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BRL

MEMORANDUM REPORT NO. 1287
JULY 1960

THIRD TECHNICAL SUMMARY REPORT
PERIOD 1 JULY 1959 - 1 JULY 1960 (U)

ARPA Satellite Fence Series

L. G. deBey

Report No. 16 in the Series

BALLISTIC RESEARCH LABORATORIES

ABERDEEN PROVING GROUND, MARYLAND

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Report No. 16 in the Series

ABERDEEN PROVING GROUND, MARYLAND

B A L L I S T I C   R E S E A R C H   L A B O R A T O R I E S

MEMORANDUM REPORT NO. 1287

LGdeBey/sec
Aberdeen Proving Ground, Md.
July 1960

THIRD TECHNICAL SUMMARY REPORT
PERIOD 1 JULY 1959 - 1 JULY 1960

ABSTRACT

A summary of the significant progress and activity is presented on the development of DOPLOC, a dark satellite tracking system, over the period from 1 July 1959 to 1 July 1960. A resumé is given of the program administration and project assignment chronology. A description of the Scanning DOPLOC System, including cost estimates for various combinations of antenna types is presented. An analysis of the proposals submitted by eleven contractors and the basis for the choice of two acceptable proposals is given. The activity in the development of mathematical processes for determining the orbital parameters from DOPLOC data and its successful application to measured data is discussed. It is noteworthy that twenty completely independent, single pass, satellite orbital solutions have been obtained. Studies supporting the development of the Scanning DOPLOC System are discussed briefly. Experimental use of the field station facilities for the tracking of non-radiating satellites is described and sample data are shown to illustrate the system performance. A compilation of the satellites tracked by reflection summarizes pertinent tracking data including signal duration, signal strength and effective reflection cross section. A discussion is presented of observed

reflection cross section variations. Evidence of ion trails of several minutes duration after the passage of 1958 Delta (Sputnik III) is noted. Tracking efforts on radiating satellites are summarized as used in connection with the design and development of DOPLOC system components and data processing.

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SECTION I

INTRODUCTION

A. Program Administration

At a conference held at Advanced Research Projects Agency (ARPA), Washington, D. C., on 19 August 1959, the Ballistic Research Laboratories (BRL) were requested to submit an outline of a program for reorienting ARPA Order 8-58 (DOPLOC Passive Satellite Detection Fence) toward the development of a second generation satellite tracking system with particular emphasis on the application of such a system to the problem of anti-satellite defense. Under the proposed revised program, BRL was to be relieved of all routine operational responsibility for the interim fence relative to satellite tracking for the purpose of furnishing data to the using agencies. The existing field facilities were to be retained by BRL as operational research tools. At the above-mentioned conference, ARPA approved immediate implementation of the work plan outlined in the Second Semi-Annual Technical Summary Report (BRL Memorandum Report No. 1220) including the installation of a 4 x 40 degree scanning beam antenna system.

By November 1959, specifications for the scanning DOPLOC system were prepared and submitted to contractors. Firm bids were received and evaluated and a final choice of systems was recommended to ARPA for implementation. Initial operation of the system was scheduled for September 1960 based on letting of contracts by January 1960.

Although not formally changing the original ARPA Order 8-58, in November 1959 ARPA advised BRL that responsibility for the dark satellite fence was being assigned to the Navy and that BRL would be given responsibility for the conduct of R&D leading toward second generation dark satellite tracking systems. At ARPA's request, BRL submitted a proposed program of

R&D,[1] including cost estimates for the implementation of a scaled down version of the scanning DOPLOC system to confirm experimentally the feasibility of the techniques previously proposed.

In January 1960, ARPA advised BRL that the DOPLOC satellite tracking system was not required to meet ARPA mission responsibilities and that the DOPLOC program pertaining to the dark fence and anti-satellite defense would be dropped entirely. BRL was requested to submit another proposal for a program that would make use of BRL talents in support of ARPA programs. As a result of several conferences called by ARPA, pertaining to problem areas in the satellite tracking, anti-satellite defense and navigational satellite fields, BRL submitted a program[2] of research and development for a precision tracking system to act as a standard of comparison for all types of tracking instrumentation systems. In view of the many types of satellite and missile tracking systems that were being developed under ARPA sponsorship, at costs large compared to the cost of the precision standard of comparison proposed the need for an adequate method for evaluating the performance characteristics of these systems became clear. Neither ARPA nor any other DOD or civilian agency was sponsoring the development of a tracking instrumentation standard. The proposed program therefore would have filled a serious gap in the tracking research and development program of the United States.

In March 1960, ARPA again informally advised BRL that they might be given the go ahead on a research and development program on a scaled down DOPLOC system.

ARPA Order 8-60, ammendment No. 5, dated 13 April 1960 informed the Director, BRL that the DOPLOC system would not meet the immediate objectives of the satellite detection and tracking program assigned to ARPA and that further research on the DOPLOC system would not be required. Ammendment No. 5

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[1] BRL Letter to ARPA Attn: Commander Holmes, dated 19 Nov 59, Subject: Second Generation DOPLOC R&D Program

[2] "Proposal for Precision Tracking Instrumentation System" submitted to ARPA by BRL 10 Mar 60.

also requested that BRL submit to ARPA a plan for termination of the project. Such a plan was forwarded to ARPA by letter dated 29 April 1960, Subject: "Schedule for Closing out ARPA Order 8-58 in Accordance With ARPA Order 8-60, Ammendment No. 5, dated 13 April 1960." By letter dated 17 June 1960 ARPA Order 8-60, Ammendment No. 6 was issued approving the above plan.

SECTION II

THE DOPLOC SYSTEM PROPOSAL

A. Summary of Previous Semi-Annual Report

The second semi-annual technical summary report, BRL Memorandum Report No. 1220 for the period 1 January 1959 to 30 June 1959, was submitted to ARPA early in August. This report recorded the status of, and results obtained with, the interim fence; reported significant progress toward obtaining a solution for orbit parameters from Doppler data only, and proposed an ultimate Doppler tracking system for nonradiating satellites. Based on the concept of the requirement for a system that would detect, track, and provide data for orbital computation and cataloging of satellites over the United States, the proposed system was the result of an extensive engineering study and provided complete volume detection coverage of the space above the United States to an altitude of approximately 2000 miles, and employed a minimum number of relatively low cost installations. It was proposed to obtain the volume detection coverage by widely spaced station pairs consisting of receiving and transmitting stations, employing scanned, coplanar, fan-shaped antennas. In order to test the feasibility of the proposed system, and to accomplish any required re-engineering on a low cost basis, this report proposed the installation of a one or two base line scale model of the ultimate system concept. In addition, a twelve month work program was outlined. This program was devoted to theoretical studies and experimental investigations to confirm or negate the practicability of the proposed ultimate system. Special attention was to be given to the following areas:

a. Optimization of fan beam antenna designs.

b. High power transmitter studies.

c. Narrow-band frequency measuring systems.

d. Data handling techniques.

e. Orbit computations.

B. Scanning DOPLOC Proposal

The original specifications for a dark satellite fence as prepared by an ARPA Ad Hoc Committee, called for a system capable of detection, tracking, and orbit computation, within one orbital period, for all objects having effective reflection cross sections greater than 0.1 square meters at all altitudes between 100 and 2000 statute miles with a reasonably high multiple target handling capability. Based on these specifications, BRL outlined the R&D program that resulted in the submission to ARPA, in August 1959, of the scanning DOPLOC concept; a system which would fully meet the ARPA detection and tracking specifications, would permit computation of orbits of detected objects within a few minutes (or seconds, depending upon the type of computer used) after the satellite pass and would be capable of handling 20 to 100 satellites simultaneously. The theory, leading step by step to a logical choice of final system design parameters, was reviewed and it was shown that the scanning DOPLOC system could be implemented with existing state-of-the-art techniques.

By letter dated 19 November 1959, subject: "Second Generation DOPLOC R&D Program," BRL submitted to ARPA a proposal covering a program of research and development work designed to validate the conclusions stated in BRL Memorandum Report No. 1220, July 1959, and to test the performance of the proposed scanning beam DOPLOC system through the installation and operation of a scaled down model.

The scanning DOPLOC system as proposed in BRL Memorandum Report No. 1220 is based on the use of the bi-static, continuous wave reflection principle and utilizes for the basic detection and tracking unit a high power radio transmitter and a high gain, narrow-band radio receiver, each coupled to high gain antennas driven through synchronizing equipment. Thin fan shaped, coplanar beams are scanned about the axis formed by a straight line between the stations to cover a space volume consisting of a half cylinder whose length is equal to the distance between the stations and a radius of 2000 miles. Computed parameters, based on the radar equation and verified by experience with the interim fence equipment, indicate that this system would detect and track objects having one tenth square meter effective cross-sectional area over an altitude range of approximately 150 to 1500 and possible 2000 miles when a two million watt output power is used at the transmitting antenna. Engineering considerations indicate that such a system is entirely feasible employing existing state-of-the-art equipment, and when compared to the cost of monostatic pulse radar equipment required to provide the same coverage with less system data accuracy, is much less expensive in terms of both equipment installation and operation costs. Since the receiving and transmitting stations can be placed 1000 miles apart, only a few pairs of stations strategically located could provide complete coverage for either the complete space volume above the United States or if located in a different pattern, the periphery of North America.

Since one of the goals of the proposed reoriented DOPLOC program is the demonstration of the technical feasibility of the concept of determining orbit parameters by passive continuous wave Doppler techniques, it is proposed to instrument two 700-mile base lines with scale models of the ultimate equipment. One of the base lines would be chosen to utilize the Aberdeen Proving Ground station as the principle research receiving station, using present equipment augmented with equipment from White Sands Missile Range receiving station. A transmitting station with two 100 kw transmitters and scanning antennas would be located at Camp Blanding near Jacksonville, Florida. With one antenna beamed toward Aberdeen, Maryland and one toward Forrest City, Arkansas, two base lines at approximately right angles to each other would provide geometrically strong data for orbit computation and would permit utilizing most effectively the technical skill of the BRL personnel without extensive travel and lost time in setting up experiments at remote field stations. A second major advantage to be derived from the installation of the scaled down system results from its relatively low cost and the short time required to arrive at an operational status.

Although the original plan recommended placing three DOPLOC stations in a two base line configuration in the southeastern section of the United States, to permit more rapid and efficient conduct of a second generation satellite tracking R&D program, the same system could be installed in the south central United States to completely fill the gap that exists in the interim dark satellite fence between White Sands Missile Range and Forrest City, Arkansas. This installation would permit the simultaneous conduct of research and development leading toward second generation systems, greater ranges on smaller targets and faster time response with application for anti-satellite defense as well.

The scaled down system would employ 100 kilowatt radio transmitters, 4 x 40 degree scanning beam antennas and base lines of approximately 700 miles. Low altitude coverage would extend down to approximately 125 miles above the surface of the earth while the high altitude limit would be about 650 miles. Such a system would provide adequate detection capability to thoroughly explore the computational techniques and would permit the test and development of any improved techniques found necessary to adapt the DOPLOC concept to the scanning beam methods.

The scanning DOPLOC system offers significant improvement over fixed beam systems in detection capability. Instead of relying on having all factors affecting detection suitable during the short period of time that a satellite falls within a severely restricted angular segment of detection volume, the DOPLOC system continuously scans a 160° sector of space volume and makes repeated observations of every object in the scanned volume. With the a priori knowledge that satellites must follow closely the classical laws of orbital motion, the multiplicity of DOPLOC observations on each satellite pass greatly simplifies the problem of distinguishing between satellites and other sources of reflected signals such as meteor trails, aircraft, ionospheric clouds, etc. In addition, it is this multiplicity of observations during a single pass which gives the DOPLOC system the capability of determining orbital parameters without waiting several hours for the satellite to complete one or more revolutions along its orbital path.

The cost of a DOPLOC type of system is quite modest, due in large part to its simplicity and the techniques used to conserve illuminating transmitter power. During the past several months, at ARPA request, a number of estimates have been submitted covering the costs of a variety of DOPLOC system configurations, including supporting services for a period of 18 months. Part of the cost variation is related to the extent of the proposed installation and the remainder is due to the particular choice of alternate techniques available to achieve the desired results. Seven programs are briefly summarized in Table I. The lower cost programs provide a scaled down version of the full scale system, yielding detection capabilities to altitudes of about 650 miles. The systems employing mechanically rotated scanning beams are less costly than those employing electronic scanning techniques, but are less desirable from the standpoint of an operational system and may have less potential for successful scaling to the full scale system. The cost figures presented in Table I for Programs I through IV are based on the results of an extensive analysis of the engineering proposals submitted by twelve teams of this Country's leading contractors in the field of high powered transmitters and high gain antenna systems. The costs of Programs V through VII providing for full scale system, are estimates based on discussions with the same contractor groups mentioned above.

C. Anti-Satellite Defense Application

The application of DOPLOC to the anti-satellite defense role offers advantages of large volume coverage, high inherent detection probability and low false alarm rate, good multiple target discrimination, short data handling time, and accurate orbit solution with minimum observational data. It appears that considerable advantage could be gained if the receiver station could operate near or coincident with the transmitter for orbit determination when only the approaching portion is measured as in a satellite defense situation. Advantages would be gained from utilizing additional data, such as range measurements by a pulse or cw modulation phase measurement technique and angle measurements by the phase-lock interferometer technique developed at BRL.

TABLE I

PROGRAM	DESCRIPTION	COST	COST OVER* 3.299
I	One base line, Rotary Antennas - 100 kw each - 1 CMF	$ 3,298,000	- 0 -
II	Two base lines, Rotary Antennas - 50 kw each - 1 CMF	3,217,000	- 0 -
III	Two base lines, Rotary Antennas - 100 kw each - 2 CMF	4,887,716	$ 1,566,716
IV	Two base lines, 1 Rotary, 1 Fixed - 100 kw each - 2 CMF	5,639,826	2,340,826
V	One base line, Fixed Antenna, 2500 kw - partial US coverage	10,000,000	6,701,000
VI	Two base lines, Fixed Antenna, 2500 kw - better coverage	20,000,000	16,701,000
VII	Four base lines, Fixed Antenna, 2500 kw - full US coverage	40,000,000	36,701,000

Note 1 - All programs include 6 months of operational support following installation.

Note 2 - Programs 1 through IV are scaled down systems - 600 mile range on 1 sq. meter.

Note 3 - Programs V through VII are full scale systems.

Note 4 - CMF - Circulating Memory Filter; required for frequency measurements.

* $3,299,000 of previously allocated ARPA funds available at BRL for applications to these programs.

D. Summary

The Ballistic Research Laboratories are firmly convinced, based on the combined judgments of its technical personnel, who performed the feasibility studies, and leading electronic contractors, that a scaled down scanning DOPLOC system can be put into operation in nine months after equipment contracts are let, which will provide the DOD with a first pass capability of satellite detecting, tracking, and establishing orbit parameters. This system will assure the DOD of early warning of any new satellites which may be launched and which are both large enough and low enough to have useful reconnaissance capabilities. The most desirable scaled down system (Program IV) can be installed and operated through July 1961 for a total cost of $5,639,826. The full scale systems, providing the DOD with a capability of determining the orbits of any reconnaissance satellites that might, and probably will, be launched by an enemy up to altitudes of 2000 miles, can be installed in 12 months and operated for 6 months for a cost of $10,000,000 to $40,000,000 depending upon the extent of coverage desired. These costs are modest compared to the costs of exotic radars and other systems having the same capabilities. As a by-product the DOPLOC system will also provide precision tracking data on satellites launched for either military or civilian scientific purposes to ranges greatly in excess of 2000 miles.

SECTION III

IMPLEMENTATION OF SCANNING DOPLOC SYSTEM

A. Requests for Proposals from Industry

Following the preparation of a performance specification[1], a briefing was held by BRL and the local procurement office on 16 September 1959 to acquaint prospective bidders with the requirements of the proposed scaled down DOPLOC system and to solicit bids covering the furnishing and installation of one and two base line systems as described in the abstract of the proposal to ARPA. The basic bid covered the supplying of the Camp Blanding-Aberdeen base line, less the receiving equipment. This included a prefabricated instrument shelter at Camp Blanding, a transmitter, two scanning beam antennas, and the antenna synchronizing equipment. As an alternate bid, proposals were requested covering the basic bid, and in addition, a second transmitter housed in the common instrument shelter and two scanning antennas with synchronizing equipment for the Camp Blanding-Forrest City base line. Approximately 25 contractor facilities were represented at the briefing. From the twenty-five facilities attending the briefing, twelve proposals, some of which were joint efforts, were received. Three principal types of antenna systems were proposed. Prices ranged from less than a million dollars per base line to approximately five million per base line. In general the lowest priced systems used rotating fixed linear arrays. Other systems were based on reflecting type, horn fed antennas scanned by organ pipe scanners, or modified Wullenweber type antennas fed with organ pipe scanners or electronic scanning systems. Technical evaluations have been made and BRL is ready to release contract information to the Contracting Officer.

[1] "Supplemental Information to Oral Briefing Pertaining to Requirements for Scanning Antenna Systems" (Confidential), BRL Specification No. 16-9-59, dated 16 September 1959.

B. Summary of Bids

In response to the briefing held on 16 September 1959, at the Ballistic Research Laboratories, twelve bid proposals were received between 26 October and 1 December 1959. A list of the companies who attended the briefing and/or expressed interest in bidding is given in Appendix I. The proposals included the transmitter with building and antennas with synchronizing equipment for one or two base lines at 150 mc and 216 mc. One bid was received for a study of the scanning antenna problem only.

Six of the proposals contained antenna designs based on scanning the fan beam by rotating the antenna array structure. Seven of the proposals contained antenna designs based on stationary antenna structures with the beam scanned by electrical or electronic methods (one company bid on both types). Table II contains a list of the proposals in order of cost for a two base line installation.

C. Analysis of Proposals

Proposals were requested for two frequencies, 150 mc and 216 mc since, at that time, the FCC had indicated that either of these frequencies might be assigned. It was also considered of value to know the relative cost of the DOPLOC system at what might be considered the lowest and highest practical operation frequencies. At the lower frequency (150 mc) the tracking range is greatest but the antenna size is larger. At the higher frequency (216 mc) the antenna size is reduced by a factor of 1.5 but the tracking range is reduced and twice the transmitter power is required compared with that required at 150 mc to maintain a 2000 mile altitude tracking capability. Fortunately the FCC has authorized the use of 150.79 mc for DOPLOC dark satellite tracking, thus permitting operation at the most desirable frequency. Therefore, in subsequent discussions only the systems proposals for 150 mc operation will be considered. It is of interest to note that the 216 mc systems antenna and 100 kw transmitter cost estimates were only between 5 and 8 percent lower than the 150 mc systems. Considering that

TABLE II

Proposals Include DOPLOC Scanning Antennas, Transmitter, With Building, and Synchonizing Equipment.

Listed in order of increasing cost for two base lines at 150 mc.

Prime Company	150 mc		216 mc			
	1 Base Line	2 Base Line	1 Base Line	2 Base Line	Antenna Type	Price
All Products Company	$ 787,552	$1,417,634	$ ----	$ ----	Rotating	Fixed
Aero Geo Astro	820,695	1,576,716	767,692	1,473,795	Fixed	Fixed
Adams-Russell	1,071,667	1,887,565	1,000,961	1,745,757	Fixed	CPFF
Radiation, Inc.	----	1,728,000	----	----	Rotating	CPFF
Radiation, Inc.	1,314,740	2,100,000	1,131,959	1,693,171	Rotating	Fixed
General Electric	1,250,621	----	----	----	Rotating	CPFF
Aircraft Armaments	1,529,817	2,357,778	----	----	Rotating	CPFF
General Electric	1,606,189	2,785,391	1,414,744	2,471,690	Rotating	Fixed
Aircraft Armaments	1,780,000	2,677,000	1,707,000	2,538,000	Rotating	Fixed
Melpar, Inc.	1,850,000	3,055,000	----	----	Fixed	CPFF
Continental Electronics	1,898,384	----	----	----	Fixed	CPFF
Sylvania Electronic	2,193,633	2,998,949	2,035,728	3,304,128	Fixed	CPFF
Airborne Instruments	2,372,469	4,056,637	----	----		CPFF
Radio Corp. of Amer.	4,011,946	6,564,033	3,761,321	6,137,318	Rotating	CPFF
Radio Corp. of Amer.	5,817,709	9,211,558	5,451,228	8,528,754	Fixed	CPFF
Ramo-Wooldridge	A n t e n n a		S t u d y	O n l y		

NOTE: CPFF = Cost Plus Fixed Fee

increased transmitter power would be required at 216 mc to obtain the desired range, the higher frequency system would actually be more expensive to install.

Very detailed reviews and analyses have been made of the technical and economic aspects of all of the proposals received. In several cases oral technical presentations have been heard from some of the companies for additional information or clarification of material in their proposals. Several of the companies did considerable work on the antenna design problems after submitting their proposals and provided valuable basic information on fan beam forming and scanning. Some of the analyses of phased array beam forming with a circular array have constituted quite basic and original work not previously available.

During the study and analysis of the proposals, a very important disclosure was made regarding what now appears to be a theoretical limitation on the use of a circular array or Wullenweber type antenna for the proposed DOPLOC system where the wide dimension of the fan beam must be tilted away from the plane of the array. This produced a provocative and controversial situation where those companies who had proposed circular arrays were certain they would work based on extrapolations of their limited preliminary design studies of the 4 x 40 degree system. A further study, made locally and by several of the companies, of the problem for the 1.4 x 40 degree antenna for the "ultimate" system, disclosed that the pattern in the plane perpendicular to the circular array breaks up at low elevation angles and becomes too narrow. The beam cross-section also degenerates from an ellipse into a "bow tie" shape. The effect of this pattern degradation on the system is that of seriously reducing its coverage volume. It is interesting and coincidental that a circular array can be designed to give a pattern whose narrow dimension is 4 degrees and whose wide dimension is 40 degrees and with the lobe tilted off from the array plane by about 35 degrees from the vertical without serious beam degradation, but when a larger circular array design is attempted for a narrow dimension of 1.4

degrees, the pattern in the wide plane breaks up badly when the beam is tilted 35 degrees off from the vertical. The break point in beam width appears to be about 4 degrees for cases where the structure size must be held to a minimum. The critical factor in the design is the ratio of the arc length excited to the diameter of the array. A circular array could be designed to produce the 1.4 degree beam but would have to be of the order of 800 to 1000 feet high. Special designs were submitted by some companies which proposed to minimize this beam degradation with narrow fan beams by programming in two dimensions the amplitude and phase distribution along the arc of a circular array. However, the feed distribution system required would be very complex and considerable additional design studies would be necessary to insure performance under field conditions.

In general, the circular array design proposals were characterized by considerable complexity, high cost and new component development requirements. Based on these factors, along with the apparent inability to scale the 4 x 40 degree design up to the 1.4 x 40 degree design without pattern degradation, the conclusion was reached that the circular array was not suitable for this application.

D. Selection of Antenna System

The choice of acceptable proposals was reduced to the following three:

1. All Products Company, $787,552 for one base line, $1,417,634 for two base lines, fixed price. This was the lowest price bid received for a rotating antenna based on sound but economical antenna engineering.

2. Radiation, Incorporated, $1,314,740 for one base line, $2,100,000 for two base lines, fixed price. This was the next lowest price bid for a rotating antenna. The antenna design is electrically identical with the All Products antenna but structurally heavier.

3. Melpar, Incorporated, $1,850,000 for one base line, $3,055,000 for two base lines, cost plus fixed fee. A mechanically fixed electrically scanned antenna design with very attractive features, which make it well

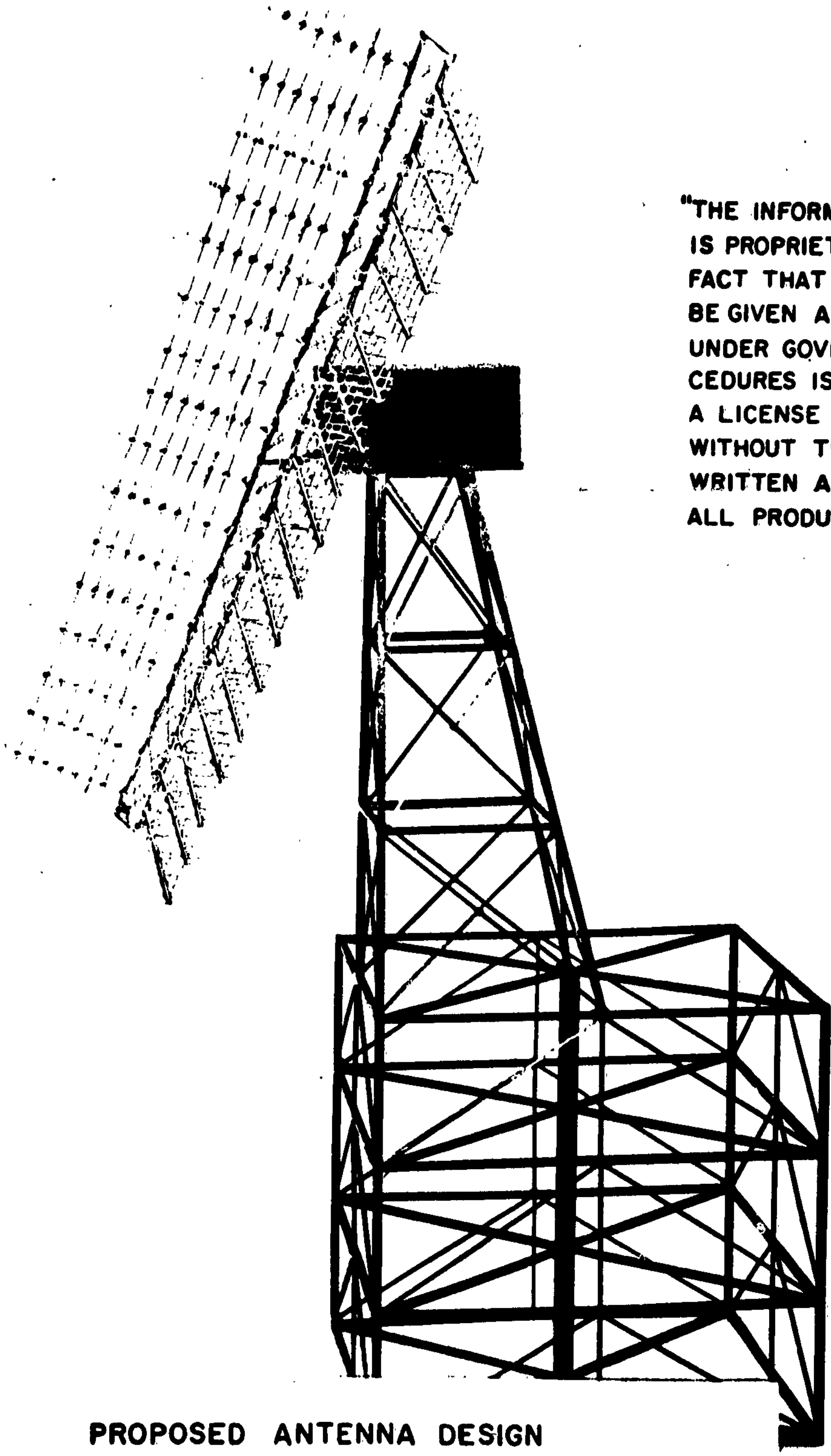
suited to the DOPLOC fan beam scanning application, was proposed by Melpar. Scanning is accomplished with an organ pipe scanner feeding a number of horns which sequentially illuminate a curved reflector. The antenna is called the Omega scanning antenna which is illustrative of the shape of the reflector.

The antenna design that meets DOPLOC specifications most economically is based on the rotating array structure proposed by the All Products Company. A linear array of radiating elements mounted on a boom generates the fan beam which is scanned by rotating the boom. Structural analysis of the boom and support tower for the interim 4 x 40 degree pattern show that it is entirely practical to rotate the antenna array at a rate of 2 rpm in winds up to 80 mph and maintain a nondegraded fan beam coplanar with a similar antenna located 1000 miles away. The servo control system required to synchronize the antennas is not complex and the motor to rotate the boom is reasonable in size. However, it is not certain that a mechanical system is practical for a 1 x 40 degree beam pattern.

Considering rotating type systems only, the lowest price of $1,417,634 (fixed price) for a two base line 100 kw transmitter-antenna system was submitted by the All Products Company, Mineral Wells, Texas. A careful scrutiny of the All Products proposal and discussions with their technical personnel in considerable design detail could show no major flaw or serious omission in their system design, company capability or financial status. This was the only company to agree readily to a fixed price contract with a penalty clause.

E. Description of All Products Company Antenna System

The All Products Company proposal for the 4 x 40 degree antenna consists of a linear array of Yagi antennas mounted on a rotating boom 73 feet long (Figure 1). Sixteen Yagis, each with seven elements, are used to form the 4 x 40 degree fan beam. Each Yagi is eight feet long and has a support mast of 2 3/8 inches diameter. Two arrays, pointed 120 degrees apart, are mounted on the boom to provide continuous scanning of the fan beam with



"THE INFORMATION HEREON IS PROPRIETARY AND THE FACT THAT A PERSON MAY BE GIVEN ACCESS THERETO UNDER GOVERNMENT PROCEDURES IS NOT DEEMED A LICENSE TO USE SAME WITHOUT THE EXPRESS WRITTEN APPROVAL OF ALL PRODUCTS COMPANY."

PROPOSED ANTENNA DESIGN
ALL PRODUCTS COMPANY

Fig. 1

continuous rotation of the boom. One array is switched to the feed line when its beam approaches 10 degrees above the horizon, then, after scanning to within 10 degrees of the opposite horizon, it is switched off and the other array switched on. Four scans per minute are made with a rotational rate of 2 rpm. All polarizations (circular right or left hand and linear vertical or horizontal) are provided by the use of crossed Yagi elements and the desired polarization is selected by changing feed connections to the Yagis. Polarization diversity can be provided by use of separate feed lines from each array through a double concentric rotating joint. The gain of each fan beam is 22 db over isotropic and side lobes will be 12 db down from the main lobe. Effects of the ground on the pattern have been calculated and shown to be negligible. Deflection of the boom, computed to be less than 0.5 degree under a 60 mph wind, will introduce negligible pattern distortion. Maximum deflection of the Yagis, considering wind gusts and vibration, has been computed to be 1 degree for 60 mph winds, which changes the gain of the antenna by a factor of only 0.9991 (.0078 db). The phase front of the pattern is not expected to be altered appreciably by any possible motion of the Yagis since that motion can only be in the plane of constant phase.

Synchronization of the transmitting and receiving antenna beams, is accomplished by a servo motor-controlled drive system which is synchronized to a precision frequency standard at each station. A General Electric system is proposed for this application. The rotation of the fan beams will be maintained in synchronism under winds up to 80 mph with a position and rate servo system which controls a 15 horsepower main drive motor and a smaller auxiliary correction motor. Provisions are also made for manual control of the antenna and an indicator is provided for reading angular position to better than 1 degree.

The four-legged tower supporting the antenna boom and motor drive system will also serve as corners for the transmitter building. The maximum deflection of the tower is computed to be 0.1 degree with 125 mph winds.

A four story building, 40 x 40 x 40 feet, is proposed and is considered large enough to house a 2 megawatt transmitter if such is required at a later date.

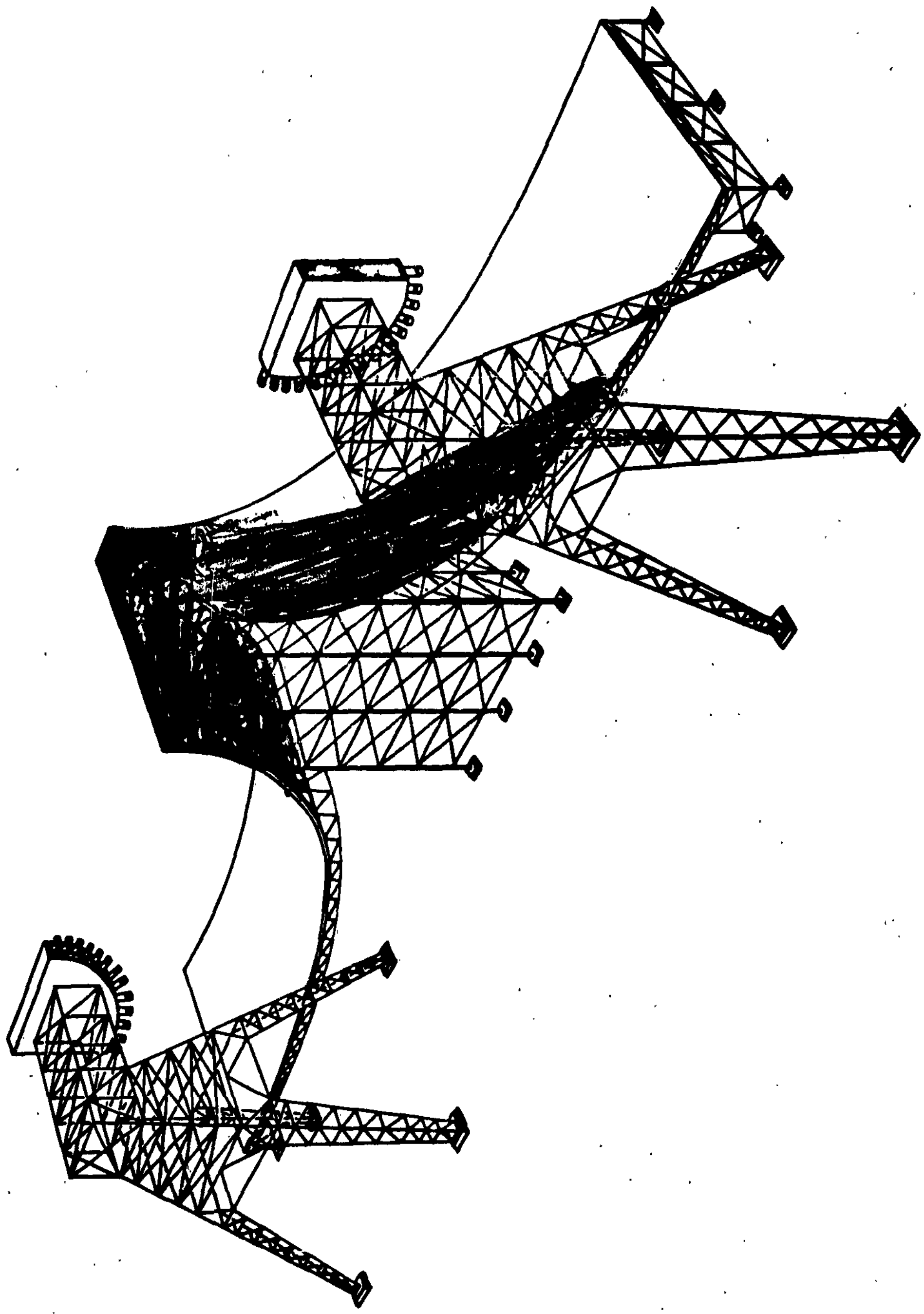
The proposed 100 kw transmitter will be designed and built by the Multronics Company, Sarasota, Florida. A Pete Sultzer type precision frequency oscillator will be employed. The final amplifier stage will be two groups of six RCA 6166 tetrodes, air cooled. Transmitter noise over a 6 mc bandwidth will be at least 70 db down.

Preliminary estimates for a megawatt transmitter have also been made by the Multronics Company. Using the RCA 2346 tube, the cost is estimated to be about $800,000 for a megawatt and $1,500,000 for 1.5 megawatts, with a six-month delivery. All Products Company has a design concept for an antenna that will handle 2 megawatts and the cost of this antenna has been estimated to be only $30,000 more than the Yagi design.

In summary, the All Products proposal appears to be a satisfactory and economical solution to the interim DOPLOC scanning antenna and transmitter problem.

F. Description of Melpar, Incorporated Antenna System

The proposal from Melpar, Incorporated, Fairfax, Virginia, was the only fixed structure antenna design that could be expected to fully meet the specifications of proper fan beam pattern shape for the interim and the "ultimate" DOPLOC system with an acceptable degree of complexity and reliability. Figure 2 shows the antenna, consisting of two complex curved surfaces arranged back-to-back. Each curved surface is illuminated by a set of horns to produce an eighty-degree scan from 10 degrees above the horizon to the vertical. The horns are fed in sequence from an organ pipe scanner. One set of horns and its reflector scans from 10 degrees above the horizon up to the vertical. The power is then fed to the other set of horns and the scan is continued from the vertical down to the opposite horizon. Thus, a basically new approach to the scanning antenna problem was made where,



PROPOSED ANTENNA DESIGN
MELPAR, INC.

Fig. 2

instead of feeding a large number of radiating elements located on the periphery of a circle, only a relatively small number of elements are fed and the curved reflecting surfaces form the narrow beam. The resultant reduction in complexity is considerable and a much desired degree of versatility is gained in control of beam pattern shape and polarization.

The Omega scanning antenna also provides the capability of achieving accurate angular information and added gain over a simple 4 x 40 degree fan beam. It is possible to incorporate a monopulse type receiving antenna feed configuration in the Omega scanning feed by the use of sum and difference feed channel. A sum and difference beam can be achieved by the use of a switching network in the receiving commutator. This would give immediate readout of the angular position in both planes without interfering with the antenna pattern or equipment used to obtain Doppler information. Added gain can be achieved by dividing the receiving pattern in the broad plane into a number of narrow beams. The multiple narrow beams together would cover the same volume as the single 4 x 40 degree beam. The gain of the system would be increased by the number of beams used. For example, four 4 x 10 degree beams would produce 6 db gain over a single 4 x 40 degree beam. Separate receivers would be required for each beam; however the cost would not increase linearly since the feed elements could be any simple type antenna such as a dipole. Separate commutators would be required for each beam but a common drive mechanism and angular indicator could be used.

Melpar has done a considerable amount of proprietary work on the basic design of this antenna. A number of radiation patterns have been measured with a scale model, which is quite simple to do with the reflector type design but almost impossible with the Wullenweber design. These patterns show that good pattern shape, high gain and acceptable side lobes are obtained over the entire 160 degree scan angle for both the interim and "ultimate" system.

G. Recommendation for Interim DOPLOC Antenna System

It is the recommendation that one base line of the All Products rotating antenna systems be installed at the Forrest City-Camp Blanding sites and that one base line of the Melpar fixed antenna system be installed at the Aberdeen Proving Ground-Camp Blanding sites. This arrangement will permit comparison of the rotating and the fixed antennas with respect to their operability, reliability, and feasibility for application to the "ultimate" system.

SECTION IV

ORBIT COMPUTATION

A. Introduction

This portion of the report presents the development of mathematical processes to determine orbital parameters of uncooperative (radio-silent) satellites from data obtained by the DOPLOC stations. In addition to the efforts of BRL on the overall problem, specific portions of the problem have been assigned to two contractors, the Western Development Laboratories of the Philco Corporation and the General Electric Company.

Both of these companies originally were assigned the task of developing a secondary type of solution which would provide a systematic means of making initial approximations of the position and velocity components. These in turn would be utilized as input data for the BRL-devised system, i.e. primary solution, for determining accurate orbital parameters by a method employing differential corrections.

Philco is continuing the task as originally assigned but the solution devised by General Electric offers promise of being applicable to the primary as well as the secondary problem and General Electric is investigating this phase.

During the period covered by this report, BRL has obtained twenty completely independent single pass satellite orbital solutions using DOPLOC field station data only.

B. Patton's (BRL) Method

The unqualified success of Patton's method of obtaining orbital parameters quickly and accurately from DOPLOC single pass data only has been demonstrated. Numerous convergent solutions have been obtained with actual field data from a system consisting of the transmitter at Fort Sill and a single receiver at Forrest City. This system complex provides a base line of

434 miles. In addition, the method has been modified to accept data that has been obtained by tracking a transmitter carried in the satellite. Receivers were available at both Forrest City and Aberdeen Proving Ground for this mode of operation, providing a base line of 863 miles. Results will be presented for both passive and active tracking. In addition, the orbital parameters published by Space Track have been converted to the epoch times of the DOPLOC reductions and are included for comparison.

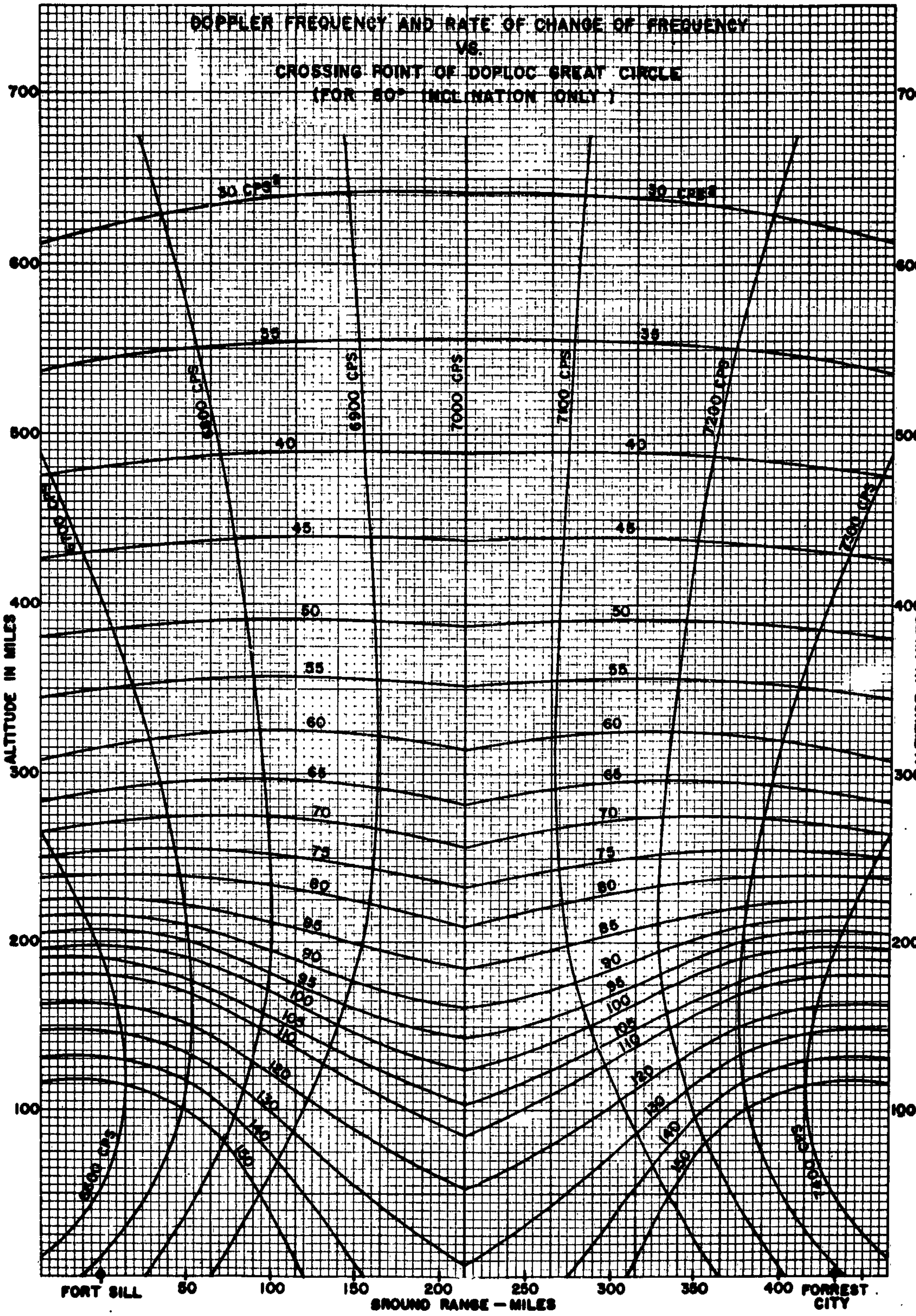
Of primary importance to the success of the method is the capability of establishing a compatible set of initial approximations for position and velocity with sufficient accuracy to permit convergence of the computing process. Several successful procedures for this phase of the problem have been developed but discussion will be confined to the method most suitable for the three fixed-beam mode of operation. However, reliable methods have been developed for the other modes of operation as well.

Satisfactory initial approximations for the three beam system are rather quickly and easily obtained by assuming circular motion and using a chart of the type presented in Figure 3. Constant contour lines have been computed and drawn for the Doppler frequency and the first time derivative of the frequency in the vertical plane which contains both the transmitter and receiver. These contours vary with inclination so that a number of charts are required for orbits of various inclinations. To obtain initial approximations for the computation, the following operations are performed:

a. Assume an inclination. Accuracy is not essential at this stage since the estimate may be in error by 15 degrees or more without preventing convergence.

b. Enter the chart with the measured frequency and the first derivative of the frequency for the center of the vertical beam of the interim DOPLOC System.

c. Determine position within the plane and then in the three dimensional coordinate system.


DOPPLER FREQUENCY AND RATE OF CHANGE OF FREQUENCY
VS.
CROSSING POINT OF DOPLOC GREAT CIRCLE
(FOR 80° INCLINATION ONLY)
ALTITUDE IN MILES
GROUND RANGE — MILES
FORT SILL
FORREST CITY
6800 CPS
6900 CPS
7000 CPS
7100 CPS
7200 CPS
30 CPS²
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
120
130
140
150
100
200
300
400
500
600
700
50
100
150
200
250
300
350
400
Fig. 3

d. Finally, velocity components are approximated. These should be consistent with the assumption of circular motion, the height determined in c, and the assumed inclination.

These results constitute the initial approximations which are required by the computing method.

The initial successful reduction for the Fort Sill, Forrest City system was achieved for Revolution 9937 of Sputnik III. The DOPLOC observations, as well as the results, are presented in Figure 4. Measurements were recorded for 28 seconds in the south antenna beam, 7 seconds in the center beam, and 12 seconds in the north beam with two gaps in the data of 75 seconds each. Thus, observations were recorded for a total of 47 seconds within a time interval of 3 minutes and 17 seconds. Using the method described above to obtain initial approximations, convergence was achieved on the first pass through the computing machine in three iterations. It will be noted in the comparison of DOPLOC and Space Track results that there is good agreement in a, e, i, and Ω, particularly for the latter two. This is characteristic of the single pass solution when the eccentricity is small and the computational input is limited to Doppler frequency. Since the orbit is very close to being circular, both σ and ω are difficult for either the DOPLOC System or Space Track to determine accurately. However, as a result of the small eccentricity, $(\omega + \sigma)$ is a good approximation of the angular distance along the orbit from the equator to the position of the satellite at epoch time and as such, provides a basis of comparison between the two systems. A comparison of this quantity is included in Figure 4. To summarize, when limited to single pass, single-receiver observations, the DOPLOC System provides an excellent determination of the orientation of the orbital plane, a good determination of the shape of the orbit, and a fair to poor determination of the orientation of the ellipse within the orbital plane.

Therefore, only a, e, i, and Ω will be considered in presenting the remaining DOPLOC reductions. The observations recorded for the Fort Sill, Forrest City complex are plotted in Figure 5 for six revolutions of

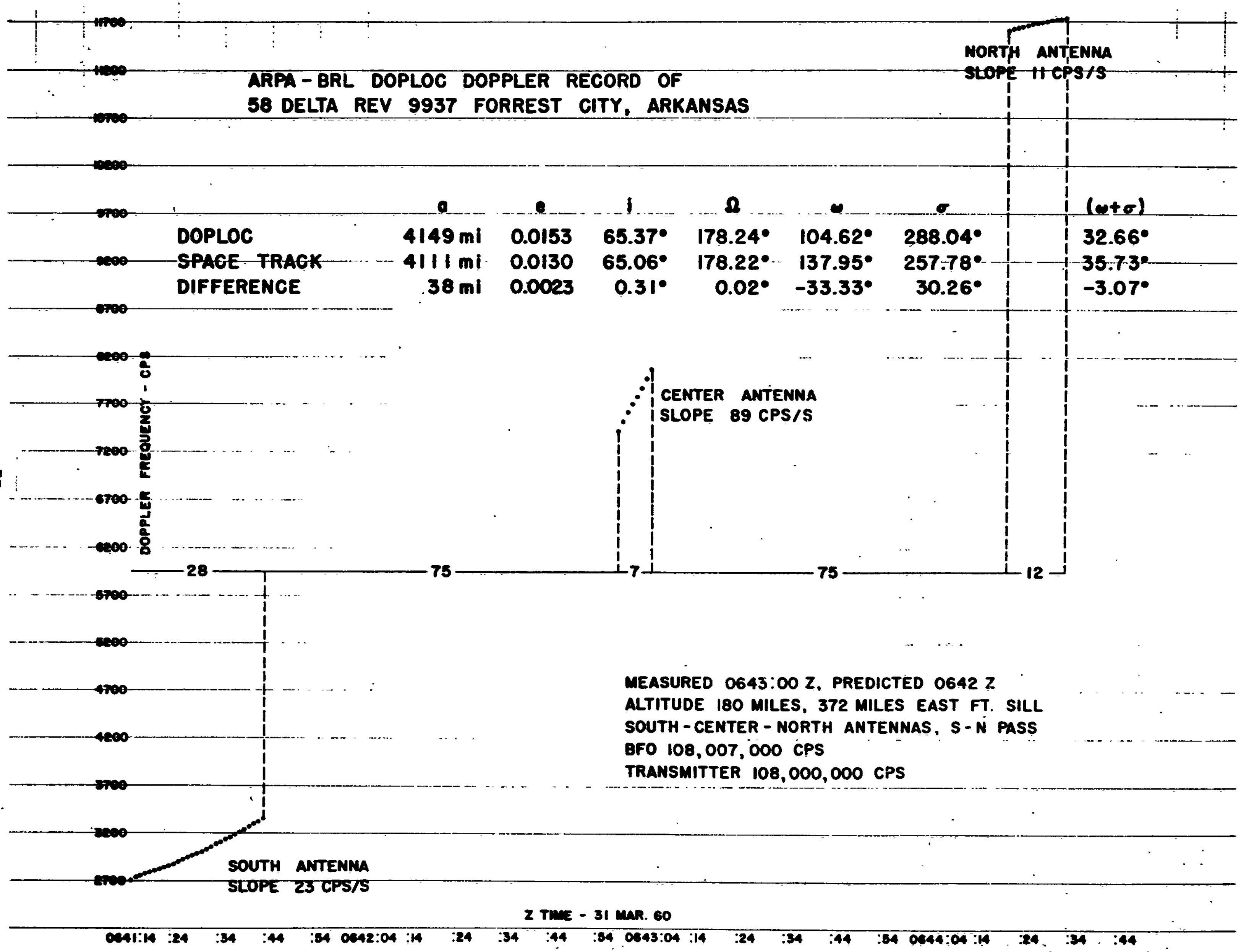
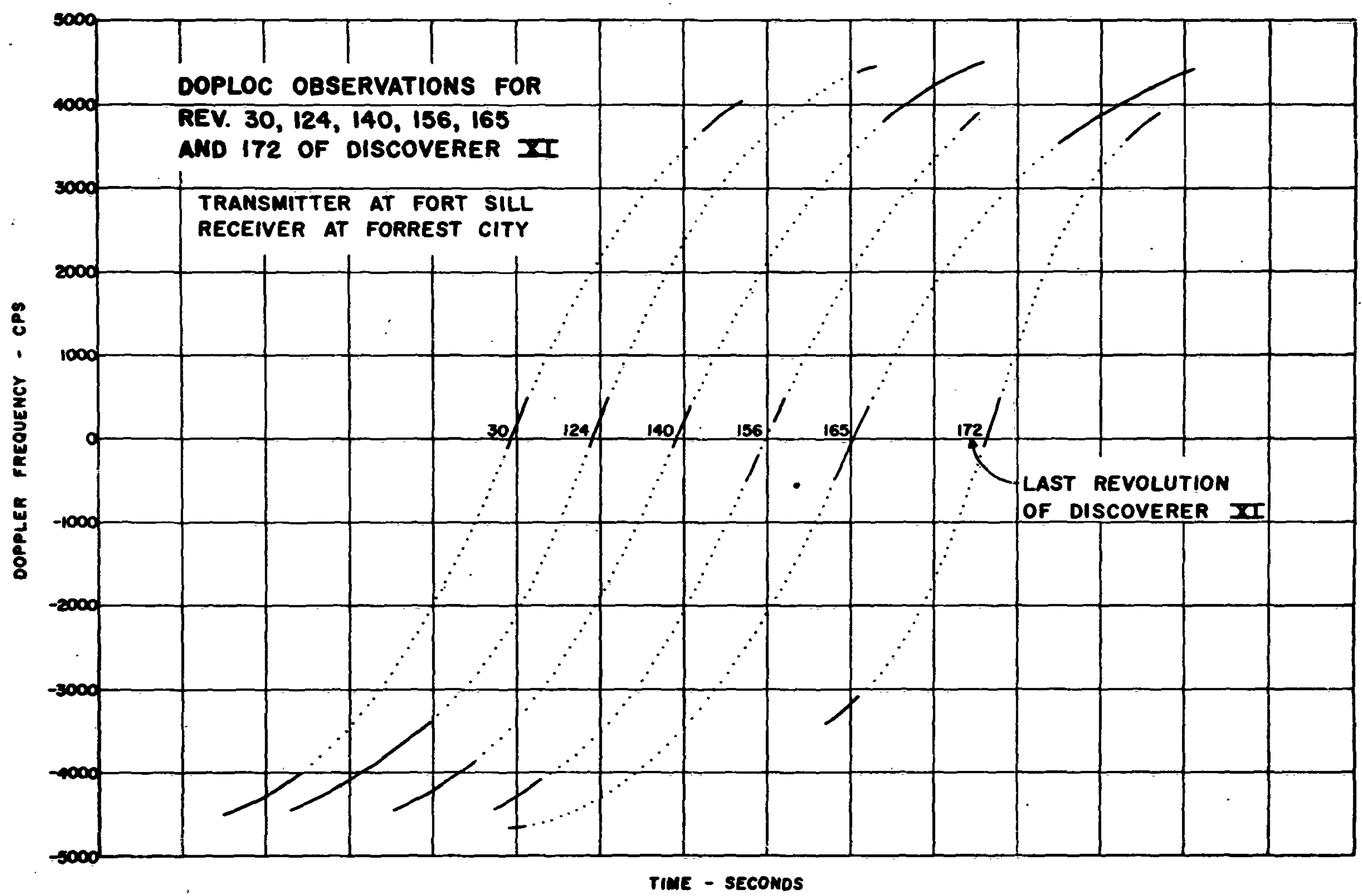

ARPA - BRL DOPLOC DOPPLER RECORD OF
58 DELTA REV 9937 FORREST CITY, ARKANSAS
a e i Ω ω σ (ω+σ)
DOPLOC 4149 mi 0.0153 65.37° 178.24° 104.62° 288.04° 32.66°
SPACE TRACK 4111 mi 0.0130 65.06° 178.22° 137.95° 257.78° 35.73°
DIFFERENCE 38 mi 0.0023 0.31° 0.02° -33.33° 30.26° -3.07°
NORTH ANTENNA
SLOPE 11 CPS/S
CENTER ANTENNA
SLOPE 89 CPS/S
SOUTH ANTENNA
SLOPE 23 CPS/S
DOPPLER FREQUENCY - CPS
28
75
7
75
12
MEASURED 0643:00 Z, PREDICTED 0642 Z
ALTITUDE 180 MILES, 372 MILES EAST FT. SILL
SOUTH - CENTER - NORTH ANTENNAS, S - N PASS
BFO 108,007,000 CPS
TRANSMITTER 108,000,000 CPS
Z TIME - 31 MAR. 60
0641:14 :24 :34 :44 :54 0642:04 :14 :24 :34 :44 :54 0643:04 :14 :24 :34 :44 :54 0644:04 :14 :24 :34 :44

Fig. 4



DOPLOC OBSERVATIONS FOR
REV. 30, 124, 140, 156, 165
AND 172 OF DISCOVERER XI
TRANSMITTER AT FORT SILL
RECEIVER AT FORREST CITY
30
124
140
156
165
172
LAST REVOLUTION
OF DISCOVERER XI
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
-4000
-5000
DOPPLER FREQUENCY - CPS
TIME - SECONDS

Fig. 5

Discoverer XI including 172, the last known revolution of this satellite. The DOPLOC determined position for this pass indicated an altitude of 77 miles as the satellite crossed the base line 64 miles west of Forrest City. A comparison of the DOPLOC reductions with the Space Track results for these observations is presented in Figures 6 through 9. In addition, DOPLOC reductions have been included for three revolutions wherein the receivers at Forrest City and Aberdeen Proving Ground tracked the air-borne transmitter in the satellite. In Figures 10 through 13, a similar comparison is presented for six separate passes of Transit 1B. Here again, all observations consist of data obtained by receivers at Forrest City and Aberdeen Proving Ground while tracking the on-board transmitter.

Finally, in Figure 14, results are tabulated for a reduction based on only seven frequency observations. These have been extracted from the complete set of observations previously presented for Sputnik III. They were selected to serve as a crude example of the type of reduction required for the proposed DOPLOC oscillating-beam system. The example shows that the method is quite feasible for use with periodic discreet measurements of frequency. Of course, the proposed system would normally yield several more observations than were available in the example.

C. Philco Corporation Contract

As stated above, the Western Development Laboratories of the Philco Corporation, working under contract No. DA-04-200-21X4992.509-ORD-1002, have been assisting with a portion of this work. This contract was initially negotiated for a total of $32,400 and covered the period 1 July 1959 to 30 September 1959. Supplemental Agreement No. 1 provided for a "no additional cost" extension through 30 November 1959, and Supplemental Agreement No. 2 extended the time to 31 January 1960 at in increase of $14,919. Supplemental Agreement No. 3 provided for a "no additional cost" extension through April 1960.

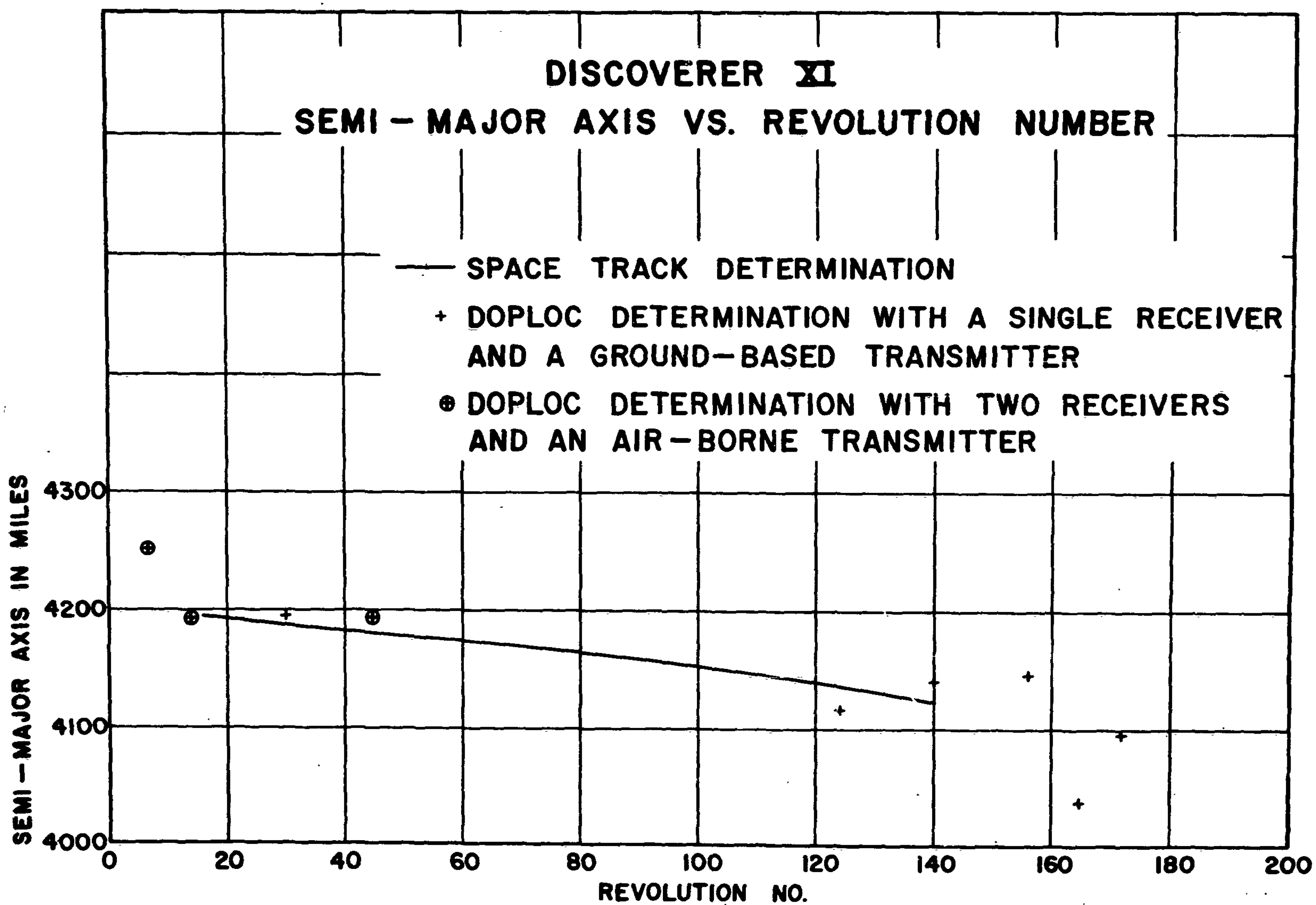

DISCOVERER XI
SEMI - MAJOR AXIS VS. REVOLUTION NUMBER
SPACE TRACK DETERMINATION
+ DOPLOC DETERMINATION WITH A SINGLE RECEIVER AND A GROUND-BASED TRANSMITTER
⊕ DOPLOC DETERMINATION WITH TWO RECEIVERS AND AN AIR-BORNE TRANSMITTER
SEMI-MAJOR AXIS IN MILES
4300
4200
4100
4000
0
20
40
60
80
100
120
140
160
180
200
REVOLUTION NO.

Fig. 6

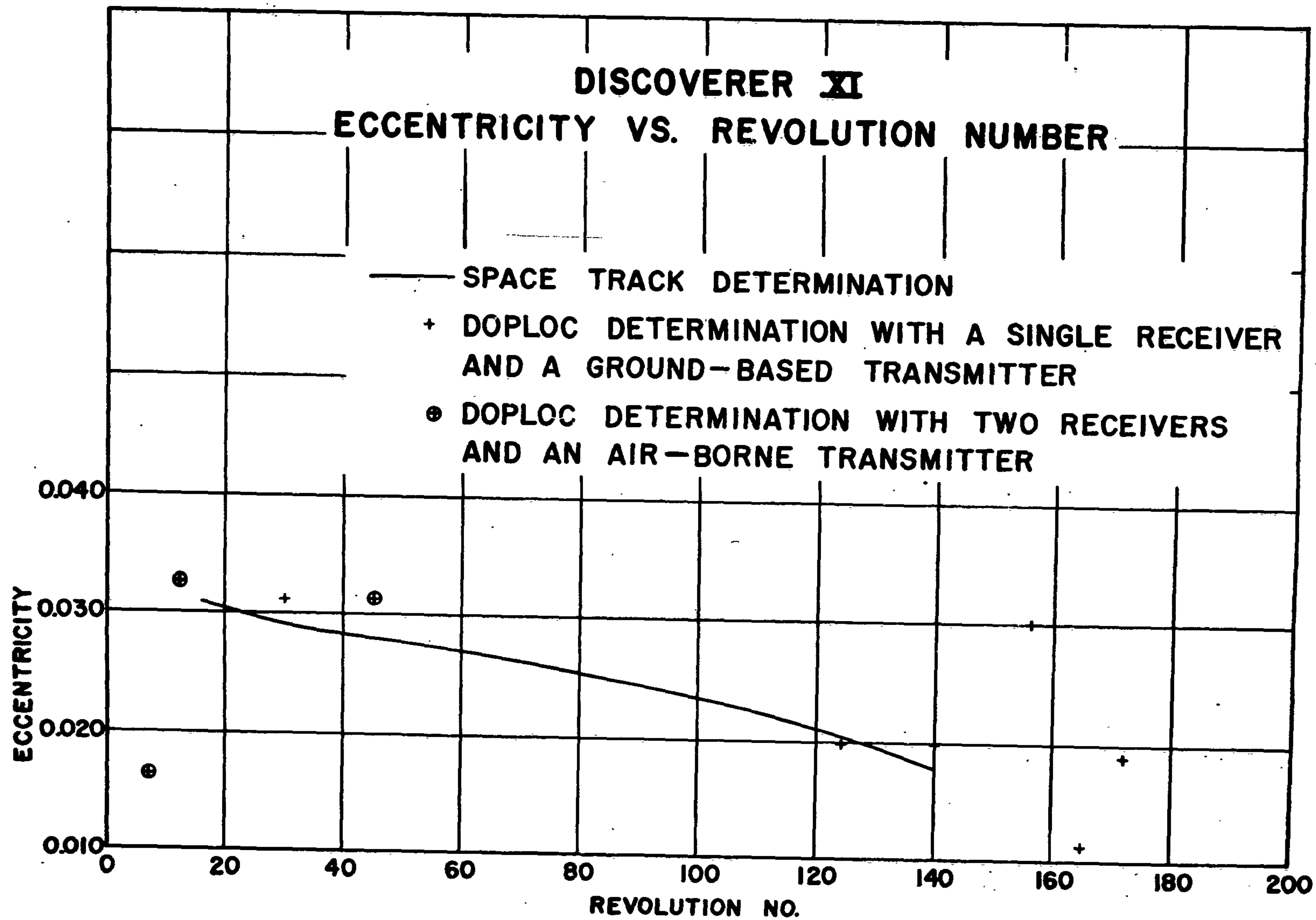

DISCOVERER XI
ECCENTRICITY VS. REVOLUTION NUMBER
SPACE TRACK DETERMINATION
+ DOPLOC DETERMINATION WITH A SINGLE RECEIVER AND A GROUND-BASED TRANSMITTER
⊕ DOPLOC DETERMINATION WITH TWO RECEIVERS AND AN AIR-BORNE TRANSMITTER
ECCENTRICITY
0.040
0.030
0.020
0.010
0
20
40
60
80
100
120
140
160
180
200
REVOLUTION NO.

Fig. 7

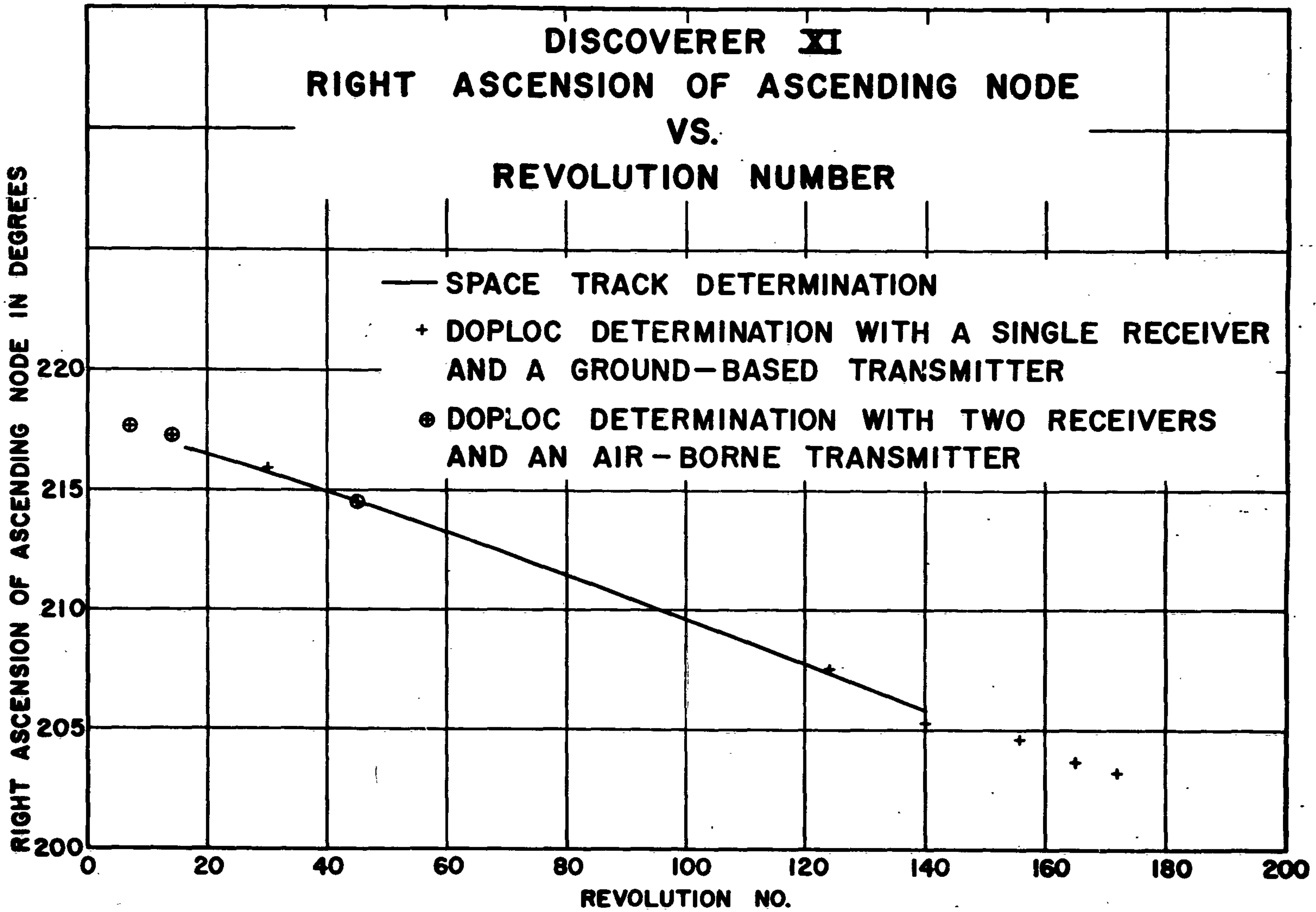

DISCOVERER XI
RIGHT ASCENSION OF ASCENDING NODE
VS.
REVOLUTION NUMBER
SPACE TRACK DETERMINATION
+ DOPLOC DETERMINATION WITH A SINGLE RECEIVER AND A GROUND-BASED TRANSMITTER
⊕ DOPLOC DETERMINATION WITH TWO RECEIVERS AND AN AIR-BORNE TRANSMITTER
RIGHT ASCENSION OF ASCENDING NODE IN DEGREES
200
205
210
215
220
0
20
40
60
80
100
120
140
160
180
200
REVOLUTION NO.

Fig. 8

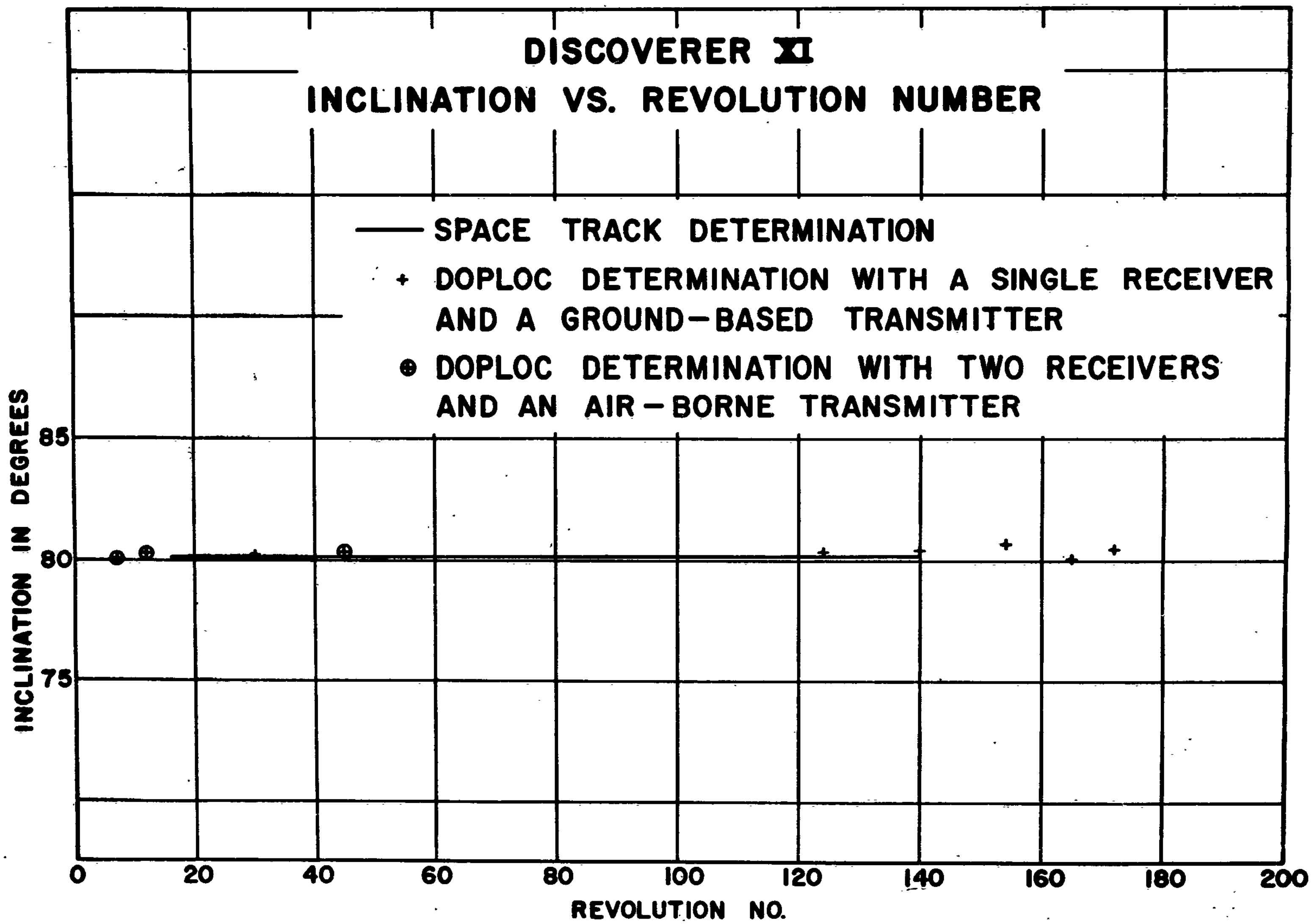

DISCOVERER XI
INCLINATION VS. REVOLUTION NUMBER
SPACE TRACK DETERMINATION
+ DOPLOC DETERMINATION WITH A SINGLE RECEIVER AND A GROUND-BASED TRANSMITTER
⊕ DOPLOC DETERMINATION WITH TWO RECEIVERS AND AN AIR-BORNE TRANSMITTER
INCLINATION IN DEGREES
85
80
75
0
20
40
60
80
100
120
140
160
180
200
REVOLUTION NO.

Fig. 9

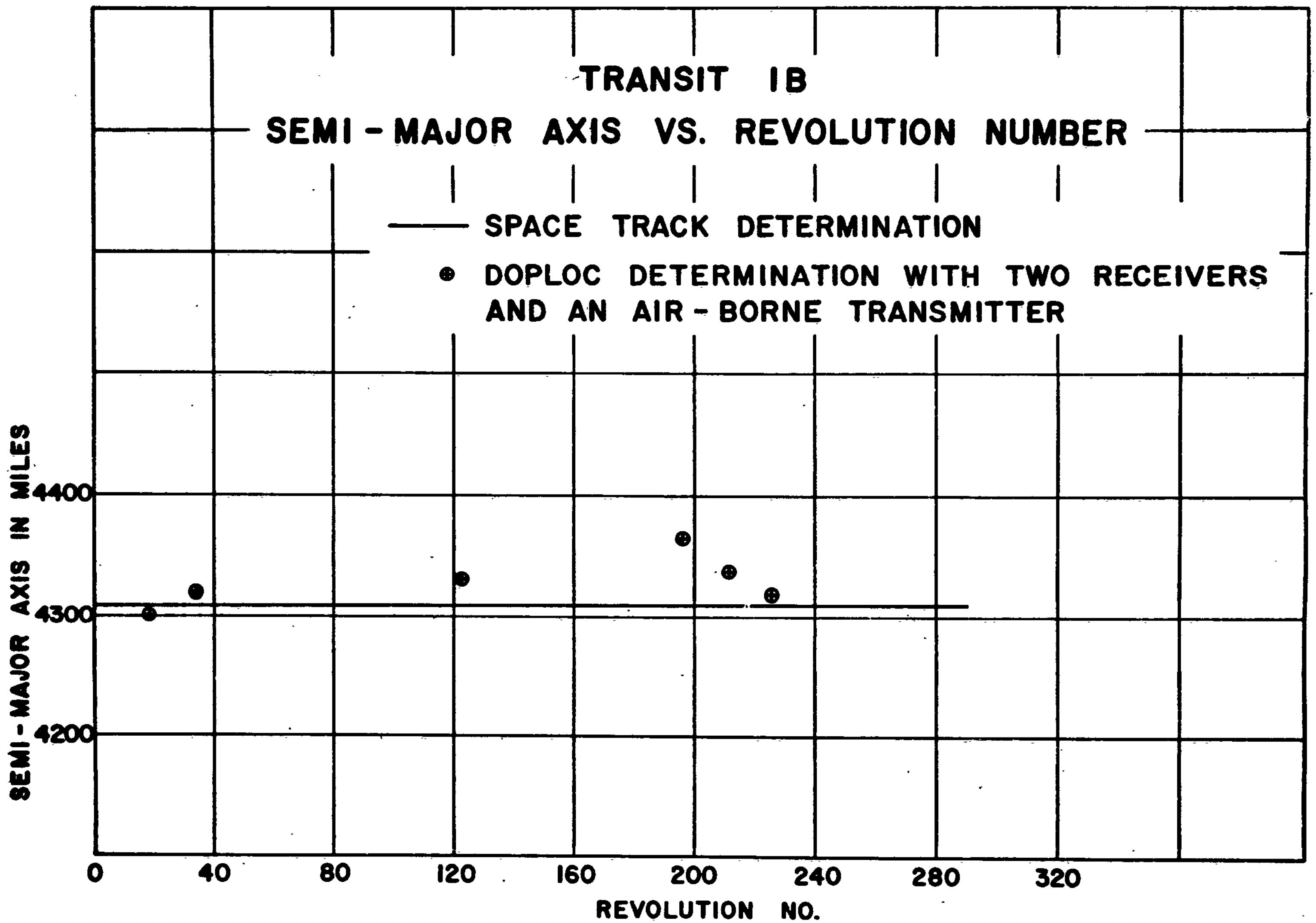
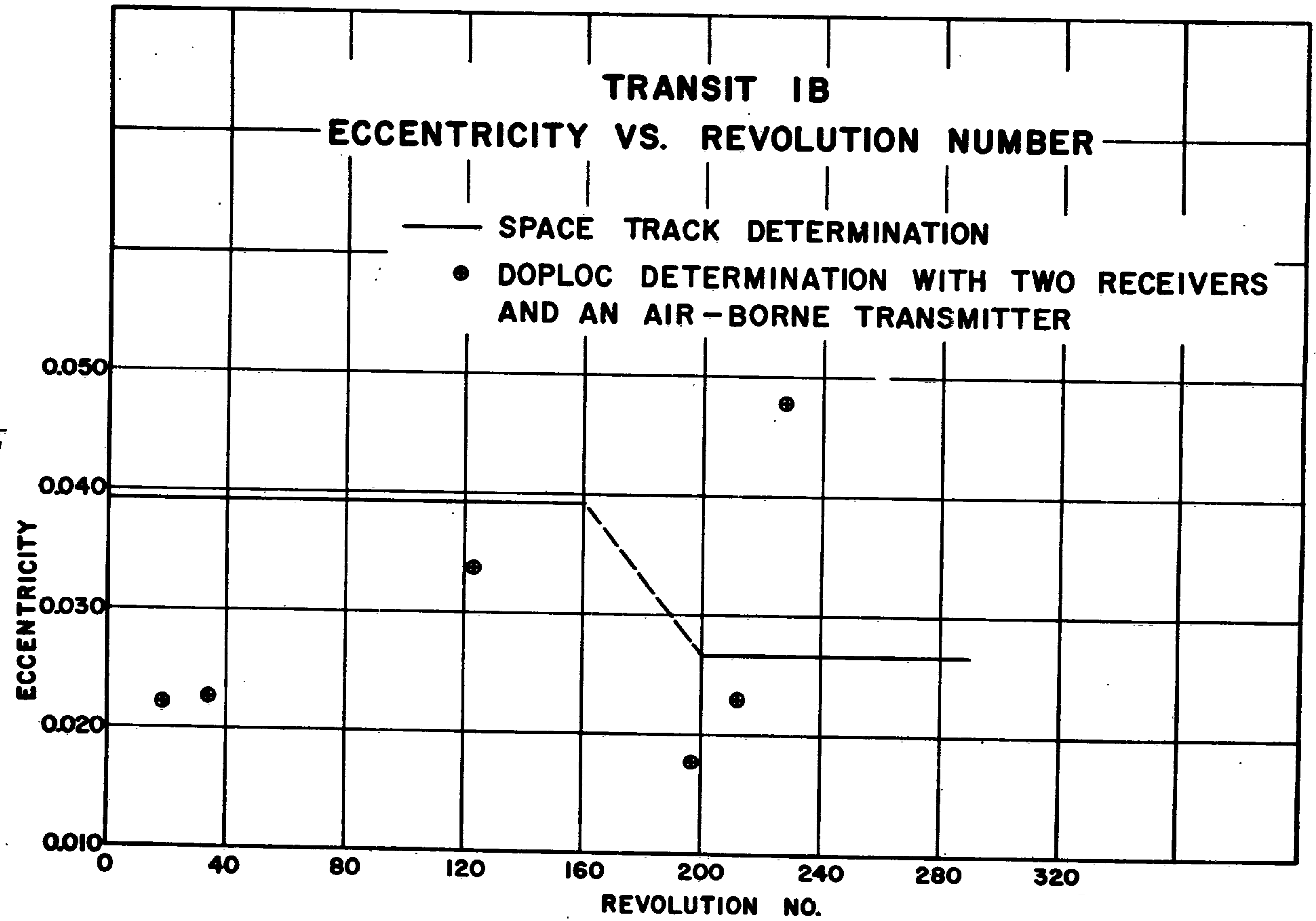

TRANSIT IB
SEMI - MAJOR AXIS VS. REVOLUTION NUMBER
SPACE TRACK DETERMINATION
DOPLOC DETERMINATION WITH TWO RECEIVERS AND AN AIR - BORNE TRANSMITTER
SEMI - MAJOR AXIS IN MILES
4400
4300
4200
0
40
80
120
160
200
240
280
320
REVOLUTION NO.

Fig. 10



TRANSIT IB
ECCENTRICITY VS. REVOLUTION NUMBER
SPACE TRACK DETERMINATION
DOPLOC DETERMINATION WITH TWO RECEIVERS AND AN AIR-BORNE TRANSMITTER
ECCENTRICITY
0.010
0.020
0.030
0.040
0.050
REVOLUTION NO.
0
40
80
120
160
200
240
280
320

Fig. 11

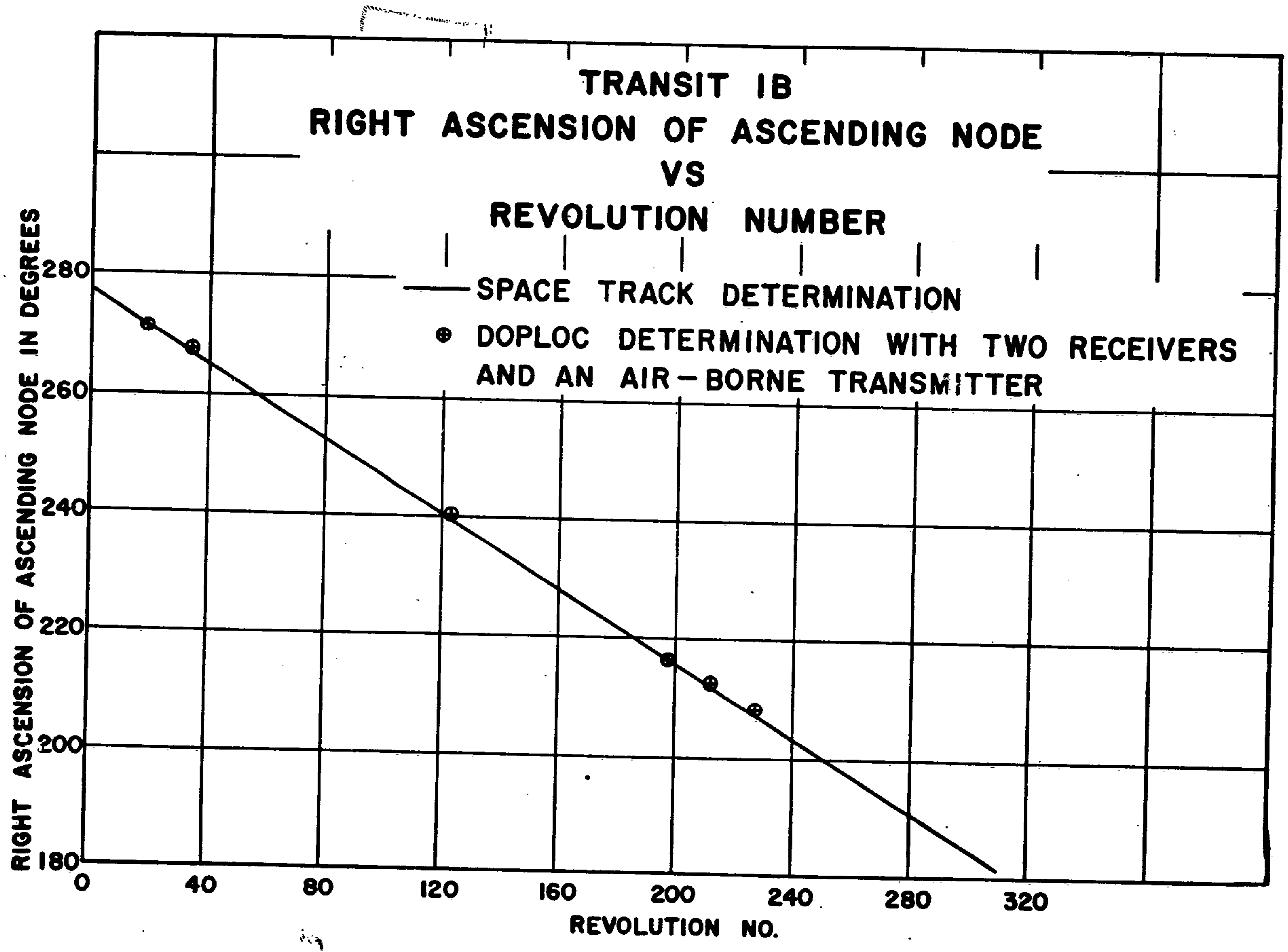

TRANSIT IB
RIGHT ASCENSION OF ASCENDING NODE
VS
REVOLUTION NUMBER
SPACE TRACK DETERMINATION
⊕ DOPLOC DETERMINATION WITH TWO RECEIVERS AND AN AIR-BORNE TRANSMITTER
RIGHT ASCENSION OF ASCENDING NODE IN DEGREES
180
200
220
240
260
280
0
40
80
120
160
200
240
280
320
REVOLUTION NO.

Fig. 12

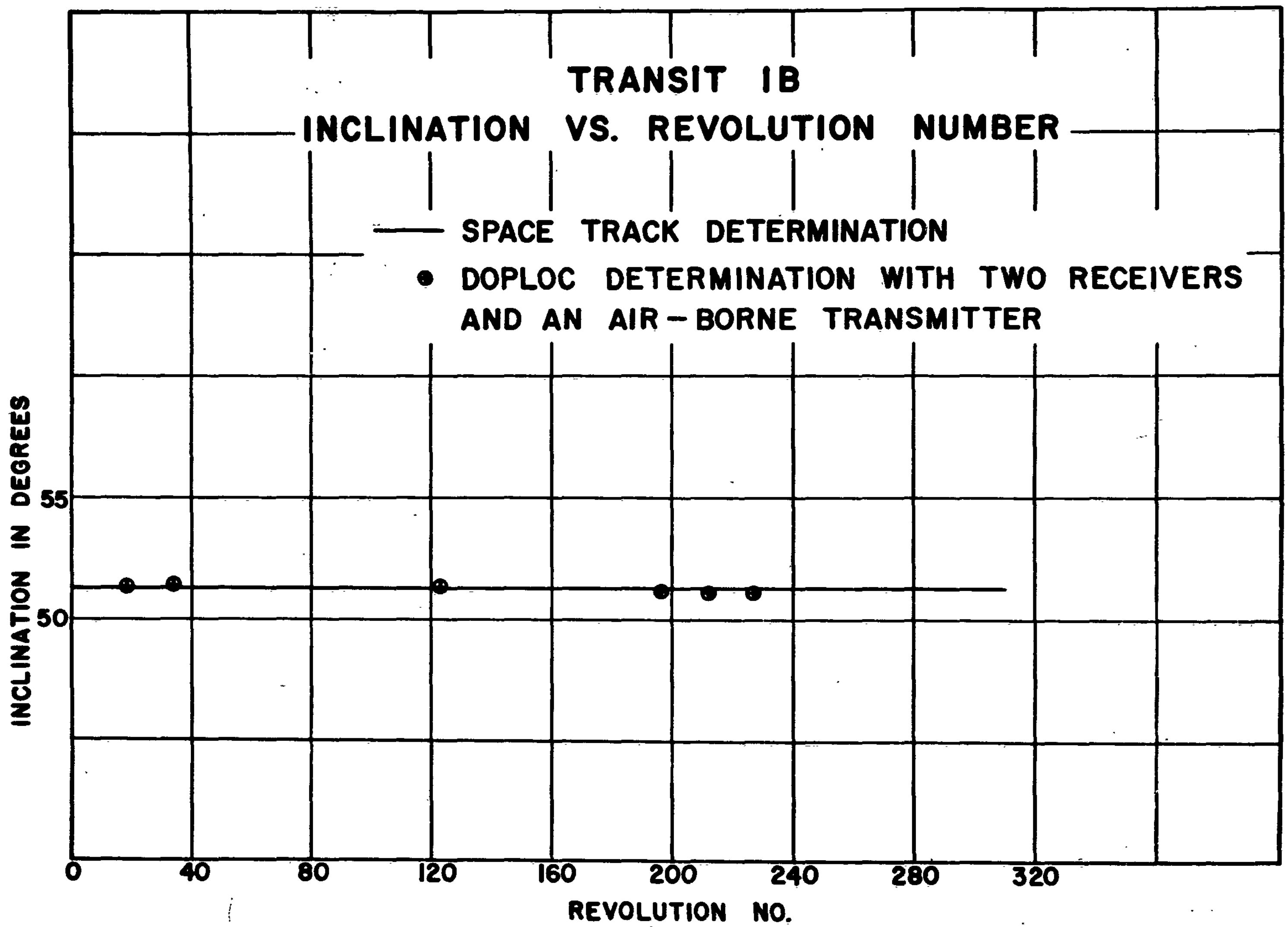

TRANSIT IB
INCLINATION VS. REVOLUTION NUMBER
SPACE TRACK DETERMINATION
DOPLOC DETERMINATION WITH TWO RECEIVERS AND AN AIR-BORNE TRANSMITTER
INCLINATION IN DEGREES
55
50
0
40
80
120
160
200
240
280
320
REVOLUTION NO.

Fig. 13

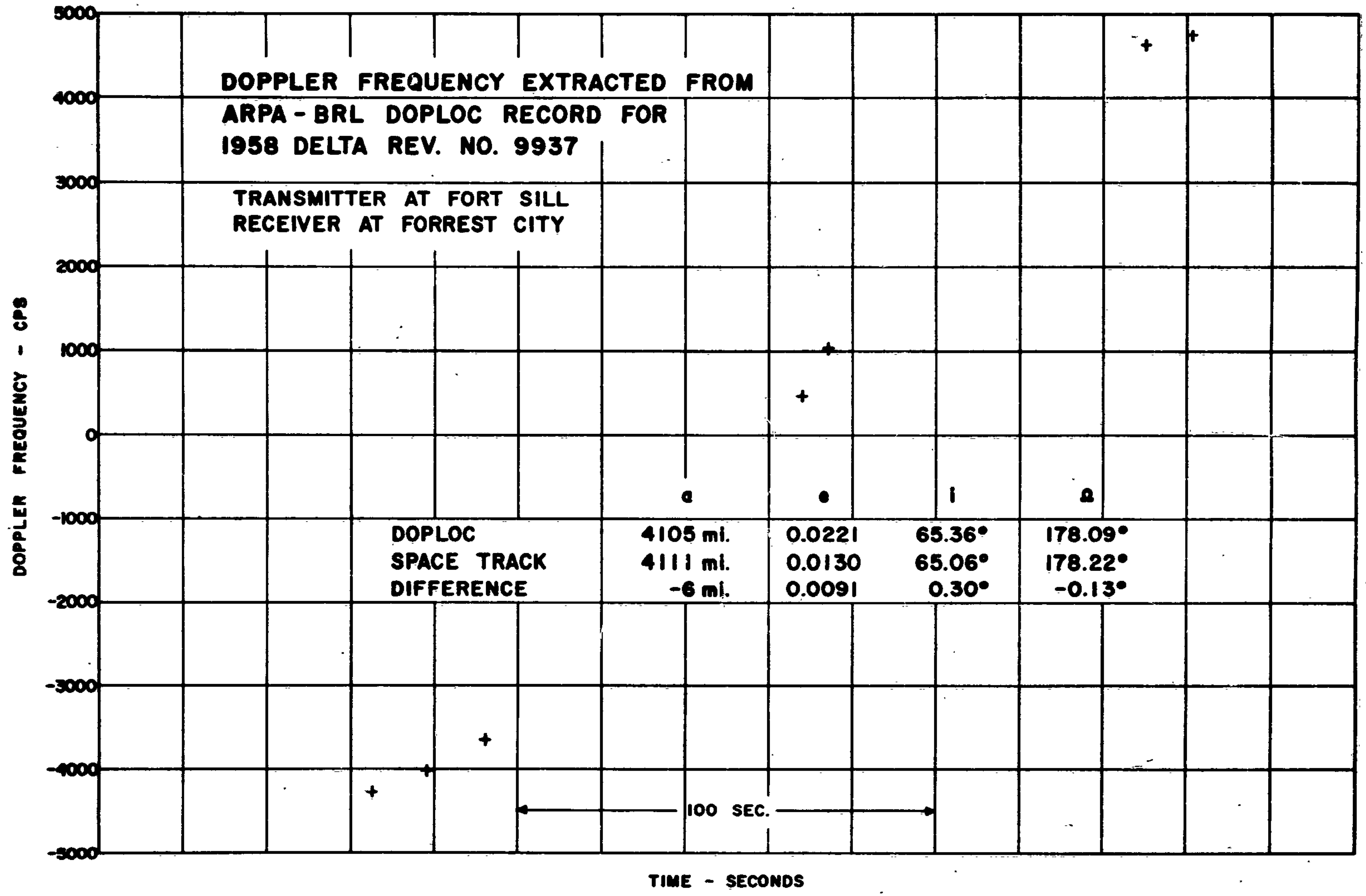

DOPPLER FREQUENCY EXTRACTED FROM
ARPA - BRL DOPLOC RECORD FOR
1958 DELTA REV. NO. 9937
TRANSMITTER AT FORT SILL
RECEIVER AT FORREST CITY
a e i Ω
DOPLOC 4105 mi. 0.0221 65.36° 178.09°
SPACE TRACK 4111 mi. 0.0130 65.06° 178.22°
DIFFERENCE -6 mi. 0.0091 0.30° -0.13°
100 SEC.
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
-4000
-5000
DOPPLER FREQUENCY - CPS
TIME - SECONDS

Fig. 14

Under the above contract the Western Development Laboratories agreed to furnish personnel and computing services and have directed efforts toward the investigation of partial solutions of orbiting satellites as computed from data obtained from the BRL-ARPA DOPLOC satellite tracking system. More specifically Western Development has directed its efforts toward devising a system for determining first approximations of the velocity and position components which in turn can be used as a starting point for the BRL primary solution to obtain detailed orbital parameters.

In pursuing this problem, Western Development has made a number of simplifying assumptions without restricting the direction of the satellite path relative to the system geometry. These assumptions include the use of a nonrotating earth, the elimination of ionospheric effects, and the assumption of a circular orbit. Both active and passive satellites have been considered, and techniques to simplify the complexity of inactive cases to the relative simplicity of an active case have been investigated. The geometry under consideration has been chosen with BRL applications in mind, but is not limited to the originally proposed White Sands Missile Range - Fort Sill - Forrest City system.

The Philco system is distinct from the oscillating beam system and is intended primarily as a back-up for other methods. While the BRL and General Electric methods require less specialized geometry and less instrumentation, it is felt unwise to limit investigations to methods for a single type of system which has not been completely tested as yet.

The original Philco solution required two transmitters and four receivers. However, changes in the method have reduced the requirements to one transmitter and four receivers. Ideally, four readings would be sufficient to determine the four initial slant ranges, but in order to linearize the equations, fourteen readings are required. The geometric conditions relating the slant ranges from any point in space to the four receivers may be expressed as a third order polynomial. If fourteen readings are available, the slant range to each receiver can be expressed in terms of the original slant range and the change in slant range, the latter to be determined from the Doppler observations. Thus fourteen additional third-degree equations are obtained. These may be combined with the original equations in such a way as to yield a system of fourteen linear equations in fourteen unknowns, four of which are the desired initial ranges. From the latter and the observed frequencies, it is relatively simple to determine initial estimates of the position and velocity vectors.

Currently an error analysis is being performed to determine the strength of the solution as a function of position and velocity. This analysis assumes a circular orbit and fixed antenna beams. Equations have been developed to perform this evaluation, and the problem is being programmed for input to the Philco Transac S-2000 computer. The results will be plotted to present the error propagation in position and velocity as a function of position. The second contract extension was negotiated to allow time and funds for this evaluation.

D. General Electric Company Contract

The General Electric Company, under contract number DA-36-034-509-ORD 3046RD, has also been assigned tasks relative to the overall problem. This contract, effective for a three-month period beginning 3 September 1959, was negotiated for $40,706 and under it General Electric is to provide engineering, mathematical, and supporting services.

The original assignment to General Electric was the development of a method for obtaining a secondary solution which would provide first approximations of position and velocity to be used as input for the BRL primary solution.

Using a technique of the statistical theory of multivariate functions, a program has been written for determining the location of the orbital elements by minimizing the sum of the squares of the errors between Doppler observations and Doppler functions computed from assumed orbital elements. This method uses a definite search pattern from the initial assumed position to establish a new approximation to the location of a minimum.

The approach to the problem taken by General Electric offers promise of providing a primary as well as secondary solution and on this basis a contract extension has been initiated to provide time for a complete evaluation of the solution. In addition, a second contract in the amount of $80,000 has been awarded General Electric to further pursue this work.

The method of solution under investigation was developed by Mr. E. R. Lancaster of the General Electric Company and has become known as the Lancaster Method. In general, it consists of a procedure for determining the minimum of a multivariate function. A special application has been developed for the reduction of DOPLOC satellite data. The method provides for a series of improvements to approximations for the position and velocity vectors of the satellite at a time which corresponds to the initiation of tracking. As in a least squares type of solution, the function which is minimized is the sum of the squares of the residuals. Let this function be represented by F. The residuals are defined to be the differences between the measured Doppler frequencies and those which are computed for the assumed initial position and velocity vectors while constraining the satellite to elliptic motion. However, the method of determining the minimum differs from the least squares procedure in that a complete second degree polynomial in the six variables, which determine the position and velocity vectors, is fitted to the function F in the neighborhood of the assumed position in six dimensional space. Then the minimum of the fitted surface is determined by equating to zero the partial derivatives of F with respect to the position and velocity components and solving the resulting system of six equations to obtain an improved estimate of the initial position and velocity. The process is repeated until convergence is achieved. In the fitting procedure, the polynomial and the function are forced to correspond at 27 points, the number of coefficients in a complete second degree polynomial in six variables. A definite search pattern is employed to determine these 27 points which, of course, are in the vicinity of the assumed position in six dimensional space.

Current work consists primarily of analytical investigation of the computer program for the purpose of speeding convergence and enlarging the volume in which convergence may be assured. In addition, the propagation of error into the orbital parameters will be analyzed and evaluated.

SECTION V

SUPPORTING STUDIES

A. Scanning Antenna Coverage

A study was conducted to determine the number of satellite passes across each of the two proposed base lines and the length of time that the satellite would be in the antenna beam during each pass. This was accomplished by using a map of the United States and representing the 4 x 40 degree antenna patterns as two space volumes, each having a width of 800 miles, a height of 400 miles and a length equal to the distance between the stations. This distance for the Aberdeen - Camp Blanding base line is 730 miles, while for the Forrest City - Camp Blanding base line is 610 miles.

Using satellite predictions furnished by Space Track Control Center, each satellite was examined during the period indicated and the total number of passes crossing each base line was recorded. The length of time-in-beam for each pass was calculated utilizing the sub-satellite trace and assuming a nominal satellite velocity of 5 miles per second. A tabulation of results is shown in Table III and a graphical representation is displayed in Figures 15 through 20.

It can be seen from these data that, of the two proposed base lines, the Aberdeen base line is the most promising, both from the standpoint of total number of passes and from the time-in-beam of these passes. The longer base line accounts for the larger total number of passes, while the geographical location of Aberdeen and Camp Blanding is such that a satellite having an orbital inclination of from 50 to 90 degrees crosses the pattern in a near diagonal and, therefore, is within the beam a greater length of time. The data also show it will be necessary to increase the antenna scan rate from 15 seconds to 7-1/2 seconds per scan to make possible 10-20 DOPLOC hits per pass for the majority of passes crossing the base line.

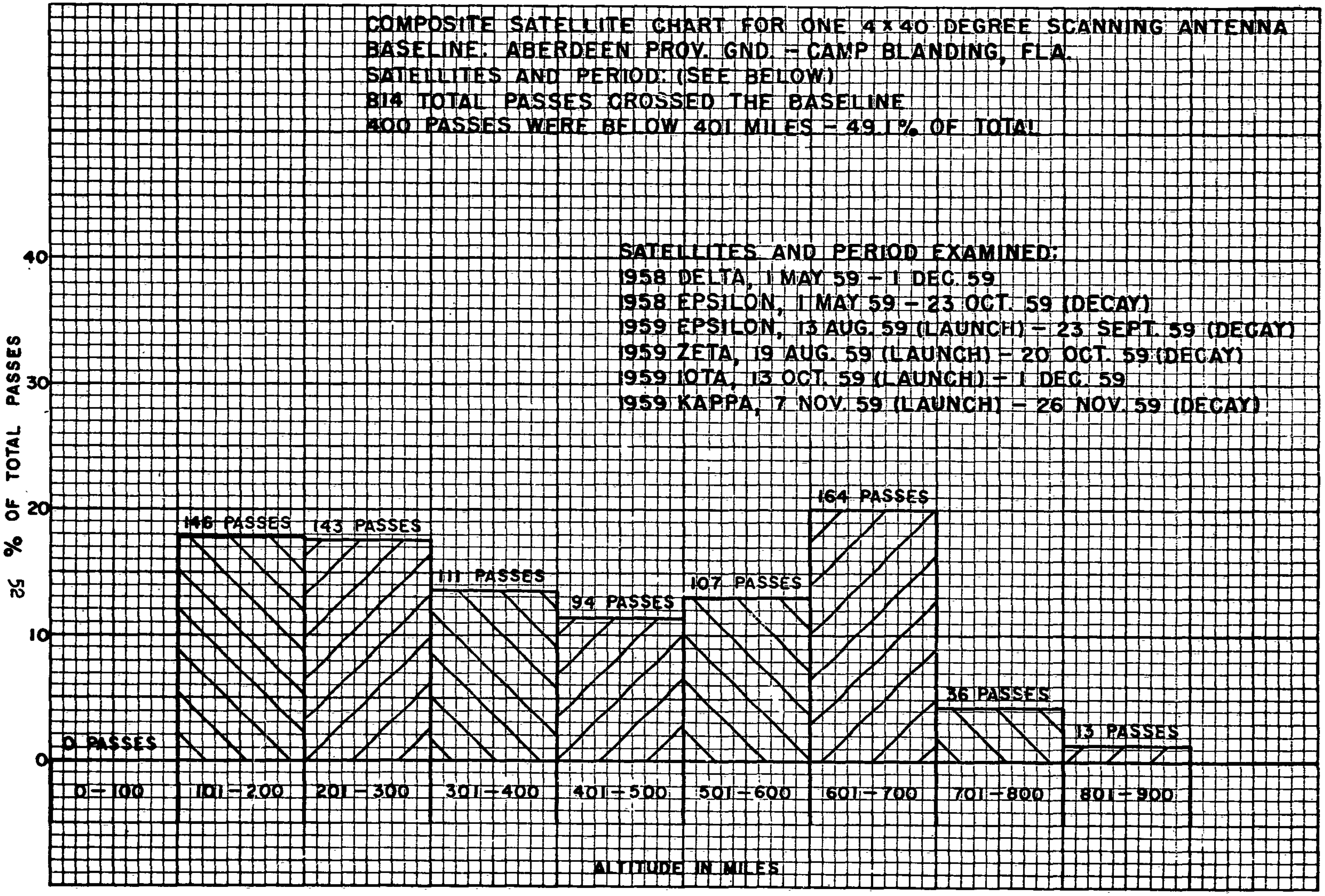

COMPOSITE SATELLITE CHART FOR ONE 4 x 40 DEGREE SCANNING ANTENNA
BASELINE: ABERDEEN PROV. GND. – CAMP BLANDING, FLA.
SATELLITES AND PERIOD: (SEE BELOW)
814 TOTAL PASSES CROSSED THE BASELINE
400 PASSES WERE BELOW 401 MILES – 49.1% OF TOTAL
SATELLITES AND PERIOD EXAMINED:
1958 DELTA, 1 MAY 59 – 1 DEC. 59
1958 EPSILON, 1 MAY 59 – 23 OCT. 59 (DECAY)
1959 EPSILON, 13 AUG. 59 (LAUNCH) – 23 SEPT. 59 (DECAY)
1959 ZETA, 19 AUG. 59 (LAUNCH) – 20 OCT. 59 (DECAY)
1959 IOTA, 13 OCT. 59 (LAUNCH) – 1 DEC. 59
1959 KAPPA, 7 NOV. 59 (LAUNCH) – 26 NOV. 59 (DECAY)
% OF TOTAL PASSES
40
30
20
10
0
0 PASSES
146 PASSES
143 PASSES
111 PASSES
94 PASSES
107 PASSES
164 PASSES
36 PASSES
13 PASSES
0 – 100
101 – 200
201 – 300
301 – 400
401 – 500
501 – 600
601 – 700
701 – 800
801 – 900
ALTITUDE IN MILES

FIG. 15

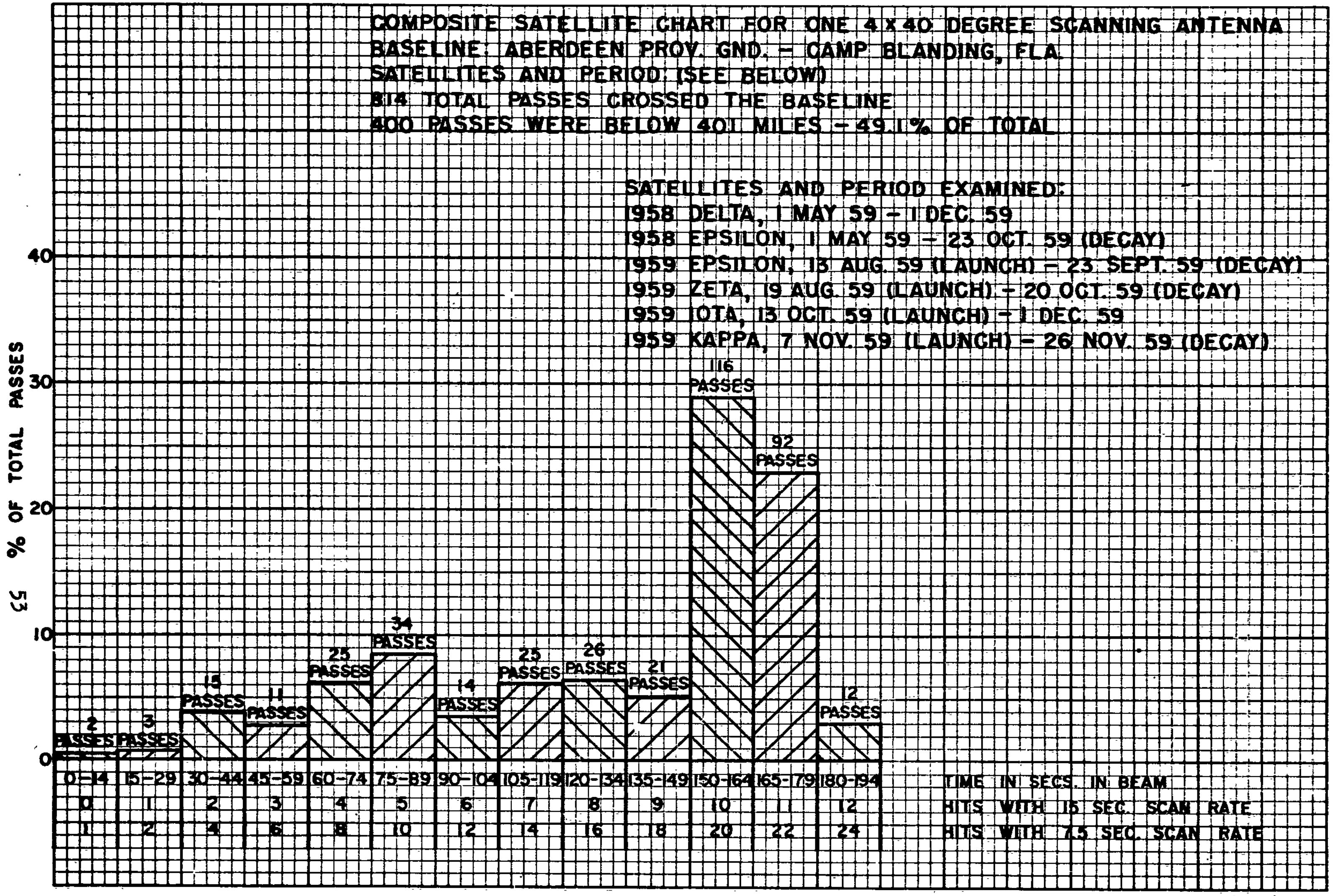
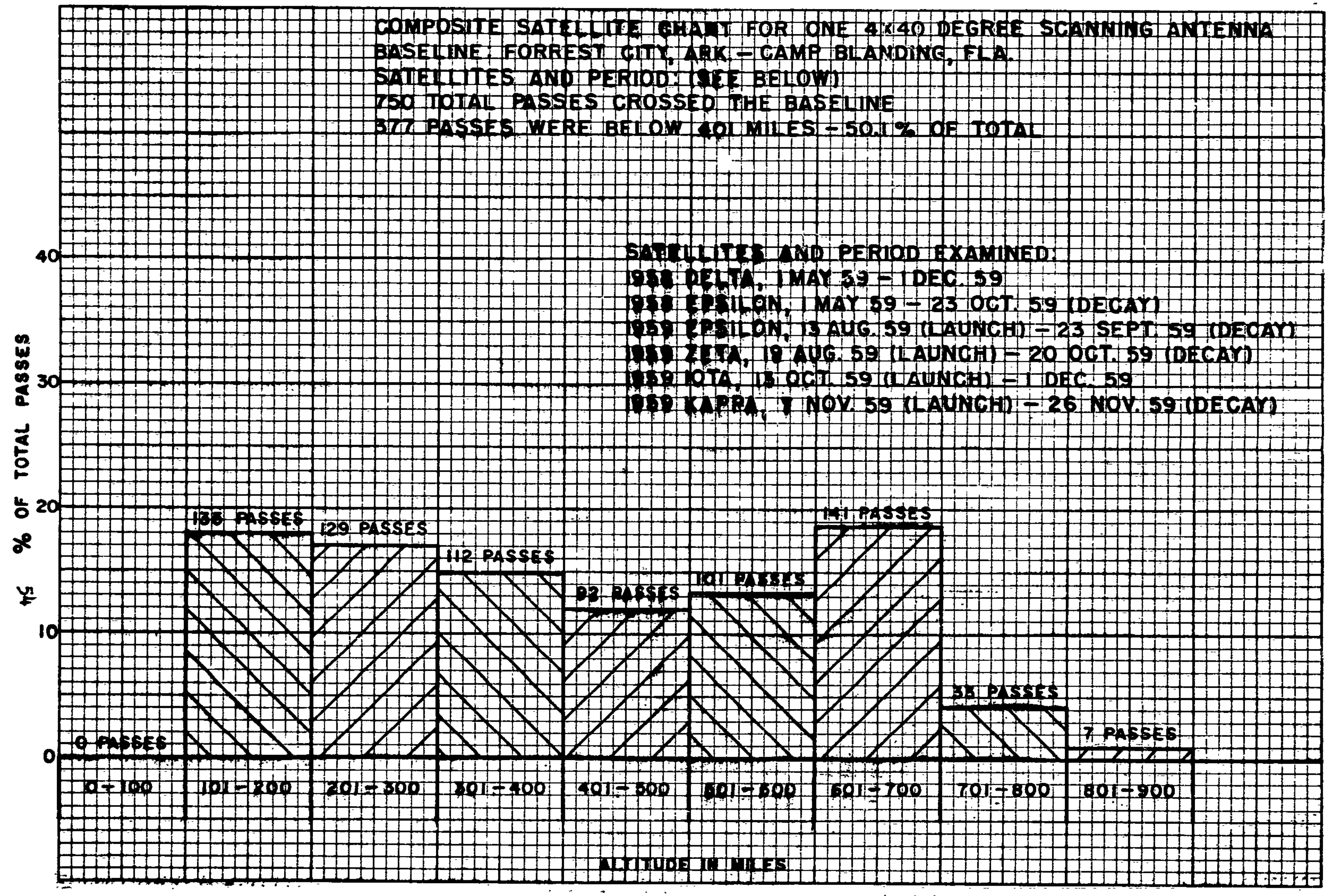
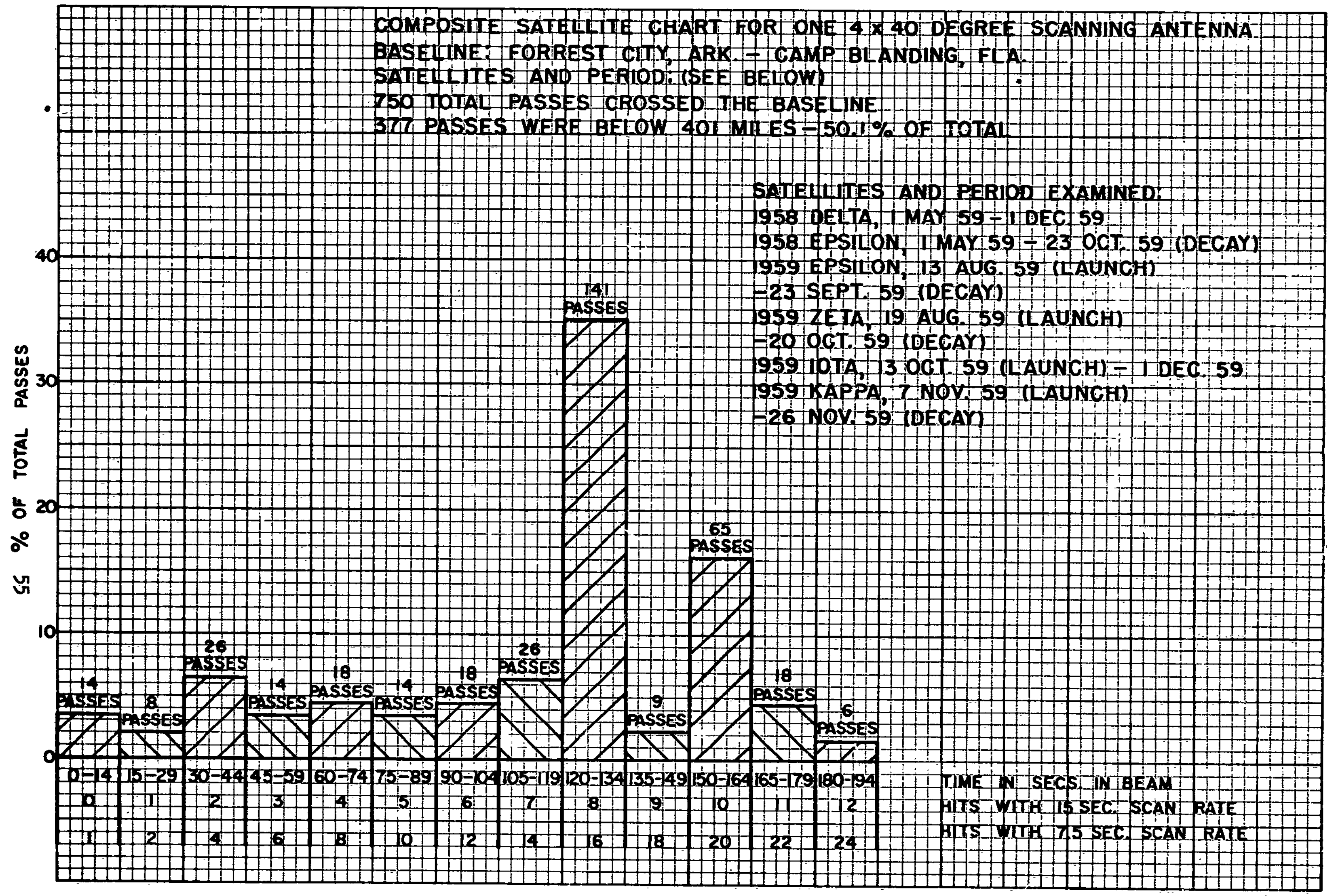

COMPOSITE SATELLITE CHART FOR ONE 4 X 40 DEGREE SCANNING ANTENNA
BASELINE: ABERDEEN PROV. GND. – CAMP BLANDING, FLA.
SATELLITES AND PERIOD: (SEE BELOW)
814 TOTAL PASSES CROSSED THE BASELINE
400 PASSES WERE BELOW 401 MILES – 49.1% OF TOTAL
SATELLITES AND PERIOD EXAMINED:
1958 DELTA, 1 MAY 59 – 1 DEC. 59
1958 EPSILON, 1 MAY 59 – 23 OCT. 59 (DECAY)
1959 EPSILON, 13 AUG. 59 (LAUNCH) – 23 SEPT. 59 (DECAY)
1959 ZETA, 19 AUG. 59 (LAUNCH) – 20 OCT. 59 (DECAY)
1959 IOTA, 13 OCT. 59 (LAUNCH) – 1 DEC. 59
1959 KAPPA, 7 NOV. 59 (LAUNCH) – 26 NOV. 59 (DECAY)
% OF TOTAL PASSES
0
10
20
30
40
2 PASSES
3 PASSES
15 PASSES
11 PASSES
25 PASSES
34 PASSES
14 PASSES
25 PASSES
26 PASSES
21 PASSES
116 PASSES
92 PASSES
12 PASSES
0–14
15–29
30–44
45–59
60–74
75–89
90–104
105–119
120–134
135–149
150–164
165–179
180–194
TIME IN SECS. IN BEAM
0
1
2
3
4
5
6
7
8
9
10
11
12
HITS WITH 15 SEC. SCAN RATE
1
2
4
6
8
10
12
14
16
18
20
22
24
HITS WITH 7.5 SEC. SCAN RATE

FIG. 16



COMPOSITE SATELLITE CHART FOR ONE 4X40 DEGREE SCANNING ANTENNA
BASELINE: FORREST CITY, ARK. – CAMP BLANDING, FLA.
SATELLITES AND PERIOD: (SEE BELOW)
750 TOTAL PASSES CROSSED THE BASELINE
377 PASSES WERE BELOW 401 MILES – 50.1 % OF TOTAL
SATELLITES AND PERIOD EXAMINED:
1958 DELTA, 1 MAY 59 – 1 DEC. 59
1958 EPSILON, 1 MAY 59 – 23 OCT. 59 (DECAY)
1959 EPSILON, 13 AUG. 59 (LAUNCH) – 23 SEPT. 59 (DECAY)
1959 ZETA, 19 AUG. 59 (LAUNCH) – 20 OCT. 59 (DECAY)
1959 IOTA, 13 OCT. 59 (LAUNCH) – 1 DEC. 59
1959 KAPPA, 7 NOV. 59 (LAUNCH) – 26 NOV. 59 (DECAY)
% OF TOTAL PASSES
40
30
20
10
0
0 PASSES
136 PASSES
129 PASSES
112 PASSES
93 PASSES
101 PASSES
141 PASSES
35 PASSES
7 PASSES
0 – 100
101 – 200
201 – 300
301 – 400
401 – 500
501 – 600
601 – 700
701 – 800
801 – 900
ALTITUDE IN MILES

FIG. 17



COMPOSITE SATELLITE CHART FOR ONE 4 x 40 DEGREE SCANNING ANTENNA
BASELINE: FORREST CITY, ARK. - CAMP BLANDING, FLA.
SATELLITES AND PERIOD: (SEE BELOW)
750 TOTAL PASSES CROSSED THE BASELINE
377 PASSES WERE BELOW 401 MILES - 50.1% OF TOTAL
SATELLITES AND PERIOD EXAMINED:
1958 DELTA, 1 MAY 59 - 1 DEC. 59
1958 EPSILON, 1 MAY 59 - 23 OCT. 59 (DECAY)
1959 EPSILON, 13 AUG. 59 (LAUNCH)
-23 SEPT. 59 (DECAY)
1959 ZETA, 19 AUG. 59 (LAUNCH)
-20 OCT. 59 (DECAY)
1959 IOTA, 13 OCT. 59 (LAUNCH) - 1 DEC. 59
1959 KAPPA, 7 NOV. 59 (LAUNCH)
-26 NOV. 59 (DECAY)
% OF TOTAL PASSES
0
10
20
30
40
14 PASSES
8 PASSES
26 PASSES
14 PASSES
18 PASSES
14 PASSES
18 PASSES
26 PASSES
141 PASSES
9 PASSES
65 PASSES
18 PASSES
6 PASSES
0-14 15-29 30-44 45-59 60-74 75-89 90-104 105-119 120-134 135-49 150-164 165-179 180-194
0 1 2 3 4 5 6 7 8 9 10 11 12
1 2 4 6 8 10 12 14 16 18 20 22 24
TIME IN SECS. IN BEAM
HITS WITH 15 SEC. SCAN RATE
HITS WITH 7.5 SEC. SCAN RATE

FIG. 18

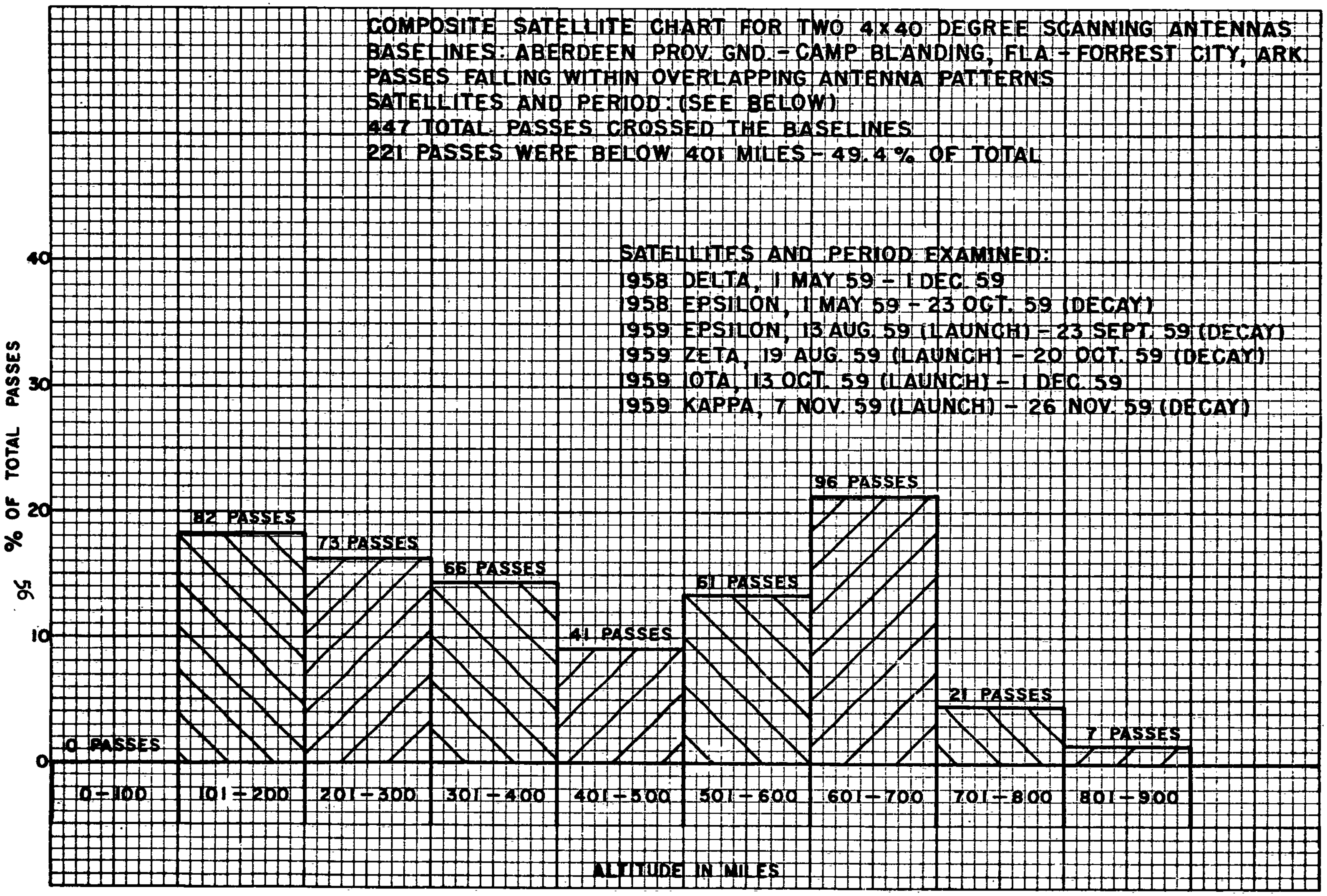

COMPOSITE SATELLITE CHART FOR TWO 4 x 40 DEGREE SCANNING ANTENNAS
BASELINES: ABERDEEN PROV. GND. - CAMP BLANDING, FLA - FORREST CITY, ARK.
PASSES FALLING WITHIN OVERLAPPING ANTENNA PATTERNS
SATELLITES AND PERIOD: (SEE BELOW)
447 TOTAL PASSES CROSSED THE BASELINES
221 PASSES WERE BELOW 401 MILES - 49.4 % OF TOTAL
SATELLITES AND PERIOD EXAMINED:
1958 DELTA, 1 MAY 59 - 1 DEC. 59
1958 EPSILON, 1 MAY 59 - 23 OCT. 59 (DECAY)
1959 EPSILON, 13 AUG. 59 (LAUNCH) - 23 SEPT. 59 (DECAY)
1959 ZETA, 19 AUG. 59 (LAUNCH) - 20 OCT. 59 (DECAY)
1959 IOTA, 13 OCT. 59 (LAUNCH) - 1 DEC. 59
1959 KAPPA, 7 NOV. 59 (LAUNCH) - 26 NOV. 59 (DECAY)
% OF TOTAL PASSES
40
30
20
10
0
0 PASSES
82 PASSES
73 PASSES
66 PASSES
41 PASSES
51 PASSES
96 PASSES
21 PASSES
7 PASSES
0 - 100
101 - 200
201 - 300
301 - 400
401 - 500
501 - 600
601 - 700
701 - 800
801 - 900
ALTITUDE IN MILES

FIG. 19

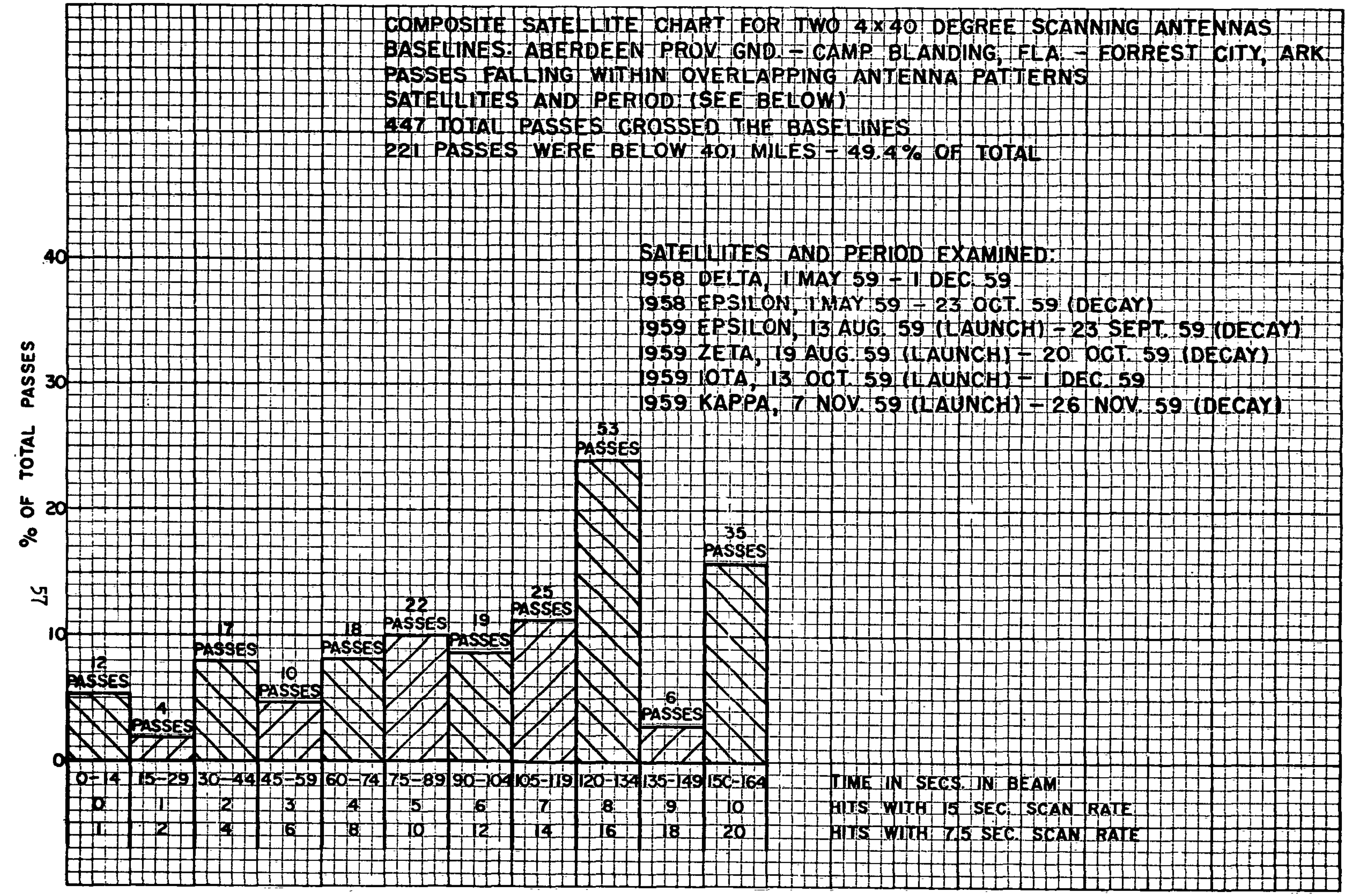

COMPOSITE SATELLITE CHART FOR TWO 4x40 DEGREE SCANNING ANTENNAS
BASELINES: ABERDEEN PROV. GND. – CAMP BLANDING, FLA. – FORREST CITY, ARK.
PASSES FALLING WITHIN OVERLAPPING ANTENNA PATTERNS
SATELLITES AND PERIOD: (SEE BELOW)
447 TOTAL PASSES CROSSED THE BASELINES
221 PASSES WERE BELOW 401 MILES – 49.4% OF TOTAL
SATELLITES AND PERIOD EXAMINED:
1958 DELTA, 1 MAY 59 – 1 DEC. 59
1958 EPSILON, 1 MAY 59 – 23 OCT. 59 (DECAY)
1959 EPSILON, 13 AUG. 59 (LAUNCH) – 23 SEPT. 59 (DECAY)
1959 ZETA, 19 AUG. 59 (LAUNCH) – 20 OCT. 59 (DECAY)
1959 IOTA, 13 OCT. 59 (LAUNCH) – 1 DEC. 59
1959 KAPPA, 7 NOV. 59 (LAUNCH) – 26 NOV. 59 (DECAY)
% OF TOTAL PASSES
0
10
20
30
40
12 PASSES
4 PASSES
17 PASSES
10 PASSES
18 PASSES
22 PASSES
19 PASSES
25 PASSES
53 PASSES
6 PASSES
35 PASSES
0-14
15-29
30-44
45-59
60-74
75-89
90-104
105-119
120-134
135-149
150-164
TIME IN SECS. IN BEAM
0 1 2 3 4 5 6 7 8 9 10
HITS WITH 15 SEC. SCAN RATE
1 2 4 6 8 10 12 14 16 18 20
HITS WITH 7.5 SEC. SCAN RATE

FIG. 20

Table III

1. Base Line

Aberdeen Proving Ground, Md. - Camp Blanding, Fla. (APG)
Forrest City, Ark. - Camp Blanding, Fla. (FCY)
Overlap - Area encompassed by both of the above patterns

2. Satellites and Period Examined

1958 Delta, 1 May 59 - 1 Dec 59
1958 Epsilon, 1 May 59 - 23 Oct 59 (decay)
1959 Epsilon, 13 Aug 59 (launch) - 23 Sep 59 (decay)
1959 Zeta, 19 Aug 59 (launch) - 20 Oct 59 (decay)
1959 Iota, 13 Oct 59 (launch) - 1 Dec 59
1959 Kappa, 7 Nov 59 (launch) - 26 Nov 59 (decay)

3. Altitude Distribution

	APG	FCY	Overlap
Total Passes	814	750	447
Passes below 401 miles	400	377	221
Percentage of total below 401 miles	49.1	50.3	49.4

4. Time-in-Beam Distribution

For APG base line 53.0% of the passes are in the beam from 150-179 secs.
For FCY baseline 54.6% of the passes are in the beam from 120-164 secs.
For overlap pattern 39.8% of the passes are in the beam from 120-164 secs.

B. DOPLOC Filters

The scanning beam concept requires that Doppler frequency measurements be made in periods of 0.1 to 1.0 second for satellite detection. New techniques have been or are being developed to meet these needs of scanning the Doppler frequency spectrum with the required narrow band filter and measuring the frequency in very short time intervals. Two techniques are being explored.

One developed at BRL is the comb filter. Unitized, transistorized printed circuit filters have been designed, tested, and found to be practical in a multi-comb filter circuit. It is proposed to expand the size of the comb filter to provide a filter giving complete coverage of the Doppler spectrum with 3 to 10 cps filter bandwidth. The second technique, using the circulating memory filter (CMF) developed for the ORDIR radar by Columbia University, has been studied with a view toward application to the DOPLOC problem and found to be theoretically sound. Specifications have been prepared and negotiations initiated for procurement of one or two CMF's for use with the scanning system. In addition, work underway through contract with Interstate Engineering Corporation to develop an improved phase-locked tracking filter was initiated but has been stopped, pending overall program direction from ARPA.

BRL Comb Filter - BRL has developed a new tracking filter system, termed the "comb Filter," to replace the Interstate Electronics Corporation's Model IV tracking filter and the BRL Automatic Lock-On (ALO) now in use.

Briefly, the new comb filter system consists of 180 printed circuit, transistorized filters each with a bandwidth that can be set between 3 and 10 cps. The center frequency of each filter is tuned 20 cps away from the center frequency of adjacent filters. The 180 filters cover a total frequency range of 3600 cps and the system can be switched to cover any 3600 cps band. Signals with a minimum duration of 0.1 second can be measured and analog recording is accomplished by means of a 200-channel chart recorder. Each filter controls an individual recording pen and the remaining 20 pens are utilized for timing reference marks and other functions. Each pen commences to write when a signal enters the frequency range of its particular filter and continues to write as long as the signal remains within the frequency range of that filter. Additional circuitry provides for rapid fault isolation and frequency calibration of the system in the field, by digitally displaying the actual individual filter frequency and the desired filter frequency simultaneously at the rate of 30 readouts per minute, thus enabling the operator to detect and correct filter drift while the system is performing. The complete comb filter system, including test and calibration equipment, will be mounted in two standard 19-inch relay racks.

Advantages of the new comb filter system over the present tracking filter and automatic lock on (ALO) system include the following:

The present system can sense and record only one signal at a time (where two signals are present simultaneously the ALO will lock-on the stronger), whereas the comb filter system can sense and record as many as 18 signals of varying strength simultaneously.

The ALO scans a 4 KC band in 0.4 second and the center frequencies of the filters are spaced 100 cps apart. The new system combines 20 cps center-to-center filter spacing and continuous operation of all 180 filters over a 3600 cps band, thus reducing the frequency range through which a signal can pass undetected as well as reducing signal acquisition time.

A strong spurious signal locks the ALO and, by doing so, prevents a true signal from being sensed anywhere else in the entire 4 kc band as long as the spurious signal is present. The comb filter system, sensing a spurious signal as strong as 1:1 S/N, locks only a 200 cps band (10 individual filters) while the other 170 filters remain available to sense a true signal.

Techniques and machinery have been developed for rapid, efficient production of the printed circuit filter boards. A printed circuit etcher, which holds 8 filter boards and etches and washes them in 2-1/2 minutes, was built to speed the etching process. A rapid silk screen printer (120 boards per hour), utilizing a photo-sensitive emulsion and a simple inked drawing, produces perfect registry between printed component designation and component mounting holes in the board. Dip soldering of the boards is accomplished using a soldering machine that incorporates a solder pump to create a wave of molten solder. The boards are passed through the crest of the wave and solder is deposited on the circuit without subjecting the board to prolonged high temperature.

The overall comb filter system, including test and adjustment, has been completed. The required 180 filter boards have been built and assembled and individually tested. The fault isolation and frequency calibration circuitry has been constructed and testing completed. Installation and operation of the complete system will be at the Forrest City receiving site.

Circulating Memory Tracking Filter (Columbia University) - In July 1959, Columbia University was requested to present a description of their circulating memory filter and digital readout to enable BRL to evaluate the system for possible use with the DOPLOC system. The main points discussed were the complexity and reliability of the circuitry, the equivalent bandwidth, the signal-to-noise ratio capability, the reaction of the system to sliding frequency, the total frequency band coverage and the time required to obtain a frequency measurement. Input and terminal equipment to be compatible with present field equipment was also discussed.

After several joint conferences to determine the system best suited to DOPLOC requirements, Columbia prepared preliminary specifications for the Circulating Memory Filter and Digital Readout. These specifications, submitted to BRL in August 1959, called for a 12 kc frequency range covered in three 4 kc steps, each step requiring 0.1 second to observe and readout the value of frequency. The nominal filter bandwidth was designated as 10 cycles with continuous control to 50 cycles.

During the period these specifications were being prepared, however, several significant changes were made in the basic DOPLOC system and requirements. The decision was made to change the r.f. carrier frequency from the present 108 mc/s to 150.79 mc/s, and the allowable frequency readout time was reduced to a minimum. In addition, the Ballistic Research Laboratories' personnel decided that the digital readout system that Columbia had initially proposed would be too easily saturated, and that more flexible and efficient readout circuitry could be produced locally.

In view of these changes, Columbia was asked to alter the original specifications to meet these new requirements and to delete the digital readout completely. The revised specifications were submitted in September 1959 and resulted in a new filter range of 24 kc to be covered in 12 kc/s steps with each step requiring 0.1 second for readout. All other filter characteristics remain unchanged. A brief review of the revised specifications is presented below:

The Circulating Memory Filter (CMF) shall have a frequency range of $10{,}994 {}^{+1}_{-0}$ to $11{,}006 {}^{+1}_{-0}$ kc with the exact frequency to be determined by the minimum overlap necessary to insure coverage of the 24 kc band in two steps. Input resistance will be 100 ± 2 ohms and the self-generated noise will be such that if 1.0 mv rms noise voltage is applied to the input, the output shall increase by no less than 3.0 db. Coherent integration time will be variable from 20 to 110 msec in approximately 1 msec steps. The CMF will begin integration of an input voltage in 1.0 msec (max.) after receiving the start command, a 5 volt positive pulse, 1-3 microsec duration, 0.5 microsec risetime. For inputs from 10-40 db the output-input comparison will be linear within 5 per cent, and above 40 db the AGC output shall not exceed 55 db. Video outputs shall be provided for entire integration time, gated video during display period and gated video during the 13 channel display times (12 signal channels and 1 calibration channel). A continuously variable threshold level will be provided from 15-35 db and nominally set at 24.4 db. The CMF will supply both positive-going and negative-going outputs in the form of a positive 2 volt pulse, 0.2-3.0 microsec duration, 0.05 microsec risetime (max.). The equipment will be operated on 105-120 VAC,50-60 cps power.

Interstate Electronics Corporation Tracking Filter - In June 1959 a contract was negotiated with Interstate Electronics Corporation, Anaheim, California, calling for a research program leading to the development of an improved phase-lock tracking filter and satellite acquisition system. Phase I of this contract required a feasibility study, Phase II the design and development and Phase III the fabrication and delivery of two tracking filters and acquisition systems. In mid-November 1959 the Phase I report was submitted to BRL and an extract is presented below.

For passive satellite detection the proposed system is made of three basic filter units, each consisting of two mixers, two band rejection filters, a local oscillator and a bank of 267 narrow-band filters with detectors and gate circuits. The narrow-band filters have a 10 cps bandwidth and the center frequencies of adjacent filters are spaced 30 cps apart. When a signal appears in the band, the proper gate is opened for an adjustable period (0.1 to 1 second) after which the signal is fed to a frequency counter. With the three basic units (801 filters) connected in parallel, a Doppler signal can be detected in any 8 kc band from 0 to 200 kc in 0.1 second, while connecting them in series permits detection in any 24 kc band from 0 to 200 kc in 0.3 second.

An important feature of the system is apparent if a signal should drop out during the counting period. Under this condition it is still possible to accurately ascertain the signal frequency, because once the gate has been opened, only the frequency components corresponding to the pass band of the filter are transmitted. Thus, once the detector has "decided" that a signal is present, the system allows accurate measurement of the resonant frequency of the gated filter. In a severe case where a signal opens the appropriate gate and then immediately drops out, calculations show that an integration period of only 0.1 second will produce an rms frequency measurement accurate to 3.2 cps. Consideration is given to the false-alarm rate and missed signal probability of the proposed system. Based on preliminary tests and available literature, it is anticipated that the false-alarm rate will be a maximum of four false alarms per hour for 801 filters and the probability of missing a signal will be 1 in 50.

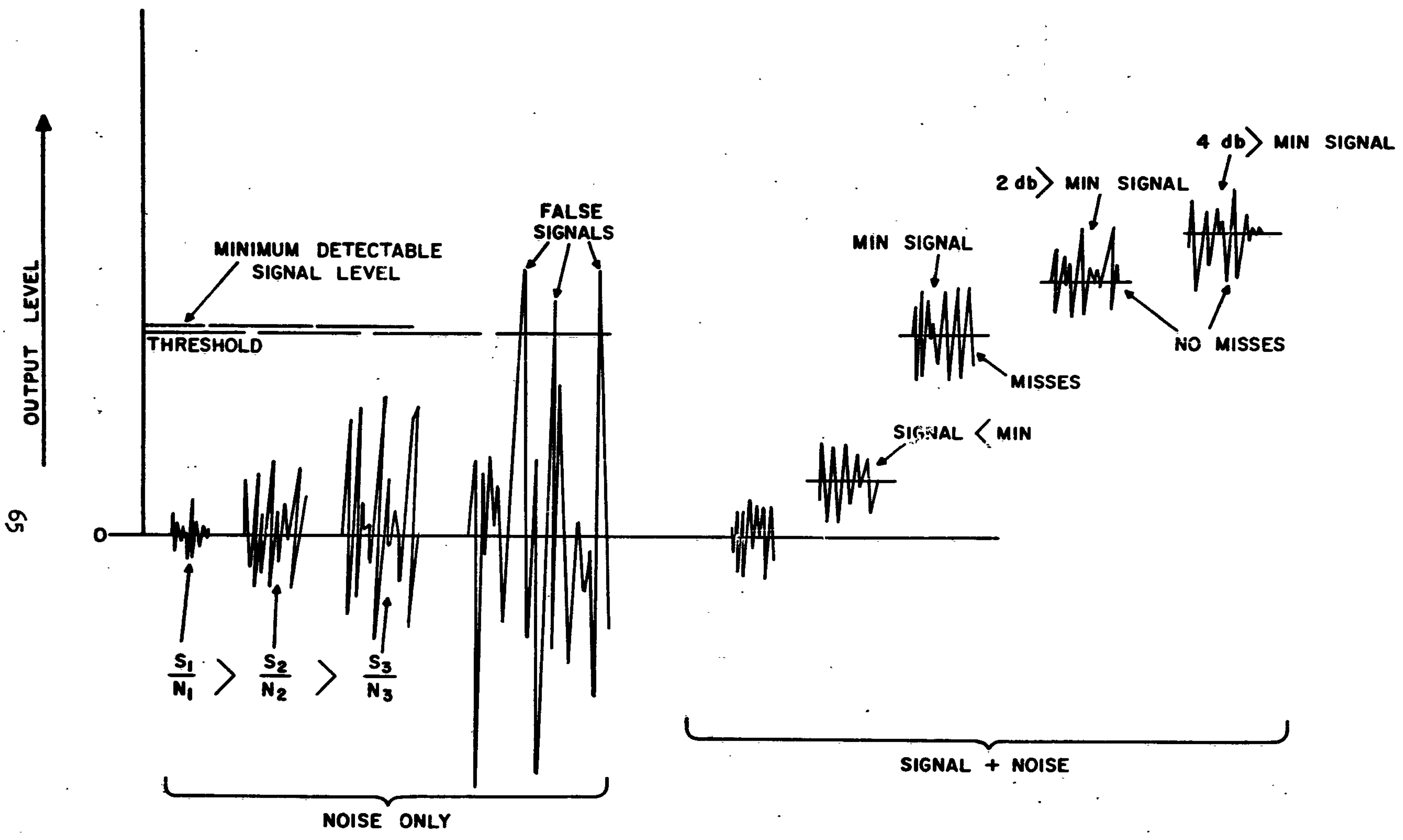
For active satellite tracking it is necessary to detect the Doppler signal and then lock the tracking filter onto the incoming signal. The active signal detection system is identical with the passive detection system; however, after the signal has been detected, it is used to servo the tracking filter to the same frequency as the input Doppler. The proposed tracking filter will be a more sophisticated version of the current Model IV, and new features include a tracking range of 100 to 200,000 cps, a maximum lock-on time of 0.5 second in an 8 kc range, a continuously variable bandwidth ranging from 3 to 300 cps, an automatic sweep for locating a Doppler signal and an automatic memory circuit which will eliminate the null meter.

Interstate concludes that both systems are entirely feasible and proposes, as a part of the early work during Phase II, the construction and test of approximately 50 filters, in order to optimize system design and more accurately predict acquisition and detection performance i.e., long-term false-alarm rate and missed signal probability.

Due to budgetary limitations, the Ballistic Research Laboratories have canceled the remaining portions of this contract.

C. Experimental Verification of Threshold Levels for Noisy Signals

In the reception of satellite signals one of the basic problems is the extraction of signal from the noise. When using narrow band filters as the means of improving the S/N ratio the problem resolves itself into setting the proper threshold level. This level must be a compromise among three things; the minimum usable signal, the number of false alarms, and the number of misses. Figure 21 is a pictorial display to aid in describing these terms. The threshold level is a level above which the signal must rise before it is recognized. The mimimum detectable signal is then the same as the threshold level. When the noise spikes are large enough to appear above the threshold level these spikes are called false alarms. When signal and noise are present and equal to or above the threshold and the noise spikes go below the threshold these intervals are called misses. As shown in Figure 21 as the minimum usable signal is raised above the threshold by 2 to 4 db, the number of misses will decrease for a given noise level. However maintaining a fixed S/N ratio as



SIGNAL WAVE FORMS

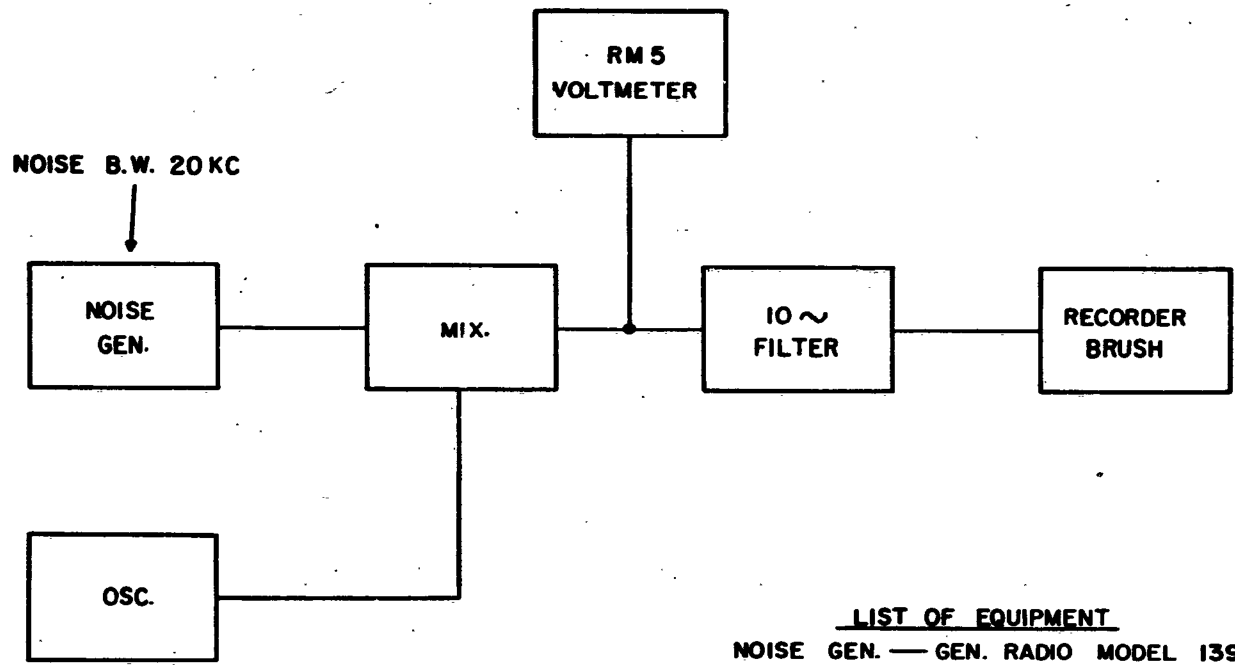
FIG. 21

the signal level is increased 2 to 4 db, the noise is also increased the same amount. The problem then is to determine what S/N ratio and signal level give the best compromise between the number of false alarms and the number of misses.

Tests were made experimentally to determine the correlation between these parameters so that a compromise solution could be obtained. Figure 22 is a block diagram of the circuit used in the tests. Two sets of tests were run. One, to find the number of false alarms versus S/N ratio with the signal at threshold, 2 and 4 db above threshold. Two, to find the number of misses versus signal to noise ratio with the signal at threshold, 2 and 4 db above threshold.

The tests were made in the following manner. The threshold of the filter was set to 4 volts. The oscillator level was adjusted until the filter output was 4.1 volts. This input level was then recorded and the oscillator signal removed. Based on the bandwidth reduction for the noise the input noise level was calculated that would give 3, 5, 7, 10, and 13 db S/N output ratio from the filter if the measured signal was applied. Each noise level was then applied and a two minute continuous recording was made of the filter output. The pulses above the threshold were then counted and plotted as the average number per 10 second interval, as shown in Figure 23. The number of false alarms that can be allowed is mainly a function of the saturation capability of the readout system.

In the second test the noise and signal were applied simultaneously and the noise varied to obtain the desired S/N ratio. The number of pulses extending below the threshold were then counted. However in plotting the number of misses it is important to evaluate their detrimental effect upon the received signal. In our particular case the received signal is 0.1 of a second in duration and will occur once every 10 seconds. If we then assume that any noise spike can be 0.1 second or longer and completely eliminate the signal, then we are interested in the probability of a noise pulse occurring in any



LIST OF EQUIPMENT

NOISE GEN. — GEN. RADIO MODEL 1390-A
VOLTMETER — BALLANTINE MODEL 320
OSCILLATOR — H.P. 200 C.D.
FILTER — 10~ ACTIVE @ 4000~
RECORDER — BRUSH MARK II

BLOCK DIA. FOR NOISE TEST

FIG. 22

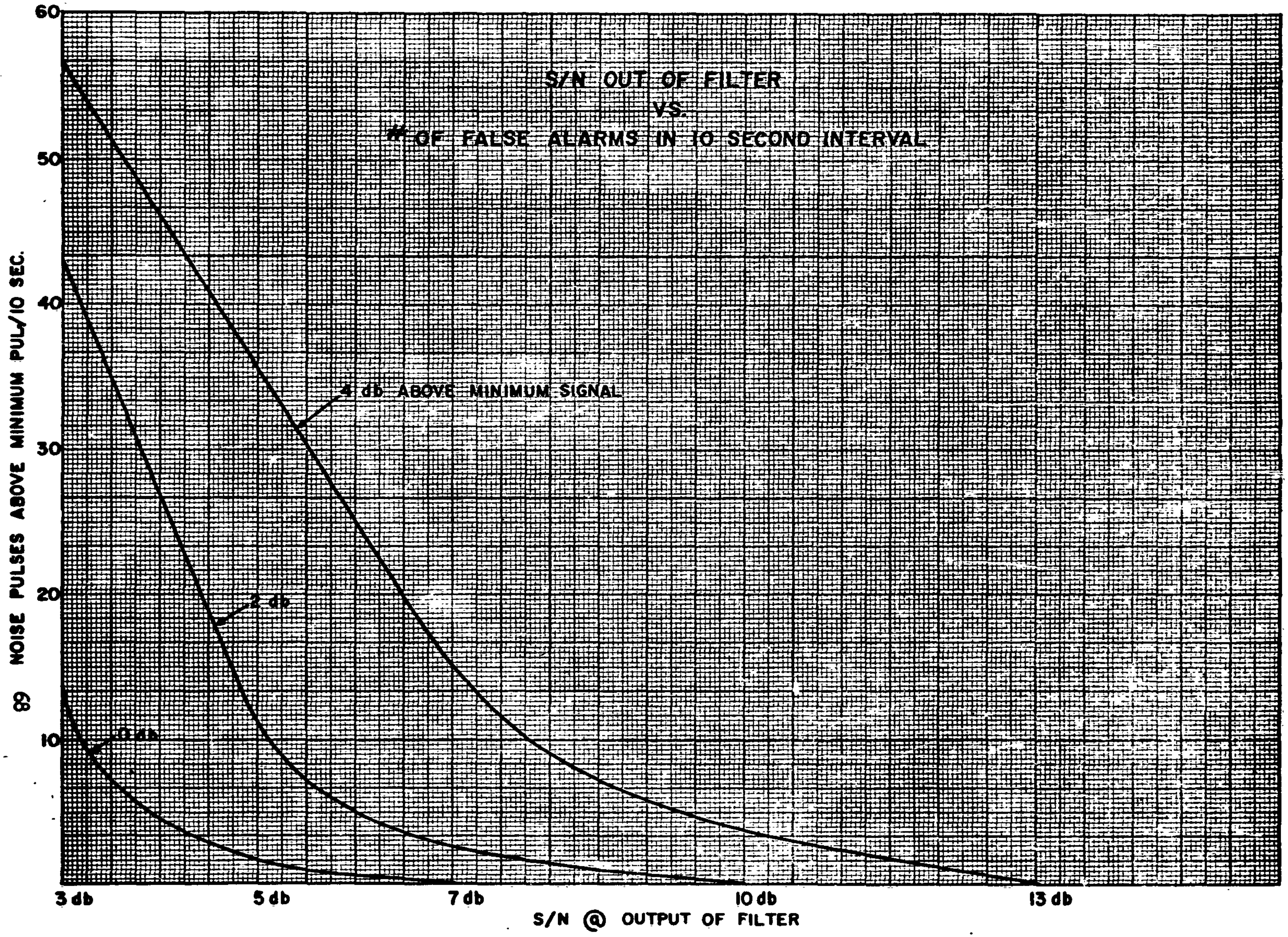

S/N OUT OF FILTER
VS.
OF FALSE ALARMS IN 10 SECOND INTERVAL
NOISE PULSES ABOVE MINIMUM PUL/10 SEC.
60
50
40
30
20
10
4 db ABOVE MINIMUM SIGNAL
2 db
0 db
3 db
5 db
7 db
10 db
13 db
S/N @ OUTPUT OF FILTER

FIG. 23

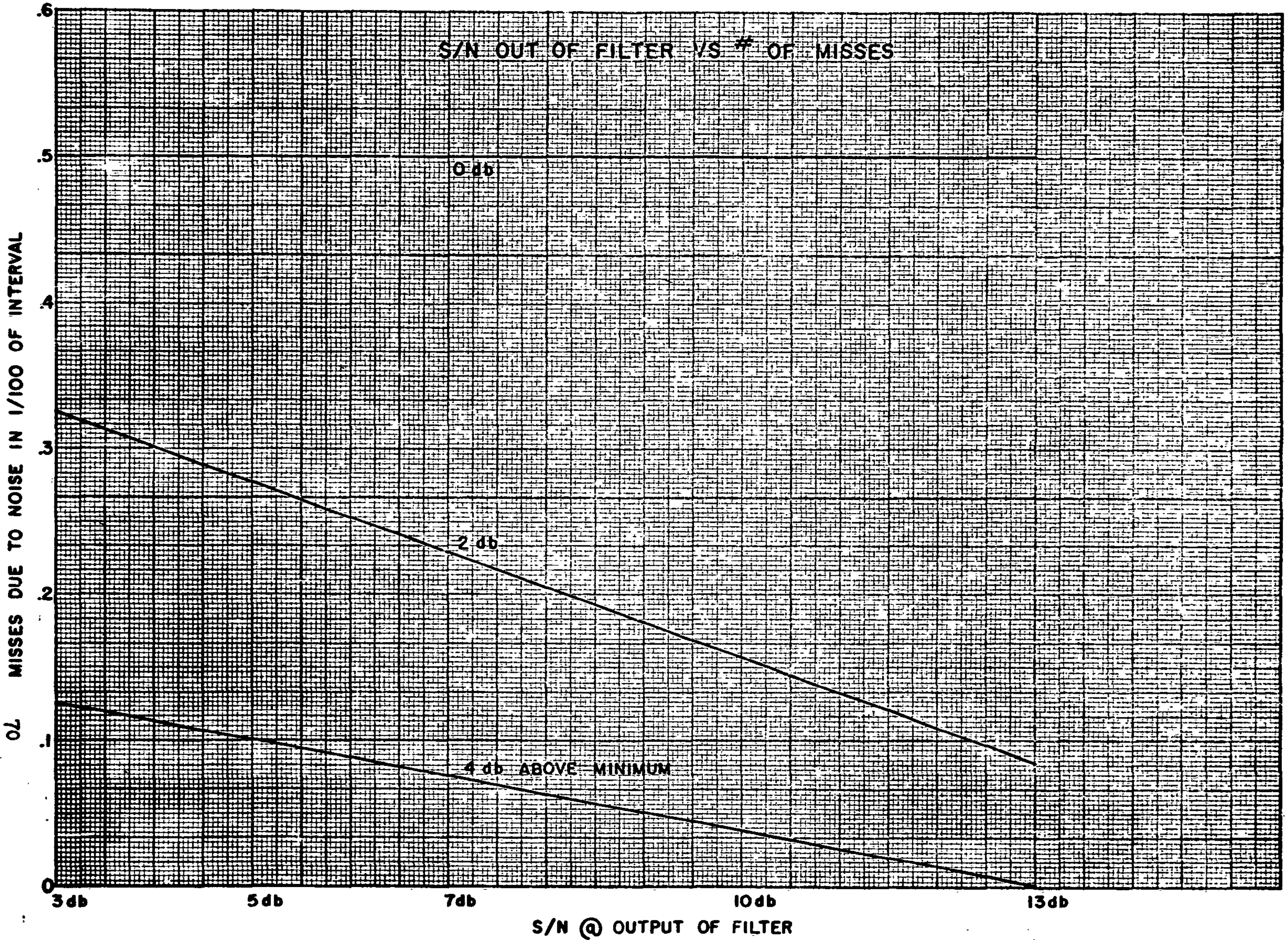
0.1 second period in the total 10 second interval. Since 0.1 second represents 1/100 of the total interval, the plot shows 1/100 of the total number of misses. This plot is shown in Figure 24.

Finding the best compromise threshold is now the next step. Assume we are trying to find a 0.1 second duration signal, in a 10 kc bandwidth, which occurred once every ten seconds. If we allow even one pulse per 10 cycle bandwidth every 10 seconds this gives a total of 1000 extra pulses per data point. This would be an almost impossible sorting problem. If we then assume we will work with essentially zero false alarms we then turn to the number of misses possible when there are zero false alarms. In Figure 23, at a S/N ratio of 7 db on the 0 db signal curve, there are zero false alarms. Carrying this to Figure 24 at 7 db S/N and 0 db signal we have a probability of 0.5, which would indicate that we would lose every other signal point. This is not acceptable. Again in Figure 23 at 10 db S/N ratio and 2 db above minimum signal, we have zero false alarms. In Figure 24 at 10 db S/N and 2 db above minimum we have a probability of 0.15. This means we would miss one out of every six data points.

The conclusions drawn from these tests indicate we must work somewhere between 10 db S/N, at 2 db above minimum, and 13 db S/N, at 4 db above minimum, if we are to approach optimum conditions.

D. Stanford Research Institute Contract

Under Contract DA-04-200-ORD-674, Stanford Research Institute conducted a brief investigation of the design of a ground-based fan beam antenna with a 4 x 40 degree beamwidth. The design objective was to obtain the required beamwidth and pattern shape with the minimum height structure. Results show that with dipole radiating elements, the greatest gain per unit array length is obtained with a dipole to dipole spacing of 5/8 wave length. A total array length of 11.9 wave lengths is required for a 4 degree beamwidth. If the elements that make up the array have more directivity than a half wave length dipole (for example, a Yagi antenna), it is possible to form the 4 degree


S/N OUT OF FILTER VS # OF MISSES
0 db
2 db
4 db ABOVE MINIMUM
MISSES DUE TO NOISE IN 1/100 OF INTERVAL
.6
.5
.4
.3
.2
.1
0
3db
5db
7db
10db
13db
S/N @ OUTPUT OF FILTER
FIG. 24

beam with fewer fed elements and an array length 0.9 wave lengths shorter. No reflecting screen would be necessary with the Yagi elements; therefore, a considerable reduction in weight and antenna feed cables is realized compared with using dipoles.

A study was made of the antenna coverage required for the simultaneous detection of satellites at more than one receiving station, using a single, common, illuminating transmitter. The conclusion reached was that it is a very inefficient use of transmitter power and difficult, if not impossible, to design an antenna system for the simultaneous tracking of a satellite at more than one receiving site using a single transmitting antenna. An exception is the case where the two receiving sites are in line with the transmitter, preferably on the same side of it. Consequently, all subsequent system designs have been based on a separate transmitting antenna for each receiving site.

The effects of varying the overall DOPLOC system sensitivity, antenna gain and pattern shape on detectable meteor rates has been investigated. Expressions relating expected meteor rates with antenna gain, system sensitivity, and bandwidth have been derived and reported in the Bi-Monthly project report. A reasonably good estimate of the number of trail echoes to be detected by a system with specified parameters can be made. However, the ratio of trail to head (Doppler) echoes for a given set of parameters is not yet understood sufficiently to make an estimate of head echo number with a high degree of confidence. The factors which determine the head echo rate are being investigated.

Studies previously made on the design and adaption of corner reflector antennas to the DOPLOC system have been completed and a report has been prepared. The report is entitled, Corner-Reflector Antenna Studies, Technical Memorandum 1, Contract DA-04-200-ORD-674, September 1959, by W. E. Scharfman, Stanford Research Institute, Menlo Park, California. The corner reflector has the desirable property of very convenient polarization change, from circular to linear, with the rotation of the feed dipole and the basic antenna configuration lends itself to a multibeam design which was once considered for large volume coverage.

A summary of the analysis of the frequency shift and frequency spectrum of the received signal as it moves across the main beam and side lobes of a high gain receiving antenna is being made. Curves of frequency shift and rate of change of frequency for a 4 degree and 1 degree beamwidth antenna scanned at a rate of 15 degrees per second have been prepared. The receiver band width required to pass the resultant information rates imposed by the moving satellite and the moving antenna can be determined from these results.

Calculations were made of the patterns produced by a Wullenweber array that is excited unsymmetrically about the beam direction. Specifically the narrowing of the broad plane pattern was investigated.

E. Cosmic Noise and Interference at New DOPLOC Frequency

Early in November, BRL received a frequency allocation at 150.79 megacycles per second for use with the scanning beam DOPLOC system. Using a dipole antenna, a preamplifier, a sensitive receiver and a decibel meter, a study was made of the interference occurring over the frequency band of 148-153 mc/s. Graphic recordings of signal level were also made. Taxi service dispatch signals were observed at 149-153 mc/s. Except for cosmic and receiver noise the band from 150-151 mc/s was clear. Calibrating the db meter to an arbitrary scale reading of 10 when the preamplifier was terminated with 50 ohms showed a cosmic noise ranging from 0.5 to 1.75 db above the reference point. Starting at 0800 hours local time the noise gradually increased to a peak at around 1200 hours and then decreased toward evening. Using the same equipment and reference point but tuned to 108 mc/s the noise level ranged from 1.5 db to 3 db above the reference with a similar amplitude distribution as a function of time between 0800 and 1630 hours. No local interference was observed except when vehicles passed within about 200 yards of the antenna.

SECTION VI

EXPERIMENTAL USE OF FIELD FACILITIES

A. Field Station Operation Schedule

Following permission from ARPA to discontinue routine twenty-four hour operation, the station personnel complement was reduced from 15 men per station to seven men per station and a basic eight hour work day was adopted on or about 1 October 1959. The actual hours of operation were chosen to adapt the work schedule to the times of most frequent predicted passes. The selection of shift hours was done in the interest of obtaining a maximum amount of data and the most dependable equipment operation. This has resulted in a nominal eight-hour work day, 5 days per week per man, at the Forrest City receiving station and at the Fort Sill transmitting station. The receiving station at the White Sands Missile Range was deactivated and closed down on 1 October 1959. The equipment from this station is being shipped to the Ballistic Research Laboratory for use in the local station and other sites selected for the proposed scanning system.

B. Experimental Techniques and Results

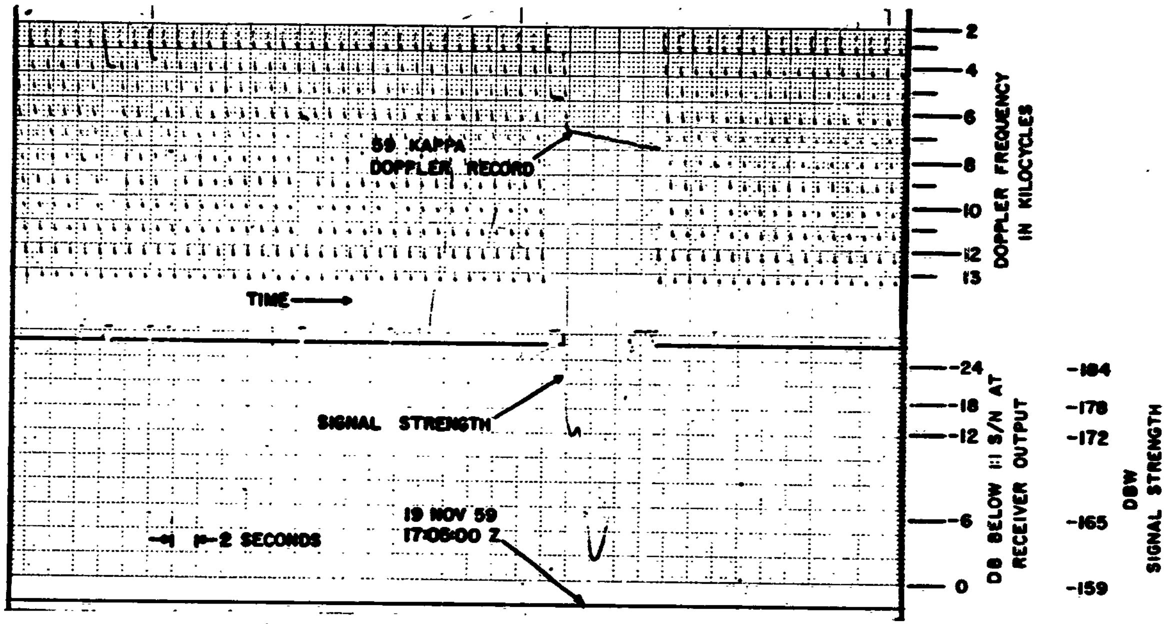
The flexible schedule by which the field stations have been operated has provided data from known satellites, unidentified flying objects (UFO's), meteors and cosmic noise which has served as the basis of the design parameters used in the advanced DOPLOC scanning system proposal. All of the data on known satellites and UFO's has been sent to Space Track via the direct teletype service from BRL. Since the stations are not operated 24 hours a day and the interim DOPLOC system now in operation does not have the transmitter power or antenna gain to give its full range capability, the data obtained to date does not constitute a complete tracking record of all of the objects known to be in orbit. However, within the capabilities of the equipment currently in use, a very effective dark satellite detection technique has evolved from the extensive field tracking experience and laboratory studies. Many satellites and UFO's have been successfully detected by the DOPLOC technique and their time of crossing, altitude, east-west position and effective reflection cross-section determined from single pass data from the single receiving station now in operation. The information on satellite crossing time and position has been forwarded to Space Track in each case for inclusion in their orbital prediction computation program.

The system used for dark satellite detection and location consists of the 50 kw, 108 mc transmitter at Fort Sill, Oklahoma, vertically directed fan beam antennas at the transmitting and receiving station, a bank of audio frequency filters, a phase-lock tracking filter and analog and digital doppler frequency recorders. A doppler signal response in one of the fixed filters activates a control circuit which pulls the tracking filter frequency over to the signal frequency and causes a phase lock to it. The tracking filter then tracks the doppler signal continuously as the satellite passes through the antenna beam. The narrow dimension of the antenna beam for transmitting and receiving is 8 degrees, at 3 db down, which results in signal durations of 3 to 11 seconds depending upon the satellite altitude and orbital inclination.

The forms in which DOPLOC doppler data are currently recorded for satellite detection are shown in Figure 25. A record of 59 Kappa, Discoverer VII, is shown. An explanation of this record and the Automatic Lock-On (ALO) system by which it was obtained follows. The upper portion of the chart is a record of the tracking filter output frequency. The short, evenly spaced, marks indicate the successive frequencies at which the tracking filter is set while the receiving system is in the search mode. The tracking filter is stepped in 1 kc intervals to maintain a frequency midway in the 1 kc spectrum to which the comb filters are set. This is done to minimize the time required to pull the tracking filter to a signal frequency detected in one of the fixed filters. The comb filter bank consists of ten filters, each with 20 cps bandwidth, spaced 100 cps apart. The filter bank "looks" at a frequency spectrum 1 kc wide for 0.1 second after which it is switched up 1 kc by a heterodyne method and the process continues, either until the full sweep spectrum has been covered or a signal is detected. Figure 25 shows the output of the tracking filter when a 12 kc scan is used. The 12 steps from 2500 to 13,500 kc to which the tracking filter is positioned

Z TIME	PERIOD
1 7 0 5 0 4	1 3 3 7 4
1 7 0 5 0 3	1 3 6 0 7
1 7 0 5 0 2	1 3 8 1 3
1 7 0 5 0 1	1 4 0 2 7
1 7 0 5 0 0	1 4 2 4 7
1 7 0 4 5 9	1 4 4 7 2

DIGITAL DOPPLER PERIOD
PRINT RECORD



ARPA — BRL DOPLOC DOPPLER RECORD OF
59 KAPPA REV 183 FORREST CITY, ARKANSAS
MEASURED 17:04:58 Z, PREDICTED 17:06 Z
ALTITUDE 115 MILES, 314 MILES EAST FT. SILL
CENTER ANTENNA, NORTH-SOUTH PASS

Fig. 25

requires 1.2 seconds of time. The ALO has also been operated with a reduced scan range of 4 kc and recently at only 2 kc to reduce the scan time and "frequency holes" in order to increase the probability of the doppler frequency matching a fixed filter frequency. Figure 26 pictorially displays the first 2 kc of the total 12 kc (2 - 14 kc) frequency scan of the original ALO. In the first 0.1 second the range 2 to 3 kc is scanned, in the second 0.1 second the 3 to 4 kc range is scanned. This continues until the 13 to 14 kc range is scanned 1.2 seconds later. The process is then repeated for the 2 kc - 3 kc range for the 0.1 second interval from 1.2 - 1.3 seconds, etc. The dark blocks represent the 20 cps bandwidth fixed filters separated by 100 cps. As noted, a doppler signal changing at a 30 cps^2 rate could be detected at a frequency just past the band of the first fixed filter. The signal with such a frequency slope would not be detected on the repeat scans at 1.2, 2.4, 3.6 or 4.8 seconds and conceivably would take considerable time to be detected. However a signal with a 120 cps^2 slope would be detected on the second scan at 2.4 seconds. Thus it can be seen that the dead bands between the fixed filters considerably lengthen the time to acquire the signal.

This limitation can be overcome by either scanning at a more rapid rate or adding more fixed filters to fill the dead space. The crossed blocks indicate earlier detection of the signal by decreasing the extent of scan by a factor of 3. Here we note that the 30 cps^2 slope signal is detected 2.8 seconds after the start of the search interval and the 120 cps^2 slope signal is detected in .8 seconds. Thus the former signal which was missed entirely by the 12 kc scan is detected in 2.8 seconds with the 4 kc scan while the latter signal is detected 1.6 seconds earlier, thereby increasing both the probability of detection and the duration of the detected signal.

Figure 27 indicates in section C (comb filters) the improvement obtained by adding more filters to comb filter. Here 10 cps wide, fixed filters, are spaced 20 cps apart. The comb filter is not electronically scanned but the shift of the signal frequency accomplishes the scanning. Here we see that the 30 cps^2 slope signal is detected in 0.5 seconds and the 120 cps^2 signal is detected in 0.1 seconds. A and B in Figure 27 are identical to Figure 26 explained above and are added for comparison purposes only.

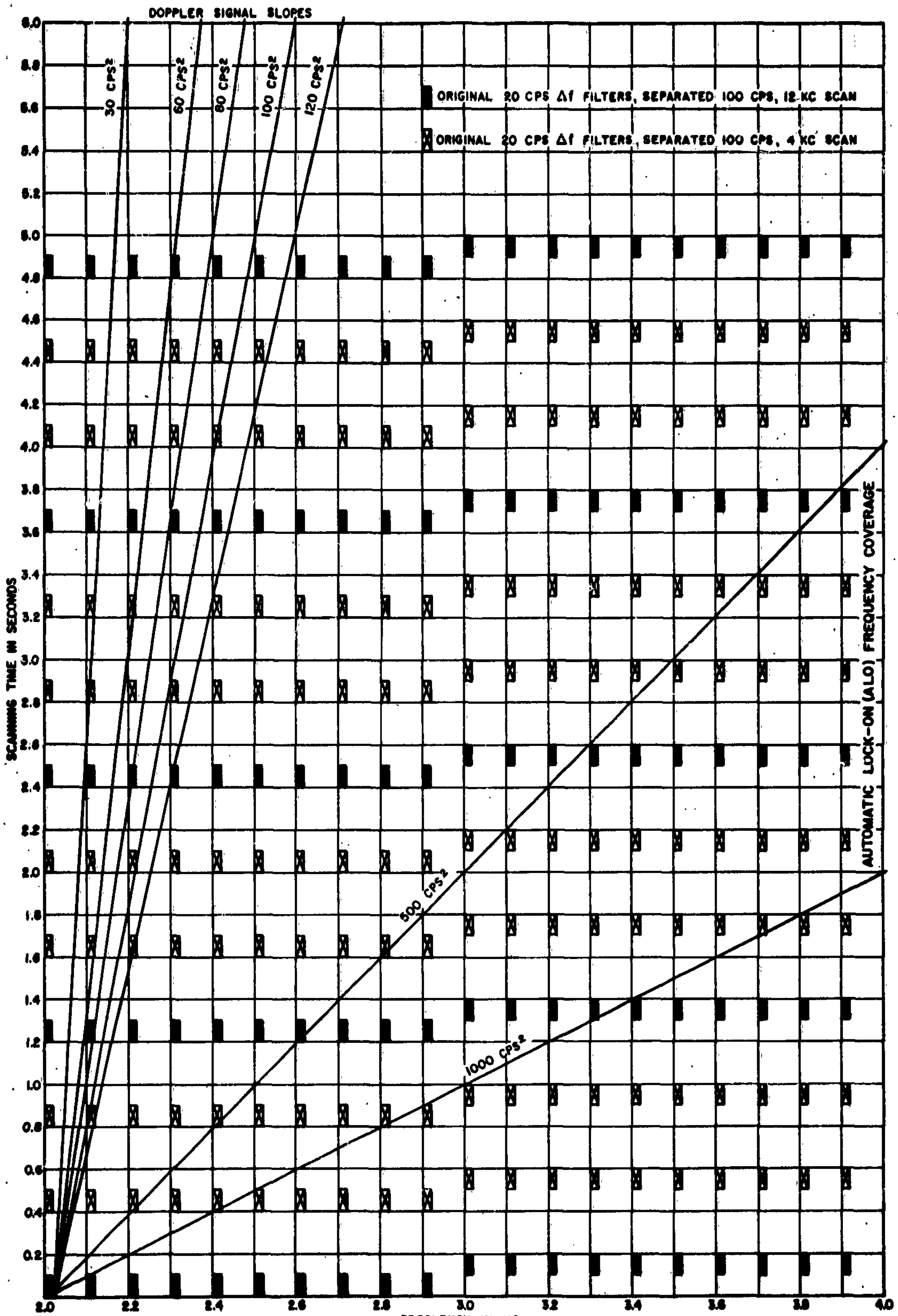
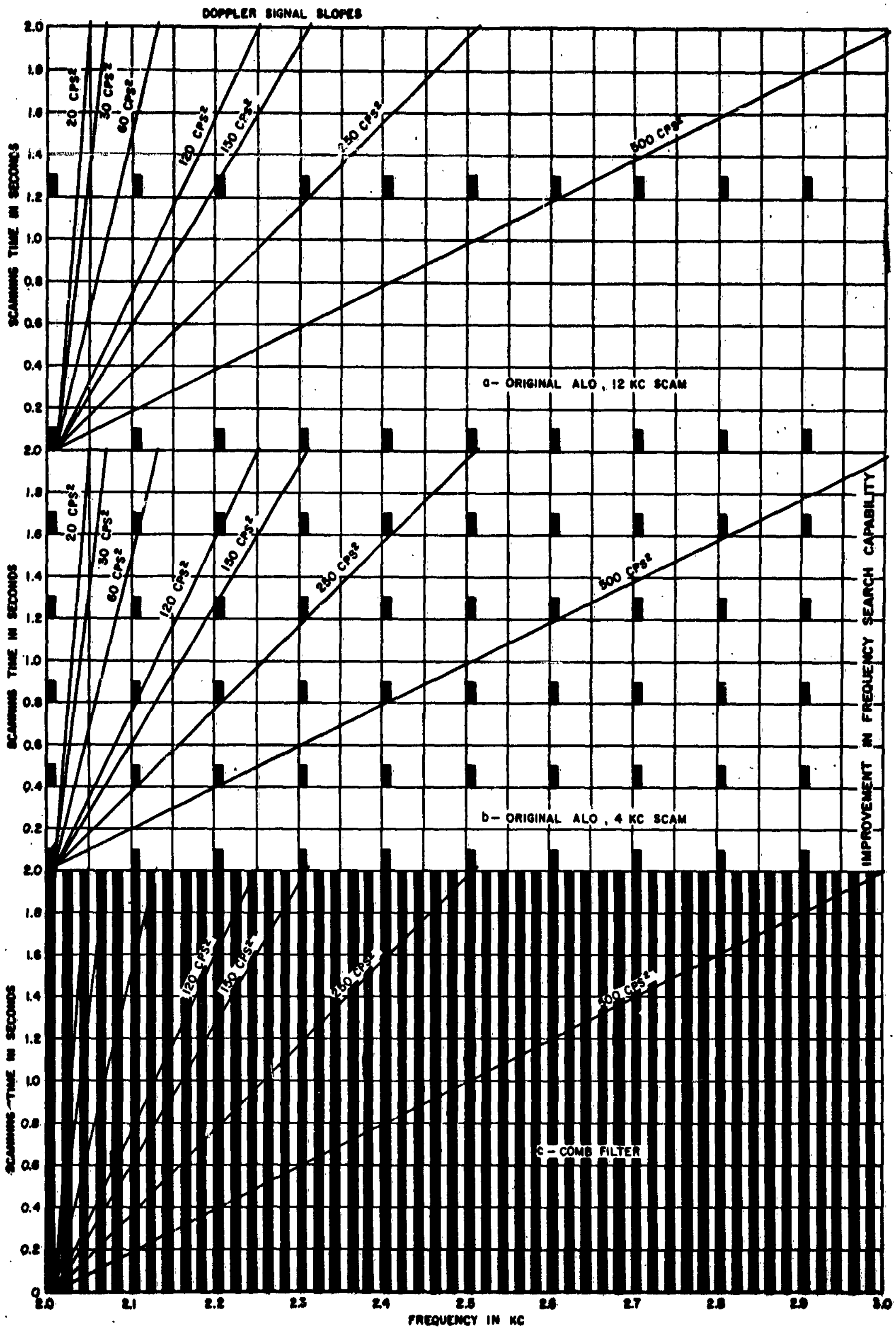

DOPPLER SIGNAL SLOPES
30 CPS²
60 CPS²
80 CPS²
100 CPS²
120 CPS²
ORIGINAL 20 CPS Δf FILTERS, SEPARATED 100 CPS, 12 KC SCAN
ORIGINAL 20 CPS Δf FILTERS, SEPARATED 100 CPS, 4 KC SCAN
AUTOMATIC LOCK-ON (ALO) FREQUENCY COVERAGE
500 CPS²
1000 CPS²
SCANNING TIME IN SECONDS
FREQUENCY IN KC
6.0
5.8
5.6
5.4
5.2
5.0
4.8
4.6
4.4
4.2
4.0
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0

FIG. 26



DOPPLER SIGNAL SLOPES
20 CPS²
30 CPS²
60 CPS²
120 CPS²
150 CPS²
250 CPS²
500 CPS²
a- ORIGINAL ALO, 12 KC SCAN
b- ORIGINAL ALO, 4 KC SCAN
c- COMB FILTER
SCANNING TIME IN SECONDS
FREQUENCY IN KC
IMPROVEMENT IN FREQUENCY SEARCH CAPABILITY
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.0
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3.0

FIG. 27

The faster scan (0.4 second) filter is being used in the field in preference to the slower (1.2 second) scan filter. The comb filter with its much greater probability of detection is presently going into operation. The initiation of phase-locked tracking is accomplished very quickly when a signal frequency is detected in one of the fixed filters. The control circuit pulls the tracking filter frequency over to the received signal frequency in about 10 milliseconds and within 80 to 90 milliseconds all transients have subsided and phased-locked tracking begins. Figure 25 shows this transition from step scan to continuous tracking at 17:14:58Z time. On the fifth scan step a signal beginning at 6910 cps was detected and tracked for 6 seconds. Concurrently the digital counter and printer was started and the time period of 1000 cycles of the doppler printed at one second intervals on paper tape. The doppler period count, corresponding to the analog doppler frequency record, is shown at the top left of Figure 25. The right five digits constitute the count. The doppler frequency in cycles per second is 10^8 times the reciprocal of the count. A doppler frequency record readable to 0.1 cps is obtained in this manner.

With the use of a family of curves relating doppler frequency and rate of change of frequency to the altitude and distance east of the transmitter, the location of the satellite as it crosses the great circle between the stations can be determined. Figure 3 is a family of such curves for satellite orbits of 80 degrees inclination. The doppler frequency at the midpoint of the record is taken as the frequency at the time of great circle crossing. By locating the intersection of the curve representing this frequency with the curve corresponding to the rate of change of frequency the location of the satellite is determined. For example the record in Figure 25 has a center frequency of 7190 cps and a slope of 114 cps^2. These values located on Figure 3 give an altitude of 137 miles and a horizontal distance of 335 miles east of Fort Sill at a time of 17:04:58Z. Space Track predictions were 115 miles altitude, 314 miles east of Fort Sill at 17:06:00Z. The agreement is very good and well within the accuracy of Space Track predictions. Analog data reduction techniques such as this one are being used for obtaining the initial point for orbit computations from DOPLOC data.

In addition to the satellite doppler frequency record on Figure 25, other short, frequency lines of about 1 second duration are evident. These are spurious responses due to strong noise pulses or meteor head echoes. It is significant to note that such a spurious frequency signal occurred just a few tenths of a second prior to the satellite doppler signal reception and the system was able to respond with full sensitivity to the desired signal. The spurious signals from meteors are identified by their short time duration and steep slopes.

The lower part of the chart in Figure 25 is a record of the AGC voltage from the tracking filter. While in the search mode, the AGC is shorted, giving the clean, straight line at 2mm deflection. When a signal is tracked, the AGC voltage first decreases, due to an initial threshold voltage of opposite polarity existing on the AGC line, causing a deflection toward zero on the chart, then as the signal amplitude increases further, the AGC voltages increases as shown by the scale calibration. The chart is calibrated in power input level (in dbw) to the receiver input terminals and also is calibrated in relative signal in terms of the signal-to-noise ratio at the output of the receiver, i.e., in db below 1:1 S/N at the receiver output. With a 10 cps bandwidth, the tracking filter can track signals that are 26 db down in the noise from the 16 kc bandwidth receiver.

The signal strength record of 59 Kappa in Figure 25 shows a maximum signal of -161 dbw which is 2 db down in the noise at the receiver output. The rather narrow, peaked signal response curve with the slight dip on the leading portion is signature information indicating considerable attitude change during the 6 second passage time through the antenna beam. The effective peak cross section of 59 Kappa was calculated to be 23 square meters from this record. A statistical analysis of signal strength vs. time shows that for 50% of the time the signal was down 6 db or less from the peak value. A plot of received signal strength vs. percent of time is shown in Figure 28 for this pass. This type of analysis and presentation of received signal magnitude has provided very useful and realistic values on which to base system design parameters.

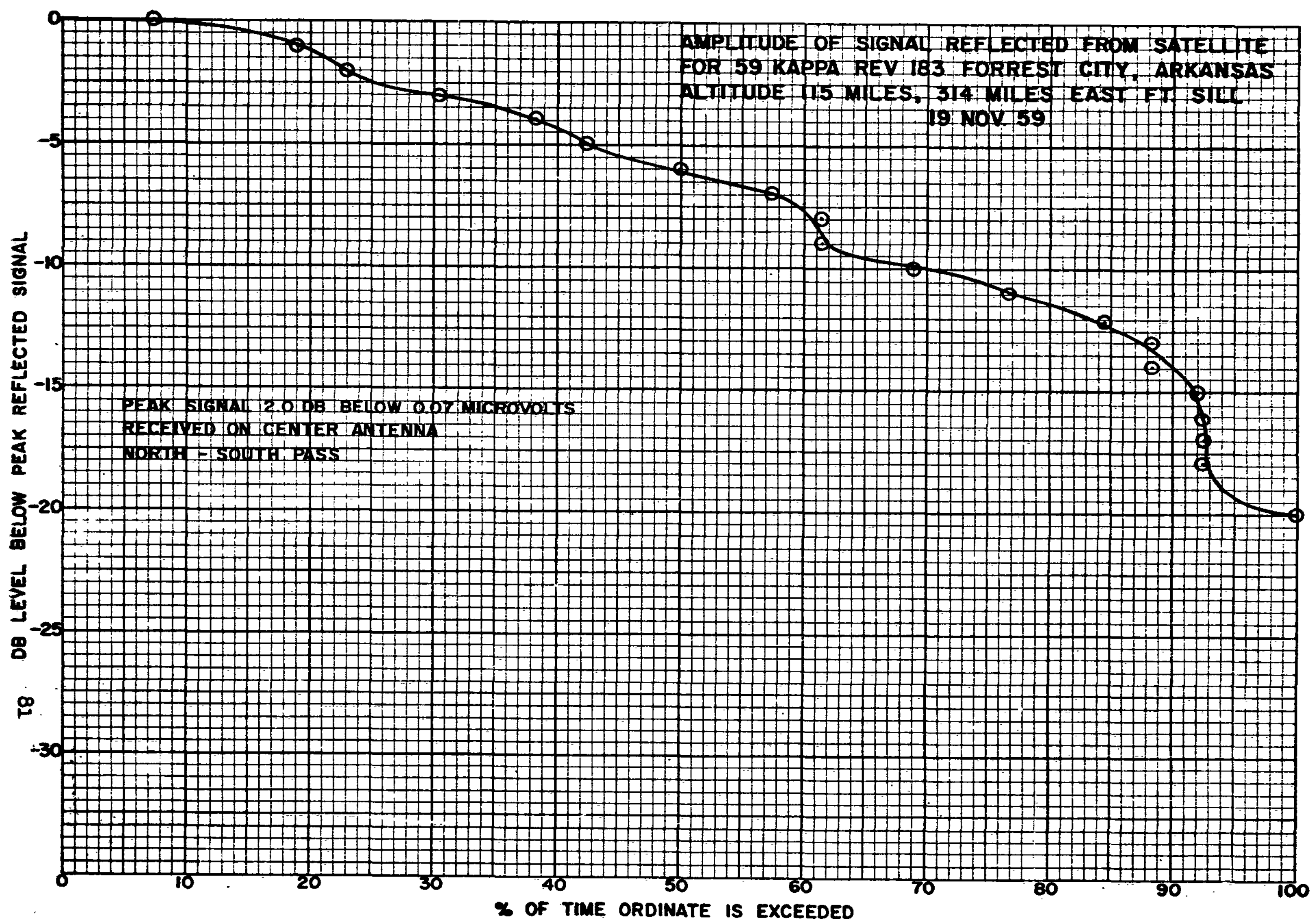

AMPLITUDE OF SIGNAL REFLECTED FROM SATELLITE
FOR 59 KAPPA REV 183 FORREST CITY, ARKANSAS
ALTITUDE 115 MILES, 314 MILES EAST FT. SILL
19 NOV 59
PEAK SIGNAL 2.0 DB BELOW 0.07 MICROVOLTS
RECEIVED ON CENTER ANTENNA
NORTH - SOUTH PASS
DB LEVEL BELOW PEAK REFLECTED SIGNAL
0
-5
-10
-15
-20
-25
-30
0
10
20
30
40
50
60
70
80
90
100
% OF TIME ORDINATE IS EXCEEDED

FIG. 28

The rather detailed treatment of this one pass of 59 Kappa has been given to illustrate something of the detailed nature, quantity and quality of information that is provided by the DOPLOC dark satellite tracking technique from a single pass recorded by a single receiving station.

A tabulation of the satellite passes recorded and analyzed between 1 July 1959 and 1 July 1960 is shown in Table IV. Figure 29 shows the altitude and horizontal range at which these satellites crossed the great circle between the Fort Sill transmitter and Forrest City receiver. Not every satellite known to pass between the transmitter and receiver has been detected, apparently because of insufficient reflected signal due to the attitude it assumed at the time the antenna beam was traversed. This assumption is borne out in the case of two 58 Delta passes, revolutions 8643 and 9255, that were in the approximate same location relative to the ground stations but presented effective reflection cross-sections that differed by a factor of 7. All other conditions in the system were known to be the same, hence only the satellite attitude and its environment remains as the factor that could cause this difference. This is similar to the glint problem with microwave radar although at 108 mc only a few nulls and maxima are obtained from satellites with dimensions of those now in orbit. Measured cross-sections reported by the M.I.T.[1,2] on satellites tracked by the Millstone Radar show nulls 10 to 40 db down from peak signals when using linear polarization. Peak cross-sections of several satellites and time variation values are shown in Table V.

TABLE V

Object	Peak Cross Section Square Meters	Approx. % of time cross section is greater than 10 square meters
57 Alpha I	120	No data
57 Beta	350	40
58 Delta I	1300	2-27
58 Delta II	26	17
59 Gamma	3	0
12 foot balloon	25	"Scintillating"

1. "Earth Satellite Observations Made with the Millstone Hill Radar", M.I.T. Lincoln Laboratories, Group Report 314-1, 25 November 1958, by Gordon Pettengill, and Leon G. Kraft, Jr.

2. Correspondence, Dr. Sebring and L. G. Kraft of M.I.T. with Kenneth Richer of BRL, 27 November 1959.

TABLE IV

DOPLOC REFLECTIONS, 1 JULY 1959 - 1 JULY 1960

Satellite Name	Revolution Number	Date 1959	Time G.M.T.	Pass Direction	Altitude Miles	GR[1] Miles	Signal Duration Seconds	Slope cps/s	Peak Effective Cross Section Sq. Ft.	Signal Decibels Below 0.07 Microvolts(1:1S/N) Peak	Signal Decibels Below 0.07 Microvolts(1:1S/N) 50% Down	Remarks
U.F.O.	-	5 Aug.	2119:34	-	-	-	1.5	117	-	- 8.0	-	
U.F.O.	-	15 Aug.	1759:38	-	-	-	3.0	42	-	0	-	
59 Epsilon	53	17 Aug.	0539:34	S-N	341	279 E	7.0	53	26.6	-18.0	-22.7	
U.F.O.(59 Epsilon 2)	-	17 Aug.	1703:30	-	125	Overhead	7.0	110	Rerun(2)	- 7.0	-	
59 Epsilon	60	17 Aug.	1704:10	N-S	140	76 W	8.0	102	18.8	-18.0	-24.4	
59 Zeta	14	20 Aug.	1741:51	N-S	136	145 E	6.0	118	132.0	- 8.0	-12.5	
59 Epsilon	121	21 Aug.	1620:02	N-S	140	100 E	20.0	20	53.5	-15.0	-22.6	South Antenna
59 Zeta	150	29 Aug.	1650:08	N-S	171	15 E	20.0	15	97.0	-14.5	-17.7	South Antenna
59 Epsilon	314	3 Sep.	0309:50	S-N	185	191 E	7.0	89	14.7	-17.8	-22.3	
59 Zeta	241	4 Sep.	1559:34	N-S	213	123 E	7.0	86	Rerun	- 4.5	- 9.0	
59 Epsilon	414	9 Sep.	1322:15	N-S	211	17 W	9.0	88	70.2	-10.0	-23.2	
58 Delta	6844	11 Sep.	0140:12	N-S	407	283 E	9.0	47	Rerun	-12.0	-14.5	
59 Epsilon	438	11 Sep.	0141:16	S-N	150	313 E	9.0	108	Rerun	- 4.5	- 6.3	
U.F.O.	-	14 Sep.	1514:01	-	-	-	3.0	35	-	-12.5	-	
59 Epsilon	532	17 Sep.	0103:49	S-N	122	32 W	20.0	18	Rerun	- 8.5	-14.5	South Antenna
U.F.O.	-	22 Sep.	0008:38	-	-	-	4.8	157	-	0	-	
U.F.O.	-	22 Sep.	1643:04	-	-	-	4.0	54	-	0	-	
58 Delta	7049	24 Sep.	2201:56	N-S	375	214 E	10.0	51	86.0	-13.0	-15.5	
59 Zeta	556	25 Sep.	0144:16	S-N	129	365 E	4.0	128	27.7	-19.0	-21.5	
U.F.O.	-	1 Oct.	0235:22	-	-	-	5.0	100	-	- 5.0	-	
59 Zeta	855	13 Oct.	2347:38	S-N	138	179 E	7.0	92	59.3	-10.0	-12.5	
59 Zeta	871	14 Oct.	2342:09	S-N	175	108 E	9.0	91	54.2	- 9.0	-12.2	
U.F.O.(59 Epsilon 2)	-	15 Oct.	1641:30	-	130	165 E	3.0	113	-	-25.0	-	
58 Delta	7358	15 Oct.	1646:25	N-S	369	74 W	3.0	60	47.0	-17.5	-20.0	
59 Zeta	887	15 Oct.	2332:58	S-N	170	123 E	7.0	93	151.2	- 5.5	-10.0	
U.F.O.(59 Epsilon 2)	-	4 Nov.	0150:39	-	115	435 E	5.0	150	-	-12.0	-	
59 Kappa	183	19 Nov.	1704:59	N-S	115	314 E	5.0	114	225.6	- 2.0	- 7.0	
59 Lambda	96	27 Nov.	1647:25	N-S	124	323 E	11.0	116	102.2	- 5.0	- 7.2	
59 Lambda	138	30 Nov.	1644:31	N-S	138	Overhead	3.0	127	60.5	- 9.0	-12.2	
59 Lambda (3)	278	10 Dec.	1503:37	N-S	218	59 E	10.0	23	Rerun	-11.5	-14.5	North Antenna
59 Lambda (3)	278	10 Dec.	1505:02	N-S	218	59 E	4.0	85	149.8	- 5.5	-10.0	
U.F.O.	-	11 Dec.	2258:01	-	-	-	6.0	142	-	- 5.5	-	
U.F.O.	-	16 Dec.	1843:18	-	-	-	3.0	67	-	- 2.0	-	
58 Delta	8386	22 Dec.	2136:23	N-S	172	176 E	7.0	81	68.5	- 7.5	-10.5	
U.F.O.	-	29 Dec.	1705:39	-	-	-	7.0	29	-	0	-	

TABLE IV (Continued)

Satellite Name	Revolution Number	Date 1960	Time G.M.T.	Pass Direction	Altitude Miles	GR[1] Miles	Signal Duration Seconds	Slope cps/s	Peak Effective Cross Section Sq. Ft.	Signal Decibels Below 0.07 Microvolts(1:1S/N) Peak	50% Down	Remarks
59 Lambda(4)	685	8 Jan.	0016:01	S-N	138	26 W	10.0	26	33.6	-16.5	-19.5	South Antenna
59 Lambda(4)	685	8 Jan.	0017:05	S-N	138	26 W	4.0	141	Rerun	-13.5	-15.0	
58 Delta	8643	8 Jan.	1647:25	N-S	158	139 E	7.0	86	25.6	-11.0	-15.0	
58 Delta	8683	11 Jan.	0651:30	S-N	413	Overhead	4.0	38	87.9	-16.0	-19.5	
58 Delta	8719	13 Jan.	1530:03	N-S	186	50 E	3.0	94	27.1	-12.0	-12.5	
58 Delta	8734	14 Jan.	1454:02	N-S	186	326 E	5.0	84	28.2	-11.0	-13.5	
U.F.O.(59 Epsilon 2)	-	14 Jan.	2056:00	-	440	110 E	6.0	46	-	-11.0	-12.5	
58 Delta	8795	18 Jan.	1358:01	N-S	146	158 E	6.0	83	15.1	-13.5	-15.0	
58 Delta	9009	1 Feb.	1011:12	N-S	134	46 W	3.0	118	40.5	-13.0	-15.5	
U.F.O.	-	11 Feb.	2119:13	-	-	-	8.0	20	-	-20	-	
58 Delta	9172	11 Feb.	2121:06	S-N	315	330 E	9.0	52	49.0	-19.0	-24.0	
U.F.O.	-	12 Feb.	2146:10	-	-	-	3.0	93	-	-18.0	-	
U.F.O.	-	13 Feb.	0056:45	-	-	-	3.0	174	-	-13.0	-	
U.F.O.	-	15 Feb.	2306:26	-	-	-	3.0	77	-	0	-	
U.F.O.	-	15 Feb.	2327:10	-	-	-	3.0	135	-	- 5.0	-	
U.F.O.	-	17 Feb.	0110:08	-	-	-	3.0	110	-	-14.0	-	
59 Lambda	1285	17 Feb.	0513:53	N-S	356	342 E	11.0	56	174.4	- 9.5	-11.5	
58 Delta	9255	17 Feb.	0523:57	N-S	128	120 E	11.0	91	178.2	- 2.0	- 6.5	
U.F.O.	-	18 Feb.	0101:22	-	-	-	5.5	55	-	0	-	
58 Delta	9286	19 Feb.	0458:45	N-S	123	39 W	5.0	106	248.0	- 7.5	-11.5	
U.F.O.	-	1 Mar.	0057:04	-	190	130 E	3.0	91	46.9	- 8.5	-	
U.F.O.	-	1 Mar.	0120:43	-	-	-	3.0	76	-	0	-	
58 Delta	9466	1 Mar.	1552:58	S-N	275	289 E	15.0	58	87.1	- 8.5	-14.5	
58 Delta	9472	2 Mar.	0127:31	N-S	130	80 W	3.0	94	292.0	-13.0	-14.5	
59 Lambda	1516	3 Mar.	0256:10	N-S	137	265 E	11.0	99	72.9	- 7.0	-10.5	
58 Delta	9503	4 Mar.	0041:30	N-S	130	56 E	7.0	90	22.9	-11.0	-16.5	
58 Delta	9581	8 Mar.	2317:41	N-S	116	33 E	8.0	104	38.0	- 9.0	-12.0	
U.F.O.	-	9 Mar.	0011:59	-	133	30 W	3.0	112	-	- 9.0	-	
U.F.O.	-	9 Mar.	1154:39	-	203	117 E	4.0	82	-	0	-	
58 Delta	9612	10 Mar.	2218:33	N-S	116	199 E	25.0	35	52.4	-12.0	-15.0	North Antenna
58 Delta	9716	17 Mar.	1114:54	S-N	275	135 E	4.0	70	16.2	-16.0	-17.5	
58 Delta	9722	17 Mar.	2044:31	N-S	113	4 E	17.0	27	24.9	-19.0	-22.5	South Antenna
58 Delta	9826	24 Mar.	0847:25	S-N	189	403 E	5.0	83	12.7	-16.5	-19.0	
58 Delta(4)	9832	24 Mar.	1812:26	N-S	100	280 E	6.0	113	7.1	-11.5	-14.0	
58 Delta(4)	9832	24 Mar.	1813:19	N-S	100	392 E	24.0	18	25.1	-16.0	-18.5	South Antenna
58 Delta	9842	25 Mar.	0848:40	S-N	182	381 E	25.0	16	75.7	-18.0	-20.5	North Antenna
58 Delta(4)	9848	25 Mar.	1811:46	N-S	100	155 E	5.0	104	22.3	-12.5	-14.0	
58 Delta(4)	9848	25 Mar.	1812:38	N-S	100	266 E	16.0	36	24.2	-14.0	-16.0	South Antenna
58 Delta	9905	29 Mar.	0659:58	S-N	171	350 E	17.0	25	43.0	-19.0	-22.5	South Antenna
U.F.O.	-	29 Mar.	0906:33	-	300	90 W	2.0	61	114.5	-15.0	-16.5	
58 Delta	9927	30 Mar.	1613:25	N-S	105	258 E	29.0	37	137.2	- 7.0	- 9.0	North Antenna

TABLE IV (Continued)

Satellite Name	Revolution Number	Date 1960	Time G.M.T.	Pass Direction	Altitude Miles	GR(1) Miles	Signal Duration Seconds	Slope cps/s	Peak Effective Cross Section Sq. Ft.	Signal Decibels Below 0.07 Microvolts(1:1S/N) Peak	50% Down	Remarks
58 Delta(5)	9937	31 Mar.	0641:14	S-N	180	109 E	26.0	23	198.6	-13.0	-17.5	South Antenna
58 Delta(5)	9937	31 Mar.	0642:57	S-N	180	372 E	7.0	89	180.0	- 3.0	- 6.0	
58 Delta(5)	9937	31 Mar.	0644:19	S-N	180	435 E	12.0	11	112.1	-19.0	-21.5	North Antenna
58 Delta(3)	9943	31 Mar.	1601:53	N-S	105	193 E	46.0	33	66.6	-10.1	-14.0	North Antenna
58 Delta(3)	9943	31 Mar.	1603:20	N-S	105	310 E	7.0	123	74.5	- 7.0	-10.0	
58 Delta	9959	1 Apr.	1547:58	N-S	103	153 E	37.0	28	140.0	- 7.0	-10.0	North Antenna
58 Delta	9975	2 Apr.	1530:24	N-S	103	96 E	6.0	28	31.8	-14.5	-15.0	North Antenna
58 Delta	9991	3 Apr.	1509:18	N-S	95	140 E	33.0	34	43.4	-11.5	-15.0	North Antenna
58 Delta(4)	10001	4 Apr.	0529:14	S-N	124	108 E	30.0	26	60.0	-13.5	-16.5	South Antenna
58 Delta(4)	10001	4 Apr.	0530:49	S-N	124	285 E	5.0	91	29.6	-10.5	-14.0	
58 Delta	10007	4 Apr.	1444:37	N-S	95	274 E	31.0	36	96.7	- 7.5	-11.5	North Antenna
58 Delta	10023	5 Apr.	1415:08	N-S	95	435 E	5.0	59	14.0	-20.0	-22.0	North Antenna
60 Delta(5)	30	17 Apr.	1838:12	N-S	111	34 E	12.0	26	49.7	-15.0	-17.0	North Antenna
60 Delta(5)	30	17 Apr.	1839:19	N-S	111	72 E	6.0	127	35.9	- 9.0	-12.0	
60 Delta(5)	30	17 Apr.	1840:06	N-S	111	110 E	7.0	35	20.3	-17.0	-19.5	South Antenna
60 Delta	61	19 Apr.	1801:53	N-S	111	250 E	15.0	36	24.3	-15.0	-18.0	North Antenna
60 Delta	61	19 Apr.	1803:50	N-S	111	326 E	9.0	19	90.9	-10.0	-12.5	South Antenna
60 Delta	117	23 Apr.	0627:41	S-N	204	125 E	17.0	11	178.2	-15.0	-16.0	South Antenna
60 Delta(5)	124	23 Apr.	1727:08	N-S	120	280 E	32.0	34	302.3	- 5.0	-15.0	North Antenna
60 Delta(5)	124	23 Apr.	1728:18	N-S	120	320 E	6.0	118	53.1	- 8.0	-11.0	
60 Delta(5)	124	23 Apr.	1729:23	N-S	120	360 E	3.0	21	17.0	-19.0	-20.0	South Antenna
60 Delta(5)	140	24 Apr.	1727:00	N-S	116	281 E	21.0	31	321.2	- 2.0	- 7.0	North Antenna
60 Delta(5)	140	24 Apr.	1728:07	N-S	116	320 E	6.0	112	20.9	-12.0	-14.5	
60 Delta(5)	140	24 Apr.	1728:57	N-S	116	359 E	24.0	29	123.3	-10.0	-11.5	South Antenna
60 Delta(5)	156	25 Apr.	1717:39	N-S	112	105 E	11.0	29	296.7	- 4.0	- 8.0	North Antenna
60 Delta(5)	156	25 Apr.	1718:40	N-S	112	143 E	9.0	115	10.6	-16.0	-16.5	
60 Delta(5)	156	25 Apr.	1719:31	N-S	112	181 E	5.0	40	20.2	-16.0	-17.5	South Antenna
60 Delta(5)	165	26 Apr.	0609:55	S-N	142	9 E	4.0	14	164.6	-13.0	-16.5	South Antenna
60 Delta(5)	165	26 Apr.	0611:13	S-N	142	99 E	8.0	112	71.5	- 6.0	- 8.5	
60 Delta(5)	165	26 Apr.	0612:06	S-N	142	189 E	34.0	27	298.2	- 6.0	-11.0	North Antenna
60 Delta(5,6)	172	26 Apr.	1653:08	N-S	77	355 E	19.0	41	37.2	-11.0	-13.0	North Antenna
60 Delta(5,6)	172	26 Apr.	1653:56	N-S	77	370 E	4.0	168	210.0	- 1.0	- 4.5	
60 Delta(5,6)	172	26 Apr.	1654:29	N-S	77	385 E	9.0	40	69.8	- 9.0	-11.5	South Antenna
60 Gamma 1	318	4 May	1257:23	N-S	500	300 E	5.0	36	94.5	-15.0	-18.0	
60 Gamma 1	403	10 May	0317:28	S-N	271	400 E	5.0	58	63.3	-12.0	-15.0	
60 Gamma 1	418	11 May	0303:26	S-N	287	212 E	11.0	54	46.4	-12.0	-17.0	
60 Epsilon 1	53	18 May	0833:05	S-N	194	252 E	20.0	26	297.1	- 9.0	-11.5	South Antenna
60 Epsilon 1	99	21 May	0821:32	N-S	200	233 W	40.0	15	-	-13.0	-16.5	North Antenna
60 Epsilon 2	106	21 May	1733:24	N-S	208	203 W	14.0	14	111.3	-17.0	-20.0	South Antenna
60 Epsilon 2	137	23 May	1635:46	N-S	209	274 E	5.0	78	23.5	-12.5	-14.5	

TABLE IV (Continued)

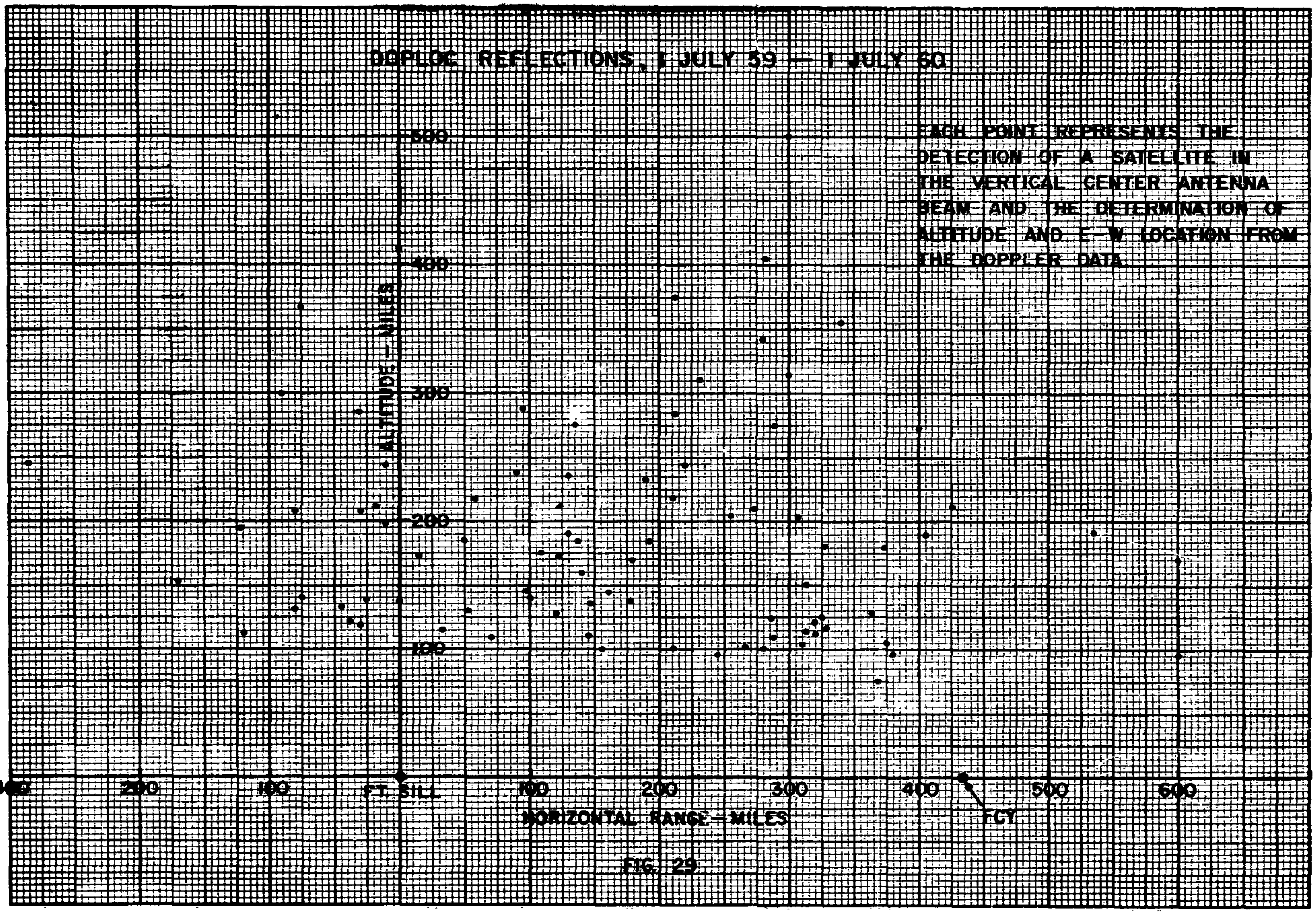
Satellite Name	Revolution Number	Date 1960	Time G.M.T.	Pass Direction	Altitude Miles	GR(1) Miles	Signal Duration Seconds	Slope cps/s	Peak Effective Cross Section Sq. Ft.	Signal Decibels Below 0.07 Microvolts(1:1S/N) Peak	50% Down	Remarks
60 Epsilon 2(3)	147	24 May	0720:57	S-N	240	90 E	8.0	81	14.0	-15.5	-20.0	
60 Epsilon 2(3)	147	24 May	0722:37	S-N	240	431 E	42.0	16	303.6	-13.5	-18.0	North Antenna
60 Epsilon 1	150	24 May	1653:44	N-S	287	291 E	20.0	10	296.1	-18.0	-20.0	South Antenna
60 Epsilon 2	153	24 May	1655:14	N-S	209	112 E	14.0	16	74.3	-19.5	-22.5	South Antenna
60 Epsilon 1	165	25 May	1624:59	N-S	288	96 E	11.0	68	303.7	- 2.5	- 7.5	
60 Epsilon 2	194	27 May	0642:00	S-N	193	159 E	45.0	22	121.2	-15.5	-20.0	North Antenna
60 Epsilon 6	265	1 Jun.	0502:06	S-N	218	210 E	14.0	67	227.0	- 3.0	- 7.0	
60 Epsilon 4	280	2 Jun.	0435:21	S-N	240	270 E	11.0	69	23.7	-13.0	-15.5	
60 Epsilon 3	280	2 Jun.	0441:29	S-N	232	358 E	12.0	74	112.0	- 7.0	-10.5	
60 Epsilon 2	303	3 Jun.	0354:58	S-N	213	420 E	7.0	81	14.0	-17.5	-20.5	
60 Epsilon 2	309	3 Jun.	1325:57	N-S	205	305 E	7.0	74	96.2	- 6.0	-10.0	
60 Epsilon 6	301	3 Jun.	1359:22	N-S	233	190 E	3.0	70	14.2	-15.0	-18.0	
60 Epsilon 2	356	6 Jun.	1240:39	N-S	201	30 E	15.0	23	314.3	-13.0	-17.5	North Antenna
60 Gamma 1	836	7 Jun.	1632:12	S-N	312	232 E	18.0	51	118.0	- 8.0	-11.5	
60 Epsilon 1	386	9 Jun.	0300:41	S-N	230	15 E	10.0	76	81.0	-10.0	-14.0	
60 Gamma 1	960	15 Jun.	2048:10	N-S	200	295 E	13.0	66	97.1	- 6.0	-10.0	
60 Epsilon 1	522	18 Jun.	0028:41	S-N	225	20 E	8.0	77	206.1	- 6.0	-10.0	
60 Epsilon 5	569	20 Jun.	2325:46	S-N	205	231 E	12.0	68	82.5	- 7.0	- 9.0	
60 Gamma 2	1042	21 Jun.	1902:09	N-S	250	235 E	11.0	57	32.4	-12.0	-15.0	
60 Epsilon 6	583	21 Jun.	2259:00	S-N	225	330 E	4.0	75	6.6	-20.0	-24.0	
60 Epsilon 2	617	22 Jun.	2218:14	S-N	203	77 E	11.0	81	6.2	-18.0	-20.0	

GENERAL NOTES:

1. Transmitting antenna tilted toward receiving antenna 26 October 1959.
2. ALO scan changed to 4 k.c. 27 November 1959.
3. All passes on center antenna unless otherwise noted.

REFERENCES:

(1) Ground range East, West or Overhead Fort Sill transmitter.
(2) Not calculated since original signal not acquired by ALO.
(3) Acquired on North and Center antennas.
(4) Acquired on South and Center antennas.
(5) Acquired on North, Center and South antennas.
(6) Terminal revolution.



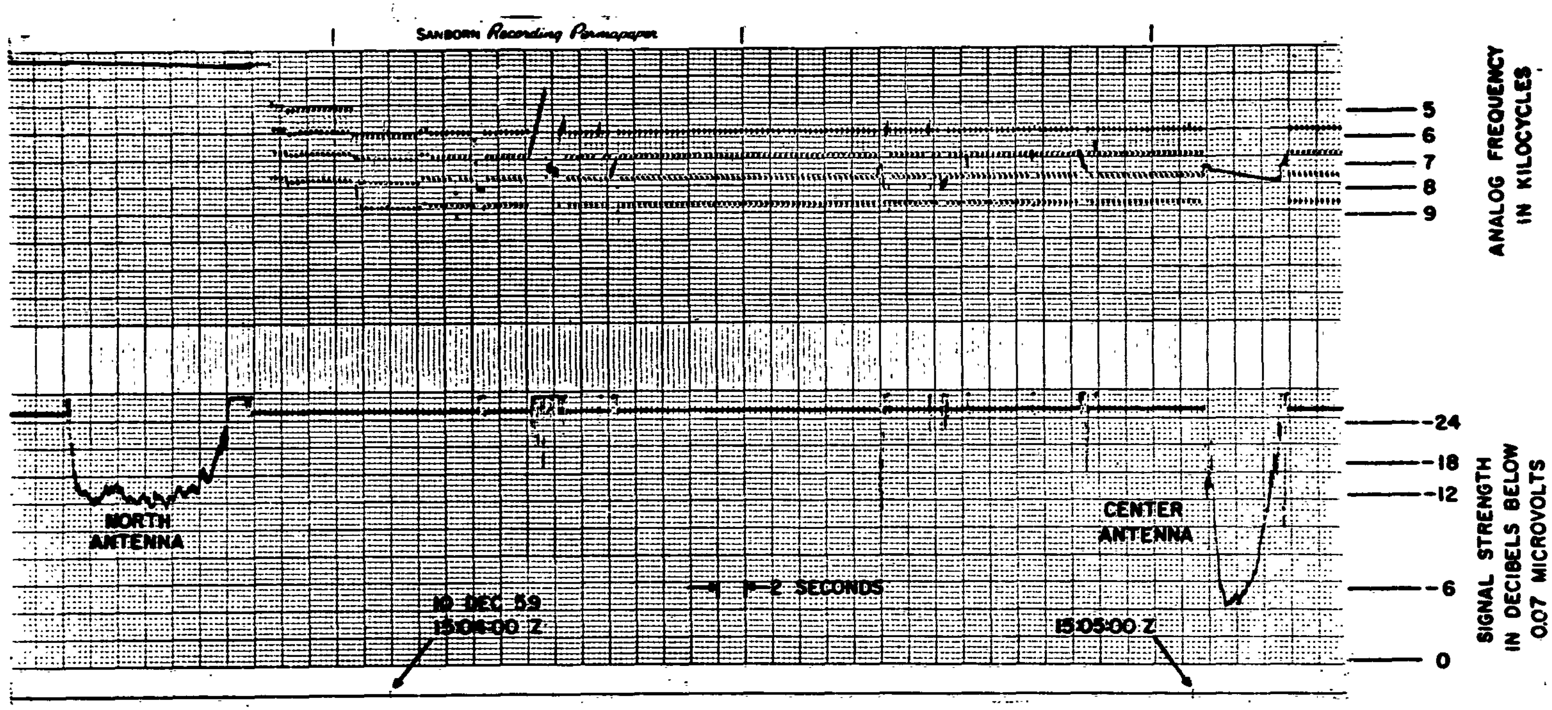
DOPLOC REFLECTIONS, 1 JULY 59 — 1 JULY 60
EACH POINT REPRESENTS THE DETECTION OF A SATELLITE IN THE VERTICAL CENTER ANTENNA BEAM AND THE DETERMINATION OF ALTITUDE AND E—W LOCATION FROM THE DOPPLER DATA
ALTITUDE — MILES
500
400
300
200
100
300
200
100
FT. SILL
100
200
300
400
500
600
FCY
HORIZONTAL RANGE — MILES

FIG. 29

The optimum polarization for the highest detection probability would be circular polarization for transmitting and polarization diversity for reception. Either orthogonal linear polarization or right and left hand polarization as a pair could be used for diversity reception. The capability of using these polarization combinations has been included in the scanning DOPLOC system.

An immediate step can be taken to markedly increase the sensitivity and detection probability of the existing DOPLOC facility by the installation of antennas at the transmitter and receiver which have a 4 x 40 degree fan beam pattern and orthogonal and/or circular polarization. Objects with a reflection cross-section area 1/16 the size of those currently tracked could be detected and tracked due to the increased antenna gain of 12 db. The detection probability would also be increased by the use of the circularly polarized transmitting antenna since it would insure illumination of the satellite regardless of its attitude. Purchase negotations were initiated for these antennas but have been stopped pending program orientation.

The previous discussion of experimental results has been largely on data obtained with the vertically directed center antennas. Figure 30 shows a doppler record of a satellite received with the north antenna and later in the center antenna. The doppler frequency has a low value and is nearly constant during the transit through the north antenna since it is directed 20 degrees above the horizon and the doppler is at the flat portion of the "S" curve. The region between the signal in the north and the center antenna is of interest in this record since it represents a period of unusually high spurious signal activity. The short, steep slope frequency marks are typical of meteor head echoes which can be seen to be readily distinguished from the satellite record by either their steep slope or their very short AGC record duration (one second or less). Two of the slopes are of opposite sign to those of the satellite record due to their extremely high velocity placing the doppler frequency on the opposite side of the heterodyne frequency. Reflections from meteor trails, which are large ionized columns moving at very low velocities, are recorded as a nearly constant frequency, called



ARPA – BRL DOPLOC DOPPLER RECORD OF
59 LAMBDA REV 278 FORREST CITY, ARKANSAS
MEASURED 15:03:36 Z, PREDICTED 15:17 Z
ALTITUDE 218 MILES, 59 MILES EAST FORT SILL
NORTH AND CENTER ANTENNAS, N-S PASS
BFO – 108,007,000 CPS
TRANSMITTER – 108,000,000 CPS

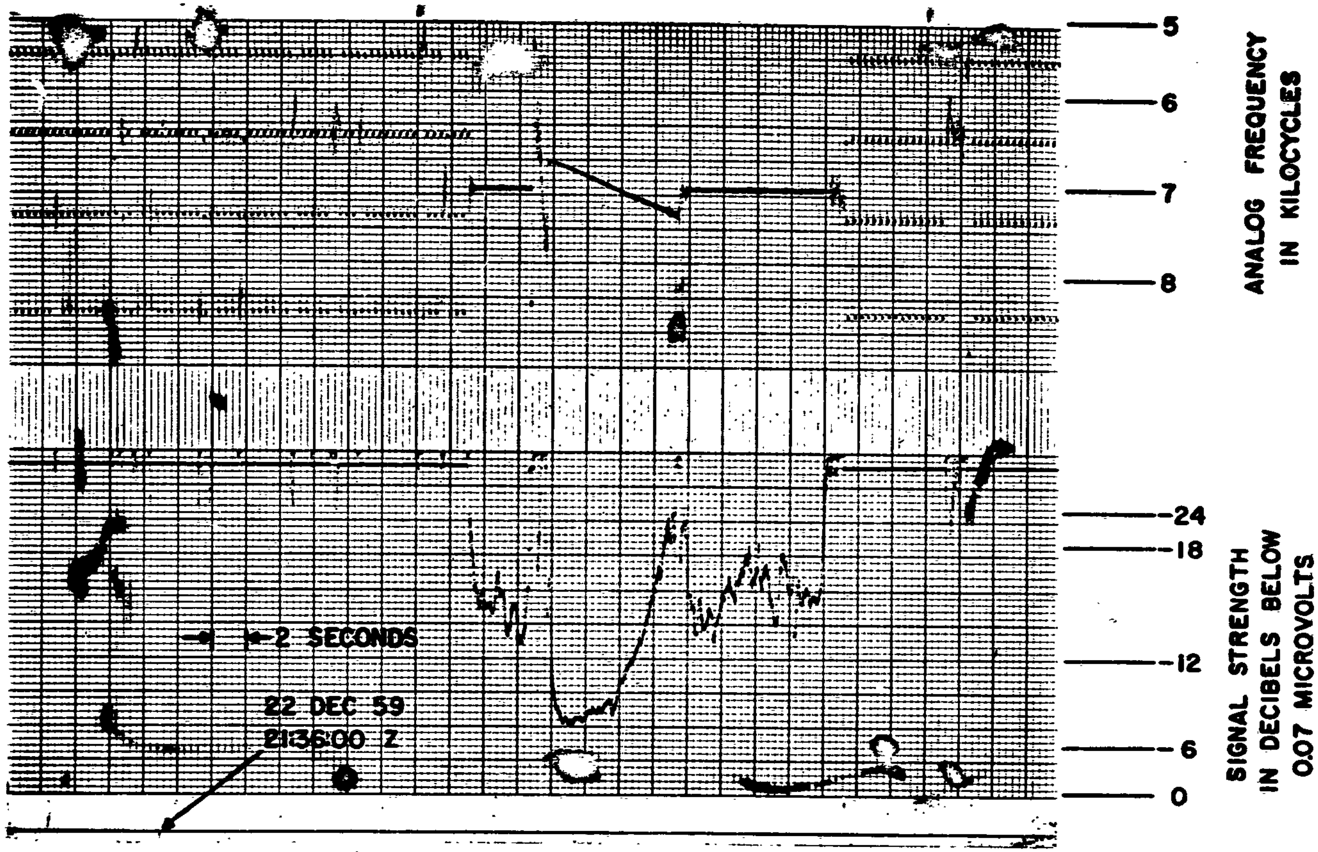
PHOTO I

Fig. 30

"flats", which are close to or equal to the bias frequency. They have been observed to last from 2 to 45 seconds. Figure 31 shows an interesting example of a simultaneous meteor trail and satellite pass. Revolution 8386 of 1958 Delta is shown coming in 3 seconds after the meteor trail started. This is a demonstration of the ability of the DOPLOC system to detect and track a satellite in the presence of a large, interfering signal.

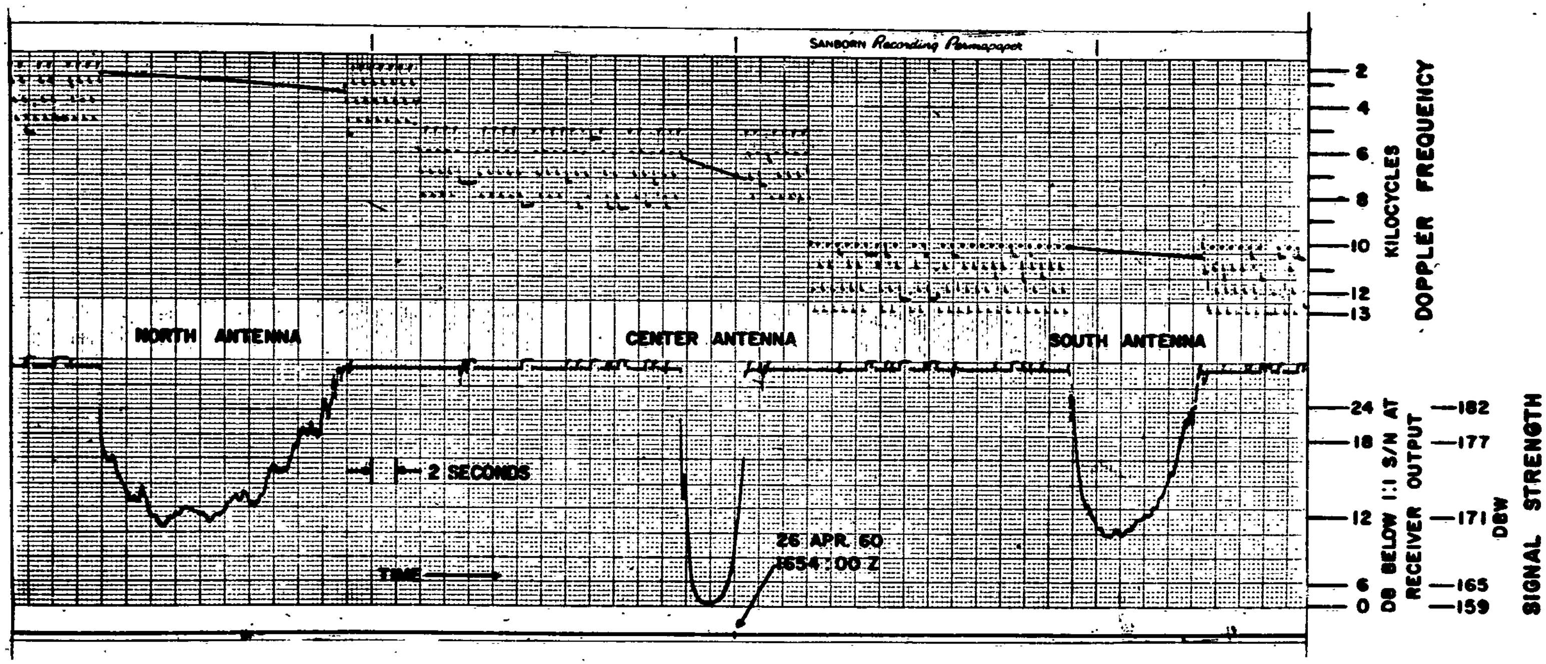
An analog record of reflected signal strength and Doppler frequency obtained from a satellite passing through the three antenna beams is shown in Figure 32. This record depicts the step-scan frequency search, lock-on, and continuous track sequence as the satellite passed through the north antenna beam, center beam and south beam. This record is of particular interest since it is the last passage of 1960 Delta, Discoverer XI, over the Northern Hemisphere before burning up in the Southern Hemisphere on this revolution.

A provocative situation exists in connection with 1958 Delta and ion trail observations. The station operators have noted in quite a number of instances that a strong, constant doppler frequency is observed just at or after 1958 Delta is predicted to be in the antenna beam. A preliminary survey has indeed disclosed that for the 10 minute period after predicted pass time for 1958 Delta, considerably more "flats" were recorded than in a randomly selected 10 minute period during the day. There also is a slightly greater tendency for "flats" associated with passes below 500 miles altitude. Figure 33 shows a compilation of "flats" observed after predicted satellite pass times. The length of the bar is proportional to the duration of the signal and the time along the abscissa is the time after predicted satellite time. Figure 34 shows a similar graph for a randomly selected 10 minute period. The larger number of "flats" in Figure 33 is quite striking. Figure 35 shows a typical record of a flat occurring immediately after a 1958 Delta pass. It is not certain at this time whether there is a statistically sound correlation between the passage of 1958 Delta and the ion clouds observed. Perhaps it has been fortuitous that pass times have been at times of high meteor activity. However, similar observations have been reported by Roberts



ARPA - BRL DOPLOC DOPPLER RECORD OF
58 DELTA REV 8386 FORREST CITY, ARKANSAS
MEASURED 21:36:23 Z, PREDICTED 21:32 Z
ALTITUDE 172 MILES, 176 MILES EAST FT. SILL
CENTER ANTENNA, N-S PASS
BFO 108,007,000 CPS
TRANSMITTER 108,000,000 CPS

PHOTO 3
Fig. 31



ARPA - BRL DOPLOC DOPPLER RECORD OF
60 DELTA REV 172, FORREST CITY, ARKANSAS
MEASURED 1653:56 Z, PREDICTED 1702 Z
ALTITUDE 77 MILES, 370 MILES EAST FT. SILL
NORTH - CENTER - SOUTH ANTENNAS, NORTH - SOUTH PASS

Fig. 32

1958 DELTA (2) N-S PASSES, 500 MILE ALTITUDE
POSITIVE, NEGATIVE AND FLAT SLOPES OCC
THE 10 MINUTE PERIOD FOLLOWING PREDIC
TIME. POSITIVES AND NEGATIVES ARE NOTE
OTHERS ARE FLATS.

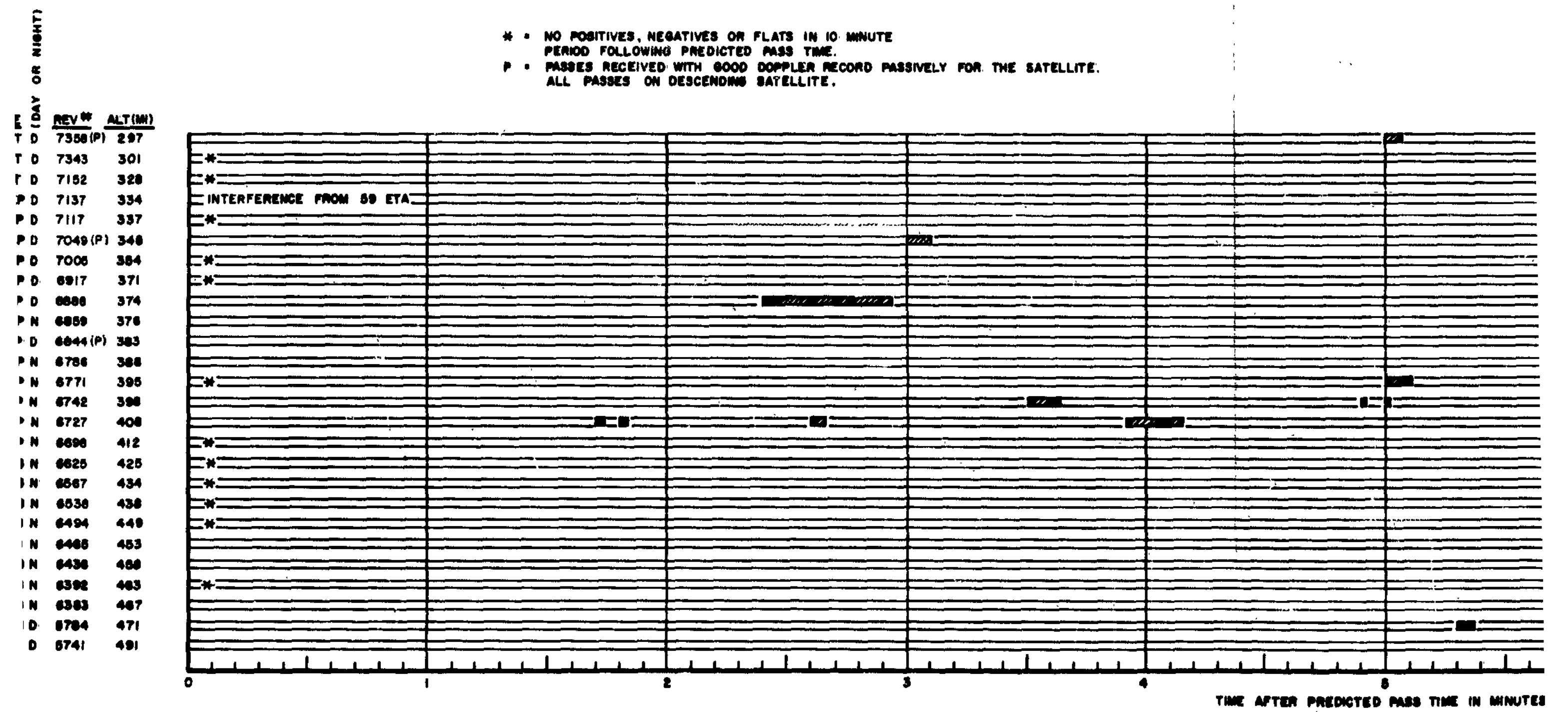


FIG. 33

1958 DELTA (2) N-S PASSES ,500 MILE ALTITUDE OR LOWER. POSITIVE, NEGATIVE AND FLAT SLOPES OCCURRING IN THE 10 MINUTE PERIOD FOLLOWING PREDICTED PASS TIME POSITIVES AND NEGATIVES ARE NOTED; ALL OTHERS ARE FLATS.

TE.

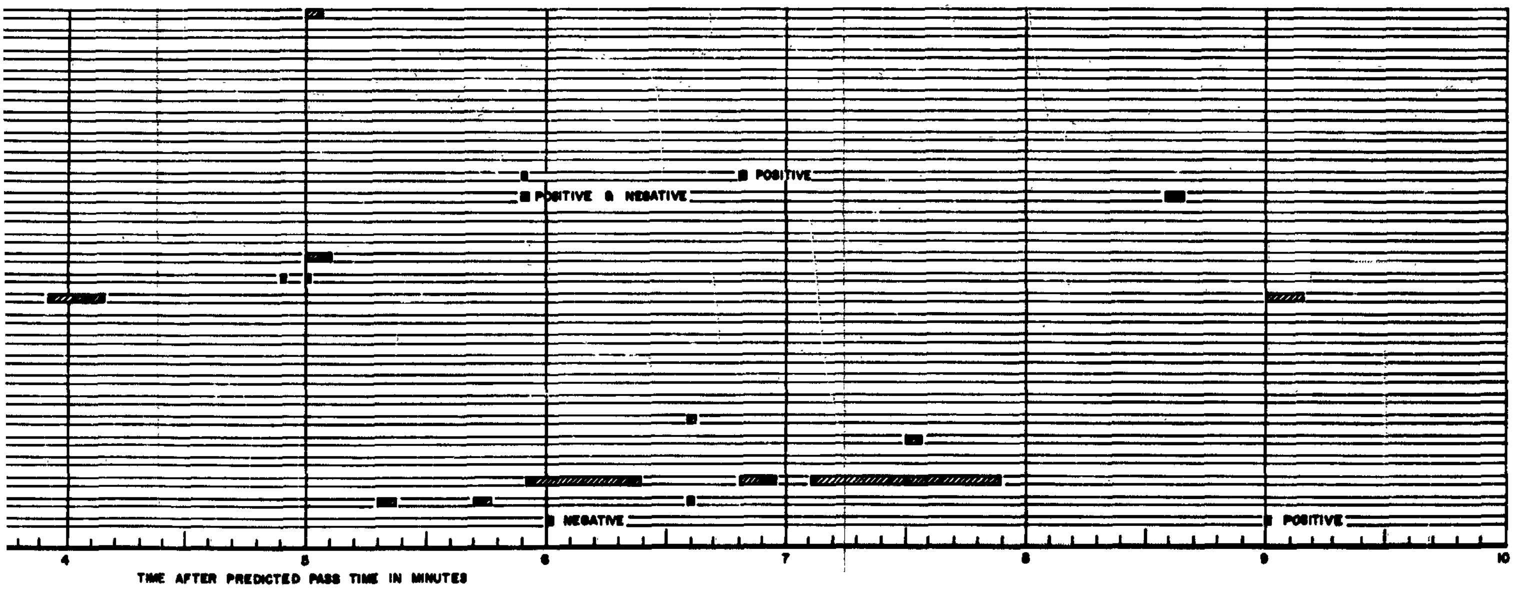


FIG. 33

EXAMINATION OF RANDOM 10 MINUTE PERIODS UNLESS OTHERWISE INDICATED ALL OCCURRENCES ARE FLATS

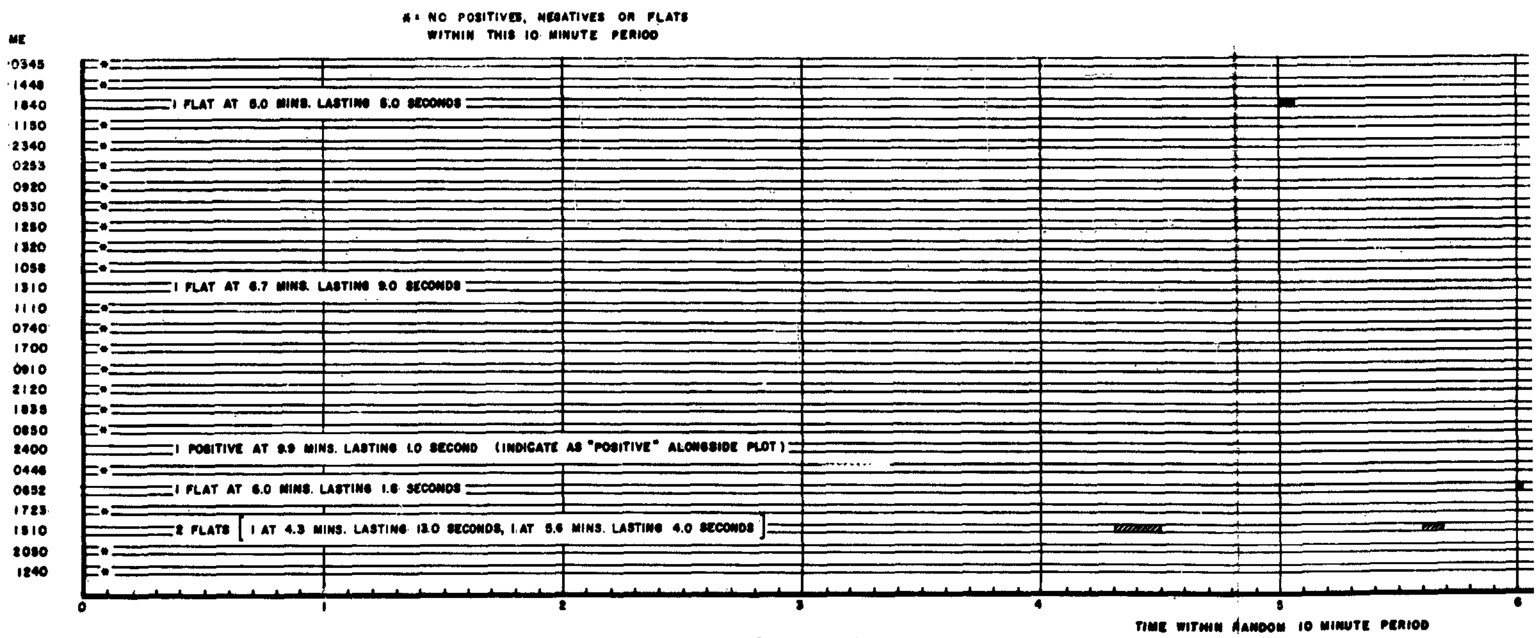


FIG. 34

IINATION OF RANDOM 10 MINUTE PERIODS UNLESS
RWISE INDICATED, ALL OCCURRENCES ARE FLATS

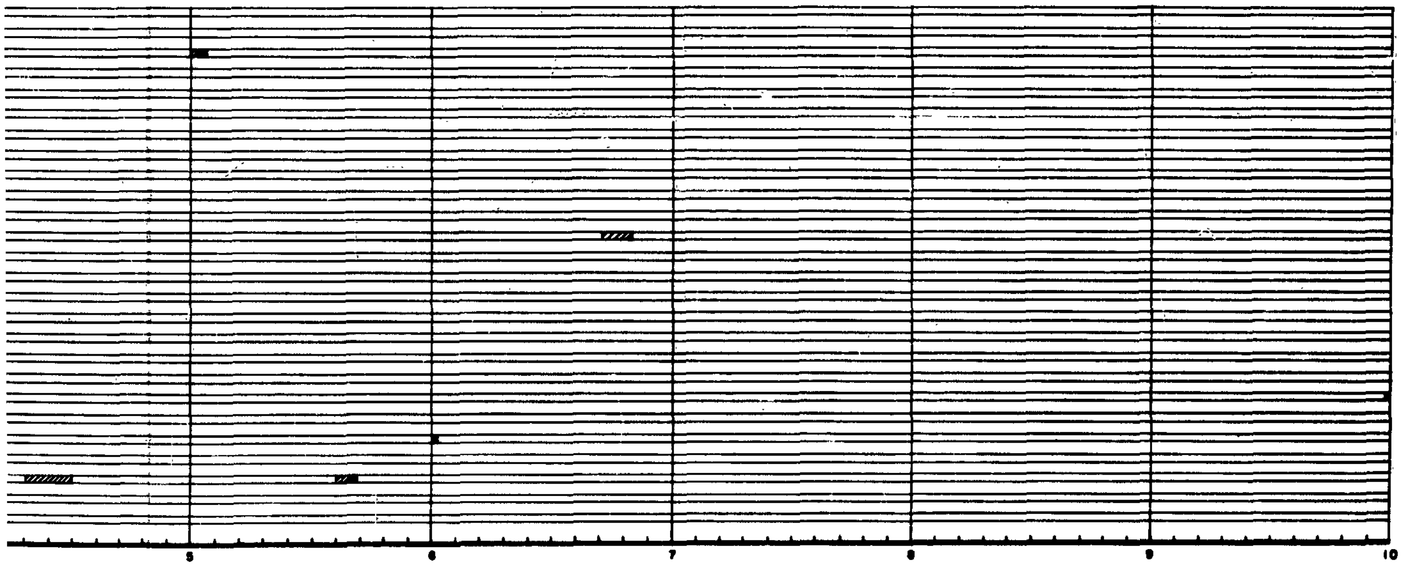
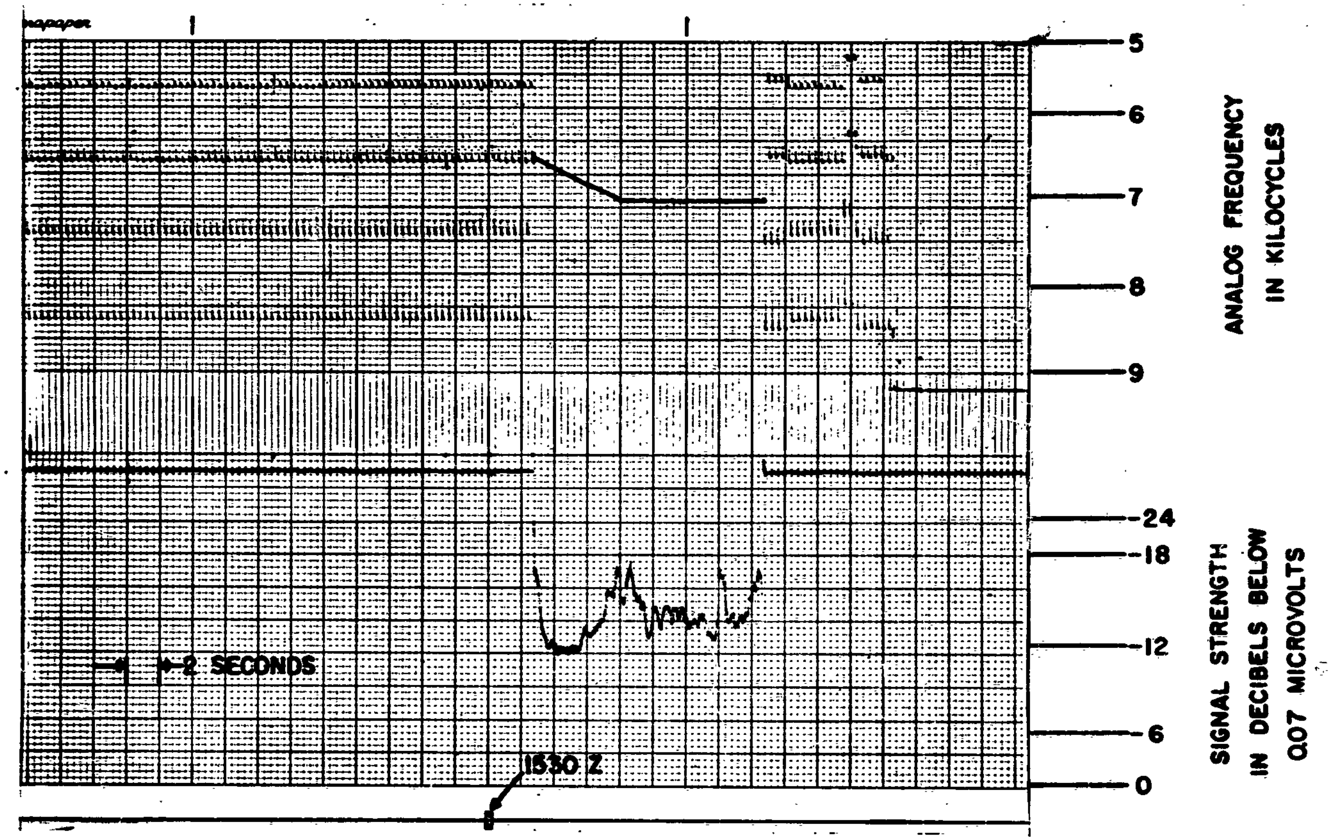


FIG. 34



ARPA—BRL DOPLOC DOPPLER RECORD OF
58 DELTA REV. 8719, FORREST CITY, ARKANSAS
MEASURED 1530:03 Z, PREDICTED 1528 Z
ALTITUDE 186 MILES, 50 MILES EAST FT. SILL
CENTER ANTENNA, NORTH—SOUTH PASS

Fig. 35

and Kirchner, QST, August 1959, p. 34, and Krause of Ohio State University Research Foundation. Equivalent radar cross-section areas of the ion clouds occurring after 1958 Delta low altitude passes vary from 1.7 to 14,600 square meters. Of 32 records examined to date, 9 show cross-sections greater than 100 square meters, 10 greater than 50 square meters, and 16 greater than 10 square meters.

SECTION VII

ACTIVE TRACKING EFFORT

A. Utilization of Data

In addition to the passive satellite tracking operations conducted at the BRL-ARPA DOPLOC stations during the period of July 1960 through December 1960, there has been a considerable amount of activity in the tracking of both active satellites and space probes. The major portion of this active tracking has been carried out at the BRL-APG station located on Spesutia Island at Aberdeen Proving Ground, Maryland. In addition to passive tracking, the station at Forrest City, Arkansas has also participated in active tracking of certain satellites. A detailed description of active tracking operations is included in part C of this section.

The primary uses to which data obtained by active tracking have been put are as follows:

a. Checking the quality of Doppler data obtained by the DOPLOC system.

b. Developing orbit computation techniques (as reported in Section IV of this report).

c. Improving overall system sensitivity and frequency coverage by the use of improved antennas, pre-amplifiers and r.f. receivers.

d. Improving and extending data handling techniques, including the automatic plotting of data from punched paper tape.

The secondary use of active tracking operations has been the furnishing of Doppler data on specific request to outside agencies, including Space Track Control Center at Cambridge, Massachusetts, NASA, and the Army Ballistic Missile Agency at Huntsville, Alabama. Information necessary for setting up the station receiving equipment prior to a launching or a tracking operation has been forwarded to BRL by classified teletype. In certain instances, the type of equipment required for a specific mission has not been readily available, because of the various transmitter frequencies now being used on different types of satellites. Over the past twelve-month period, the necessary receiving equipment has either been built or procured to allow complete radio frequency coverage over the range of 55 mc. to 970 mc. at the BRL-APG station. In addition to this equipment, special receivers have been built to operate phase-coherently at 20 mc. and 40 mc. and modifications have been made to existing gear to operate at 37 mc. for BRL ionosphere probe measurements.

B. Quick-Look Activity

Active tracking operations at the receiving stations have been of two basic types, although the same general instrumentation has been used for each. The first type is classified as a "Quick-Look" operation and, as the name implies, it serves to furnish information to the requesting agency as rapidly as possible following a satellite launching. Direct communication via commercial teletype allowed transmission of Doppler data vs. time within a few minutes of signal reception. These data have been most helpful in the determination of rocket stage operation and of satellite orbiting. The BRL-APG station is in a good geographical location for covering the launch phase of missiles fired in an easterly or north-easterly direction from the Atlantic Missile Range. Signals at this station are obtained within approximately two and one-half minutes after lift-off and remain at a sufficiently high level to obtain data at separation of the various rocket stages. Although the Forrest City Station is physically farther away from the Florida launch site, successful launch data has been obtained from it also.

The second type of tracking operation is classified as the routine tracking of satellites and probes as they orbit within range of the stations for the purpose of obtaining the Doppler "S" curve and trajectory data.

A brief summary of active tracking operations for the period 1 July 1959 - 1 July 1960 is shown in Table VI.

TABLE VI

Name	No. of Revolutions Tracked APG*	FCY**	Number of Simultaneous Tracks at two stations
Sputnik III, 1958 Delta	6	12	3
Explorer VI, 1959 Delta	18	15	12
Discoverer V, 1959 Epsilon	3	2	2
Discoverer VI, 1959 Zeta	15	8	2
Explorer VII, 1959 Iota	11	1	1
Discoverer VII, 1959 Kappa	3	0	0
Discoverer VIII, 1959 Lambda	3	0	0
Midas I	1	0	0
Pioneer V, 1960 Alpha	3	0	0
Juno II	1	0	0
Tiros I, 1960 Beta 2	18	4	4
Transit 1B, 1960 Gamma 2	39	19	19
Discoverer XI, 1960 Delta	4	3	3
Echo I	1	1	1
Sputnik IV, 1960 Epsilon	8	3	3
Midas II, 1960 Zeta	2	0	0
Shotput I	1	0	0
Transit 2A, 1960 Eta 1	3	3	3
Totals:	130	71	53

* Aberdeen Proving Ground, Maryland

** Forrest City, Arkansas

C. ACTIVE TRACKING OPERATIONS, 1 JULY 1959 - 1 JULY 1960

Date	Name	Test No.	Agency	Revolution Number	Station*	Duration of Track	Remarks
16 Jul 59	Explorer	AM-16	ABMA	Launch	APG	-	Unsuccessful
7 Aug 59	Explorer VI, 59 Delta	AMR-1005	ABMA	Launch	APG	5m. 48s.	
8 Aug 59	Sputnik III, 58 Delta	-	-	6348	FCY	7m. 9s.	
8 Aug 59	Explorer VI, 59 Delta	-	-	2	APG	8m. 50s.	
8 Aug 59	Explorer VI, 59 Delta			2	FCY	14m. 6s.	
9 Aug 59	Sputnik III, 58 Delta			6363	FCY	11m. 0s.	
9 Aug 59	Explorer VI, 59 Delta			4	APG	11m. 4s.	
9 Aug 59	Explorer VI, 59 Delta			4	FCY	29m. 42s.	
10 Aug 59	Explorer VI, 59 Delta			6	APG	2h. 11m. 24s.	
10 Aug 59	Explorer VI, 59 Delta			6	FCY	10h. 3m. 43s.	
10 Aug 59	Sputnik III, 58 Delta		-	6383	FCY	6m. 54s.	
11 Aug 59	Explorer VI, 59 Delta			8	APG	15m. 3s.	
11 Aug 59	Explorer VI, 59 Delta			8	FCY	11m. 53s.	
12 Aug 59	Explorer VI, 59 Delta			10	APG	12m. 4s.	
14 Aug 59	Explorer	AM-19B	ABMA	Launch	APG	13m. 46s.	Good launch data, did not orbit
14 Aug 59	Explorer	AM-19B	ABMA	Launch	FCY	14m. 0s.	(same)
14 Aug 59	Discoverer V, 59 Epsilon	-	Spacetrack	6	APG	5m. 46s.	
14 Aug 59	Discoverer V, 59 Epsilon	-		7	APG	7m. 15s.	
				7	FCY	7m. 4s.	
14 Aug 59	Discoverer V, 59 Epsilon			14	APG	6m. 14s.	
14 Aug 59	Discoverer V, 59 Epsilon			14	FCY	3m. 29s.	

*APG - Aberdeen Proving Ground, Maryland
FCY - Forrest City, Arkansas

DETAILED SUMMARY OF ACTIVE TRACKING OPERATIONS, 1 JULY 1959 - 1 JULY 1960

Date	Name	Test No.	Agency	Revolution Number	Station*	Duration of Track	Remarks
15 Aug 59	Explorer VI, 59 Delta			15	APG	10m. 4s.	
15 Aug 59	Explorer VI, 59 Delta			15	FCY	4m. 3s.	
16 Aug 59	Explorer VI, 59 Delta			17	FCY	6m. 55s.	
16 Aug 59	Sputnik III, 58 Delta			6474	FCY	10m. 8s.	
17 Aug 59	Explorer VI, 59 Delta			19	APG	17m. 44s.	
17 Aug 59	Explorer VI, 59 Delta			19	FCY	7m. 36s.	
18 Aug 59	Explorer VI, 59 Delta			21	APG	1h. 10m. 20s.	
18 Aug 59	Explorer VI, 59 Delta			21	FCY	5m. 35s.	
18 Aug 59	Sputnik III, 58 Delta			6503	FCY	9m. 50s.	
20 Aug 59	Discoverer VI, 59 Zeta	-	Spacetrack	7	APG	11m. 11s.	
20 Aug 59	Discoverer VI, 59 Zeta			13	APG	4m. 50s.	
21 Aug 59	Discoverer VI, 59 Zeta			21	APG	7m. 14s.	
21 Aug 59	Discoverer VI, 59 Zeta			22	APG	11m. 6s.	
21 Aug 59	Discoverer VI, 59 Zeta	-	Space track	28	APG	7m. 10s.	
22 Aug 59	Discoverer VI, 59 Zeta			43	APG	7m. 18s.	
22 Aug 59	Discoverer VI, 59 Zeta			44	APG	3m. 50s.	
23 Aug 59	Discoverer VI, 59 Zeta			58	APG	7m. 16s.	
23 Aug 59	Discoverer VI, 59 Zeta			59	APG	4m. 56s.	
24 Aug 59	Explorer VI, 59 Delta			32	APG	5m. 44s.	
25 Aug 59	Explorer VI, 59 Delta			34	APG	6m. 10s.	
25 Aug 59	Sputnik III, 58 Delta			6605	FCY	8m. 25s.	

*APG - Aberdeen Proving Ground, Maryland
FCY - Forrest City, Arkansas

DETAILED SUMMARY OF ACTIVE TRACKING OPERATIONS, 1 JULY 1959 - 1 JULY 1960

Date	Name	Test No.	Agency	Revolution Number	Station*	Duration of Track	Remarks
26 Aug 59	Explorer VI, 59 Delta			36	APG	8h. 10m. 3s.	
26 Aug 59	Explorer VI, 59 Delta			36	FCY	9m. 43s.	
26 Aug 59	Discoverer VI, 59 Zeta			98	FCY	5m. 24s.	
26 Aug 59	Discoverer VI, 59 Zeta			104	FCY	4m. 54s.	
27 Aug 59	Explorer VI, 59 Delta			38	APG	7h. 9m. 55s.	
27 Aug 59	Explorer VI, 59 Delta			38	FCY	9h. 27m. 0s.	
27 Aug 59	Discoverer VI, 59 Zeta			119	APG	3m. 48s.	
28 Aug 59	Discoverer VI, 59 Zeta			134	APG	6m. 52s.	
1 Sep 59	Discoverer VI, 59 Zeta			195	APG	7m. 18s.	
2 Sep 59	Discoverer VI, 59 Zeta			210	APG	7m. 56s.	
2 Sep 59	Discoverer VI, 59 Zeta			210	FCY	5m. 50s.	
2 Sep 59	Explorer VI, 59 Delta			49	APG	7m. 38s.	
3 Sep 59	Discoverer VI, 59 Zeta			225	APG	7m. 28s.	
3 Sep 59	Explorer VI, 59 Delta			51	APG	9m. 48s.	
4 Sep 59	Discoverer VI, 59 Zeta			234	FCY	6m. 26s.	
4 Sep 59	Sputnik III, 58 Delta			6751	FCY	6m. 57s.	
5 Sep 59	Discoverer VI, 59 Zeta			249	FCY	1m. 45s.	
5 Sep 59	Discoverer VI, 59 Zeta			256	FCY	2m. 48s.	
6 Sep 59	Sputnik III, 58 Delta			6780	FCY	6m. 18s.	
8 Sep 59	Discoverer VI, 59 Zeta			295	FCY	3m. 5s.	

*APG - Aberdeen Proving Ground, Maryland
FCY - Forrest City, Arkansas

DETAILED SUMMARY OF ACTIVE TRACKING OPERATIONS, 1 JULY 1959 - 1 JULY 1960

Date	Name	Test No.	Agency	Revolution Number	Station*	Duration of Track	Remarks
10 Sep 59	Discoverer VI, 59 Zeta			332	APG	8m. 38s.	
10 Sep 59	Discoverer VI, 59 Zeta			332	FCY	6m. 4s.	
11 Sep 59	Explorer VI, 59 Delta			68	FCY	7h. 44m. 49s.	
13 Sep 59	Explorer VI, 59 Delta			70	FCY	9h. 2m. 11s.	
14 Sep 59	Sputnik III, 58 Delta			6897	FCY	9m. 27s.	
17 Sep 59	Transit I	-	Spacetrack	Launch	APG	13m. 3s.	Good launch data, did not orbit.
17 Sep 59	Transit I		Spacetrack	Launch	FCY	8m. 18s.	
21 Sep 59	Explorer VI, 59 Delta	-	-	85	APG	2h. 20m. 14s.	
21 Sep 59	Explorer VI, 59 Delta			85	FCY	2h. 22m. 44s.	
29 Sep 59	Explorer VI, 59 Delta			100	APG	2h. 18m. 38s.	
29 Sep 59	Explorer VI, 59 Delta			100	FCY	2h. 16m. 35s.	
30 Sep 59	Explorer VI, 59 Delta			102	APG	1h. 15m. 54s.	
30 Sep 59	Explorer VI, 59 Delta			102	FCY	1h. 17m. 56s.	
4 Oct 59	Lunik III, 59 Theta	-	Spacetrack (Probe)	-	APG	-	Unsuccessful tracking, no signal rec'd.
13 Oct 59	Explorer VII, 59 Iota	AM-19A	ABMA	Launch	APG	5m. 21s.	
13 Oct 59	Explorer VII, 59 Iota			1	APG	8m. 38s.	
13 Oct 59	Explorer VII, 59 Iota			2	APG	7m. 27s.	
13 Oct 59	Explorer VII, 59 Iota			3	APG	14m. 0s.	
13 Oct 59	Explorer VII, 59 Iota			3	FCY	9m. 22s.	

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DETAILED SUMMARY OF ACTIVE TRACKING OPERATIONS, 1 JULY 1959 - 1 JULY 1960

Date	Name	Test No.	Agency	Revolution Number	Station*	Duration of Track	Remarks
14 Oct 59	Explorer VII, 59 Iota			14	APG	7m. 5s.	
14 Oct 59	Explorer VII, 59 Iota			15	APG	6m. 35s.	
15 Oct 59	Explorer VII, 59 Iota			28	APG	3m. 30s.	
15 Oct 59	Explorer VII, 59 Iota			29	APG	6m. 0s.	
8 Nov 59	Discoverer VII, 59 Kappa	Agena 1051	Spacetrack	6	APG	3m. 28s.	
8 Nov 59	Discoverer VII, 59 Kappa			7	APG	6m. 0s.	
8 Nov 59	Discoverer VII, 59 Kappa			8	APG	5m. 50s.	
10 Nov 59	Strongarm I, (BRL Inosphere Probe)		BRL	Full Trajectory	APG	24m. 30s.	
18 Nov 59	Strongarm II, (BRL Inosphere Probe)		BRL	Partial Trajectory	APG	2m. 8s.	
21 Nov 59	Discoverer VIII, 59 Lambda	Agena 1050	Spacetrack	6	APG	15m. 5s.	
21 Nov 59	Discoverer VIII, 59 Lambda			7	APG	4m. 10s.	
21 Nov 59	Discoverer VIII, 59 Lambda			12	APG	3m. 16s.	
25 Nov 59	Explorer VIII, 59 Iota			603	APG	10m. 22s.	
25 Nov. 59	Explorer VII, 59 Iota			604	APG	11m. 34s.	
26 Nov 59	Lunar Probe, Atlas-Able 4		Spacetrack	Launch	APG	-	Unsuccessful launch
2 Dec 59	Explorer VII, 59 Iota			705	APG	11m. 38s.	
26 Feb 60	Midas I	-	Spacetrack	Launch	APG	00m. 04s.	Did not orbit
11 Mar 60	Pioneer V, 60 Alpha	-		Lanch	APG	02m. 05s.	

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FCY - Forrest City, Arkansas

DETAILED SUMMARY OF ACTIVE TRACKING OPERATIONS, 1 JULY 1959 - 1 JULY 1960

Date	Name	Test No.	Agency	Revolution Number	Station*	Duration of Track	Remarks
11 Mar 60	Pioneer V, 60 Alpha			-	APG	14m. 07s.	
11 Mar 60	Pioneer V, 60 Alpha			-	APG	12m. 50s.	
23 Mar 60	Juno II	AM-19C	Spacetrack	Launch	APG	04m. 06s.	Did not orbit
31 Mar 60	Sputnik III, 58 Delta	-		9942	APG	02m. 30s.	
1 Apr 60	Tiros I, 60 Beta 2	-	Spacetrack	Launch	APG	02m. 50s.	
1 Apr 60	Tiros I, 60 Beta 2			Launch	FCY	08m. 10s.	
1 Apr 60	Tiros I, 60 Beta 2			1	APG	10m. 55s.	
1 Apr 60	Tiros I, 60 Beta 2			2	APG	13m. 00s.	
1 Apr 60	Tiros II, 60 Beta 2			3	APG	12m. 16s.	
1 Apr 60	Tiros I, 60 Beta 2			4	APG	10m. 50s.	
1 Apr 60	Tiros I, 60 Beta 2			5	APG	10m. 02s.	
1 Apr 60	Sputnik III, 58 Delta	-		9958	APG	04m. 55s.	
1 Apr 60	Sputnik III, 58 Delta			9959	APG	02m. 52s.	
1 Apr 60	Sputnik III, 58 Delta			9959	FCY	04m. 36s.	
2 Apr 60	Sputnik III, 58 Delta			9975	APG	03m. 42s.	
2 Apr 60	Sputnik III, 58 Delta			9975	FCY	01m. 20s.	
2 Apr 60	Tiros I, 60 Beta 2			17	APG	09m. 59s.	
2 Apr 60	Tiros I, 60 Beta 2			18	APG	10m. 00s.	
2 Apr 60	Tiros I, 60 Beta 2			18	FCY	05m. 00s.	
2 Apr 60	Tiros I, 60 Beta 2			19	APG	11m. 00s.	
2 Apr 60	Tiros I, 60 Beta 2			19	FCY	11m. 44s.	

DETAILED SUMMARY OF ACTIVE TRACKING OPERATIONS, 1 JULY 1959 - 1 JULY 1960

Date	Name	Test No.	Agency	Revolution Number	Station*	Duration of Track	Remarks
4 Apr 60	Tiros I, 60 Beta 2			45	APG	09m. 42s.	
4 Apr 60	Tiros I, 60 Beta 2			46	APG	13m. 30s.	
4 Apr 60	Tiros I, 60 Beta 2			47	APG	10m. 39s.	
4 Apr 60	Tiros I, 60 Beta 2			48	APG	06m. 56s.	
4 Apr 60	Tiros I, 60 Beta 2			48	FCY	14m. 14s.	
4 Apr 60	Sputnik III, 58 Delta			10007	APG	03m. 43s.	
4 Apr 60	Sputnik III, 58 Delta			10007	FCY	03m. 54s.	
5 Apr 60	Sputnik III, 58 Delta			10023	APG	09m. 00s.	Erratic signal
5 Apr 60	Tiros I, 60 Beta 2			61	APG	13m. 13s.	
6 Apr 60	Tiros I, 60 Beta 2			74	APG	09m. 56s.	
6 Apr 60	Sputnik III, 58 Delta			10039	APG	00m. 05s.	Very weak
7 Apr 60	Tiros I, 60 Beta 2			90	APG	12m. 38s.	
8 Apr 60	Tiros I, 60 Beta 2			104	APG	12m. 58s.	
11 Apr 60	Tiros I, 60 Beta 2			147	APG	11m. 24s.	
13 Apr 60	Transit 1B, 60 Gamma 2		Spacetrack	Launch	APG	09m. 04s.	
13 Apr 60	Transit 1B, 60 Gamma 2	-		Launch	FCY	02m. 00s.	
13 Apr 60	Transit 1B, 60 Gamma 2			2	APG	10m. 14s.	
13 Apr 60	Transit 1B, 60 Gamma 2			3	APG	10m. 03s.	
13 Apr 60	Transit 1B, 60 Gamma 2			4	APG	08m. 56s.	
13 Apr 60	Transit 1B, 60 Gamma 2			4	APG	07m. 42s.	

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DETAILED SUMMARY OF ACTIVE TRACKING OPERATIONS, 1 JULY 1959 - 1 JULY 1960

Date	Name	Test No.	Agency	Revolution Number	Station*	Duration of Track	Remarks
14 Apr 60	Transit 1B, 60 Gamma 2			16	APG	09m. 37s.	
14 Apr 60	Transit 1B, 60 Gamma 2			16	FCY	01m. 36s.	
14 Apr 60	Transit 1B, 60 Gamma 2			19	APG	09m. 28s.	
14 Apr 60	Transit 1B, 60 Gamma 2			19	FCY	09m. 35s.	
14 Apr 60	Transit 1B, 60 Gamma 2			20	APG	07m. 53s.	
14 Apr 60	Transit 1B, 60 Gamma 2			20	FCY	12m. 26s.	
15 Apr 60	Transit 1B, 60 Gamma 2			34	APG	11m. 06s.	
15 Apr 60	Transit 1B, 60 Gamma 2			34	FCY	07m. 58s.	
16 Apr 60	Discoverer XI, 60 Delta	-	Spacetrack	6	APG	03m. 42s.	
16 Apr 60	Discoverer XI, 60 Delta			7	APG	08m. 43s.	
16 Apr 60	Discoverer XI, 60 Delta			7	FCY	06m. 13s.	
16 Apr 60	Discoverer XI, 60 Delta			14	APG	04m. 52s.	
16 Apr 60	Discoverer XI, 60 Delta			14	FCY	06m. 06s.	
18 Apr 60	Discoverer XI, 60 Delta			45	APG	03m. 10s.	
18 Apr 60	Discoverer XI, 60 Delta			45	FCY	05m. 12s.	
18 Apr 60	Transit 1B, 60 Gamma 2			79	APG	03m. 40s.	
18 Apr 60	Transit 1B, 60 Gamma 2			79	FCY	07m. 27s.	
20 Apr 60	Transit 1B, 60 Gamma 2			108	APG	08m. 26s.	
20 Apr 60	Transit 1B, 60 Gamma 2			108	FCY	10m. 09s.	
21 Apr 60	Transit 1B, 60 Gamma 2			123	APG	07m. 50s.	
21 Apr 60	Transit 1B, 60 Gamma 2			123	FCY	08m. 41s.	

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DETAILED SUMMARY OF ACTIVE TRACKING OPERATIONS, 1 JULY 1959 - 1 JULY 1960

Date	Name	Test No.	Agency	Revolution Number	Station*	Duration of Track	Remarks
22 Apr 60	Transit 1B, 60 Gamma 2			138	APG	07m. 31s.	
25 Apr 60	Transit 1B, 60 Gamma 2			182	APG	09m. 04s.	
25 Apr 60	Transit 1B, 60 Gamma 2			182	FCY	07m. 37s.	
26 Apr 60	Transit 1B, 60 Gamma 2			197	APG	06m. 34s.	
26 Apr 60	Transit 1B, 60 Gamma 2			197	FCY	07m. 24s.	
27 Apr 60	Transit 1B, 60 Gamma 2			212	APG	08m. 02s.	
27 Apr 60	Transit 1B, 60 Gamma 2			212	FCY	10m. 03s.	
28 Apr 60	Transit 1B, 60 Gamma 2			227	APG	06m. 10s.	
28 Apr 60	Transit 1B, 60 Gamma 2			227	FCY	08m. 18s.	
29 Apr 60	Transit 1B, 60 Gamma 2			242	APG	08m. 34s.	
2 May 60	Transit 1B, 60 Gamma 2			286	APG	07m. 46s.	
2 May 60	Transit 1B, 60 Gamma 2			286	FCY	06m. 01s.	
3 May 60	Transit 1B, 60 Gamma 2			301	APG	07m. 28s.	
3 May 60	Transit 1B, 60 Gamma 2			301	FCY	07m. 52s.	
13 May 60	Echo I	-	Spacetrack	Launch	APG	04m. 15s.	Did not orbit
13 May 60	Echo I			Launch	FCY	08m. 18s.	
16 May 60	Sputnik IV, 60 Epsilon 1			26	APG	02m. 50s.	
16 May 60	Sputnik IV, 60 Epsilon 1			27	APG	06m. 03s.	
16 May 60	Sputnik IV, 60 Epsilon 1			28	APG	05m. 20s.	
17 May 60	Sputnik IV, 60 Epsilon 1			43	APG	10m. 24s.	
17 May 60	Sputnik IV, 60 Epsilon 1			43	FCY	09m. 19s.	

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DETAILED SUMMARY OF ACTIVE TRACKING OPERATIONS, 1 JULY 1959 - 1 JULY 1960

Date	Name	Test No.	Agency	Revolution Number	Station*	Duration of Track	Remarks
18 May 60	Sputnik IV, 60 Epsilon 1			58	APG	09m. 58s.	
19 May 60	Sputnik IV, 60 Epsilon 1			73	APG	08m. 38s.	
19 May 60	Sputnik IV, 60 Epsilon 1			74	APG	08m. 27s.	
19 May 60	Sputnik IV, 60 Epsilon 1			74	FCY	06m. 55s.	
20 May 60	Sputnik IV, 60 Epsilon 1			89	APG	09m. 06s.	
20 May 60	Sputnik IV, 60 Epsilon 1			89	FCY	08m. 49s.	
20 May 60	Transit 1B, 60 Gamma 2			563	APG	06m. 14s.	
20 May 60	Transit 1B, 60 Gamma 2			563	FCY	07m. 48s.	
25 May 60	Transit 1B, 60 Gamma 2			637	APG	06m. 22s.	
26 May 60	Transit 1B, 60 Gamma 2			652	APG	06m. 26s.	
26 May 60	Transit 1B, 60 Gamma 2			652	FCY	07m. 48s.	
26 May 60	Midas II, 60 Zeta	-	Spacetrack	28	APG	05m. 34s.	
27 May 60	Midas II, 60 Zeta			43	APG	03m. 02s.	
27 May 60	Transit 1B, 60 Gamma 2			667	APG	05m. 06s.	
27 May 60	Transit 1B, 60 Gamma 2			667	FCY	07m. 17s.	
31 May 60	Transit 1B, 60 Gamma 2			726	APG	05m. 12s.	
31 May 60	Shotput I, 100' Balloon	-	NASA	Launch	APG	09m. 12s.	
1 Jun 60	Transit 1B, 60 Gamma 2			741	APG	04m. 17s.	
1 Jun 60	Transit 1B, 60 Gamma 2			741	FCY	08m. 20s.	

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DETAILED SUMMARY OF ACTIVE TRACKING OPERATIONS, 1 JULY 1959 - 1 JULY 1960

Date	Name	Test No.	Agency	Revolution Number	Station*	Duration of Track	Remarks
6 Jun 60	Transit 1B, 60 Gamma 2			815	APG	05m. 24s.	
6 Jun 60	Transit 1B, 60 Gamma 2			815	FCY	09m. 30s.	
7 Jun 60	Transit 1B, 60 Gamma 2			829	APG	07m. 02s.	
7 Jun 60	Transit 1B, 60 Gamma 2			830	APG	06m. 40s.	
8 Jun 60	Transit 1B, 60 Gamma 2			844	APG	07m. 18s.	
8 Jun 60	Transit 1B, 60 Gamma 2			845	APG	05m. 10s.	
9 Jun 60	Transit 1B, 60 Gamma 2			859	APG	06m. 34s.	
9 Jun 60	Transit 1B, 60 Gamma 2			860	APG	06m. 34s.	
10 Jun 60	Transit 1B, 60 Gamma 2			874	APG	07m. 38s.	
13 Jun 60	Transit 1B, 60 Gamma 2			919	APG	06m. 17s.	
21 Jun 60	Transit 1B, 60 Gamma 2			1041	APG	06m. 58s.	
22 Jun 60	Transit 1B, 60 Gamma 2			1056	APG	07m. 30s.	
22 Jun 60	Transit 2A, 60 Eta 1		Spacetrack	9	APG	10m. 43s.	
22 Jun 60	Transit 2A, 60 Eta 1			9	FCY	14m. 50s.	
23 Jun 60	Transit 2A, 60 Eta 1			23	APG	12m. 00s.	
25 Jun 60	Transit 2A, 60 Eta 1			23	FCY	15m. 30s.	
25 Jun 60	Transit 1B, 60 Gamma 2			1071	APG	06m. 10s.	
24 Jun 60	Transit 1B, 60 Gamma 2			1086	APG	03m. 51s.	
24 Jun 60	Transit 2A, 60 Eta 1			37	APG	11m. 40s.	
24 Jun 60	Transit 2A, 60 Eta 1			37	FCY	09m. 00s.	

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FCY - Forrest City, Arkansas

SECTION VIII

ACKNOWLEDGEMENTS

This report was prepared by members of the staff of the Electronic Measurements Branch, Ballistic Measurements Laboratory of the Ballistic Research Laboratories.

L. G. deBEY

Appendix I

COMPANIES REPRESENTED AT BRIEFING
AT BALLISTIC RESEARCH LABORATORIES
ABERDEEN PROVING GROUND, MARYLAND
16 September 1959

Adams-Russell Co., Inc.
200 Sixth Street
Cambridge 42, Massachusetts
ATTN: Mr. Gerald J. Adams

Aero-Geo Astro Company
Alexandria, Virginia

Airborne Instruments Lab., Inc.
160 Old Country Road
Mineola, New York

Andrew-Alford Consolidated Mfg. Co.
299 Atlantic Avenue
Boston 10, Massachusetts

Aircraft Armaments
Cockeysville, Maryland

All Products
714 Jackson Street
Dallas, Texas
ATTN: Commdr. Rivers,
Insp. Naval Material

Avco Research Laboratory
1329 Arlington Street
Cincinnati, Ohio

Bendix Aviation
Bendix Radio Division
E. Joppa Road
Baltimore 4, Maryland

Blaw-Knox Co.
Blaw-Knox Equipment Division
Pittsburgh 38, Pennsylvania
ATTN: Mr. Raymond D. Levith

Collins Radio Company
855 35th Street, N.W.
Cedar Rapids, Iowa

Continental Electric Mfg. Co.
4212 S. Buckner Street
Dallas, Texas

D. A. Kennedy & Company
Route 3A
Cohassit, Massachusetts

Electronic Communications, Inc.
1501 72nd Street, North
St. Petersburg 10, Florida

Fairchild Aircraft
Hagerstown, Maryland

Technical Appliance Corp.
1 Taco Street
Sherburne, New York

Gates Radio Corp.
1705 Taylor Avenue
2090 Barnes Avenue
Bronx 62, New York

General Electric Co.
777 14th Street, N.W.
Washington, D.C.
ATTN: Mr. H. N. McIntyre

Levinthal Elec. Co.
Stanford Industrial Park
Palo Alto, California

Lenkurt Electric Co.
1105 County Road
San Carlos, California
ATTN: J. A. Stewart, Res. Staff

Lenkurt Electric Co.
425 13th Street, N.W.
Washington 3, D.C.

Melpar, Inc.
3000 Arlington Blvd.
Falls Church, Virginia

Page Communications Engineers
710 14th Street, N.W.
Washington 3, D.C.

Radiation, Inc.
P.O. Box 37
Melbourne, Florida

RCA
Missile Electronics & Controls Dept.
Burlington, Mass.

Ramo-Woolridge Corp.
Antenna Design Dept.
Inglewood, California

Scanwell Labs Inc.
6601 Scanwell Lane
Springfield, Virginia

Sylvania Electric
Waltham Labs
100 First Street
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L. G. deBey

BRLM Report No. 1287 July 1960

Report No. 16 in the Series

UNCLASSIFIED Report

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Radar tracking - Satellites
Doppler tracking systems - Design

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Radar tracking - Satellites
Doppler tracking systems - Design

A summary of the significant progress and activity is presented on the development of DOPLOC, a dark satellite tracking system, over the period from 1 July 1959 to 1 July 1960. A resume is given of the program administration and project assignment chronology. A description of the Scanning DOPLOC System, including cost estimates for various combinations of antenna types is presented. An analysis of the proposals submitted by eleven contractors and the basis for the choice of two acceptable proposals is given. The activity in the development of mathematical processes for determining the orbital parameters from DOPLOC data and its successful application to measured data is discussed. It is noteworthy that twenty completely independent, single pass, satellite orbital solutions have been obtained. Studies supporting the development of the Scanning DOPLOC System are discussed briefly. Experimental use of the field station facilities for the tracking of non-radiating satellites is described and sample data are shown to illustrate the system performance. A compilation of the satellites tracked by reflection summarizes pertinent tracking data including signal duration, signal strength and effective reflection cross section.