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THE CANADIAN FORCES/NORAD SATELLITE IDENTIFICATION SENSOR AT ST. MARGARETS

Reconnaissance and Weapon Delivery Division

September 1977
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Final Report for Period May 1972 - May 1975

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Following a decade of developmental work at the USAF Avionics Laboratory (AFAL), a new operational surveillance sensor has been established by NORAD/ADCOM for a electro-optical identification of orbiting spacecraft. The Space Object Identification (SOI) System utilizes the original R&D sensor, reengineered by AFAL to simplify and automate many of its functions. It has been located in the Maritime Provinces in Eastern Canada, operated by the Canadian Forces Air Command. The automation of the test-bed sensor included a novel hybrid control computer, a microprocessor for data logging and recording, timing control of all operational functions (including computer cycling) by an atomic standard, and use of celestial reference sources for self-calibration of both the pointing command system and the target signature system. Using existing hardware with special interfaces and software has reduced significantly the cost and acquisition time of this first on-line system.

The Canadian optical SOI sensor is described as placed into operation at the Satellite Identification & Tracking Unit (SITU) at St. Margarets, New Brunswick.

FOREWORD

This report documents the deployment configuration of an optical WOI sensor developed at the AF Avionics Laboratory in 1972-1975 to allow the recording of spacecraft signatures of targets out to geosynchronous altitudes (6 earth radii). The paper is based on an invited discussion, presented to the Optical Systems Group, Range Commander's Council on 15 March 1977, of the Satellite Identification Sensor deployed to St. Margarets, N.B. The original system was begun under Task 7114-00-03 under Program Element 61102F at the Aerospace Research Laboratories, and completed under Work Unit 7660-03-17, Program Element 62204F and AFSC Engineering Support Project NORAD001. This report covers the final period of effort which included deployment, on-site testing, and initial testing. Further efforts at improving the SIS sensor are underway within Canadian Air Command with technical support by AFAL. This includes additions and modifications to the system as described herein, but the report is current as of August 1977.

Many people besides the authors have contributed to the final system, officially dedicated at St. Margarets on 9 November 1976. They include key personnel of Systems Research Laboratories, Inc.: Messrs. Randy Smith, William Fahle, Steve Koranda, and Don Pedrick of SRL did much of the detailed structure of software and hardware. Capts John Koval and earlier, Louis S. Macknik outlined the original digital/analog interface and the pulse-counting photometer. Messrs. F. T. Tyson, Joseph Warren, and Capt John V. Lambert of the former AFAL Cloudcroft Observatory provided valuable advice and software which was incorporated into the final system. Lt Col Thomas Spruston, Lt Col Brian Wooding of the Canadian Forces contingent at NORAD, and Capt Geoffry Hodgson of National Defence Headquarters played key roles in the detailed site configuration.

Major George MacManus, the SITU Commander and Capt A. A. Jacobsen, SITU Operations Officer, as well as several of the NCO's at SITU, including SWO Stan Smith, Sgt M. MacKinnon and Master Corp. Harry Fossheim, have contributed significantly to establishment of the operational system.

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Introduction

Since the mid-1960's, the use of passive optical techniques has become increasingly attractive for the study of spacecraft or distant missiles. Several independent R&D facilities were built at locations as diverse as Patrick AFB (RML), Lincoln Laboratory (Firepond), Holloman AFB (Cloudcroft), Socorro, N. Mexico (Lincoln Lab), Mt. Haleakala, Hawaii (AMOS), and Sulphur Grove, Ohio (later moved to Yellow Springs). Each of these facilities was motivated by different applications, at least initially, but all have commonality in that they have utilized computer-controlled optical systems of large aperture (0.6 to 1.5 meters) to track and collect energy reflected or emitted from orbiting space objects. In most cases this energy originates from the sun and is either scattered directly from the target surfaces or is absorbed and re-emitted by a change to thermal infrared or by fluorescence. As is well-known to all range users of passive optical instruments, the signal-to-noise of a radiometric system falls off only with the inverse square (rather than inverse-fourth with a radar or lidar) and linear resolution falls of linearly with range. The performance of passive optics in performing many missions then falls off more slowly with range than does a conventional radar.

The specific interests in use of large-aperture optical systems for space-type targets stem from:

(1) direct imaging of targets or target complexes at ranges not exceeding a few hundred kilometers (i.e., the targets subtend a

few arcseconds). Direct imaging is useful even with the well-known diffraction and seeing limitations in the visible region of the spectrum and

(2) information content in the visible, near-UV, or IR spectral region, which sheds unique "light" on the problem at hand. Use of large systems in the latter case may be more for collection of sufficient luminous flux than for resolution, but the ability to resolve spatially (discriminate) the target from the background or foreground effects is also of importance in radiometric applications.

Of the R&D instruments mentioned above, only one has been, to date, transitioned to an operational role. The other systems remain currently as R&D tools or test beds occasionally supporting range launches and on-orbit operations or responding to special tasking by operational commands. The 61-cm OPOS telescope, however, used for the original research, development, and validation of radiometric (photometric) techniques for space object identification (SOI), has been mated with an appropriate hybrid control computer and digital detector/data logging system so that operation by trained field personnel is practical. The refurbished system has been moved from Ohio to a new site established by the Canadian Forces Air Command at St. Margarets, New Brunswick, and is operated now in support of NORAD by Canadian personnel (Reference 1).

This report describes briefly the features of the optical configuration, the detectors, the semi-automatic control system, and the data recording system. Specifically discussed are the procedures used for metric and radiometric calibration, and special features of the real-time control software which simplify the editing of data for transmission to a central site.

Optical System/4-Axis Mount

The heart of the Space Object Identification System (SOI) is a fairly conventional Cassegrain reflector designed by Joseph Nunn to provide a simple, rugged instrument of the largest possible aperture to nest within an additional gimbal ring into one of his Baker-Nunn triaxial mounts, thus yielding a 4-axis variant to the familiar B-N satellite tracking camera. The resulting system is an f/16, 61-cm tracking telescope capable of following small-circle arcs over 130° of track angle down to within a few degrees of the horizon. This 4-axis system was made necessary by the very much better tracking precision demanded (Ref. 2) by photometric measurements in order (1) to use a simple photodetector and (2) to restrict the field-of-view to no more than a few tens of arc-seconds so as to reject sky background/foreground light and to reduce the number of encounters with stellar noise sources. The SOI optical tracker is shown in Figures 1 and 2 as it is installed at the Satellite Identification Tracking Unit (SITU) in New Brunswick, Canada.

The mount provides two servo-controlled axes supported by an azimuth axis and an elevation axis. The definition of axes and range of adjustment are shown schematically in Figure 3. Azimuthal adjustment is by hand to an accuracy of $\pm 0^{\circ}.01$. Elevation adjustment, motorized to aid the operator, is set to $\pm 0^{\circ}.01$. These axes then remain fixed during tracking operations. Software in the digital control computer verifies that the operator has correctly made these two settings before automatic positioning of the two servo-controlled axes (designated TRACK and DECLINATION). A compact luminous encoder display gives the operator a readout of all four axes to $\pm 0^{\circ}.01$ from absolute brush-type encoders. These encoders are used only for initializing the mount or for update during tracking operation if the target should be lost and a new acquisition position is to be established downtrack. The encoders are not used in the servo commands for tracking because the least-significant bit is too coarse for smooth motion of the instrument.

Mechanization of the TRACK axis is by a direct-current torque motor with an integral tachometer. When driven by a 500-W dc power amplifier through a hybrid computer, discussed below, the system provides tracking rates for the 500-Kg telescope assembly from below earth rate to 3°/second. The upper limit is determined by a scale-factor in the hybrid computer and can be set higher with a penalty of granularity in the tracking smoothness at low velocities. For sidereal tracking during stellar reference calibration, a pure analog mode of velocity control is available. The track-axis servo is purely a velocity servo with the mount acting as a mechanical integrator of the sequence of velocity commands. This avoided the need for higher-resolution shaft encoders, which would have necessitated major modifications.

In contrast, the DECLINATION axis is mechanized in a position-servo by a stepping-motor with a step size of approximately 2 arcseconds. By use of anti-backlash gearing and careful static balancing of the telescope, this has proven quite satisfactory since the granularity of motion is less than 10% of the field-of-view. The maximum rate of this axis is approximately 0.3^{o}/sec.

As is seen in Figure 1, the system operator is provided with a choice of finding/guiding auxilliary optics of 12.7 to 25-cm aperture. These are coupled to the main telescope by a precision parallelogram assembly which allows both finders to remain boresighted with field-of-view of the photometer detector package at the Cassegrain focus. Targets are measured only if they are bright enough to be detected a reasonable fraction of the time by the observer/operator.

These finder instruments allow three functions by the operator:

(1) recognition that the target is arriving early or late at the acquisition point and delaying the automatic initiation of telescope movement

(2) fine guiding of the instrument to place the target or a calibration star into the sensor field-of-view (or removing it when background reference data are to be taken)

(3) establishing which way the instrument is drifting from the target (as the result of divergence of the open-loop servo commands from the true target velocity/position) so as to generate new fine-guiding commands. Loss of target is signalled to the observer by a voltage-controlled audio oscillator modulated by the photodetector output.

Detector Systems

Two types of photoelectric photometers are provided, one especially suited for faint target brightnesses characteristic of deep-space vehicles, i.e., more than 5000-km in altitude, and one especially suited for low-altitude spacecraft. The typical low-altitude target is frequently comparable in brightness to the brightest stars and can sometimes vary rapidly in brightness over factors of several hundred to several thousand times.

Digital Detector

The deep-space detector is a modification of a commercial photon counter made by Princeton Applied Research Corp. (PAR Model 1108) with a special interface card to couple it to the hybrid control computer. This unit is comparable to currently accepted technology in photon counters used in astronomical research. It uses an ITT FW-130 low-noise photomultiplier with S-20 response,operated at a voltage which minimizes the internal noise-pulse generation while providing good electron-multipler gain into a PAR Model 1120 preamplifier-discriminator located within the detector package. The 1108 multimode microprocessor provides:

a. scaling of the discriminated photon counts,

b. a timing system slaved to the SOI rubidium standard for selecting different integration times,

c. a 32-word memory for interim storage of data, and

d. a processor which controls the cycling of signal integration and storage, and of communication with the master XDS 910 computer. This allows the brightness measurements to be recorded on a continuous basis in a synchronized measurement buffer while the read-out to the XDS 910 is mixed with metric and time-tagging information, generated separately, for recording in intermittent blocks on the raw data tape. The data tape contents will be discussed below, where the connection to a normalized calibrated data record is developed.

The pulse-counting photometer operates with a fixed field-of-view determined by the sensitive area of the photocathode and the 9.8-meter focal-length of the telescope. It is 54 arcseconds in diameter, thus requiring tracking to better than the least-significant-bit of the shaft encoders. This is the basic reason that the servo-control uses software techniques to allow motion of the telescope independent of the encoder readouts except for set-up operations. This small field-of-view is essential for target brightnesses fainter than +11 stellar magnitudes. (equivalent to targets of about 1-m^2 cross section at 10,000 kilometers slant range)

Analog Detector

For low-altitude targets, larger fields-of-view are allowable and desirable since the trajectories are less well predicted. The target brightnesses are also much greater and typically can reach +2 stellar magnitude, or 10X as bright as the counting-rate capability of the PAR photon counter. For this reason a second photometer system is provided which presently utilizes an analog recording system. This analog photometer is of a logarithmic character adopted from a photographic densitometer invented by M. H. Sweet of the Ansco Corp. (Ref. 3) in the 1940's. It employs negative feedback to control the dynode voltage of an 11-stage RCA 4526 extended-red multi-alkali (ERMA 111) photo multiplier to maintain a constant anode current from the multiplier. The resulting fluctuation in dynode voltage is inverse to the logarithm of the incident photon flux onto the photocathode over a dynamic range of 10^4 to 10^6 (10-15 stellar magnitudes). By care in design of the circuit, a frequency response of 1 Khz is obtainable over most of this dynamic range. Such a device makes an excellent CW detector for target signatures of low-altitude targets in rapid dynamic motion. Figure 4 shows a simplified schematic of this logarithmic photometer. Figure 5 shows a typical calibration curve, and Figure 6 a target signature obtained from a typical spacecraft of the spin-stabilized type. Note that the target brightness changes by some 7.5 stellar magnitudes. (factor of 1000X).

The choice of detector system is made by interposing a first-surface mirror into the emerging beam behind the tail piece (See Figure 7). Different calibration procedures are required for each system.

Detector Calibration

As is indicated in Figure 5, the detectors are calibrated by reference to well-established celestial brightness sources. Since the space targets are unresolved on the detector, their brightness can be compared directly with the point-source stars. Referring to a catalog of several hundred standard stars scattered over the celestial sphere, all of whose exo-atmospheric colors and brightnesses have been well-established by astronomers to accuracies of a few percent, we can measure some 10 or 12 of these well-distributed about the sky, and simultaneously establish the instrument response and the amount of absorption produced by the atmospheric slant path at any point of the target track. These measurements require several blocks of calibration time during the night's operation and enable the data to be normalized to exo-atmospheric conditions. The techniques are adapted directly from astronomical practice (Ref. 4) Software is provided for the SOI to acquire automatically the selected standard stars and subsequently log the data for later reduction. The basic procedure requires no precision standards calibration since it is self-calibrating.

Metric Calibration

It is obvious that the multi-axis mount has many more degrees of freedom than the altitude-azimuth mounts used on flight test ranges. The relatively open structure of the mount, which was chosen to minimize weight and which reduces wind-loading, allows more flexure than might be desired. In the course of normal target tracking, periodic recording of mount position is very useful and is provided automatically (every 0.32 seconds if 100 data samples are taken each second). It is, of course, easy to establish that the target is definitely in the sensing aperture during a given data block, by examining the photometer record. If the mount shaft encoders are calibrated and mechanical and flexure terms taken into account, accuracies of 2 arc minutes can be expected. In addition, if the identity of a bright star, seen simultaneously with the target as the result of a near occultation, can be ascertained, metric data in celestial coordinates can be obtained to an accuracy of ±50 arcseconds. This normally happens at a number of points along the track, but the data reduction can be tedious.

While the SOI system is not intended or expected to be a metric instrument, it was quite necessary to align the mount initially and to establish whether drifts of pier position are occurring as the new construction in a sandy, swampy area settles. A MOUNTCAL procedure and software package was devised to allow referencing to well-established stellar sources selected from the American Ephermeris and Nautical Almanac fundamental stars. This procedure requires that positions of the mount be recorded for approximately 20 stars. A solution for the off-sets, misalignments, and flexure parameters is made by a recursive, least-squares software routine which has the capability of extension to more complete mount models.

Automatic Control System with Observer Intervention

As implied above, the SOI System uses a hybrid servo velocity control in one coordinate and a full-digital servo in the other. This section will deal with the reasoning behind these choices and the methods by which the observer introduces corrections into the open-loop approximation of the target motion. The two servo loops will be discussed separately and the system operation then described.

Track-Axis Loop

Figure 8 shows the apparent path across the sky for a particular spacecraft, one which is typical of lower-altitude vehicles (e.g., below 2000 km). Three key points are to be made: (1) the spacecraft departs significantly from motion along a great circle, (2) the spacecraft motion is well-approximated by a small-circle path which is only a few degrees offset from a great circle (13°.66 in this case) and (3) while a nearly-constant offset in the DECLINATION axis allows tracking of the target in that coordinate, the TRACK axis undergoes a large, monotonic change in value while experiencing large changes in angular rate. Since an orbiting target follows Kepler's laws of planetary motion, its path and the angular velocity are well-predicted, smoothly-varying functions. The track velocity first increases by a factor of approximately 3 from the mechanical limit of the mount to the point-of-closest-approach (PCA or culmination point), and then similarly decreases. This angular velocity is reasonably approximated by a function

$$\dot{T} = \frac{dT}{dt} = \bar{V}\,\frac{\mathrm{Sin}^2 T \sin E}{\cos D} \tag{1}$$

where T, E, and D are as defined in Figure 3, and $\bar{V}$ is the angular velocity of the target if it were passing directly overhead. This approximation best fits a target in circular orbit.

An earlier analog computer used such a model to control the mount motion in a very satisfactory way. When the decision was made to provide automatic set-up of the mount and semi-automatic tracking, the analog velocity loop was retained for smoothness of acceleration. The velocity signal is generated with high accuracy rather than by approximation, however, by a direct solution of the target orbital elements in the 4-axis coordinate frame. This eliminates the circular orbit approximation. The velocity voltage, for comparison with the tachometer output at the summing junction, is then derived from a 12-bit D/A converter. This yields a velocity granularity of 2.6 arcseconds/second, adequate for tracking of spacecraft. For stellar calibration operations this granularity is inconvenient; hence a mode is provided to generate a sidereal-rate drive. The mount is then removed from hybrid operation and placed in an analog mode. For the analog mode the mount is provided with precision resolvers which generate the trigonometric functions ($\mathrm{Sin}^2 T$, sin E) needed in Equation 1. With the system parameters implemented, the system response is approximately

Transient Response: 0.1 Second rise-time, zero overshoot

Frequency Response: 4.5 Hz

The maximum drive rate has been chosen as 3°/second, requiring less than 60 seconds to slew from limit to limit and stabilize for acquisition of a new target. Figure 9 shows the analog loop of the hybrid track-velocity control.

Declination-Axis Loop

As indicated above, the declination axis (sometimes referred to as the cross-track axis because it is orthogonal to the tracking direction) employs an anti-backlash worm drive actuated by a stepping motor. The motor is capable of 200 steps/second, each step equivalent to 1.8 arc seconds. This step-size is only 1/20 the least-significant/bit (LSB) of the cross-track encoder. In order to provide the initial set-up of the mount, the declination axis operates as a position servo and establishes correspondence of the encoder to the predicted position at the acquisition time within the 36-arcsecond LSB. Following acquisition, this loop departs from a position servo. It is controlled by an anticipatory position command generated by the real-time software such that the position change which is to occur in the next servo cycle is translated into pulse commands to a buffer/translator. This buffer operates to ration the pulses over an interval to smooth the acceleration and deceleration of the system. Thus, at the end of each control cycle, the mount has already executed all of the command step. Declination motion produced by this system is smooth with discontinuities only in the case of large departures from the small-circle approximation. The observer also can generate blocks of correction pulses in either direction. These correction pulses bias the position derived from summing the original position and the subsequent commands. This semiautomatic system does require operator skill, but the required cross-track motion seldom exceeds ±1 degree during the 5 to 30 minutes of tracking. One seldom experiences more than a few step commands per second. This allows the observer/operator to concentrate almost entirely on the TRACK control function after initial DECLINATION corrections are made to adjust for prediction errors.

Digital Control Program

Tracking operations with the SIS mount are based on an ephemeris table computed with the XDS 910 in advance of the mission, utilizing predicted orbital data. These prediction data and orbital elements come from the central computer in the Cheyenne Mountain Complex of NORAD. A table of 150 to 300 mount positions, at constant time steps between a selected acquisition time and an end-time, is computed using a FORTRAN II program. This program establishes a small-circle approximation to the trajectory between these two times and generates the TRACK, TRACK VELOCITY, and DECLINATION values for each step, and the target SLANT RANGE as well. The spacing is automatically chosen to be a binary multiple of the 200-msec control-program cycle time, i.e., 0.2, 0.4, 0.8,...12.8... seconds. The tabular values are expressed in integer format; this allows the binary interpolation of the table by efficient right/left shifts in the real-time control program. A parabolic interpolation is made to the $\dot{T}$ and D values. The $\dot{T}$ value so determined is used in each 200-msec cycle for the D/A converter to drive the mount for the next 1/5-second. The difference in D values is used to compute the number of cross-track stepper pulses to be applied in the next 1/5 second.

Actuation of a momentary DECL control button applies additional stepper commands at the constant rate of a few per second to give prompt but fine response in this coordinate. The content of a $\dot{T}$ correction register is added to the interpolated $\dot{T}$ value as described below.

Need for Operator Corrections

Because the prediction ephemerides are extrapolations of the satellite motion during prior orbits, fine-guiding commands are needed to place the target within the sensor field-of-view and to maintain precise target track. These track-velocity guiding commands are entered into the digital control loop such that the small corrections are stored in memory locations checked in each 1/5-second cycle. The corrections, once determined in the early part of the track, can then be retained even though the target may be lost temporarily due to clouds or due to a decrease in target brightness. The corrections may also be reset immediately to zero by a button command, restoring the mount to the interpolated ephemeris table value. Different options are available to the operator, all implemented through the software, to allow for early or late arrival of the target, to initiate a new acquisition cycle if the target is judged to be lost, or to abort if tracking should be terminated. In order to avoid a confusing proliferation of control buttons, multiple interpretation of each button is used, with the commands interpreted differently in the software depending on the situation, e.g. waiting for acquisition, actively tracking, or signal commanded continuously rather than momentarily. A discussion of the track-angle control algorithm used in this operator/mount interface is briefly outlined below. It exploits the hierarchy of interrupts available within the XDS 910 computer. Two fundamental axioms underlie the control scheme:

(1) Do not apply corrections too rapidly. (Avoid over correction.)

(2) Refer back to the trajectory. The target orbit dynamics have continuity in position and velocity which are superior to the short-term motion of the mount.

In accordance with these principles, all observer corrections are introduced gradually and, in case of overcorrection, can be erased in one control-loop cycle (0.2 seconds) so as to return to the predicted path.

Track Control Algorithm

Correction of errors in the track direction requires a more complicated approach. To see the problem let us imagine the situation at the acquisition point and use this to illustrate both the coarse acquisition problem and the fine guiding technique. At the acquisition point the telescope has been moved under real-time control to the initial predicted point, with the operator setting two axes, A and E, and the controller setting the other two axes, T and D. The real-time clock is constantly checked, and periodic output messages alert the system operator of time remaining to acquisition. The acquisition point is normally the first entry in the table, but if the mount-ready command is given late, the control program pages ahead to allow 60 seconds from the initiation of real-time control for the slew and settling time. The mount begins motion at the calculated rates upon clock-coincidence with the predicted time, unless the mount operator intervenes in one of three ways.

1.) An ABORT returns control to the observer from the real-time run program. This always has priority.

2.) Closure of a GO switch begins mount motion immediately. Table values are promptly time-tagged to whatever the real-time clock reads at this time. This allows for early arrival of the target. The mount will execute the pre-calculated trajectory but with a constant advance in time.

3.) Closure of a WAIT switch delays the initial mount motion until the button is released. Mount motion will begin immediately when the switch is opened, and the table values delayed in time-tagging. The mount executes the pre-calculated trajectory with a constant time delay.

The artillery concept of "rigidity-of-trajectory" applies to satellite orbits in that the shape of the apparent trajectory remains almost the same as the epoch is varied or the orbit plane position is adjusted. If correcting off-sets are made to bring the telescope trajectory into coincidence with the target path, the actual target trajectory will depart only slowly from the pre-calculated one. The key problem is now to establish coincidence in track angle.

Adjustments in D have already been discussed. To adjust T when the mount is already in motion at an almost-correct and accelerating rate, we have provided two strategies.

1. The target lies almost within the sensing aperture but up or down track by a few aperture radii. Momentary closure of a track-correction button ($0.2<\Delta t<0.4$) will result in a brief change in velocity for $\Delta t \approx 0.1$ second such that the mount skips quickly up or down track by approximately 20 arcseconds (1/3 of the photon-counter aperture). The mount then resumes the original mount velocity.

2. If the target lies to one edge of the finder-field and thus position errors of $0\overset{\circ}{.}5$ to 2° must be corrected or if the target velocity differs significantly from the predicted one, the appropriate TRACK-correction button can be held down for more than 0.4 seconds. This results in an accumulation of a velocity correction value in a register added to each new value interpolated from the $\dot{T}$ table. The $\Delta\dot{T}$ register accumulates geometrically with each control cycle to be 1, 2, 4, 8, 16, ... percent of the table value until the correction button is released. Within 2 seconds one has more than tripled the velocity of the mount, allowing rapid motion of the boresight relative to the target. When the operator judges that the target is at the center of the field he can clear the $\Delta\dot{T}$ register to zero, restoring $\dot{T}$ to the table value. If he wishes to retain the value he can leave the register untouched or add additional corrections to $\Delta\dot{T}$ with either the up-track or down-track buttons. Additional corrections always build geometrically from 1% in the first command interval exceeding .4 seconds.

If the target is lost while tracking, due to cloud or a reduction in brightness, a GO command is interpreted as an instruction to depart from the tracking, advance 30 seconds into the ephemeris table and set-up for a new acquisition. The $\Delta \dot{T}$ entry is preserved so that it is not necessary to repeat previous correction operations.

Data Logging

Since it is necessary to apply calibration corrections to the individual measurements to account for instrument sensitivity and atmospheric absorption, each block of 32 photometric measurements is tagged with the time of the last measurement, the four mount angles at this time, the predicted slant range to the target, and a geocentric state vector for the satellite at the beginning of the ephemeris table. By writing on the data tape the necessary time and metric parameters associated with the target trajectory, one eliminates the need to correlate other data with the photometric record. This greatly reduces to post-mission data reduction time, found at R&D facilities to be an onerous task.

It should be noted that all machine operations, mount interrupts, data transfers, etc. are controlled by the real-time system clock which has replaced the XDS 910 internal clock. This clock is slaved to LORAN C, and driven by a rubidium secondary-standard oscillator, thus assuring that all machine operations are locked to U.T. time to within a few microseconds. This allows quite specific time-tagging of all data.

After calibration the data are normalized to a standard slant range (1000 km) to bring them into a standardized representation (equivalent to dbSM in radar) and converted into a standard code for efficient communication to the central NORAD data center. The scheme used (Ref. 5) employs alphabetic characters in the military communications system,using base 26 (icosahexal) to transmit the data in a logarithmic format at an accuracy level of 5%. A total dynamic range of 10^8 is allowed in this data scheme, covering nearly all practical brightnesses observed.

The utilization of photometric data in the identification of space objects through recognition of signatures, visually or automatically, is beyond the scope of this paper. References 6 through 9 are suggested as a source of further insight.

SUMMARY

A brief description has been given of the semi-automatic tracking telescope at the SITU. The integration of the original R&D instrument with an existing digital control computer was made to simplify the tracking operations for the mount observer, reducing the skills-level required. An additional computer/recording system operator is brought into play. This allows the dark-adapted mount observer to concentrate on the acquisition/guiding duties under the open sky, while the planning/data recording/bookkeeping and general operating details are carried out in the closed control room. The introduction of a low-light-level TV system in the near-future will allow a further reduction of the mount-observer's work load. The computer/data recording system is shown in Figure 10.

The overall configuration of the system, the division of tasks into mission-planning, pre-transit calculations, real-time data collection, calibration missions, and post-transit data normalization has been planned to allow use of the control computer off-line to do all possible tasks in the daytime in such a way as to allow the hybrid computer to complete its control cycle in 0.2 seconds. To provide these four functions, the computer is expected to operate nearly continuously on all three shifts. Despite the 1964 vintage of the machine, the XDS 910 reliability has been excellent, with down-time produced almost entirely by the electro-mechanical peripherals.

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Figure 1 - SIS Computer-Controlled
Semi-Automatic Mount at SITU

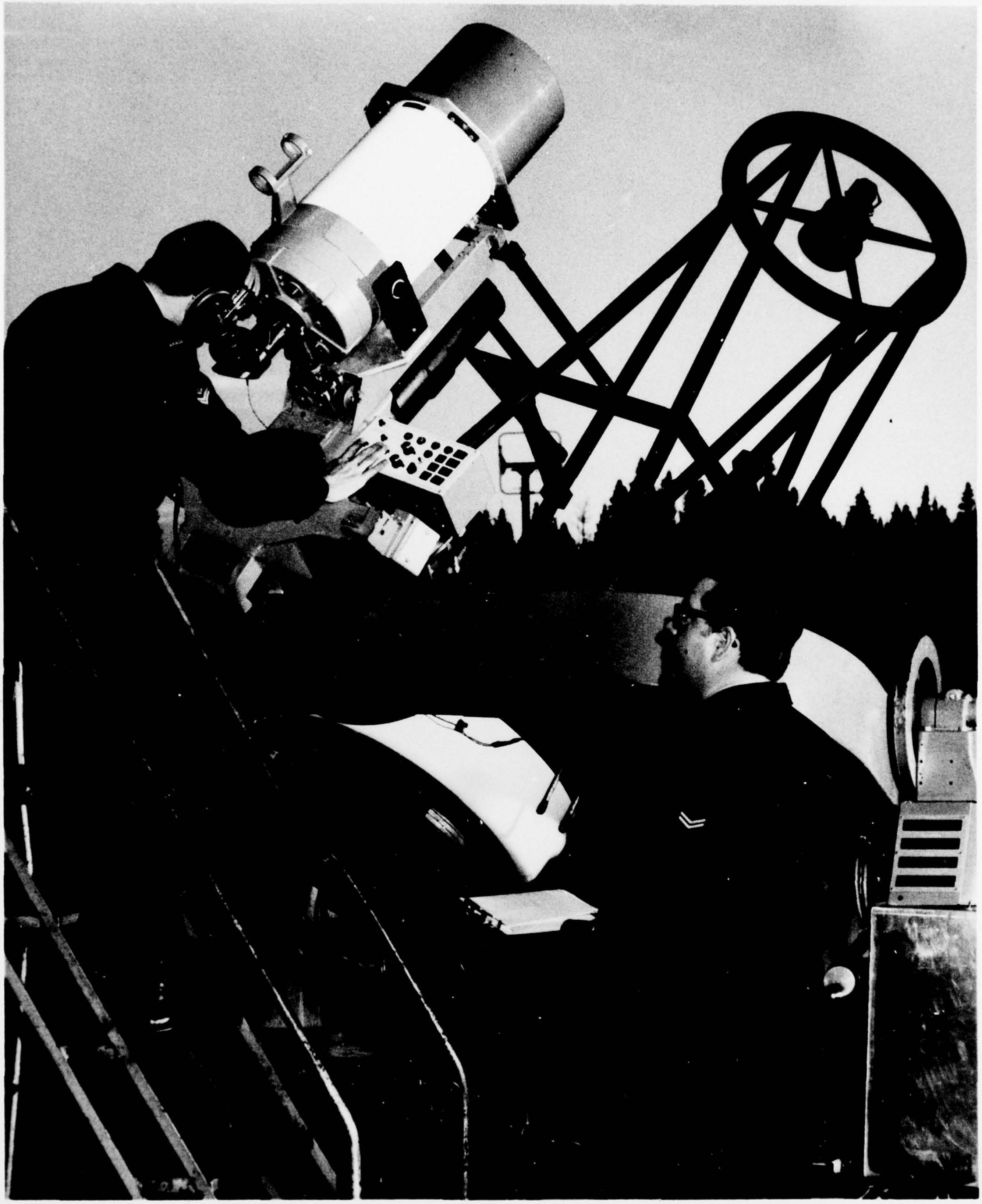


Figure 2 - Observer Control System for the SIS at SITU, St. Margarets, N.B.

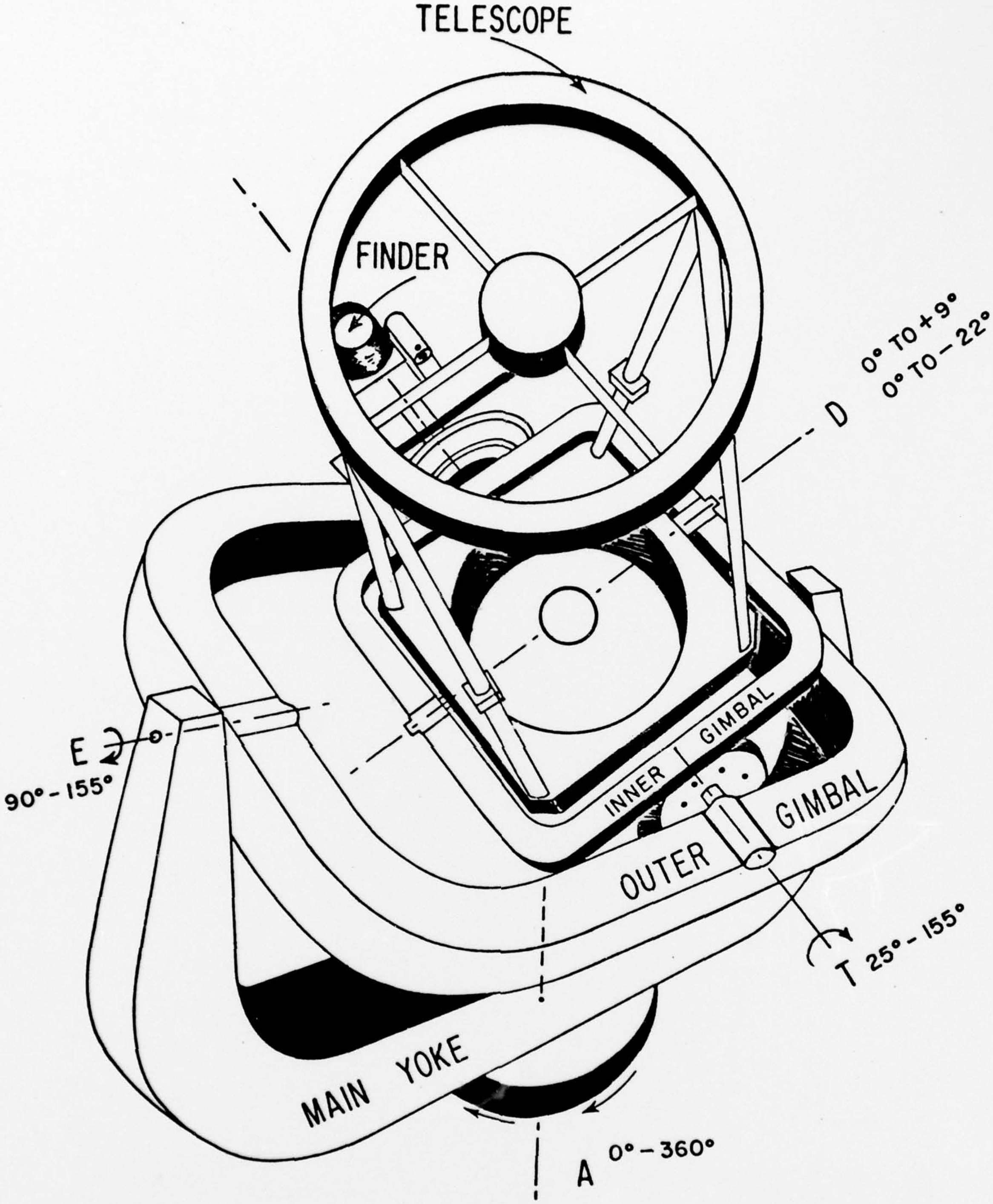


Fig 3
p. 20

Figure 3

Illustration of Mounting Nomenclature and Symbols for the Space Object Identification Optical Tracker

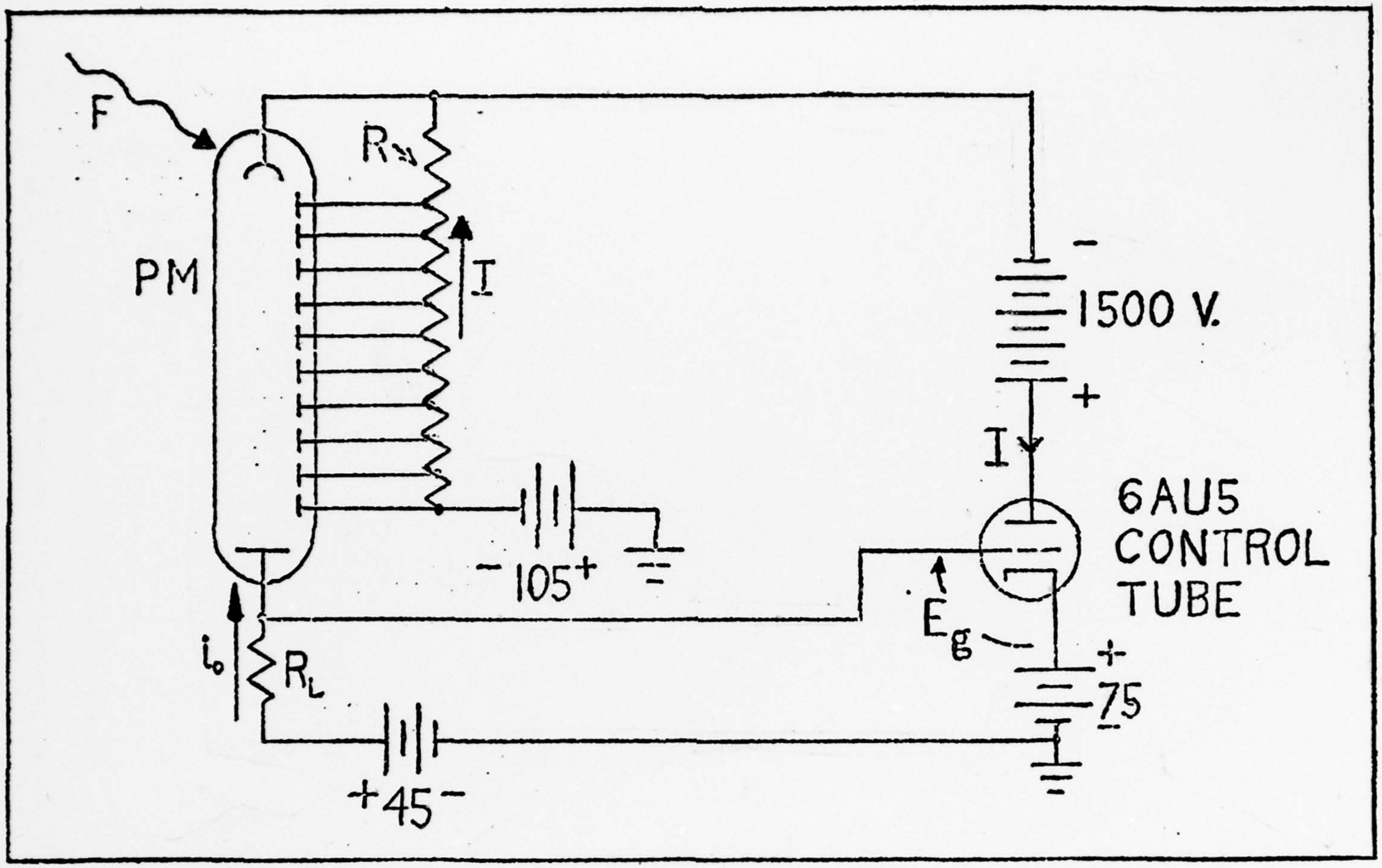


Figure 4

Simplified Schematic of Logarithmic Photometer

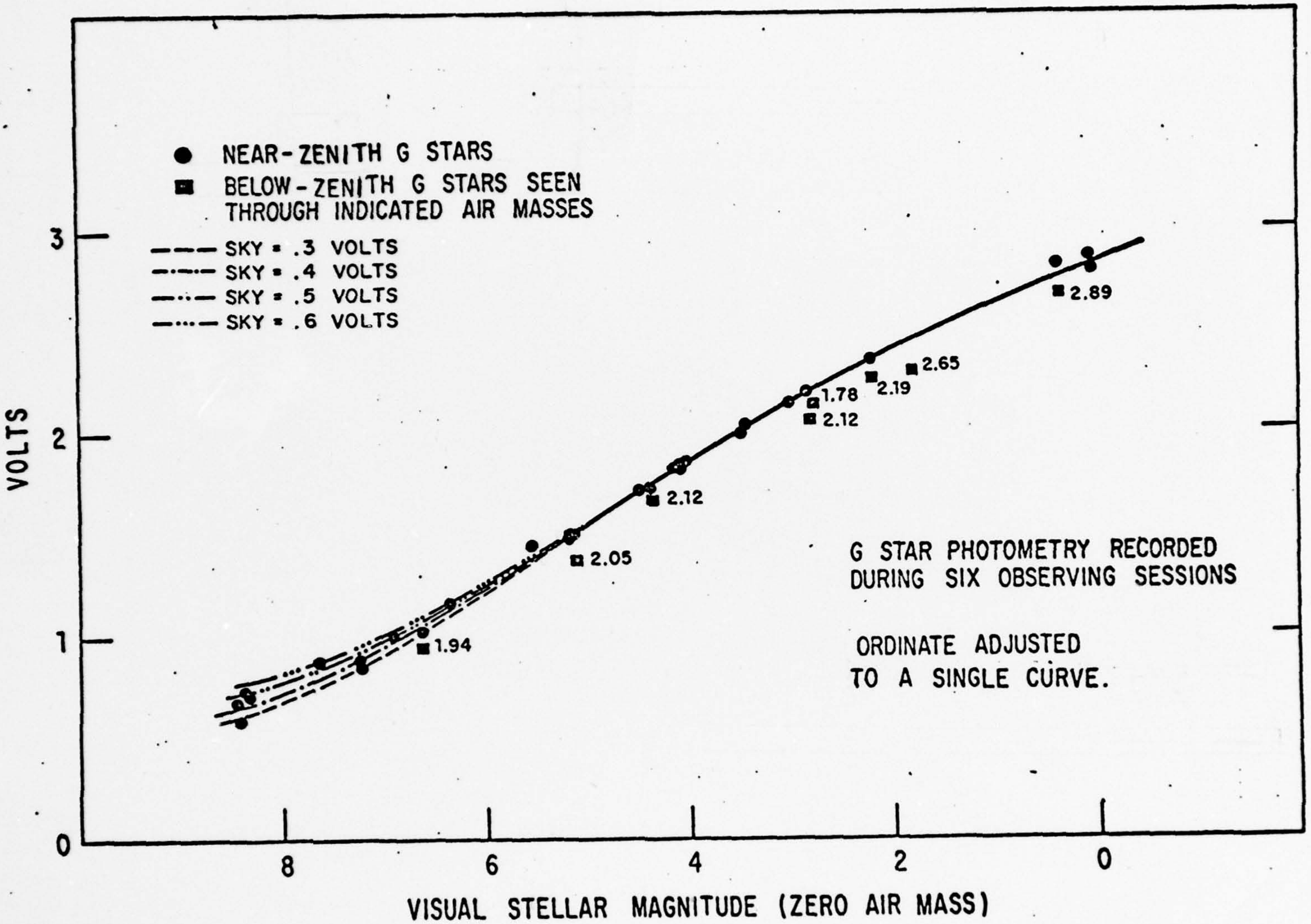


Figure 5. Typical Calibration Curve of the Analog Photometer. Increasing twilight sky brightness on the toe of the curve reduces the sensitivity at high sky-background levels.

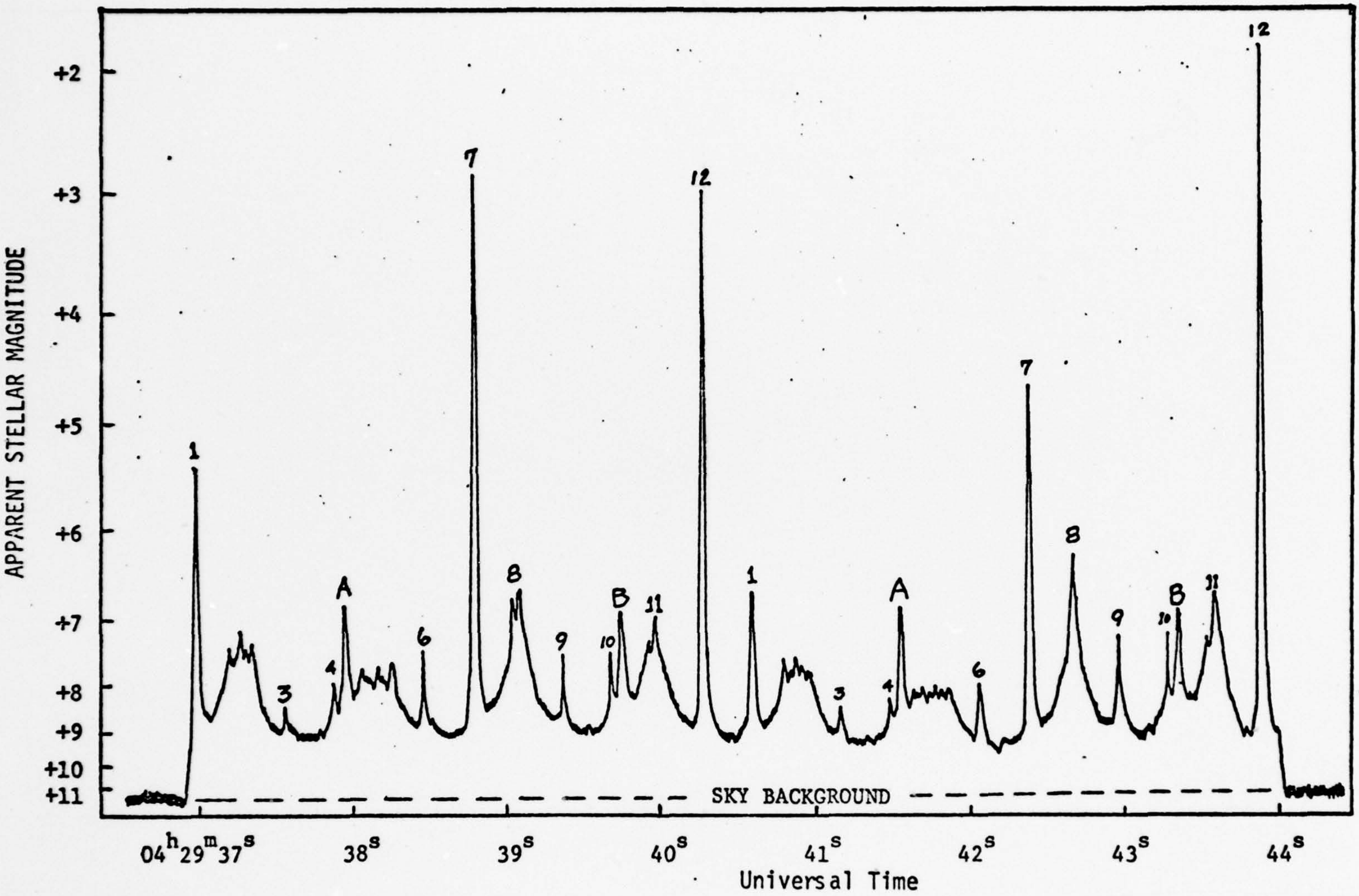
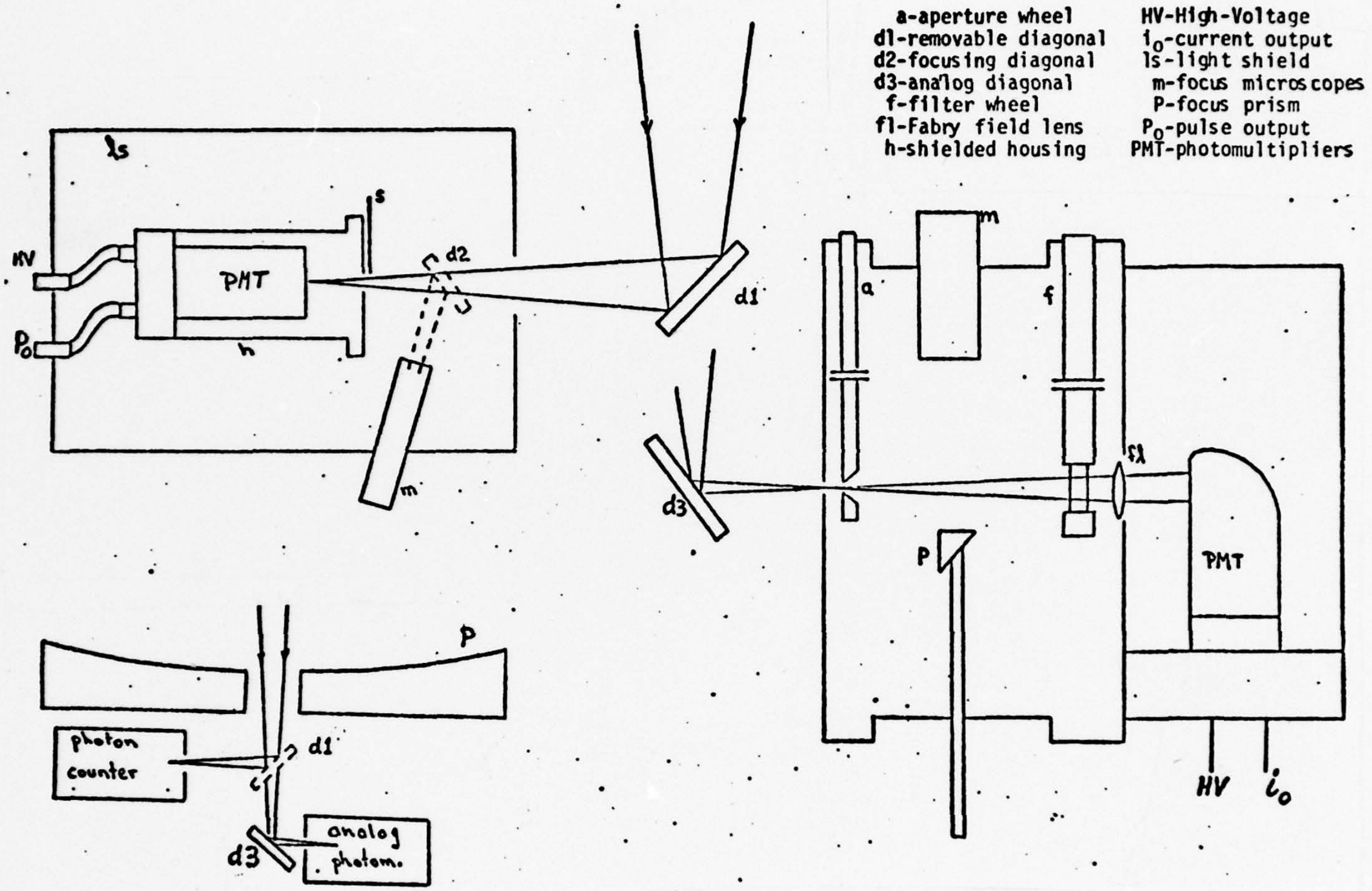


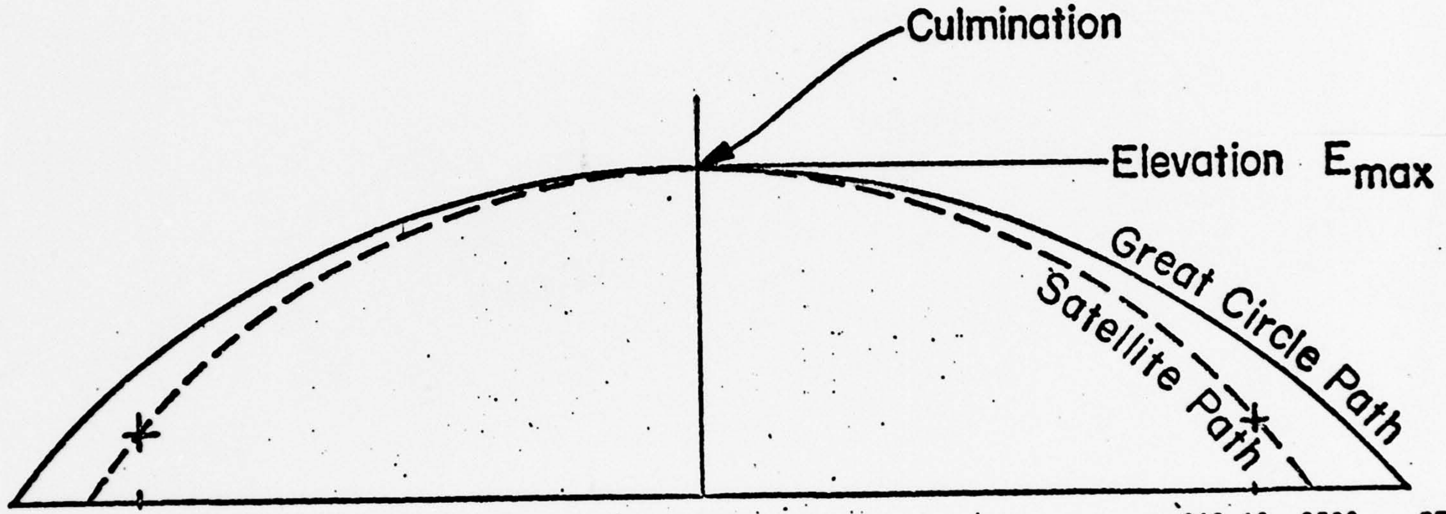
Figure 6. Photoelectric Photometry of UK Spacecraft ARIEL-4 with the SOI Analog Photometer, 6 July 1972, showing two Rotations of the Spin-Stabilized Spacecraft. Variations in Brightness of the Glints from the 12 Solar Panels Indicate Unbalance of Rotation by 2.2°.



a-aperture wheel
d1-removable diagonal
d2-focusing diagonal
d3-analog diagonal
f-filter wheel
fl-Fabry field lens
h-shielded housing

HV-High-Voltage
i_0-current output
ls-light shield
m-focus microscopes
P-focus prism
P_0-pulse output
PMT-photomultipliers

Figure 7. Optical Arrangement of the Digital and Analog Detector Systems at the Cassegram Focus of the 61-cm Telescope.



Azimuth	90°	110°	117.6°	180°	242.4°	250°	270°
Elevation		0°	6.48°	30°	6.48	0°	
Mt Azim		180.00	180.00	180.00	180.00	180.00	
Mt Elev		43.66	43.66	43.66	43.66	43.66	
Track		165.25	155.00	090.00	025.00	014.75	
Declination		113.66	113.66	113.66	113.66	113.66	
Track Velocity (°/sec)		0.0212	0.0585	0.3274	0.0585	0.0212	

Figure 8. Great-circle approximation to the apparent trajectory of a satellite. Also shown are 4-axis mount coordinates for small-circle approximation. The crosses represent the mechanical tracking limits of the SOI mount.

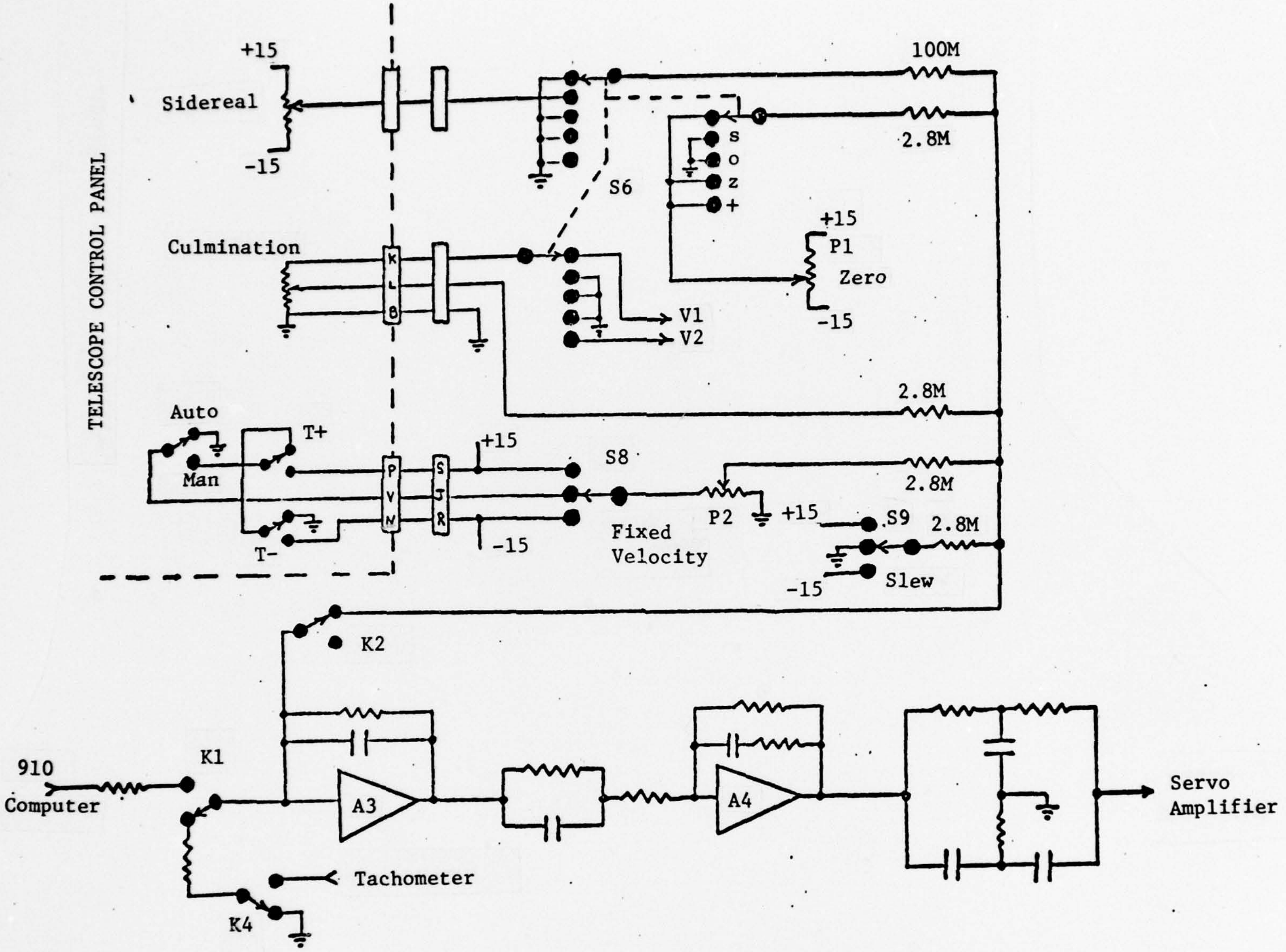


Figure 9
Hybrid Track-Velocity Control System Diagram

reduce

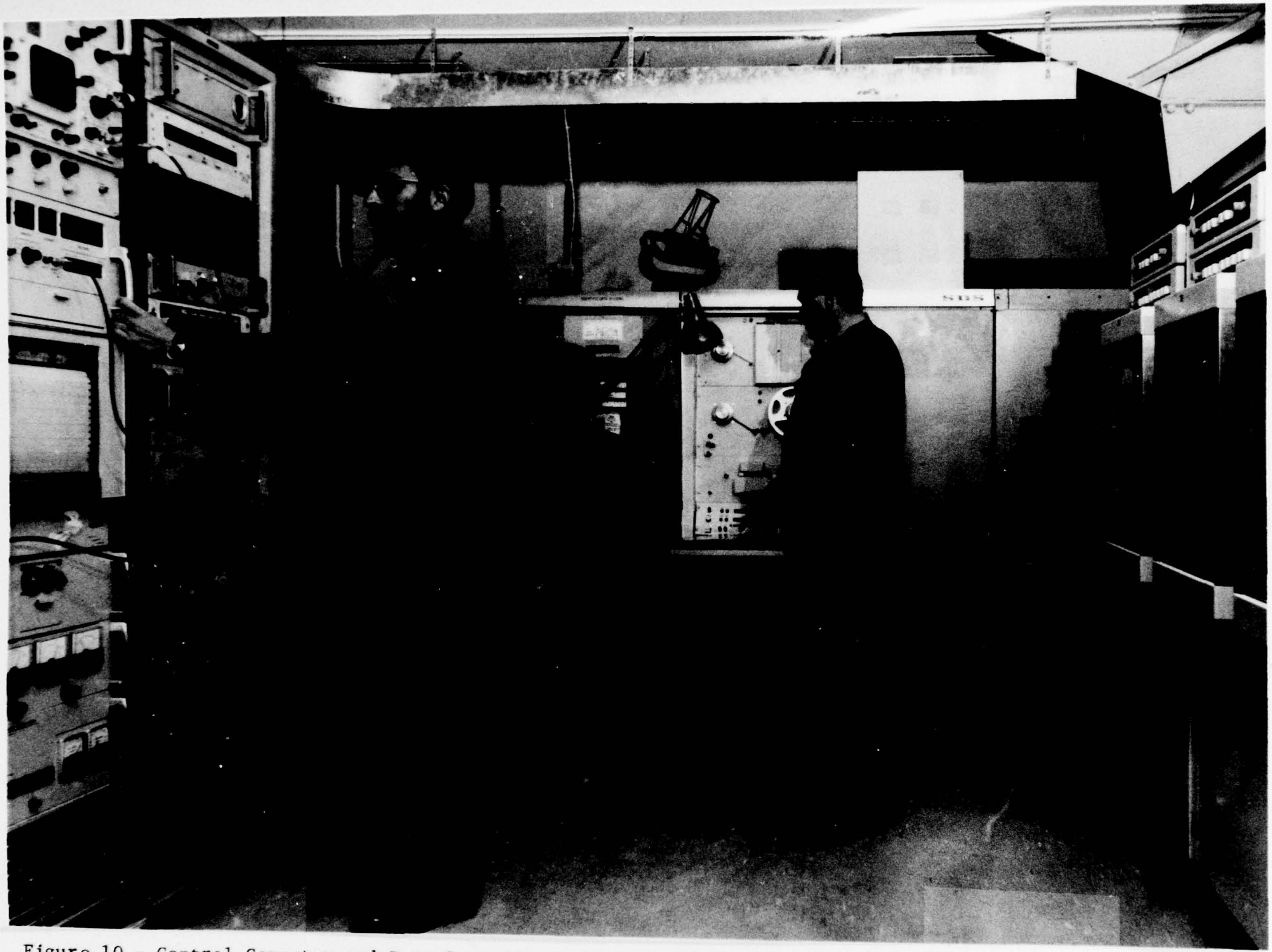


Figure 10 - Control Computer and Data Recording System of the Satellite Identification System as installed at St. Margarets, N.B. At left are the rubidium clock and detector electronics, at right the digital recorder system.