale at the left of Figure 3A that the response was extremely nonlinear and that determinations of maximum flash brightnesses have large errors.

The signature shown in Figure 4A was recorded from object 83540 (unknown catalog number) on 5 April 1975 at 01:40 UT. In the author's opinion it is probably that of a tumbling third stage, although no positive identification has been made yet by ADC.

The trade-off between sensitivity of the system and time resolution can be seen in the signature, of object 5851, on 2 April 1975 at 04:53 UT; Figure 5A illustrates.

The sampling rate was changed from 4 Hz to 8 Hz by changing the multiple-frame integration selector on the camera. In both cases the readout was at a rate of 125 ms/frame, but operation at 4 Hz recorded two frames of integration prior to each readout. It can be seen that the sensitivity of the systems decreased when the rate was changed from 4 Hz to 8 Hz. Much finer structure can be seen in the signature at 8 Hz, however. In this case the satellite was bright enough that the decreased integration did not limit detection.

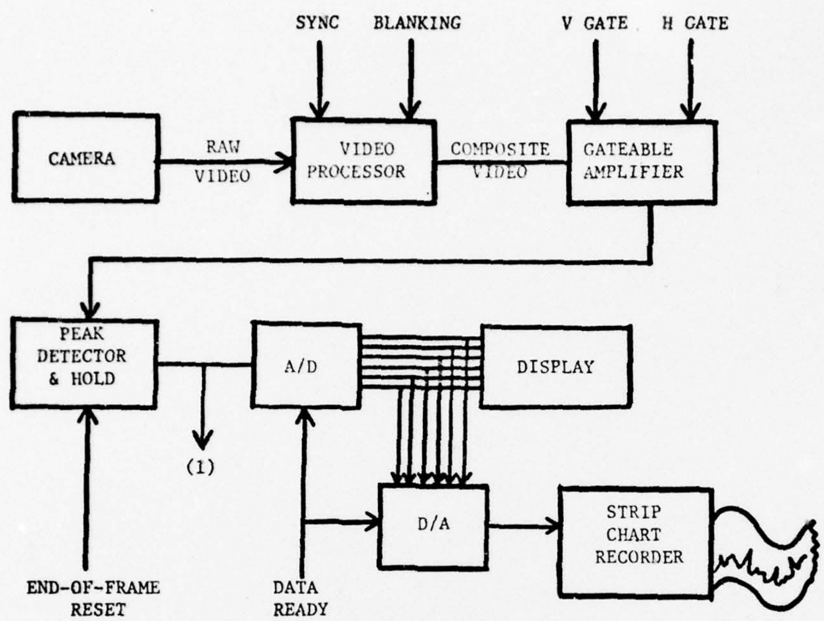

Figure 1A System Block Diagram

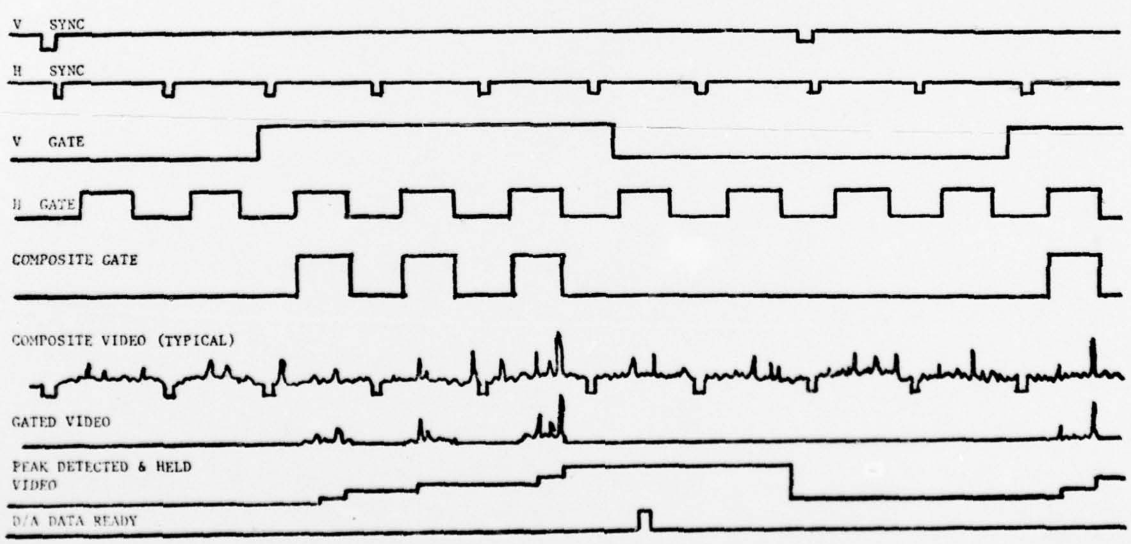

Figure 2A System Timing

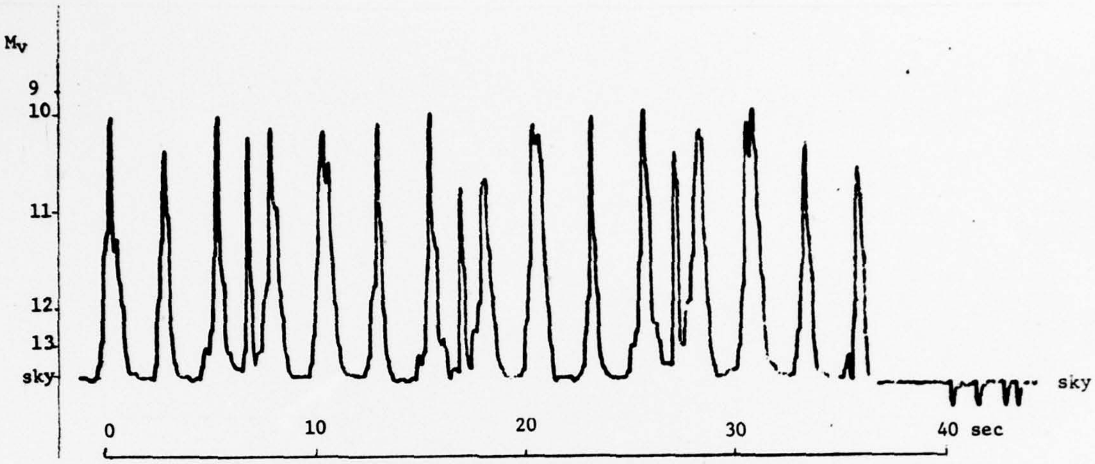

Figure 3A Peak-Reading Voltmeter Signature of Space Object 5851 in Near-geostationary Orbit on 9 Mar 75

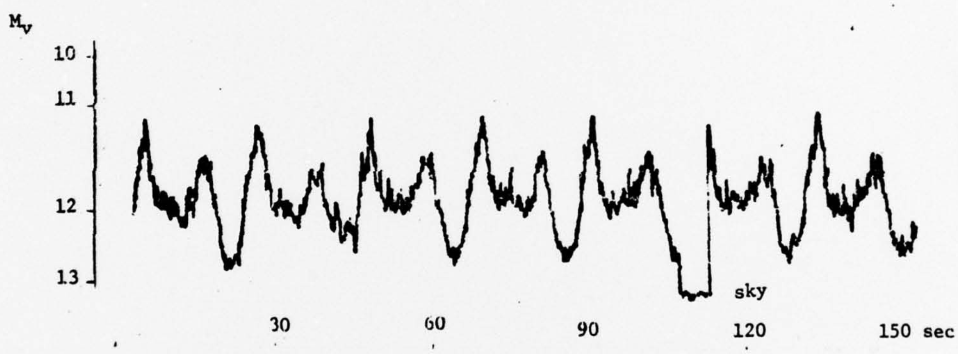

Figure 4A Signature of Space Object 83540, as yet not Associated with a Particular Launch Operation

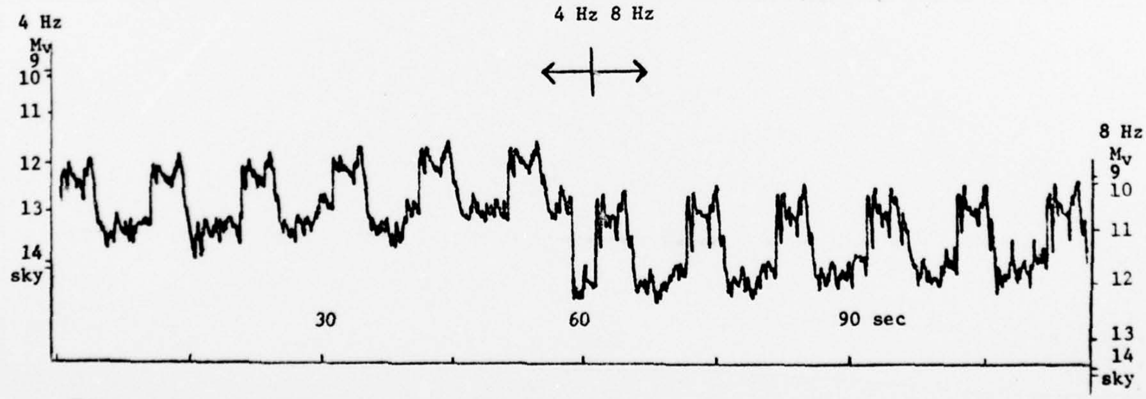

Figure 5A Peak-Reading Voltmeter Signature of S.O. 5851 on 2 Apr 75 at a Different Illumination/Observation Geometry from Figure 3A. (Note the increased time resolution, but decreased signal when the camera frame rate is increased from 4 to 8 frames/sec)

Satellites with rapid signature fluctuations, allowing only few samples per signature period, may show beat effects between the sample rate and the signature rate or have very poor signature resolution, usually manifested in poor signature repeatability from period to period. This is seen in Figure 6A showing the signature of object 83515 from 1 April 1975 at 09:25 UT.

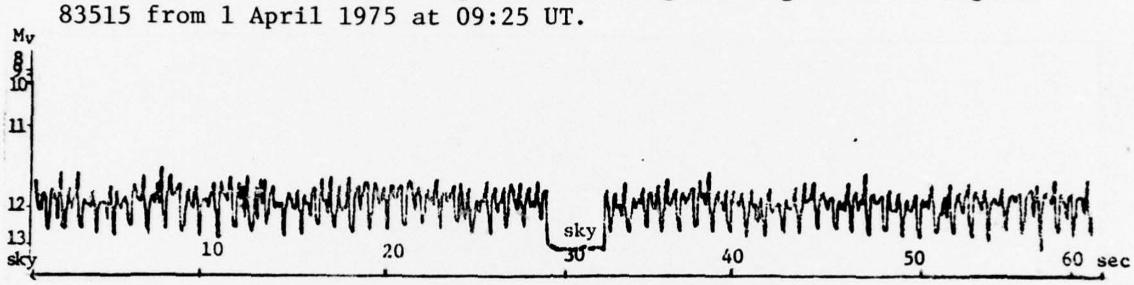

Figure 6A Space Object 83515 Showing Beat Effects Between Sampling Rate and Signature Period

It should be noted that there is an uncertainty in the level recorded since the system is essentially a peak detector. Noise such as tube scintillations may be detected instead of the satellite and produce false increments in the signature. This is a statistical problem related to the nature of the noise mechanisms in the camera. The signature shown in Figure 7A illustrates this effect and shows the variations over a 30-minute period for a satellite whose signature is essentially constant, ATS-6 with its 30-foot parabolic antenna, as recorded on 5 April 1975 at 05:50 UT.

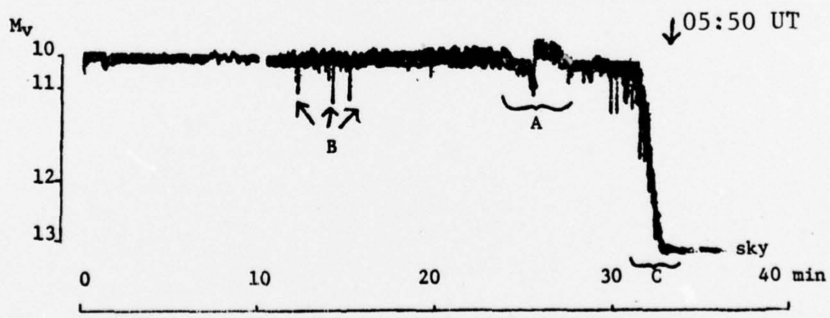

Figure 7A Signature of Space Object 7318, ATS-6 Spacecraft, on 5 Apr 75, Showing the Effect of Noise Fluctuations During Long Periods of Observation

The portion of the signature labeled "A" shows where the satellite drifted partially out of the video gates. This seeming decrease in apparent brightness should be ignored. The portions of the signature labeled "B" are caused by noise spikes generated by EMI in the observatory building (air conditioner start-up) which caused large positive spikes on the video. The D/A converter could not convert signals over 1 volt and consequently generated a negative spike[1]. The portion of the signature labeled "C" shows the satellite going into eclipse by the Earth's shadow. Calibration of the system was accomplished by observing calibrated star fields (Reference 2) and applying the star calibrations directly to the stripchart recording for comparison with satellite observations. The calibration observations were always made on the Landolt field nearest the satellite observation. Since all satellite signatures were taken on quasi-synchronous objects, the Landolt fields were sufficiently close to assume the extinction for both satellite and calibration stars to be the same. All given magnitudes, therefore, are as would be observed at the top of the atmosphere. None of the given magnitudes have been corrected to a standard range.

A calibration data record is shown in Figure 8A to illustrate the non-linear calibration. The data were taken on 4 April 1975 at 04:35 UT from the Landolt Field located in selected area #107.

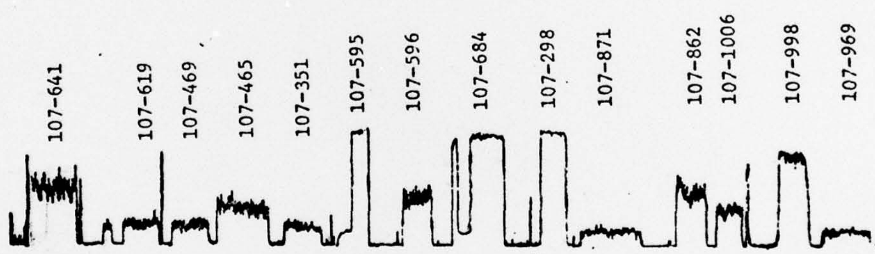

Figure 8A. Example of Star Calibration of 4 Apr 75. Catalog numbers above pen deflections identify Landolt program stars in Kapteyn Selected Area 107.

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[1]Several places on the original stripchart are labeled "D/A drop-out". The A/D converter had more bits available than the available D/A converter. Consequently, the D/A unit converted only that part of the digital signal less than the integer, i.e., a digital signal of .75v, 1.75v and 2.75v were all converted to .75v. Since most of the video signals were less than 1 volt, this was a minor problem.

[2]UBV Photoelectric Sequences in the Celestial Equatorial Selected Areas 92-115, Astronomical Journal, Vol. 78, No. 9, November 1973, Arlo U. Landolt.

The numbers above each star are the catalog numbers used by Landolt. Figure 9A below shows the log of the displacement of the pen on the strip-chart as a function of known star brightness. The extreme nonlinear response of the system can easily be seen.

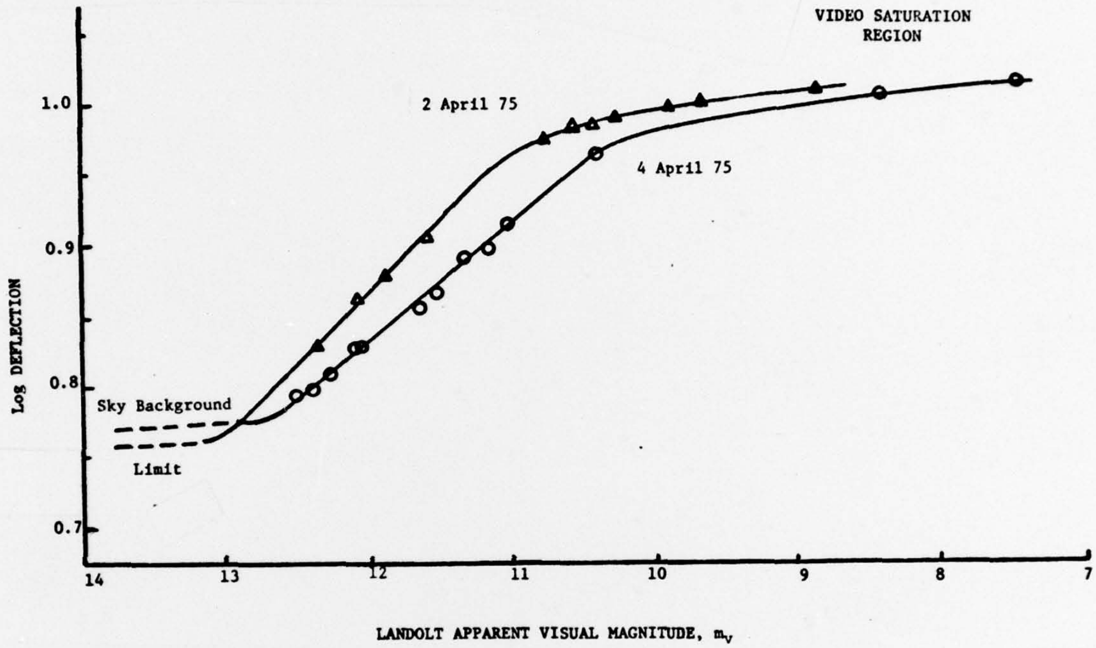

Figure 9A. Calibration Curves of the Video Peak Photometer for 2 Nights of Operation.

The "linear region" is very small in this case. This is because the nonlinearities of system response caused by the charge spreading on the target from brighter stars occur at much lower light levels than actual charge saturation of the target. This is more marked because the photometry system is based on a peak detector. If the system were based on an area integrator, the effects of charge spreading should be mostly compensated and the linear region much larger. For this reason, the uncertainties of brighter signatures are larger than those of the fainter signatures falling in the linear region.

Comparison of calibrations from night to night show that the slope of the graph above remains essentially constant, but the changing sky background moves the curve up and down on the graph. This implies that nightly calibrations are required and, if the sky brightness should change during the observation session, multiple calibrations are required. Observations far from the Landolt fields will require measurement of the extinction coefficient and its application to the individual observations.

The period of the satellite signature proved to be the most useful quantity to the telescope operator in recognizing particular spacecraft since the signature often changes shape drastically with the solar phase angle. For this reason, a thresholding circuit was added in parallel with the chart recorder and the pulses generated by the thresholder were fed to either a counter or a frequency meter. It should be noted that although the 4-Hz or 8-Hz sample rate implies a sizeable uncertainty in determining the period of the signature from a single cycle, especially if the period is on the order of 1 second, the period can be determined very accurately by sampling many cycles. There will always be a residual uncertainty due to the finite sample time, but this uncertainty can be spread over many rotations of the spacecraft and made small by observing many periods.

Altogether, 16 hours, 2 minutes, and 34 seconds of signature data were gathered. These data will be forwarded to SDC along with the star field calibrations and indexes of the data observed by day and by satellite number.