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NRL ~~Memorandum~~ Report. 1078

SPACE SURVEILLANCE SYSTEM

TECHNICAL SUMMARY REPORT NO. 4

ARPA Order No. 7-58

Applications Research Division

338443

June 30, 1960

U. S. NAVAL RESEARCH LABORATORY
Washington, D.C.

[redacted]

CONFIDENTIAL

SECURITY

Previous Reports in This Series

"Space Surveillance System, Technical Summary Report No. 1," Applications Research Division, NRL Memorandum Report 896 (Confidential), December 31, 1958

"Space Surveillance System, Technical Summary Report No. 2," Applications Research Division, NRL Memorandum Report 954 (Confidential), June 30, 1959

"Space Surveillance System, Technical Summary Report No. 3," Applications Research Division, NRL Memorandum Report 1025 (Confidential), December 31, 1959

CONTENTS

ABSTRACT

The U.S. Navy Space Surveillance System consisting of two sensor complexes, one in the eastern portion and one in the western portion of the United States, and the Operations Center at Dahlgren, Virginia, continued 24-hour-per-day operation throughout the reporting period. The increase in number of satellites in orbit has produced a corresponding increase in number of observations. A total of 2080 passes on 24 different satellites were recorded during the past six months.

Funds have been supplied to complete the automatic digital data processing, installation of an alert system at all receiving stations, and installation of a 500-kw transmitter in the center of the line.

The 1600-foot receiving antennas at Fort Stewart have been evaluated and put into operation. Also, at Fort Stewart, the loss of passes as a result of using a single linear polarization has been evaluated. Indications are that of the total passes received on two orthogonal polarizations, 25 percent are missed on either of the single linear polarized systems.

Comparison of signals received by reflection from meteor trails at frequencies of 432 and 108 Mc indicates very few reflections at the higher frequency compared to those at 108 Mc.

PROBLEM STATUS

This is the fourth Semiannual Technical Summary Report covering work from January 1, 1960 through June 30, 1960. Work is continuing.

AUTHORIZATION

NRL Problem R02-35
ARPA Order No. 7-58

SPACE SURVEILLANCE SYSTEM TECHNICAL SUMMARY REPORT NO. 4

BACKGROUND

Under sponsorship of ARPA, the U.S. Naval Research Laboratory initiated a program in June 1958 to develop, install, and operate the Space Surveillance System for the detection, tracking, and orbital prediction of nonradiating satellites. Experimental detection and tracking stations are located in two Complexes providing an Eastern and Western portion of a space surveillance line extending across the Southern United States (Fig. 1). Each Complex consists of a 50-kw cw transmitting station and two receiving stations spaced about 285 statute miles from the transmitter, one to the west and the other to the east. Illumination for the entire line is to be provided by a 500-kw transmitter scheduled for installation at Kickapoo Lake, Texas. All stations are located on the same great circle. The transmitter radiates in a thin east-west fan beam and the reflections from objects passing through this beam are picked up at the receiver sites on antennas having a similar beam shape. At the receiving stations interferometer techniques are employed to provide data for accurate computation of angle of arrival. Eight channels of output data are transmitted in analog form over telephone lines to the Space Surveillance Operations Center at Dahlgren, Virginia. The recorded data provide: (a) time of passage through the beam, (b) signal level and shape, and (c) electrical phase angles between the signals from pairs of antennas having various baselines. The data are used by the NORC computer to compute zenith angle of the observations, determine orbital elements and produce future position predictions for those satellites within the observational capability of the system. Satellite observations in the form of time, zenith angle, and receiving station identification are transmitted on a daily basis to Space Track (Cambridge, Mass.).

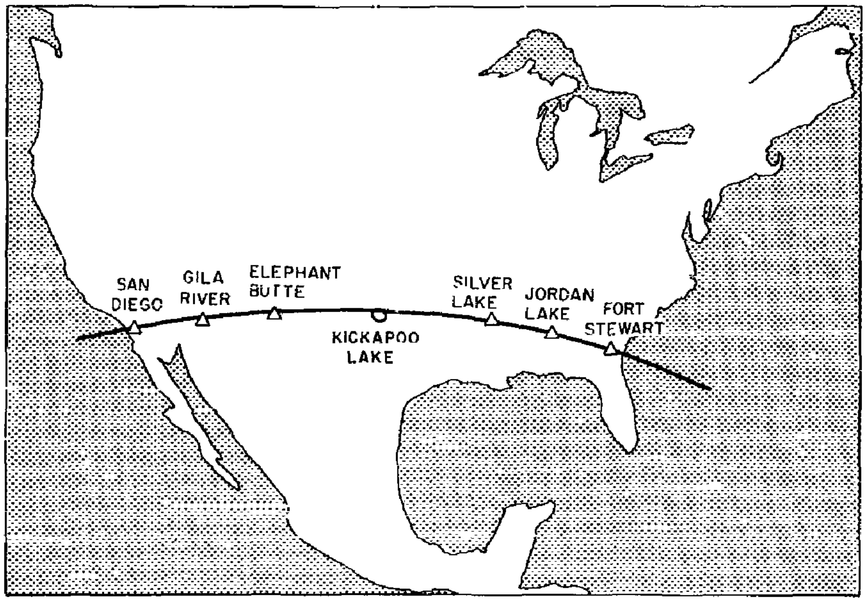

Fig. 1 - Space Surveillance Stations

SPACE SURVEILLANCE SYSTEM
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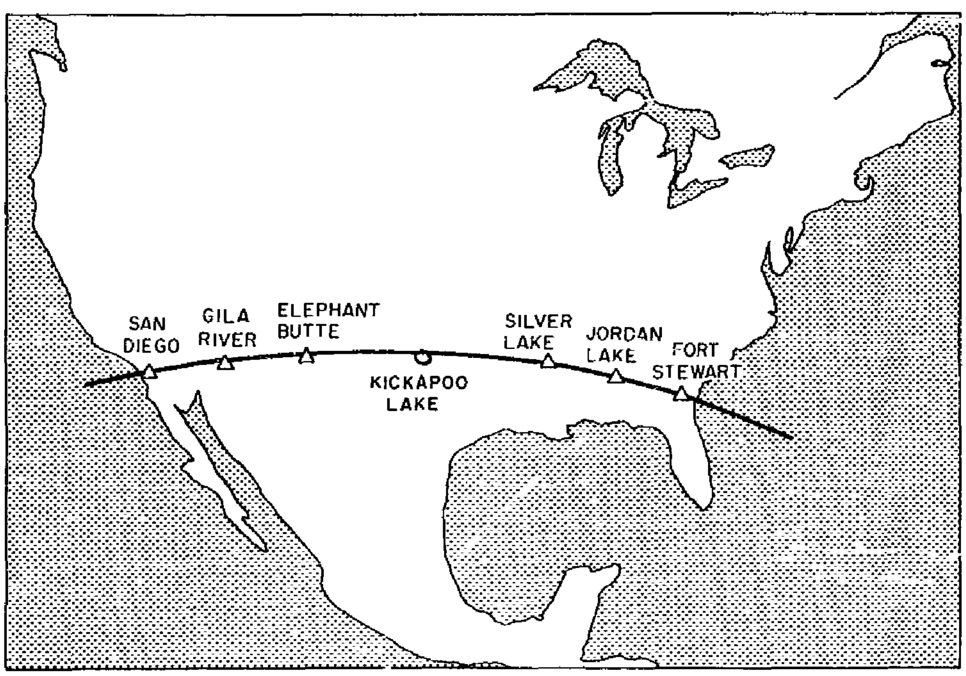

Fig. 1 - Space Surveillance Stations

STATUS

Transmitting Stations

The transmitting station at Gila River was provided with new radiating elements during May and June. The new elements consist of dipoles having the two radiating elements located orthogonally to increase the East-West beamwidth.

During the installation it was discovered that the 3-1/8-in. Styroflex insulating spiral had collapsed in one of the lines carrying 25 kw. Further investigation disclosed that these spirals had collapsed in all the 3-1/8-in. lines, even those carrying only 6-1/4 kw. The manufacturer states that the cause of the failure is high ambient temperature and recommends shading the line and elevating it from direct contact with the ground.

The most seriously damaged line has been replaced and the station placed on the air at a reduced power level of 40 kw. Meanwhile the cost of replacing this line with that of the rigid type is being investigated.

Investigation of the lines in use at Jordan Lake has revealed similar, though less severe, difficulties.

Receiving Stations

The change in antenna polarization at the Gila River transmitter permitted rotating all of the elements at San Diego and Elephant Butte to collinear polarization. This change has been accompanied with baseline changes at these receiving sites (as well as at Silver Lake) to provide the capability of using the baselines shown in Fig. 2. With these changes, ambiguity resolution can be improved since baseline ratios of about 2:1 can be used. Also the North-South baselines can now be used. Figure 3 shows the antenna configuration in the Eastern Complex.

In addition to changed baselines, each of these three receiving stations now has one 1600-foot antenna made up of four 400-foot sections. These sections are used for various baselines, and the complete antenna is to be used to provide additional gain for the alerting system.

The dipole elements at Fort Stewart and at Silver Lake are of the presurized type. The Silver Lake 1600-foot antenna uses the elements previously used at the Gila River transmitter. The elements at San Diego and Elephant Butte are not pressurized. Since the rainfall at these two sites is low, these unpressurized elements cause little difficulty.

Operations Center

Except for station down times, analog data from all four receiving stations have continued to be recorded 24 hours a day at the Space Surveillance Operations Center, described in the previous progress report.* The data handling techniques employed have been those previously described.†

*Technical Summary Report No. 3, pp. 4-5.

†Technical Summary Report No. 3, pp. 16-18.

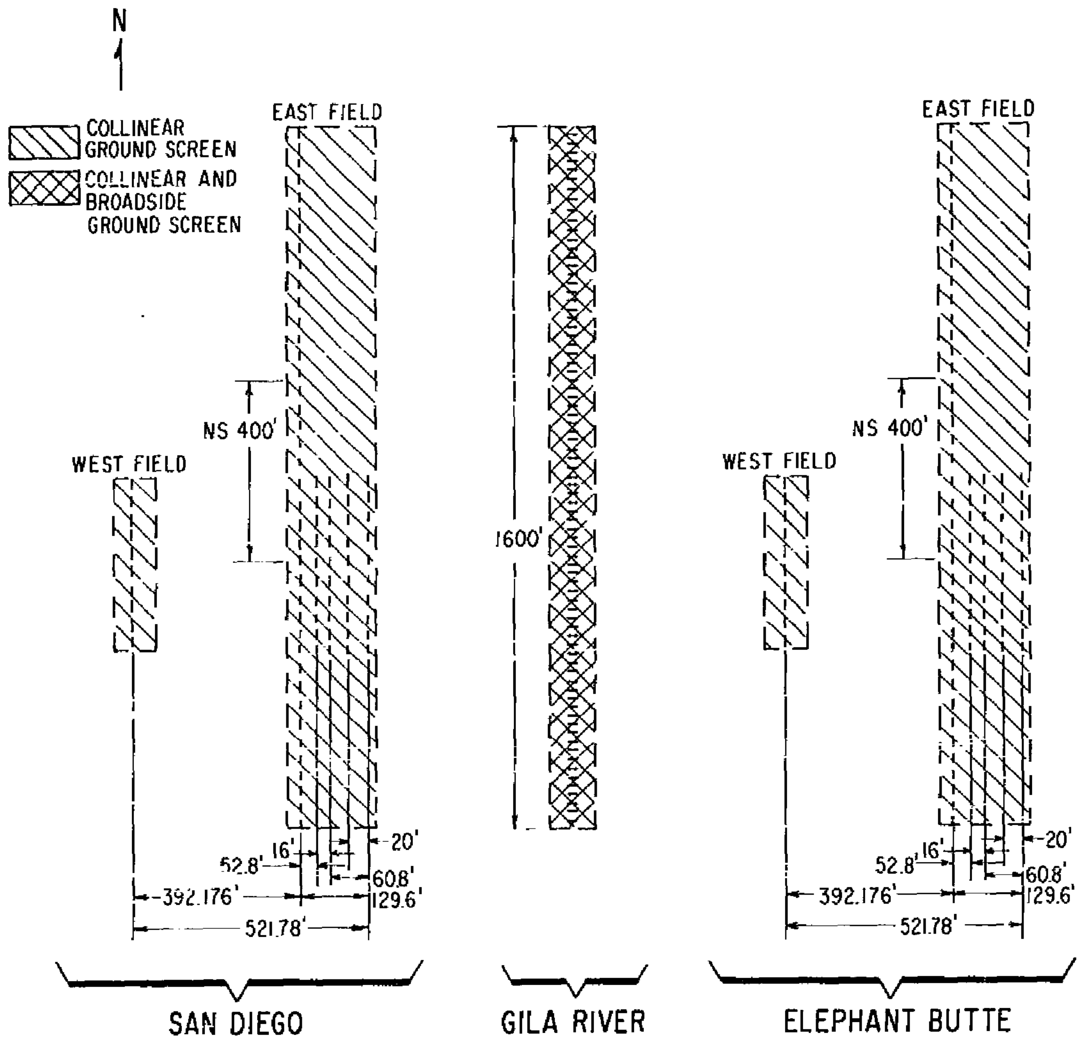

Fig. 2 - Antenna configurations for Space Surveillance System Western Complex as of June 30, 1960

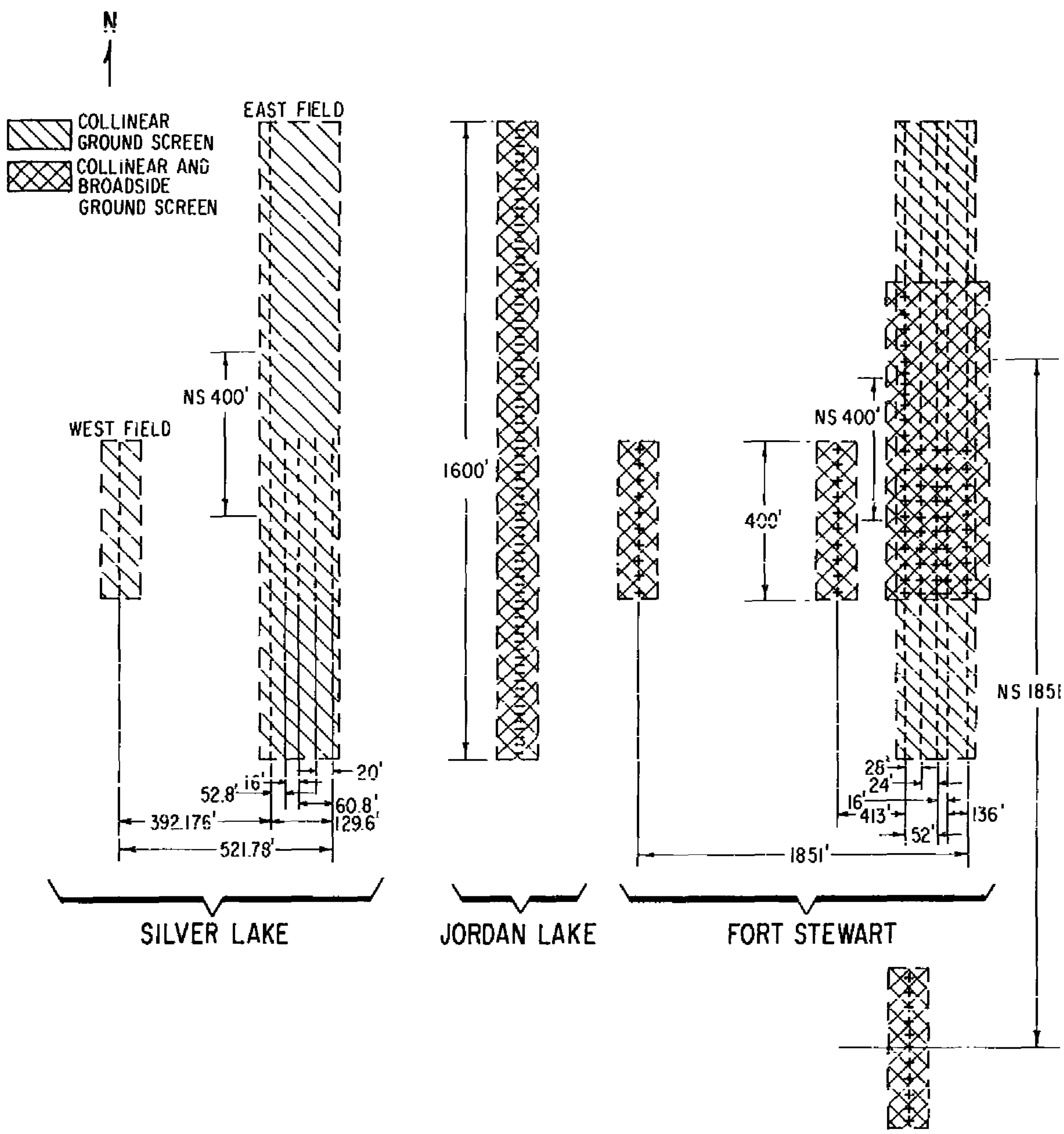

Fig. 3 - Antenna configurations for Space Surveillance System Eastern Complex as of June 30, 1960

Data Transmission and Recording

Since February 18, 1960, in addition to the eight channels of analog data transmitted from Fort Stewart for operational use, eight channels of similar data have been transmitted over a second telephone data line both to the Operations Center and to NRL to allow comparative evaluation of a differently polarized antenna system. At the Operations Center, all the additional data are recorded 24 hours a day on a single 8-channel Sanborn recorder.

In May 1960 an "off-line" calibration system was initiated on the additional Fort Stewart data line to develop new calibration procedures for the entire system. Precision oscillators have been installed at the Operations Center which simulate the band edge frequencies of the subcarrier channels of the analog data transmission system and are used to calibrate and adjust the minimum and maximum pen positions for each channel of the Sanborn recorders without interrupting data recorded on the on-line recorder. A few minutes before the recording paper in the on-line recorder reaches the end of the roll, the data are switched to a standby recorder which has previously been calibrated by the test signals of the precision oscillators. When the recording paper change has been completed, the test signals are used to adjust and calibrate this recorder after which the data are returned to the on-line recorder. The test signals also provide a systematic method for isolating component failures and system errors in the data recording system at the Operations Center. In addition, standard voltages are employed at Fort Stewart to permit off-line calibration of station data transmitters and Sanborn recorders without interrupting the transmission of data. The employment of off-line calibration techniques minimizes data outage times for overall calibration requirements and improves the techniques for determining the source of data transmission system malfunctions.

Originally all recordings were made on 200-foot rolls of Sanborn recording paper. This necessitated changing paper and adjusting the paper misalignments of Sanborn recorders at the Operations Center every three hours. During May 1960 adapters were provided and 100-foot rolls of paper were procured to give a continuous recording capacity of 15 hours. This resulted in a five-to-one reduction in data outages due to adjustments for paper misalignment at paper change times.

The stations have not recorded any data since May 26, 1960, but operate their recorders at 1/4 millimeter per second to monitor station performance.

Development and Financial Plans

Late in the reporting period ARPA approved major developments in the system and provided funds for their completion. Funding has been provided to install the 500-kw central transmitter, to complete the digital transmission of data from all receiving stations, and to complete the alert system at all stations.

U.S. Naval Space Surveillance Facility

The Secretary of the Navy established the U.S. Naval Space Surveillance Facility at the U.S. Naval Weapons Laboratory, Dahlgren, Virginia, on April 19, 1960. This Facility will be of assistance to the Laboratory through gradually assuming routine operational and military functions in connection with the system operations and thus permit the Laboratory personnel to devote their efforts to R&D.

EQUIPMENT

Central Transmitter

A transmitter providing 500-kw output power is to be located in the center of the existing line near Archer City, Texas. The Eighth Naval District is currently preparing the specifications necessary for the construction of buildings on the site. The Radio Corporation of America has been selected to provide and install the transmitter. Specifications for the associated antennas have been prepared and requests for bids made.

The transmitter will employ multiple output amplifiers each feeding one antenna bay. Electronics ahead of the final amplifiers will be dual channel for reliability. Any individual final amplifier may be off without affecting the remaining ones. This feature not only provides reliability but permits servicing each section while maintaining operations with the remainder.

IF Preselector Alerting System

The IF preselector consists of a comb filter receiving signals from an antenna of higher gain than those used in the phase comparison system. The detection of a signal in one of the teeth of the comb switches on a local oscillator in the phase comparison system so that the phase comparison system is tuned to receive the frequency detected in the comb filter.

The prototype system now installed at Silver Lake consists of 256 30-cycle filters and 256 local oscillators. This system operates from a signal received at a 1600-foot antenna while the phase system uses 400-foot antennas. When a signal is received of such amplitude as to provide a signal-to-noise ratio of 13 db, the system is alerted. (This signal-to-noise ratio reduces false operation arising from noise peaks to less than one per day per channel.) To avoid transients, all of the local oscillators operate continuously, but at a low power level. The alert signal causes the proper local oscillator frequency to be amplified to a sufficient level to act as a local oscillator for all of the phase channels.

Each phase channel final IF employs a narrow double-pass frequency filter, the two passbands being separated by 1000 cycles, the separation frequency of the phase-locked local oscillators. Each passband is approximately 150 cycles wide giving an overall IF bandwidth of 300 cycles. In the IF band the signal-to-noise ratio will be poorer than in the comb filter by the product of the ratios of antenna gains and bandwidths. This ratio is approximately 12. However, the S/N ratio in the alerting comb must be high to prevent false alerts. In the phase measurement channels it need only be high enough to measure phase angles. By reducing the ratios of the baselines to approximately 2/1, the two systems have been made to have nearly equal sensitivities.

In any system that requires a high post-detection S/N ratio, little advantage is gained by making the predetection bandwidth excessively narrow. On this basis an investigation has been conducted into the possibility of widening the predetection bandwidth of the comb filter teeth and narrowing the post-detection bandwidth. Since the minimum post-detection filter that can be used depends on the observation time, use of a single bandwidth for both nearby and distant objects serves to limit the capability of the system. From the analysis, suitable values of post-detection bandwidth appear to be ten cycles and one cycle. A predetection bandwidth of 100 cycles was selected. The prototype unit, described previously, has an effective post-detection bandwidth of approximately 10 cycles.

The system under procurement is designed to operate with separate detectors on the 10-cycle and one-cycle filters. The first filter detector actuated will actuate a corresponding local oscillator and also a similar post-detection filter in the phase meter. The philosophy of using the two post-detection bandwidths is that for nearby objects the signal level will be high and hence will actuate the ten-cycle filter. For distant objects the signal level will be low but will be in the antenna beam for a time long enough to actuate the one-cycle filter. Since the narrower post-detection filter is intended for distant objects, the doppler frequency associated with these objects will be less than the doppler associated with nearby objects. As a result only the 100-cycle filter sections near the center of the doppler coverage utilize both post-detection filters. The remaining 100-cycle filters have only a single, ten-cycle, post-detection filter. This results in a reduction of the number of filters used and increases the detection range capability.

Digital Data Transmission

The plans for the ADDAS (Automatic Digital Data Assembly System) are essentially unchanged from those outlined in the previous progress report.* The number of Spasur receiving stations which can be accommodated has been increased to 15 from 14, and the number of NORC tape units to be employed is three instead of two. The schedule previously outlined is expected to be met. The first installation of digital receiving-station equipment is planned for the Fort Stewart station during October 1960. Immediately thereafter, testing of the ADDAS will begin with this one receiving station and one NORC tape unit. The Silver Lake station will be instrumented by Spring 1961, completing the Eastern Complex, and the Western Complex will be instrumented by Summer 1961. During the latter half of 1961, it is planned to operate both the digital system and the present analog transmission and recording system until continuous reliable operation has been demonstrated by the digital system.

Design and construction of the ADDAS are progressing satisfactorily. Of the equipment which will be required before October 1960, all is either under construction or entering the final stages of design. Several sections of the system, such as the digital clock and the digital equipment for the first receiving station, have already been completed. The central core memory for the message assembler has been received, and the manufacturers of the required magnetic tape transports are making satisfactory progress. Delivery rates on digital modules have been satisfactory.

Tests on six telephone line loops from the Space Surveillance Operations Center (Dahlgren, Va.) to the Space Surveillance receiving stations and back, ranging in total length from about 1500 to about 6000 statute miles have been completed using the Rixon Sebit-25 digital transceiver. From these tests it has been concluded that rates of data transmission of at least 1500 bauds (pulses per second) can be achieved on the worst lines, as they now exist. The tests include many hours of operation at different times of day on each line. Since it has not been feasible to make these tests on a round-the-clock basis, there remains an element of uncertainty as to overall performance. The principal factor limiting transmission rates appears to be delay distortion on the telephone lines rather than noise (Fig. 4). Delay measurements are made with NRL-developed equipment using conventional techniques. In comparison with other lines for which such measurements have been made by Western Union, American Telephone and Telegraph, and others, these lines are exceptionally poor with respect to delay, even when account is taken of the double line length necessarily arising in loop tests.

*Technical Summary Report No. 3, pp. 9-11, 26-28.

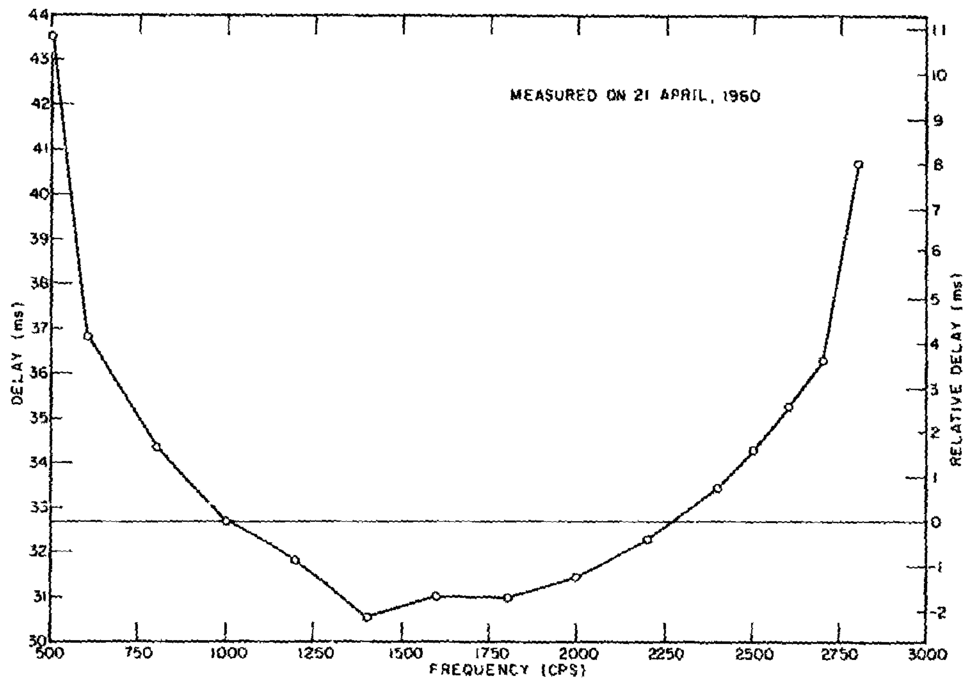

Fig. 4 - Loop delay between NRL and SPASUR Station at Silver Lake, Mississippi

Every effort is being made to obtain improved service from the telephone companies in order that higher transmission rates may be used. However, because of the remote location of the line terminals, better service may not be available for some time. Alternative solutions to the problem are being investigated.

Another type of data transmission device (the Collins Radio Co. Kineplex TE 206-A) has been obtained on a rental basis for testing. This equipment, although more complex and expensive than the Sebit-25, offers some possibility of improved performance under the conditions of severe delay distortion. It will be tested over a data line to Fort Stewart in alternation with the Sebit-25 in order to obtain comparative results. A second approach will attempt to develop delay compensating techniques adequate to provide satisfactory overall data transmission. Two commercial devices are available for this purpose but their capabilities are inadequate for these data lines unless a prohibitive number of the devices is used. Consequently, a different approach employing very long audio delay lines (5-ms delay), developed by the Sound Division of NRL in connection with another problem, is being investigated. This approach will be feasible only if the delay characteristics of the telephone lines are reasonably stable, since large magnitudes of delay distortion are being removed by compensation. It is intended to attempt to keep delay distortion within ±0.2 ms for telephone lines whose delay distortion between 50 and 2800 cps is as much as 4 ms for one-way transmission (roughly 8 ms for loop transmission). All available information indicates that the telephone lines should be sufficiently stable to meet this criterion for reasonably long periods. NRL measurements have shown no change in delay distortion even when large changes in amplitude response have been observed.

Figure 5 shows changes in loop delay on the existing data line to San Diego, the longest line used, on four different dates. There appear to be fairly large changes in gross delay with the measuring frequency, but that, for the most part, the changes in delay distortion with time are minor. The measured delay versus the physical length of the telephone line is shown in Fig. 6 for several of the lines. The measurements were made from NRL and thus the section NRL to Dahlgren was not included in the individual measurements to the stations since the lines route through Washington to Dahlgren.

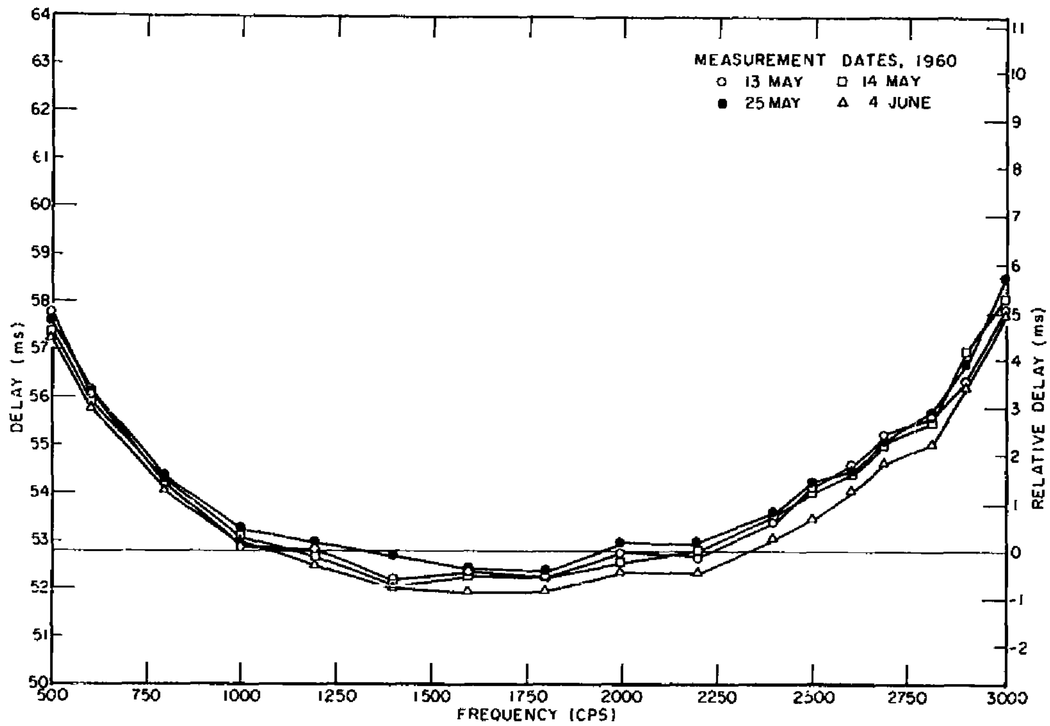

Fig. 5 - Loop delays between NRL and SPASUR Station at San Diego, California

Signal Processing

As a part of the automatic digital data transmission and processing system, it is required to determine at the receiving stations which signals have characteristics of satellite returns.

Examination of the received automatic gain control (AGC) signals indicates that satellite signals differ in their characteristics from the signals of meteorites and/or their associated ionization trails, from atmospheric noise signals, and from other undesirable signals. Satellite signals are normally symmetrically hump-shaped and are related to the

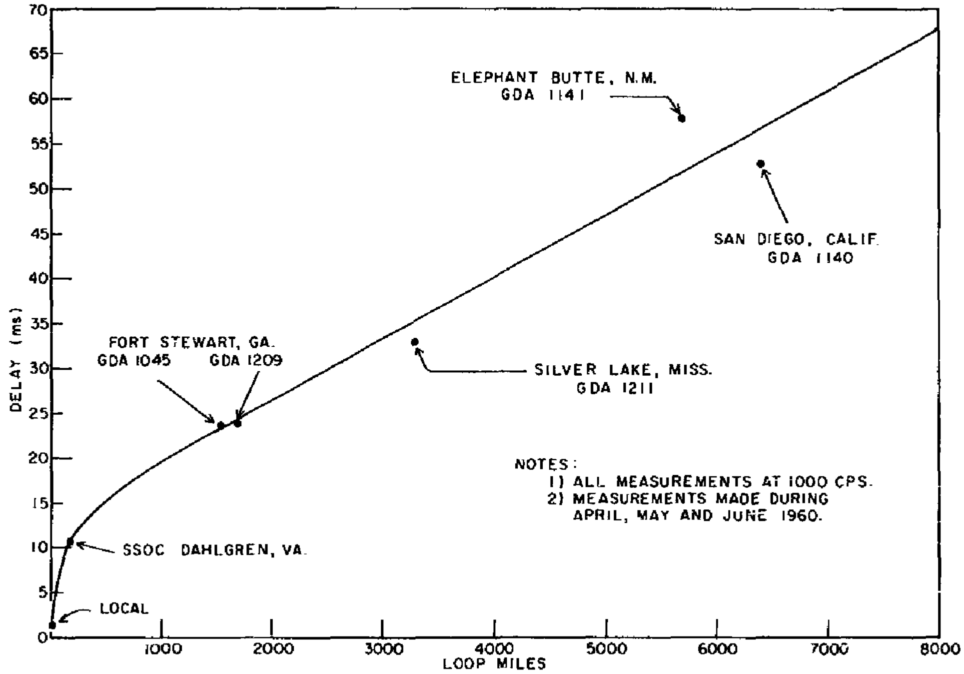

Fig. 6 - Delay vs telephone line loop length in miles from NRL to Station and return

receiving antenna pattern. For a first approximation, the shape of the satellite signal may be given by

$$y = E \sin \frac{\pi t}{T} (0 \leq t \leq T).$$

The satellite signal duration T is a function of the antenna configuration employed and in the present system is in general greater than 0.2 second. It may, therefore, be possible to eliminate from further consideration signals of duration less than some established minimum. In general, undesirable signals are unsymmetrical, having sharp rise times and exponential decay times, however some have sharp rise times and sharp fall times.

Equipment is being developed to recognize automatically the satellite signal produced by the automatic gain control channel. The equipment will incorporate three distinct techniques related to satellite signal characteristics. It is intended that the three techniques will collectively supplement each other to produce a high probability of satellite recognition and a minimum false alarm rate. General descriptions of the three techniques follow.

Symmetry - One of the characteristics which has been chosen for this analysis is the symmetry shown by all satellite signals. A dc delay line has been developed to provide about one second of signal storage. By simultaneously scanning the line from its center to each end and comparing the outputs of the two scanners, a succession of comparator outputs will be delivered when a symmetrical signal is centered in the delay line. When scanned rapidly and repetitively, the system will function in real time. These outputs will be weighted to give greater significance to the comparisons nearest the center of the delay line to accommodate the minimum duration signals. A succession of comparator outputs are integrated, and upon exceeding a preset threshold, the equipment will deliver a binary output announcing a satellite-type signal.

Frequency Spectrum - The general appearance of the nonsatellite signals received by the system suggests that their frequency spectrum should be different from that of a satellite signal. An analysis of these signals by the Fourier Integral Method showed that their spectrums were significantly different. The spectrum of the typical hump-shaped satellite signal showed a high ratio of low-frequency to high-frequency content, while the others did not. To implement the classification of various signals by their frequency spectrum, the area under the signal, which is approximately proportional to the low-frequency content of the signal, is determined. The signal is also passed through a high-pass filter. The area under the absolute value of the output of the filter, which is proportional to the high-frequency content of the signal, is also determined. These two areas, after appropriate scaling, are then compared, and if the low-frequency area is larger the signal is called a satellite type, but if the high-frequency area is larger the signal is called a nonsatellite.

Shape-Area - This technique accomplished the function of recognizing a satellite AGC signal by comparing the area under the signal to the area of a standard shape having the same peak amplitude and duration as the received signal. On the basis of a few examples, it appears that this area-comparison technique provides a sensitive measure of the conformity of a received shape to a standard, in this case the positive half of a half-wave rectified sine wave.

Equipment incorporating these techniques has been built and is in the process of being tested and evaluated. The testing and evaluation includes the use of either simulated AGC signals or actual recordings of various satellite and nonsatellite-type signals. The simulated signal consists of half-wave rectified sine waves to which noise has been added. The duration of the signal is continuously variable from 0.2 to 2 seconds. For representative actual AGC signals, short continuous loops of magnetic tape on which are recorded selected signals from a master tape made at Fort Stewart are used. The minimum length of loop is about 5 feet at present, which represents 8 seconds of playing time. The proportion of signal time in relation to loop time is low, and shorter loops would be desirable. A total of 25 tape loops have been made up with different signals. On ten of the loops, signals from satellites 1959 Iota 1 and 2 and 1960 Gamma 1 and 3, having durations of 0.7 to 1.6 seconds and levels from 111 to 126 db below one milliwatt are recorded. Another ten loops have signals assumed to be meteors which range in duration from 0.2 to 0.7 second and up to minus 105 dbm in level. The remainder are signals having some similarity to satellite returns with durations from 2 to 5 seconds. The signals were selected on the basis of having some characteristics normally attributed to satellite returns, and thus present greater difficulty in discriminating between them. With the exception of 1959 Iota 1, which has a distinctive periodic modulation superimposed on its response, there is not much difference between the traces of other satellites to distinguish between them.

Station Calibration

An experimental program has been initiated to make use of visible satellites, such as the Echo, Sputnik IV, and Transit to improve the calibration of the Space Surveillance stations. For this purpose the satellite will be photographed against a star background as it crosses the detection line and a comparison of the computed angle made with that derived from the radio interferometer readings. A concrete pad and shelter are being constructed at Fort Stewart for housing a camera and auxiliary equipment. An equatorially mounted camera is on hand and tests have been made by photographing 1960 Epsilon 2.

The preliminary tests indicate the present ballistic camera is adequate for photographing the Echo satellite, however, more photographic sensitivity will be required to use the presently orbiting satellites for station calibration purposes. The uncertainty of a successful Echo orbit has led to an evaluation study of other cameras which have more sensitivity.

16-Channel Recorders

The amount of paper consumed in making continuous recordings of all station data is substantial. Each recorder now has the capacity to record 8 channels, but the manufacturer has found it possible to produce a 16-channel model using the same paper width. It has been decided to change to this new model in the Operations Center after determining there would be no significant deterioration in the reading of data because of the reduced channel width. The first unit is to be delivered in July 1960.

An experiment was run to determine the effect of using the 16-channel recorder, with reduced channel width, upon signal detection and upon accuracy of phase reading. Also, the possibility of running the 16-channel recorder at half speed was investigated since the relation of time scale to channel width would be maintained under this condition. Three conditions were investigated: (a) normal 8-channel operation at normal speed (5 mm/sec), (b) a simulated 16-channel arrangement with scale amplitude reduced by one-half, and at normal speed, and (c) the simulated 16-channel configuration but with the recorder running at 2.5 mm/sec. The results were as follows:

1. In signal detection whether using AGC level or phase quieting as a signal indication, there was no statistically significant advantage in any of the three conditions in detecting signals.

2. One was able to read slightly more accurately at the higher speed, but at that speed there was no statistically significant difference between the 8-channel and simulated 16-channel situations. In addition, the reading accuracy was high in all cases.

Meteorite Experiments

An experiment is being conducted to determine the simultaneous relative amplitudes of reflected signals from meteorite trails at the frequencies of 432 Mc and 108 Mc. This experiment is being conducted with equipments located at the Jordan Lake transmitting station and the Silver Lake receiving station. The experiment was described in greater detail in the previous semiannual report.*

Following the installation of the 432-Mc system, preliminary tests were made. The system was found to be operating satisfactorily as indicated by the returns obtained from airplanes and satellites. However the returns from meteorites were down so far in amplitude and duration that the number recorded was so small as to make a statistical comparison

*Technical Summary Report No. 3, p. 8.

at the two frequencies impossible in a reasonable time. As a result, the preliminary conclusion is that meteorites would not be a problem in a 432-Mc system. Some modifications of the 432-Mc system are being considered which would increase the number of meteors observed and thus permit the collection of data for a statistical comparison.

A comparison of meteorite activity on 108 and 432 Mc was made over a total period of 579 minutes during times when meteorite activity was at a maximum on April 29, May 3, and May 4. On the 108-Mc receiver a total of 160 signals were detected while on the 432-Mc receiver only two signals were obtained, both having durations of less than 0.1 second. Signal levels were read to the nearest 5-dbm point and were distributed as shown in Table 1.

Table 1
Comparison of Meteor Signals on Frequencies at 108 and 432 Mc

Signal Level (dbm)	Number of Observations	
	108 Mc	432 Mc
95	3	0
100	2	0
105	8	0
110	27	0
115	58	1
120	57	0
125	4	1
130	1	0
Total	160	2

Both of the signals that appeared on the 432-Mc system appeared as 95-dbm signals at 108 Mc. The one appearing at 125 dbm on 432 Mc had a duration of 0.6 and the other a duration of 0.3 second at 108 Mc. Their duration at 432 Mc was less than 0.1 second. It would appear that signals due to meteorites will be less by a factor of more than 100 in similar systems operating at a frequency of 432 Mc as compared with a frequency of 108 Mc. The duration of the signals at 432 Mc is so short compared to satellite signals that it would appear feasible to discriminate by duration at the higher frequency.

Another interesting meteorite experiment has been conducted at the Fort Stewart station. The number of meteorite signals received through both polarizations are plotted against their angle of arrival (Fig. 7). It was expected that a really overwhelming majority of the signals would appear from the meteorite altitude over the transmitter. Such has not been the case and at present theory is being investigated to explain the distribution obtained.

At Silver Lake an experiment is being run with the experimental preselector to determine the doppler component of the meteorite return. Most of the signals have a near zero doppler but insufficient data have been gathered to provide a statistical average.

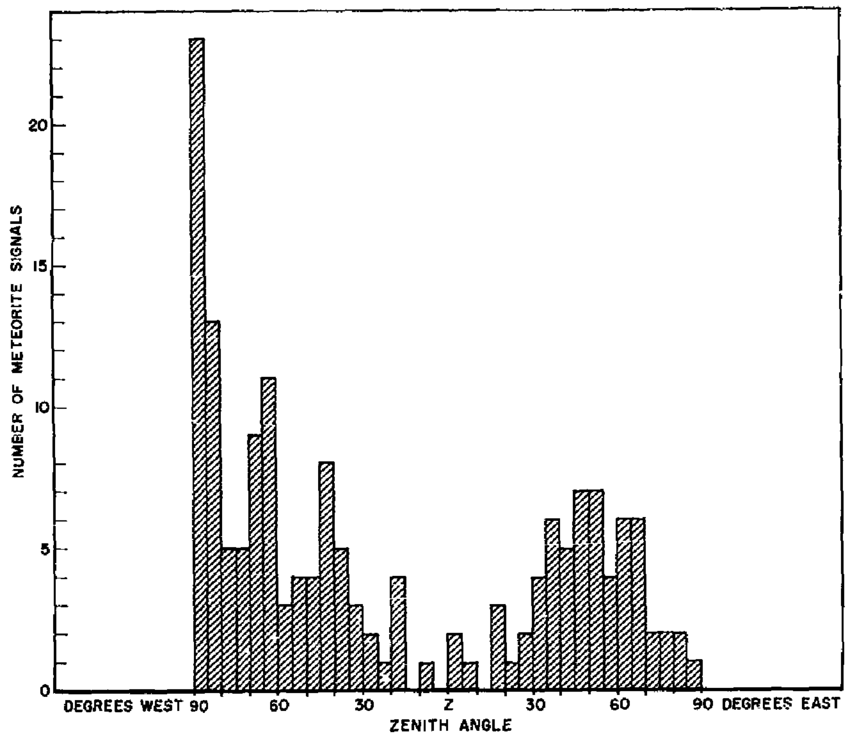

Fig. 7 - Number of meteorite signals vs angle of observation at Fort Stewart

DATA PROCESSING

Orbit Determination and Prediction

The NORC computer programs described in the previous report* have been used on a continuing basis to determine the satellite orbital parameters from the Space Surveillance observations and to make predictions as required, particularly for beam crossings and Spasur ephemerides.

Of the satellites not radiating on 108.00 Mc, the system is making, as of June 30, sufficient observations to provide orbital elements and beam crossing predictions on 1958 Alpha, 1959 Epsilon 2, 1959 Eta, 1959 Iota 1 and 2, 1960 Gamma 1, 1960 Epsilon 1 through 8, 1960 Zeta 1 and 2, and 1960 Eta 3. Predictions for other satellites are based upon elements provided by NASA (for those radiating on 108.00 Mc), by NWL (for Transit), and Space Track and Smithsonian for remaining.

*Technical Summary Report No. 3, pp. 14-16.

As an illustration of the prediction accuracy obtained from orbital elements based solely on Space Surveillance System observations, the satellite 1960 Epsilon 3 (Fragment of Sputnik IV) has been selected as being of current interest. Its orbital elements are as follows:

Epoch: 1960 May 19/000000Z

Inclination: 64.93 degrees

Anomalistic period: 94.268 minutes

Eccentricity: 0.027901

Perigee height: 181.2 statute miles

Apogee height: 419.1 statute miles

Argument of perigee: 86.02 degrees

Right ascension of the ascending node: 254.68 degrees

Mean anomaly: 5.97 degrees

These elements were computed from 18 observations made from May 19 through May 31, 1960. Beam-crossing predictions were calculated from these elements for the month of June, and the comparison of these with the June observations shows a maximum error in predicted time of 3 seconds for the first week, 11 seconds for the second week, 28 seconds for the third week, and 48 seconds for the fourth week.

At present the zenith angle data output of the system is provided to the nearest degree. Using such data several orbits have been calculated for the 1960 Eta 2 satellite. This satellite is radiating at 108.00 Mc so observations are obtained on both sides of the orbit and can be compared to the NASA Minitrack orbital elements (Table 2). This experiment shows the general accuracy of the orbital elements that will be obtained on nonradiating objects when the new alert systems and the high-powered transmitter are operational. It does not show the accuracy of orbital elements that will be obtained if advanced calibration techniques are funded and available when this new capability becomes operational. Such calibration techniques can improve the observational accuracy by at least a factor of five and probably by a factor of twenty.

Ephemeris for Fleet Operations

For the purpose of fleet training and the development of countermeasures against possible reconnaissance satellites, Spasur ephemerides* have continued to be released from the Space Surveillance Operations Center for Soviet satellites on a weekly basis. Ephemerides on 1958 Delta 2 (Sputnik III) were discontinued after the satellite was destroyed upon re-entry into the earth's atmosphere on April 6, 1960. Spasur ephemerides were resumed on May 15, 1960, after the launching of 1960 Epsilon 1 (Sputnik IV) and have been sent to the Fleet on a weekly basis for this satellite since that time.

*Technical Summary Report No. 3, pp. 22-25.

Table 2
Comparison of Orbital Elements for the Satellite 1960 Eta 2 Derived from a Minimum of Space Surveillance Data with NASA Minitrack Elements Used as a Reference

Elements* Derived from	Space Surveillance Elements Minus NASA Elements								
	Anomalistic Period† (min)	Inclination (deg)	Eccentricity	Argument of Perigee (deg)	Right Ascension of Ascending Node (deg)	Mean Anomaly at Epoch (deg)	Perigee Height (statute miles)	Apogee Height (statute miles)	Semi-Major Axis (statute miles)
NASA	101.64526	66.769	0.03070	232.720	105.525	234.811	382.1	657.4	4,483.1
Revolution									
1 & 10	-0.00026	0.023	-0.00050	-2.39	-0.025	1.70	2.2	-2.3	0.0
15 & 24	-0.00026	-0.013	-0.00100	-6.37	-0.055	5.95	6.2	-6.3	0.0
66 & 71	0.00074	-0.190	-0.00071	-3.12	-0.065	3.56	3.2	-3.2	0.0
85 & 94	-0.00016	-0.195	-0.00045	-4.46	0.015	0.55	2.0	-2.1	0.0
127 & 136	0.00044	-0.154	0.00008	0.51	0.055	-7.57	-0.3	0.3	0.0

*The elements for each set of revolutions have been adjusted to the epoch of the reference elements, namely 1960 June 22/062000Z.
†Period can be determined to ± 0.002 minutes using consecutive revolutions. To illustrate variation of computed values period was determined from data 14 revolutions apart.

Observations

During the first six months of 1960, reflected-signal observations were made on all the satellites listed in Table 3, with the exception of 1958 Beta 1 and 2, 1959 Theta 1 and 2, 1960 Beta 1 and 2, 1960 Gamma 3, and 1960 Eta 1 and 2. The satellites 1960 Beta 2 and 1960 Eta 2 have been radiating on 108.00 Mc since their launchings and therefore have been regularly received as they crossed the surveillance line. Satellite 1960 Eta 1 was not observed since it has not separated a sufficient distance from 1960 Eta 2 to be outside of the radiated signal received from 1960 Eta 2. The satellites 1959 Theta 1 and 2, 1960 Beta 1, and 1960 Gamma 3 are beyond the detection range of the present Space Surveillance System. 1958 Beta 1 and 2 have been observed previously, but these satellites, even at their closest approaches, are at the limit of the current detection range and so were not seen during the present reporting period.

The reflected-signal observations for the Space Surveillance System for January through June 1960 have been summarized in Table 4. There were 2080 observed satellite passes yielding 2827 individual station observations of 24 different satellites. A total of 747 passes were observed simultaneously by two receiving stations. More observations were made by the Eastern than by the Western Complex because of the greater amount of down time for the Western Complex due to extensive station modifications. A zenith angle was included in 77% of the observations. For the remaining 23%, the angle was omitted because of insufficient phase information, due primarily to the limited range capability of the present system.

On February 2, 1960, it was determined that a dark satellite, previously undetected, was in orbit. This satellite was designated 1960 UNK-1 (for first unknown satellite of 1960) until February 19, 1960, when sufficient evidence had been found from searching back through Space Surveillance recordings to establish its identity as the re-entry capsule of Discoverer V. Since then it has been called 1959 Epsilon 2 in accordance with astronomical practice. The existence of this satellite was first determined from a coincident observation in the Eastern Complex on January 31, 1960, and from three subsequent single-station observations (one on January 31 and two on February 1, 1960, all of the observations being on the same side of the orbit. Initial orbital elements were given in the first Spasur Bulletin on 1960 UNK-1 including an inclination of 80° and a period of 104.5 minutes. Subsequently, by laborious searching of Spasur analog recordings, it was found that the earliest observation for this satellite was made on 15 August 1959. Back computing from this observation and one for 1959 Epsilon 1 (Discoverer V) resulted in an effective orbital injection time for 1959 Epsilon 2 of 1959 Aug. 14/214429Z. At that time the nodal period of 1959 Epsilon 1 (inclination of 78.9 degrees) was 109.175 minutes. The difference in inclination and period could be accounted for by an additional velocity of about 1100 feet per second imparted to the re-entry capsule by the retro-rockets. On February 19, 1960, the final revised set of orbital elements computed on the NORC for 1959 Epsilon 2 and based only on Spasur observations from January 14 through February 7, 1960, were issued as follows:

Epoch: 1960 January 31/051509.0Z
Inclination: 78.88 degrees
Anomalistic period: 104.624 minutes
Eccentricity: 0.10594
Perigee height: 122.7 statute miles
Apogee height: 1091.1 statute miles
Argument of perigee: 85.93 degrees
Right ascension of the ascending node: 118.97 degrees
Mean anomaly: 316.10 degrees

The life of this satellite is expected to end September 1961.

Table 3
Satellites in Orbit During Period of January Through June 1960
(Orbital Elements as of June 1, 1960, Unless Otherwise Noted)

Satellite	Popular Name	Launch Date	Nodal Period (min)	Inclination (degrees)	Perigee Height (statute miles)	Apogee Height (statute miles)
1958 Alpha	Explorer I	1-31-58	108.07	33.20	217	1,207
1958 Beta 1	Third Stage Vanguard I	3-17-58	138.23	34.27	405	2,684
1958 Beta 2	Vanguard I	3-17-58	133.89	34.26	403	2,452
1958 Delta 2*	Sputnik III	5-15-58	91.47	65.30	108	322
1959 Alpha 1	Vanguard II	2-17-59	125.43	32.88	347	2,051
1959 Alpha 2	Third Stage Vanguard II	2-17-59	129.71	32.93	345	2,284
1959 Delta 1†	Explorer VI	8-07-59	743.2	46.95	145	25,730
1959 Delta 2	Final Stage Explorer VI	8-07-59	Similar to 1959 Delta 1			
1959 Epsilon 2	Capsule Discoverer V	8-13-59	101.25	78.94	121	893
1959 Eta	Vanguard III	9-18-59	129.97	33.36	321	2,321
1959 Theta 1‡	Lunik III	10-4-59	22,696.	80.5	25,077	297,000
1959 Theta 2‡	Final Stage Lunik III	10-4-59	Similar to 1959 Theta 1			
1959 Iota 1	Explorer VII	10-13-59	101.19	50.27	344	673
1959 Iota 2	Final Stage Explorer VII	10-13-59	101.08	50.30	343	668
1959 Lambda§	Discoverer VIII	11-20-59	95.70	80.65	116	567
1960 Beta 1	Third Stage Tiros I	4-01-60	99.11	48.41	429	467
1960 Beta 2	Tiros I	4-01-60	99.15	48.41	429	470
1960 Gamma 1	Second Stage Transit IB	4-13-60	94.87	51.28	198	442
1960 Gamma 2	Transit IB	4-13-60	95.68	51.28	232	458
1960 Gamma 3	Disc Transit IB	4-13-60	93.87	51.29	177	403
1960 Delta**	Discoverer XI	4-15-60	92.31	80.37	103	375
1960 Epsilon 1	Sputnik IV	5-15-60	94.26	65.04	179	420
1960 Epsilon 2	Final Stage Sputnik IV	5-15-60	91.23	64.90	195	220
1960 Epsilon 3	Fragment Sputnik IV	5-15-60	94.28	65.08	177	423
1960 Epsilon 4 through 8	Other Fragments Sputnik IV	5-15-60	Similar to 1960 Epsilon 3			
1960 Zeta 1	Midas II	5-24-60	94.43	33.00	300	321
1960 Zeta 2	Cover Midas II	5-24-60	94.40	33.00	300	317
1960 Eta 1††	Transit IIA	6-22-60	101.66	66.77	389	651
1960 Eta 2††	Solar Radiation Transit IIA	6-22-60	101.66	66.77	389	651
1960 Eta 3††	Second Stage Transit IIA	6-22-60	101.37	66.77	383	639

*Elements as of March 1, 1960; life ended April 6, 1960.
†Approximate values obtained by extrapolating previous elements.
‡Values previously listed for December 1, 1959: current values unknown.
§Elements as of February 1, 1960; life ended March 8, 1960.
**Elements as of April 15, 1960; life ended April 26, 1960.
††Elements as of June 22, 1960.

Table 4
Summary of Reflected-Signal Observations for the Space-Surveillance System for January Through June 1960

Satellite	Western Complex		Eastern Complex		Heights (statute miles)
	Two-Station Coincidence	Single-Station Observations	Two-Station Coincidence	Single-Station Observations	
1958 Alpha (Explorer I)	23	35	29	49	220-800
1958 Delta 2 (Sputnik III)	44	87	57	75	85-450
1959 Alpha 1 (Vanguard II)	5	10	14	21	350-705
1959 Alpha 2 (Third Stage Vanguard II)	2	11	3	27	350-855
1959 Delta (Explorer VI)	-	-	2	-	195-215
1959 Epsilon 2 (Capsule Discoverer V)	12	49	19	44	125-485
1959 Eta (Vanguard III)	7	29	4	29	320-650
1959 Iota 1 (Explorer VII)	35	66	44	99	345-680
1959 Iota 2 (Final Stage Explorer VII)	19	57	23	75	340-680
1959 Lambda (Discoverer VIII)	21	40	27	35	60-720
1960 Gamma 1 (Second Stage Transit IB)	24	59	33	60	200-485
1960 Gamma 2 (Transit IB)	12	37	21	50	230-520
1960 Delta (Discoverer XI)	4	8	-	6	100-300
1960 Epsilon 1 (Sputnik IV)	26	29	34	34	185-260
1960 Epsilon 2 (Final Stage Sputnik IV)	18	17	19	8	185-230
1960 Epsilon 3 (Fragment Sputnik IV)	23	14	28	24	185-260
1960 Epsilon 4 (Fragment Sputnik IV)	1	2	5	10	185-260
1960 Epsilon 5 (Fragment Sputnik IV)	1	3	4	8	185-260
1960 Epsilon 6 (Fragment Sputnik IV)	3	10	6	18	185-260
1960 Epsilon 7 (Fragment Sputnik IV)	2	6	3	12	185-260
1960 Epsilon 8 (Fragment Sputnik IV)	1	4	3	12	185-260
1960 Zeta 1 (Midas II)	12	7	27	27	300-315
1960 Zeta 2 (Cover Midas II)	16	8	30	19	300-315
1960 Eta 3 (Second Stage Transit IIA)	-	2	1	1	520-650
TOTALS	311	590	436	743	

In the case of the satellite 1959 Lambda (Discoverer VIII), an exceptional opportunity occurred for observing it with the Space Surveillance System. On March 8, 1960 at 011251.3Z, the Fort Stewart receiving station apparently observed it during the terminal phase of its last revolution. The signal from the final pass of this satellite at a height of about 60 statute miles is shown in Fig. 8 and, for comparison, a typical signal for a normal pass at a height of 150 statute miles is given in Fig. 9. It is of special interest to note the change in the shape of the signal-level response. In Fig. 8, Discoverer VIII can be seen as several pieces providing a jagged response stretched out over 2.5 seconds of time compared to the normal response of about 0.3 second. Since a satellite at this height would be subjected to great heating due to high atmospheric drag, the burning object, reported by various observers to have passed southward across the eastern part of the United States shortly after 8:00 p.m. EST on March 7, 1960, was undoubtedly Discoverer VIII.

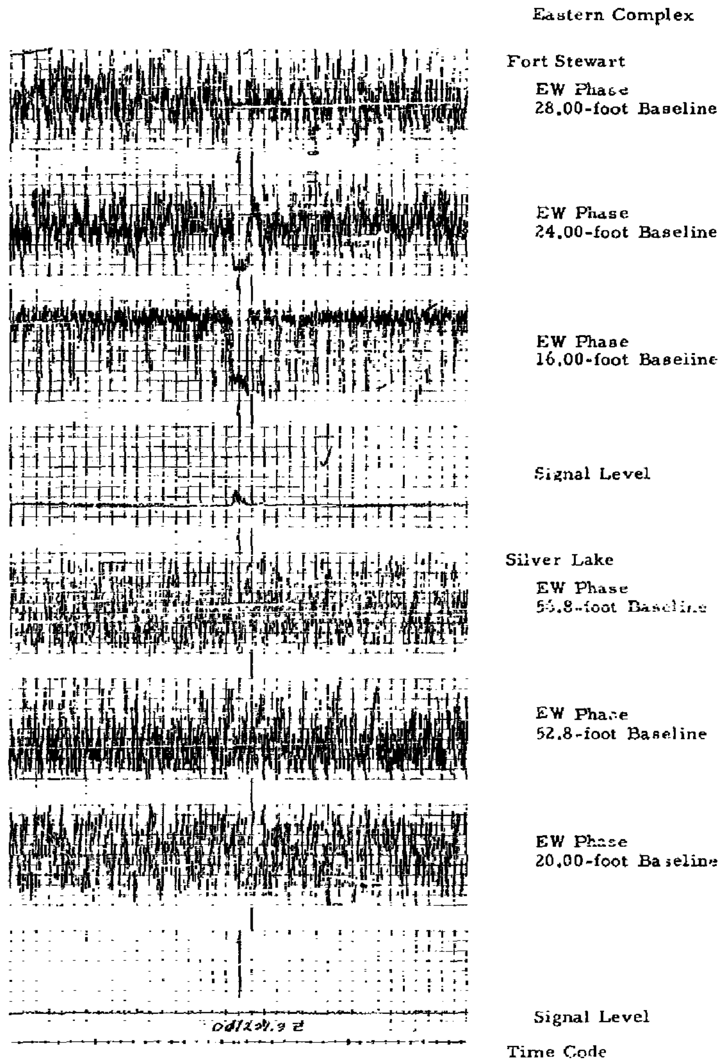

Fig. 8 - Eastern Complex record of Discoverer VIII pass at 011251.3Z on March 8 at a height of 60 statute miles. (Signal received during terminal phase of atmospheric re-entry.)

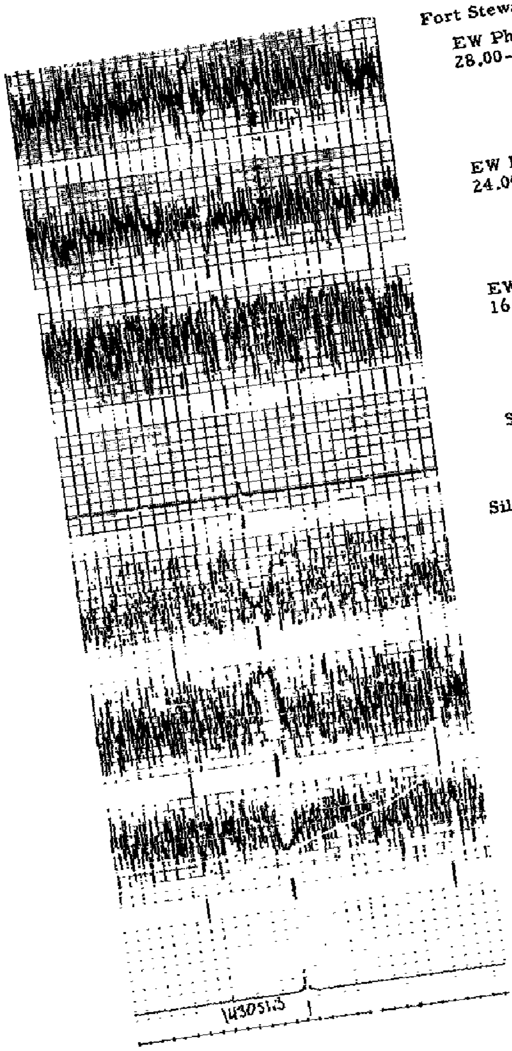

Fig. 9 - Eastern Complex record of Discoverer VIII pass at 14051.3Z on March 7 at a height of 150 statute miles. (Typical signal received on a normal pass.)

On May 15, 1960, the Soviet Union launched Sputnik IV (1960 Epsilon 1), which was described as a 4.5-metric-ton experimental space ship, into an orbit having initially an inclination of 65.0 degrees, a perigee height of 189 statute miles, apogee height of 225 statute miles, and a nodal period of 91.25 minutes. The last stage rocket (1960 Epsilon 2) used in launching the satellite went into an orbit similar to that of 1960 Epsilon 1. Both objects were regularly observed by the Space Surveillance System. A plot showing the difference in times of passage of these satellites across the surveillance line is given in Fig. 10 from launch to the re-entry attempt.

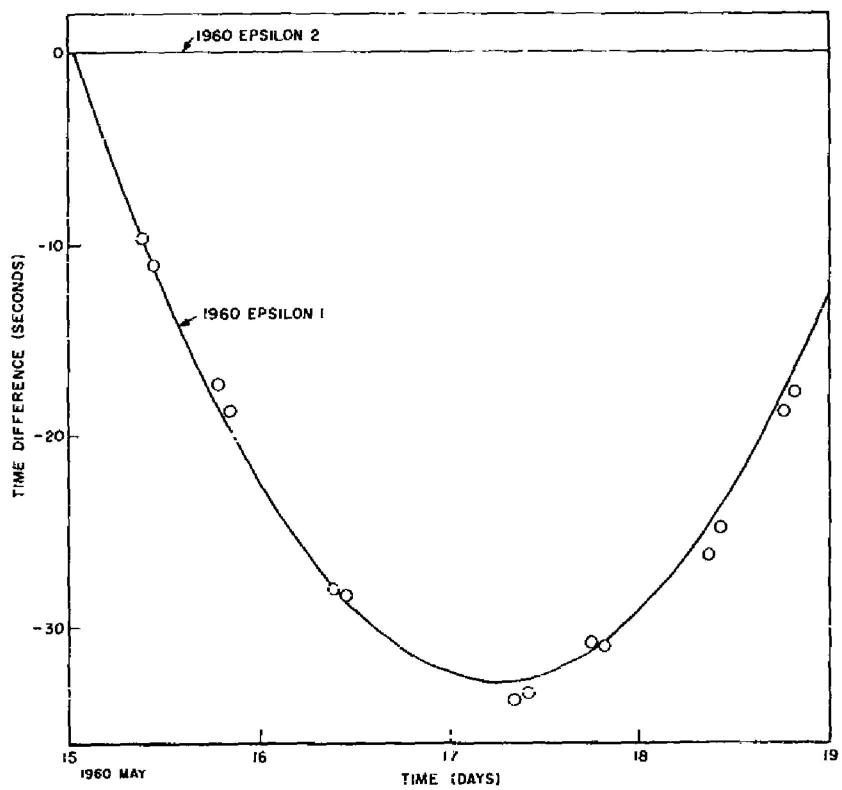

Fig. 10 - Time delay in observing 1960 Epsilon 1 after passage of 1960 Epsilon 2 through the Space Surveillance beam

On May 18, 1960, at about 2340Z, an attempt was made to change the orbit of Sputnik IV so that it would re-enter the earth's atmosphere and possibly be recovered. Due to malfunction, the increment of velocity from the retro-rocket was added (instead of subtracted) to give 1960 Epsilon 1 an orbit having a period of 94.25 minutes, inclination of 65.04 degrees, perigee height of 179 statute miles, and apogee height of 420 statute miles. Six additional objects of various sizes observed by the Space Surveillance System probably separated from Sputnik IV at this time. These fragments have been designated as 1960 Epsilon 3 through 8. Epsilon 3 does not appear to be tumbling and its period has the least rate of decay indicating a comparatively high mass-aspect ratio. The orbit of Epsilon 3 has an inclination of 65.08 degrees, perigee height of 177 statute miles, apogee height of 423 statute miles, and period of 94.28 minutes. The other five objects are in slightly larger orbits and thus initially trailed Epsilon 1 and 3 as they crossed the Space Surveillance System beam. Due to variation in the drag experienced by the various bodies, they have begun changing order from that which they assumed shortly after the change in orbit. The AGC signals recorded for 1960 Epsilon 3 and Epsilon 6 were of the smooth hump type normally associated with a nontumbling object going through the beam, while the signals for the other bodies had a ragged appearance which would indicate tumbling objects (Fig. 11). A plot showing the time relationships of the satellites 1960 Epsilon 4 through 8 with respect to 1960 Epsilon 3 in crossing the beam is given in Fig. 12 for the first few weeks after their injections into separate orbits.

SYSTEM EVALUATION

Expected Detection Range

Figure 13 shows range contours of expected triangulation detection for various probabilities of detection of objects of one-square-meter average cross section with the system using the new type preselectors and the 500-kw transmitters operating into a circularly polarized antenna. These curves were obtained in the following manner. The rms average effective cross-sectional area of the objects being detected is assumed to be one square meter with a log-normal variation. The probability of detection at the calculated maximum range using the radar equation is assumed to be 0.5 for a single polarization used on the transmitter and a single polarization used on the receiver. Use of circular polarization is assumed to be equal to requiring detection from one out of two receiving sites resulting in a detection probability of 0.75. The increase in capability at the center of the diagram results from the possibility of reception at four stations. At intermediate positions the possibility of reception at three stations exists while at the edges where only two stations can receive, the range capability is decreased.

The use of log-normal distribution is based on the experimental cross-sectional areas computed from data on two satellites. A plot of effective area versus number of observations is shown in Fig. 14 for 1958 Beta 2, the 6-inch Vanguard I sphere and for 1959 Epsilon 2, the re-entry body of Discoverer V. These data were taken with single polarization on transmission and reception. Since the observed objects have a regular shape, it was expected that the observed data would resemble a cosine-squared curve, but it did not. The log-normal distribution differs but little from the Rayleigh distribution. The two are compared in Fig. 15.

Polarization Effects

Since Fort Stewart is equipped with two receiver polarizations it has been used to determine the added effectiveness of using two orthogonal polarizations. Two tests were run. In one the collinear and broadside arrays were both 400 feet long. In the other the collinear array was 1600 feet long – the broadside array was 400 feet long.

During the period February 7, 1960, through April 18, 1960, the Fort Stewart collinear receiver used the 1600-foot antenna. A total of 215 satellite passes were detected; 198 were seen on collinear, 140 were seen on broadside. Many passes were recorded on both systems. The larger number seen on the collinear system could be explained by the four times greater receiver gain. To verify this assumption, a comparison of the two polarizations using antennas of equal length was made.

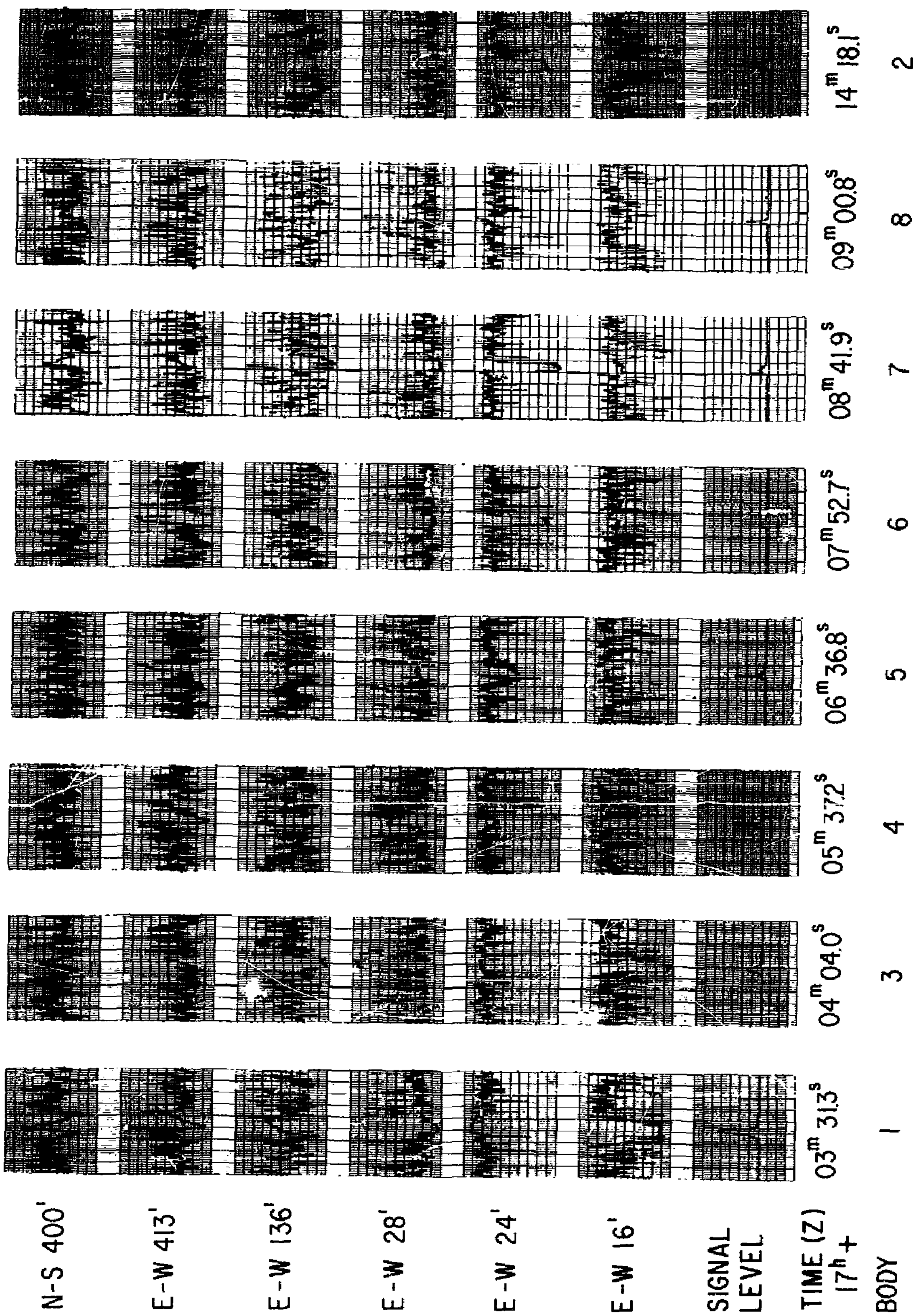

Fig. 11 - Observations of 1960 Epsilon 1-8 (Sputnik IV) at Fort Stewart on May 20, 1960

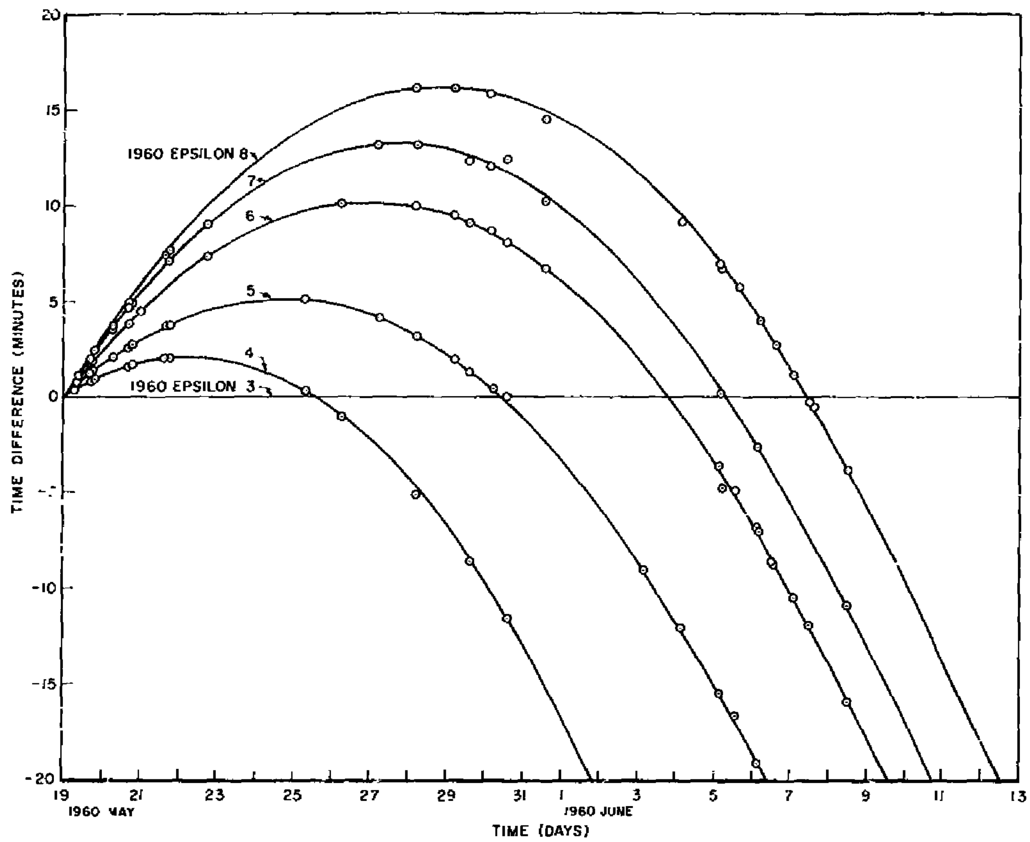

Fig. 12 - Time difference in observation of Epsilon fragments with respect to the passage of 1960 Epsilon 3 through the Space Surveillance Beam

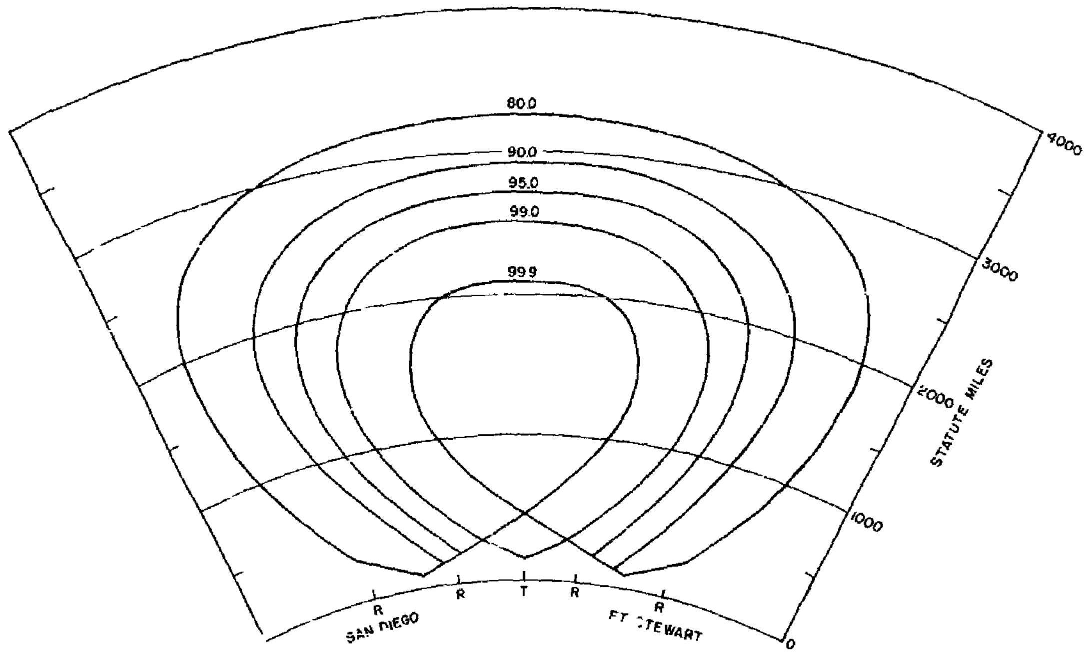

Fig. 13 - Observational probability vs coverage for funded developments ($\sigma = 1M^2$)

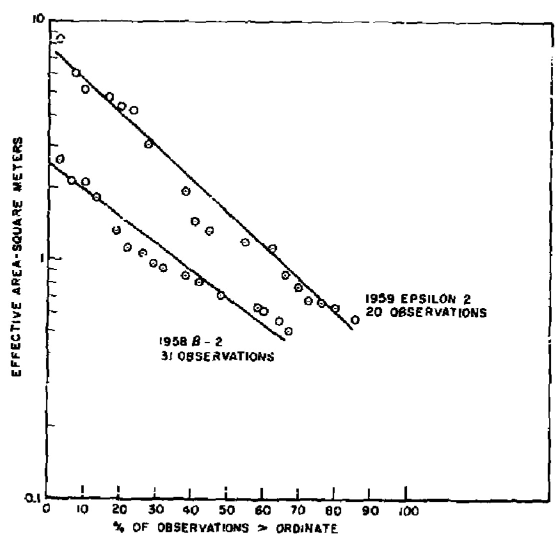

Fig. 14 - Distribution of radar cross section as observed by the Space Surveillance System

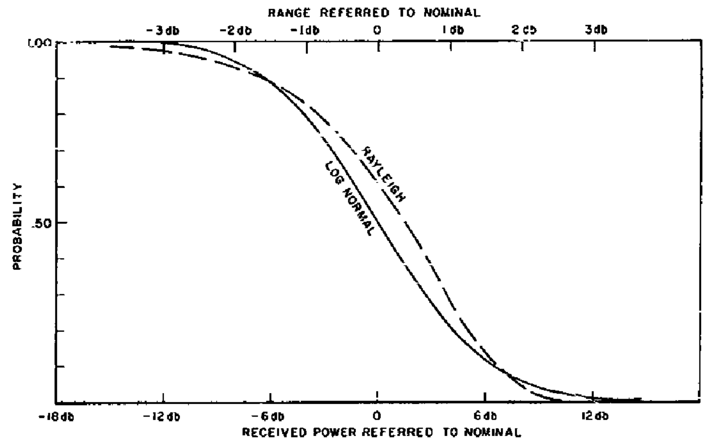

Fig. 15 - Probability that received power or range will exceed a chosen value

During the period from April 19, 1960, through June 2, 1960, polarizations were compared using 400-foot antennas. A total of 163 satellite passes were logged with approximately equal numbers seen on the two receiving systems; 123 on the broadside and 120 on the collinear. Thus, of the passes observed about 25% are missed when using either polarization alone.

* * *

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