RADC-TR-65-85

PRECISION ANTENNA PATTERN RECORDING TECHNIQUES
PHASE II

Jack B. Chastain
(Scientific-Atlanta, Inc.)

TECHNICAL REPORT NO. RADC-TR-65-85

June 1965

Techniques Branch
Rome Air Development Center
Research and Technology Division
Air Force Systems Command
Griffiss Air Force Base, New York

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AFLC, GAFB, N.Y., 22 Jul 65-126

FOREWORD

This third quarterly interim report was prepared under Contract No. AF30(602)-3425, Project No. 4506, and Task No. 450604 by Jack B. Chastain, J. Searcy Hollis, Samuel F. Hutchins, and Rezin E. Pidgeon, Jr., Scientific-Atlanta, Inc., Atlanta, Georgia 30324. The RADC Project Engineer was Martin Jaeger, EMATA.

This technical report has been reviewed and is approved.

Approved: MARTIN JAEGER
Project Engineer
Antenna & Coherent Optical Section

Approved: ARTHUR J. FROHLICH, Chief
Techniques Branch
Surveillance & Control Division

ABSTRACT

Third quarterly report of work accomplished on precision antenna pattern recording techniques, under Contract AF 30(602)-3425, is presented. This contract is for continuation of work performed under Contract AF 30(602)-2737, in which a study and investigation was made to prove the feasibility of precision amplitude- and angle-measuring devices, combined with sophisticated recording and display techniques, for antenna pattern measurements. The current program includes development of a stabilized transmitter, a precision, high data rate receiver and associated equipment, and continuation of the theoretical investigation reported under the previous contract. The transmitter and receiving equipment will be installed and tested at the USAF Antenna Proving Range at Newport, New York.

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1. INTRODUCTION

Contract AF 30(602)-3425* is for development of equipment to enhance the antenna measurement capability of ground-based antenna test ranges, and for a continuation of theoretical studies performed under Contract AF 30(602)-2737*. Efforts accomplished under Contract AF 30(602)-2737 were reported in Investigation of Precision Antenna Pattern Recording and Display Techniques, Final Report, RADC-TDR-63-247.[1] Figure 1 is a graphical presentation in system-block-diagram form of the technical goals for the overall antenna pattern-measurement system.

Equipment that is being developed under Phase II includes an amplitude- and frequency-stabilized signal source for the frequency range of 2 Gc to 4 Gc, and a precision, high data rate receiver with logarithmic readout of data in digital and analog form. The receiver incorporates new logarithmic conversion techniques, which were investigated for feasibility under Phase I. The receiver will be designed to cover the frequency range of 2 Gc to 4 Gc, but will be evaluated experimentally over the frequency range of 0.2 Gc to 12 Gc. A block diagram showing the equipment supplied under Phase II and incorporation of this equipment into the antenna measurements system is shown in Figure 2.

The scope of the theoretical studies includes an investigation of environmental effects and an analysis of parallax errors as related to high-accuracy antenna measurements; an investigation of antenna-positioning and angle-measuring equipment; and a determination of optimum techniques for a high-speed precision recording system.

This technical report describes work accomplished by Scientific-Atlanta, Inc., for Rome Air Development Center under the subject contract entitled "Precision Antenna Pattern Recording Techniques, Phase II," during the period 9 November 1964 to 29 January 1965.

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*In this report the current contract is referred to as Phase II; the previous contract is referred to as Phase I.

[1] ASTIA No. AD-415 912

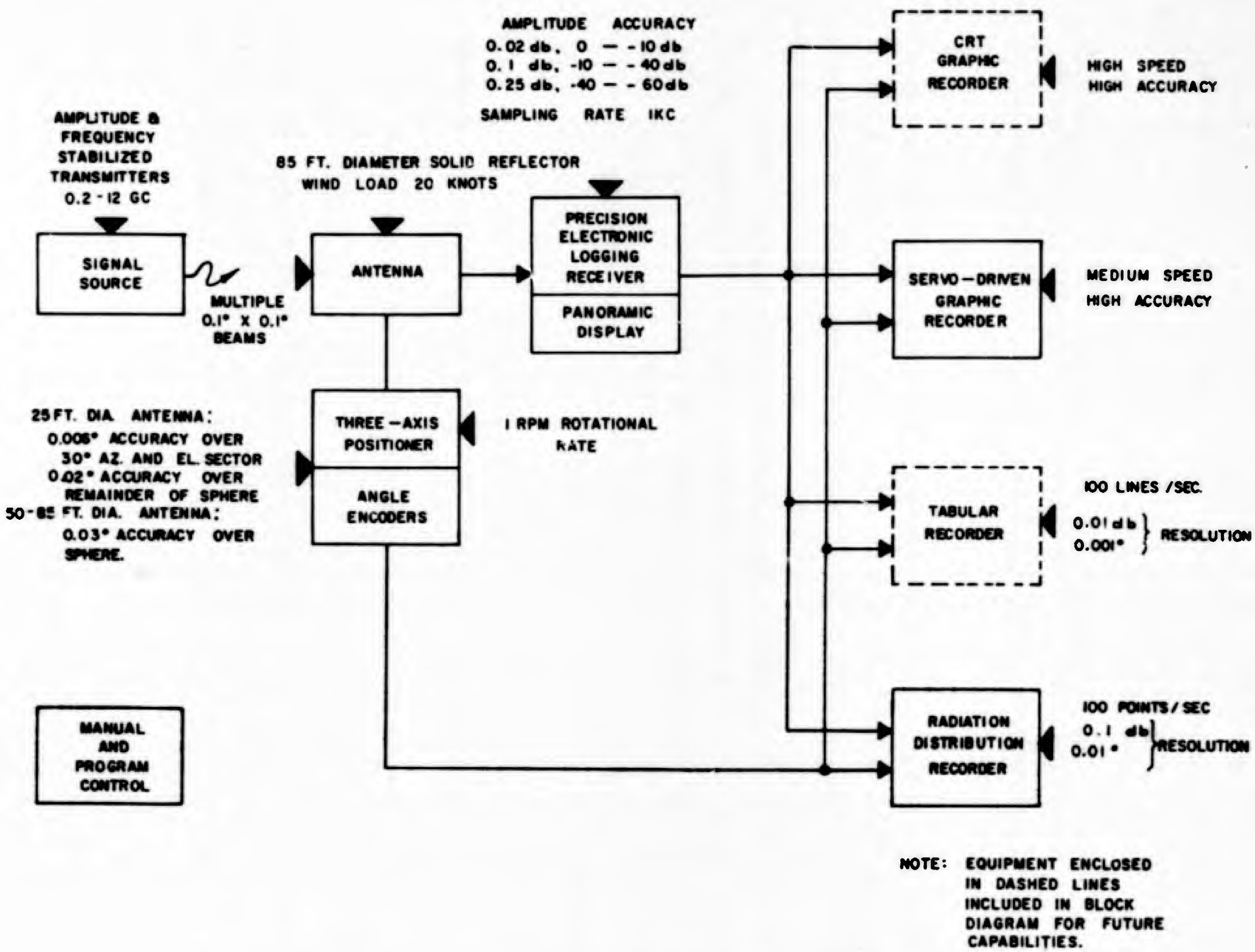

Figure 1. Technical Goals for Precision Antenna Pattern Measurement System

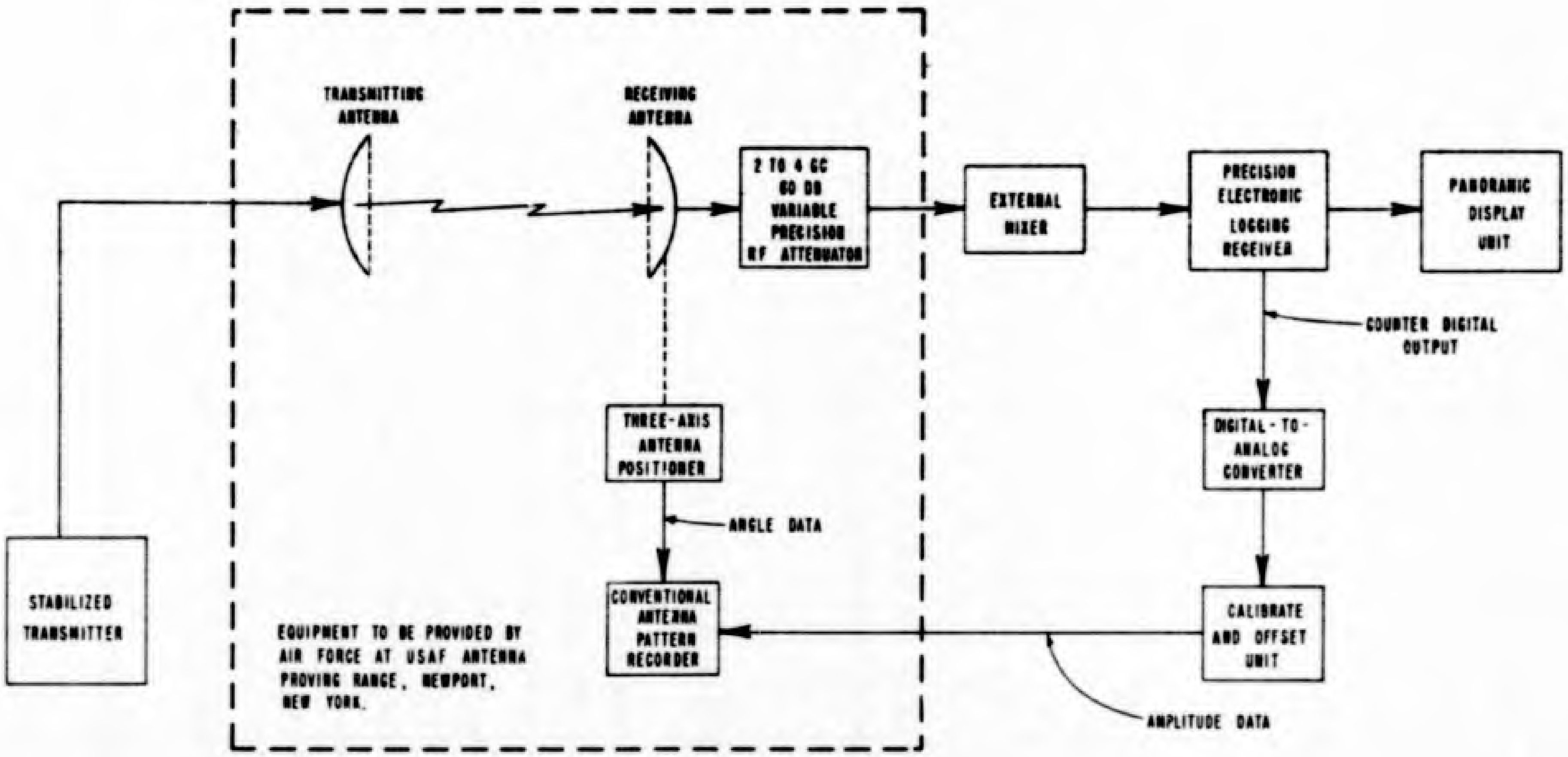

Figure 2. Phase II of Antenna Measurement System, Block Diagram

2. TECHNICAL DISCUSSION

The first and second quarterly reports submitted under this contract included specifications, simplified block diagrams, and a brief discussion of the principles of operation of each of the major units under development. The final report of Phase I contains additional information on the precision receiver, results of preliminary measurements on a breadboard model of the receiver, and a discussion of the integration of the receiving and recording equipment into the antenna-measurement system. Methods of recording and analyzing antenna pattern data have been discussed previously. The high-speed, three-dimensional antenna pattern recorder which is being investigated under this contract was proposed during the previous study and discussed in the final report of Phase I as a method of obtaining a concise presentation of the radiation pattern of an antenna over the sphere of radiation or a solid sector.

The final report of this contract will contain a description and an evaluation of all items under development, and will present results of the theoretical studies.

2.1 Stabilized Transmitter

During the third quarter of Phase II, a breadboard model of the signal source was constructed. The phase synchronizer, power meter, and thermocouple detector have been received. The phase synchronizer, which was manufactured by Frequency Engineering Laboratories, was described in the first quarterly report. The power meter and detector, which were manufactured by the General Microwave Corporation, were referred to in the second quarterly report. The phase synchronizer operates satisfactorily with the breadboard signal source to maintain the oscillator frequency-locked to harmonics of the crystal reference. Modification of the power-meter circuitry to achieve amplitude stabilization has not been completed.

A block diagram of the stabilized transmitter is shown in Figure 3. The signal source employed consists of a microwave triode oscillator in a mechanically-tunable cavity that covers the frequency range of 2 Gc to 4 Gc. The frequency of the oscillator is varied electronically by varying the voltage applied to two

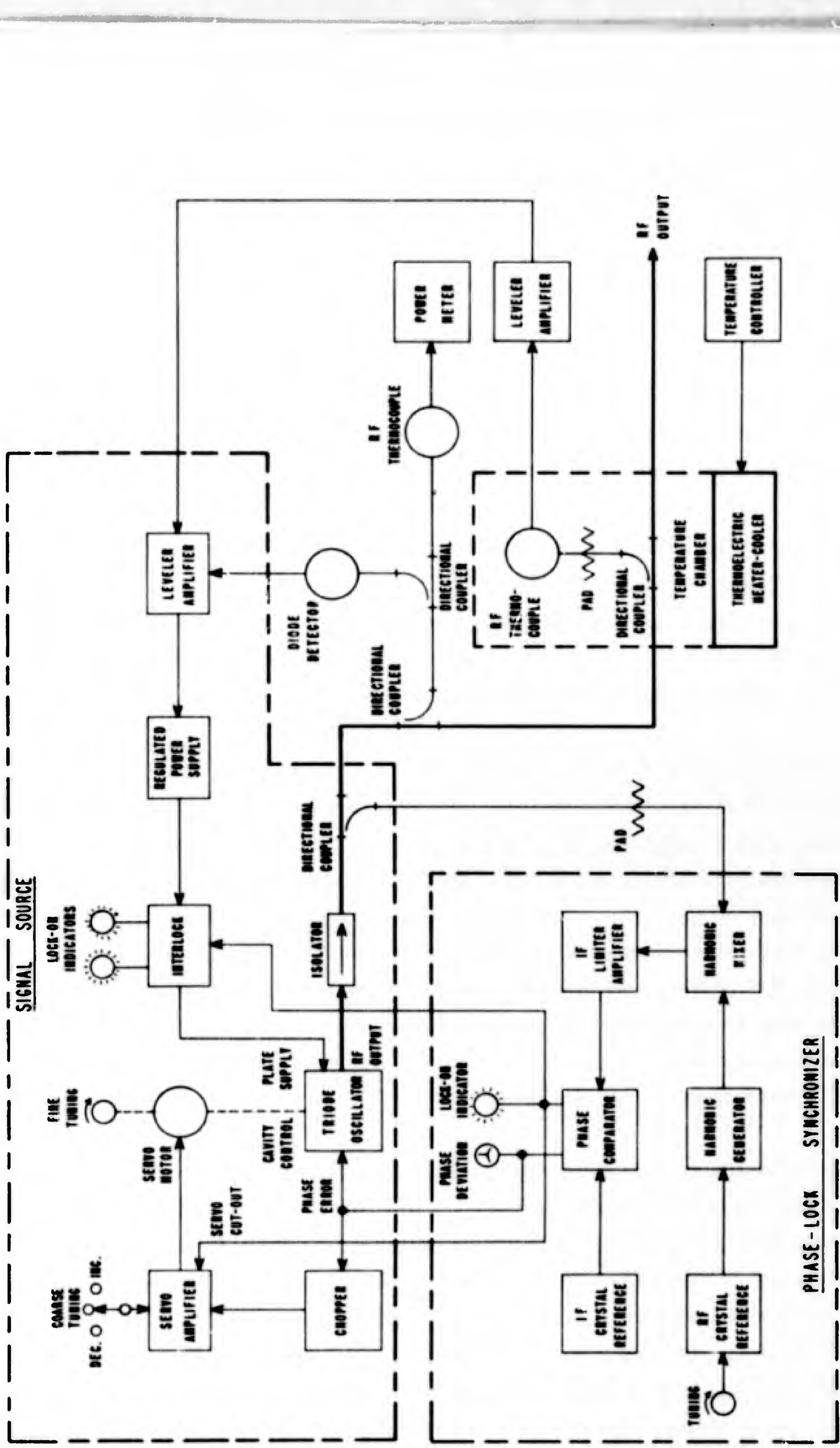

Figure 3. Stabilized Transmitter Block Diagram

microwave varactor diodes placed in a coupling loop in the coaxial cavity. A frequency deviation of ±0.5 Mc or greater has been achieved in the prototype oscillator with negligible interaction on output power. This control range is adequate to maintain a tight phase-lock condition.

The oscillator is mechanically tuned by a servo system as shown in Figure 3. The chopper compares the dc varactor bias voltage with the output of the phase synchronizer to develop an ac error signal that is fed to the servo amplifier. The output of the servo amplifier is fed to the tuning motor, which operates to reduce the dc component of the synchronizer output to zero. Thus, any tendency for the oscillator frequency to drift is compensated for automatically by retuning the oscillator, and frequency-modulation of the source is eliminated by the electronic phase loop employing the varactors. The tracking servo is disabled while manually setting the oscillator to the desired frequency, and is disabled automatically should the system drop out of phase lock.

Amplitude-stabilization of the signal source is achieved by varying the plate voltage to the triode oscillator to maintain the output power constant. This method is preferred over that which employs a voltage-controlled attenuator using PIN diodes (as discussed in the previous quarterly reports) because of the insertion loss of the diode attenuator and because of simplifications in the circuitry with plate modulation. The plate voltage is manually set to provide 1 watt RF output and is controlled automatically by the amplitude-stabilization loop to maintain the output constant. The bandwidth of the regulator is greater than 10 kc to enable reduction of oscillator noise modulation to less than 0.001 decibel.

It had been anticipated that the detector for the high-frequency amplitude-stabilization loop would be a barretter. A barretter theoretically has greater amplitude-modulation sensitivity for modulation components below 1 kc than a crystal because of the 1/f crystal diode noise. However, recently available microwave backward diodes exhibit considerably less noise than point-contact diodes when used as a mixer with low sideband (or IF) frequencies. The backward diode, low-noise, point-contact diode, and barretter will be compared for sensitivity, and the one most suitable will be selected.

The output directional coupler and detector will be mounted in a temperature-controlled chamber to reduce temperature errors to less than 0.002 decibel. The inside of the chamber will be maintained at normal room temperature by a thermoelectric cooling module whose operation is based on the Peltier effect. By reversing the polarity of the voltage applied to the thermoelectric unit, the direction of heat flow is reversed. A proportional-control regulator will be employed to maintain the temperature at the set point, nominally 25°C. Regulating the temperature at a value near room temperature, as compared with maintaining a constant elevated temperature with a heater, shortens the time required to stabilize the system and can result in greater accuracy due to the lower thermal gradients.

2.2 Amplitude Measurement Receiver

The principle of operation of the receiver has been described in the previous quarterly reports. The block diagram is repeated in Figure 4 with minor changes. A solid-state switch has been purchased for switching the input of the main IF amplifier between the signal channel and the exponential reference channel. These switches appear to have isolation and stability characteristics that are compatable with the accuracy requirements of the receiver. The switch in the exponential reference channel will also be controlled to attenuate the start of the decaying exponential to prevent saturation of the main IF amplifier. When the exponential reference decays to a value approximately 6 db greater than the received signal level, the switch is biased for minimum insertion loss. This technique is preferred over that which employs the saturation limiter previously described because it avoids the transient effects that might occur if the AGC voltage were controlled to prevent IF amplifier saturation.

A 1/10 scale model of the $\lambda/4$-wave reference-oscillator cavity has been constructed with a movable end wall. This model will be used to empirically determine the dimensions required for the final model, and the sensitivity of the resonant frequency to the gap distance between the open-ended line and the end wall. The actual cavity will be approximately 55 inches long with an outside diameter of approximately 20 inches, and will mount in the lower rear part of the three-section receiver console.

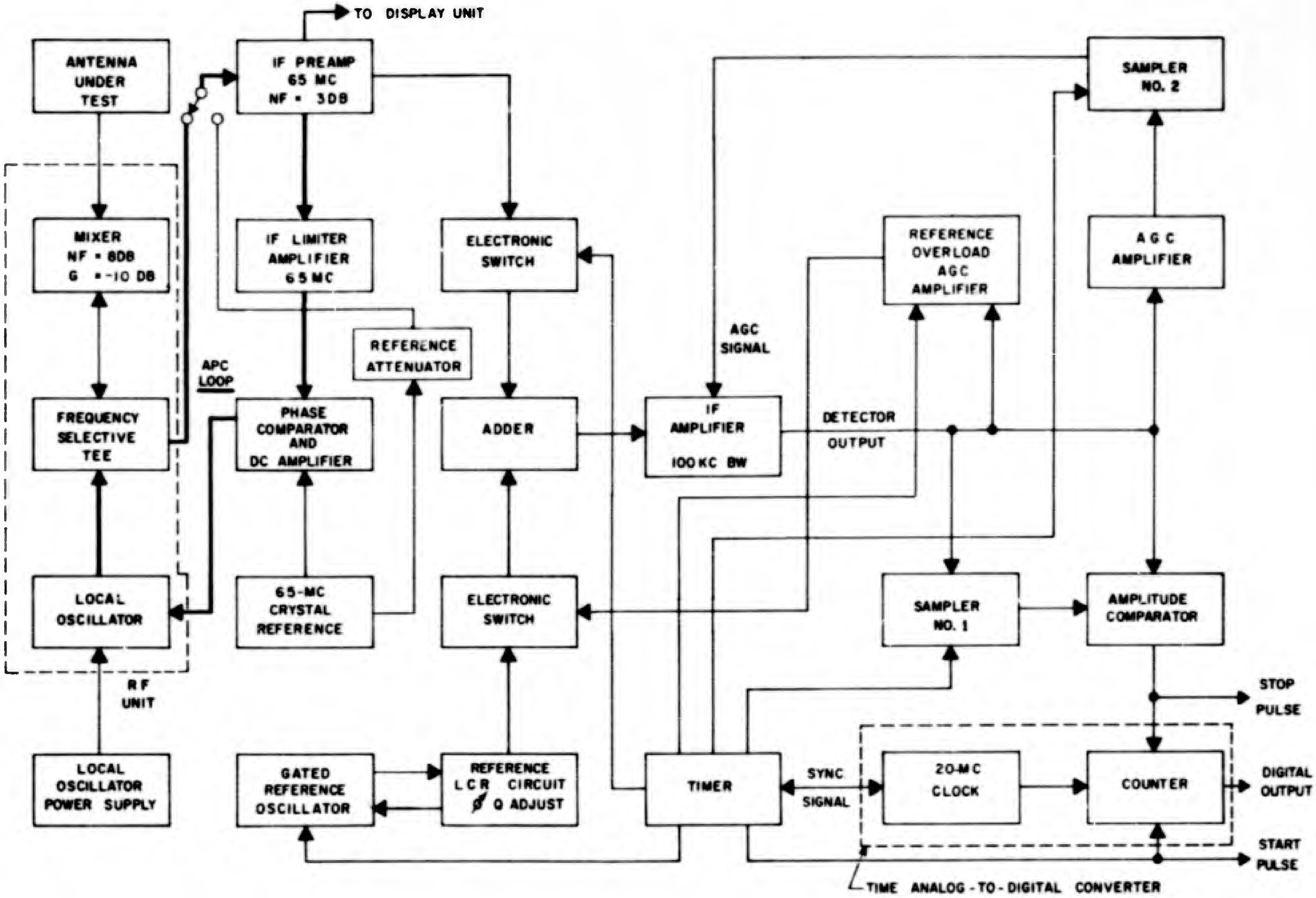

Figure 4. Amplitude Measurement Receiver Block Diagram

A Weinschel Engineering Model PA-3 Precision IF Attenuator, modified for 65-Mc operation, has been purchased for measuring the receiver linearity at the IF frequency, and for adjusting the Q of the reference-oscillator cavity during operation. The stated accuracy of this unit is 0.005 db/10 db or 0.005 db, whichever is greater; the resolution is 0.002 decibel.

The time analog-to-digital converter was received during the second quarter. However, the unit did not contain the storage feature in the digital output that is required for operation with the digital-to-analog converter. The unit was therefore returned for modification. The unit was found to be satisfactory, however, in all other major aspects.

Development of the remaining circuits for the precision receiver is in progress. Construction of the breadboard circuits for the amplitude comparator and AGC loop around the main IF amplifier was initiated during the second quarter.

2.3 Panoramic Display Unit

Construction of the panoramic display unit has been completed and the unit has been tested. This unit, which has been described in the previous quarterly reports, and is similar to the display unit of the conventional Scientific-Atlanta antenna measurement receiver, provides convenience in tuning the precision receiver.

2.4 Digital-to-Analog Converter

This unit was purchased from Preston Scientific, Inc. It will be incorporated in the receiving system to operate a conventional antenna pattern recorder, and has the capability of operating with a future high-precision, high-speed recorder. The converter has been tested and conforms to all required specifications.

2.5 Calibrate and Offset Unit

Construction of this unit has been completed. The tests that are in progress indicate some circuit modifications may be required. This unit will provide selectable scale expansions from 5 db to 60 db full scale and a continuously adjustable calibrated zero offset for the pattern recorder.

2.6 Study and Investigation of Environmental Effects on High Accuracy Antenna Measurements

Consideration is being given to the prediction of errors that may be caused by reflections from terrain in a high-performance antenna range such as the USAF Antenna Proving Range at Newport, New York. As an aid in the investigations, a three-dimensional, contoured model of the range has been fabricated, using U.S. Geological survey maps of the area. Estimates that are based on frequency, the character of the terrain, the level of illumination of the terrain by the source antenna, and the directional pattern of postulated test antennas will be presented in the final report.

2.7 Study and Investigation of Parallax Errors in Antenna Measurements

In Phase I, consideration was given to the theoretical probelm of determining parallax errors that occur in testing axially symmetric antennas. It was shown that on the assumption of axial symmetry a parallax error occurs in the measured direction of the beam maximum if the phase center is not located at the origin of the antenna-measurements coordinate system, but at another point on the axis of symmetry. This error can be calculated and accounted for. An additional parallax error occurs in the measured beamwidth and direction of the side lobes of narrow-beam antennas because of ambiguity in the axial location of the center of phase. This error cannot be accounted for if the axial location of the center of phase is not known, but it increases nearly linearly from the axis of the beam and usually results in negligible error in beamwidth measurements, except for large displacements of the phase center.

Under Phase II, consideration of parallax errors is being extended to include testing of asymmetrical antennas. This problem is of particular importance, for example, in the testing of highly accurate amplitude-monopulse antennas[2] where the maximum allowable boresight error may be a small fraction of the half-power beamwidth of the sum pattern of the antenna. In the operating environment of the monopulse system, there is usually a large separation between the antenna and its target, which may be either passive or active, and infinite-range conditions are approached. In the typical boresight test

[2] Rhodes, D. R., Introduction to Monopulse, McGraw-Hill Book Co., Inc.; 1959

range, on the other hand, practical considerations dictate that the separation between the antenna under test and the source antenna be maintained relatively short. However, the boresight direction measured at shorter ranges will differ from the inifinite-range boresight direction if the antenna does not possess mirror symmetry about the two boresight planes. The usual rule-of-thumb criterion of setting the separation between test and source antenna equal to $2d^2/\lambda$, where d is the maximum projection of the antenna on the incident wavefront and λ is wavelength, is of no direct value, because the allowable separation for boresight measurement depends on the degree of asymmetry of the antenna and on the required boresight accuracy.

As an approach to the problem, a program is being written for the Burroughs Datatron 5000 computer of the Rich Electronic Computer Center of the Georgia Institute of Technology to perform calculations for certain representative problems. Results of these calculations will be presented in the final report.

2.8 Study and Investigation of Antenna Positioning and Angle Measurements

The rate of effort for this phase of the study program was reduced during the third quarter in order to concentrate on the experimental study of the radiation distribution recorder. The study is on schedule, however, because of the higher rate of effort during the first and second quarters.

2.9 Study and Investigation of a High-Speed, Three-Dimensional Antenna Pattern Recorder and Display System

Experimental measurements have been conducted to determine the feasibility of a radiation distribution recorder* of the type proposed in paragraph 6.2.3 of the final report of Phase I. In the proposed system, characters are formed on the face of a cathode-ray tube (CRT) and imaged on photographic film.

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*A radiation distribution recorder presents in tabular form the measured relative antenna gain at discrete increments of the space coordinates θ, ϕ. The numbers displayed are normally quantized in decibels, and may be quantized in tenths of a decibel in the high-resolution system under study. Consideration is being given to methods of presenting a three-digit sample and techniques for emphasizing the contour effect.

The film is mounted on a digitally-controlled X-Y film carriage. Numbers are written across the film by alternately projecting 2-digit or 3-digit numbers onto the film surface and stepping the film in the X (ϕ coordinate) direction. The film is advanced one increment in the X direction by a stepping motor for each angular increment of rotation of the antenna in ϕ. Upon completion of each ϕ scan, the film is stepped one increment in the Y (θ coordinate) direction for another line of recording in the X direction.

The purpose of the experimental tests was to

(a) Investigate dynamic characteristics of the carriage and drive mechanism,

(b) Determine practical stepping rates,

(c) Investigate film characteristics, and

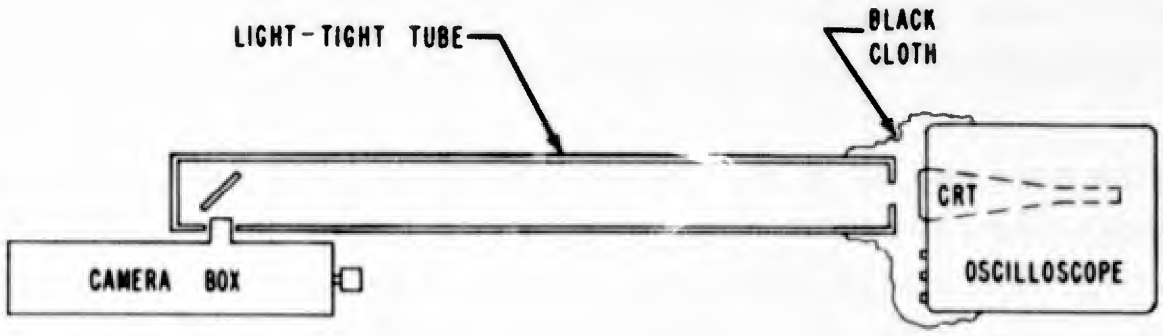
(d) Investigate associated optical and mechanical problems.

2.9.1 Description of Experiment

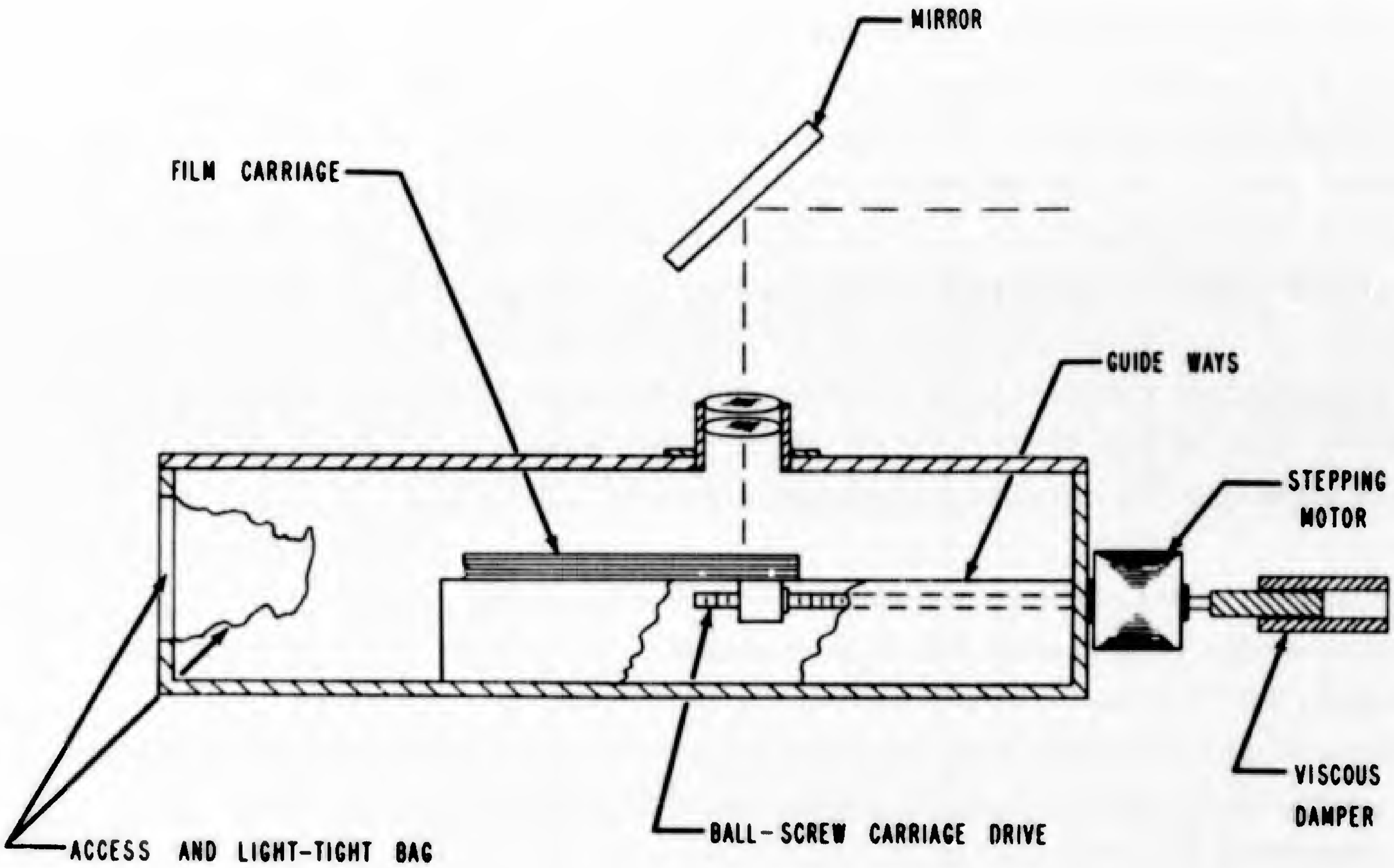
The configuration of the experimental set-up is shown in Figure 5. Straight traces and two-digit numbers (consisting of the digits "0" and "1") were written on the screen of the CRT by auxiliary equipment that was synchronized with the carriage stepping rate. The traces and characters were focused on the film surface by a lens mounted in the camera box. The film carriage was positioned by a ball-screw drive connected to a Sigma stepping motor.

The film carriage mechanism consists of a modified Polaroid 4x5 film holder (No. 500) with attached guide members which ride in a vee-block. The film carriage is thus restricted to a single degree of freedom. The carriage drive motor, which is rigidly mounted to one end of the light-tight box in which the carriage moves, has 20 incremental static positions per revolution. A 0.2222-inch pitch ball screw is attached to the motor, and the ball-bearing nut is held fixed in the base of the carriage. Each 18-degree step of the drive motor advances the film carriage approximately 0.011 inch.

The base of the film holder was grooved to permit the use of a vacuum hold-down to ensure that the film was flat during exposure. A photograph



A. RDP Test Configuration



B. Film Transport Mechanism

Figure 5. Experimental Recording System

of the experimental recorder, taken before modifications were made to the carriage mechanism, is given in the second quarterly report.

A viscous damper was fabricated to control the overshoot of the carriage. The device consists of a two-inch long cylinder that rotates in a tube with approximately 0.0005-inch clearance for an oil film. The amount of damping was adjusted by changing the oil viscosity and by varying the depth of insertion of the cylinder in the tube.

The stepping motor was controlled by a flip-flop driver with adjustable pulse width. Satisfactory operation was achieved with pulse widths of 7 to 15 milliseconds.

A Tektronix Model 545A laboratory oscilloscope with a P-11 phosphor CRT was employed for the experiments. The digits "0" and "1" were generated by an external circuit, and the display size was adjusted so that two digits were within a 0.5-inch square on the CRT screen. The character size was large enough so that the quality of the photographed image was not degraded by the line width or halation of the cathode-ray tube.

The traces and characters written on the CRT screen were focused on the film surface with a 58-mm focal-length Primoplan camera lens. All of the tests were performed with a lens opening of f/2.8.

The image-to-object magnification factor for the experimental set-up was 1/45 in order to reduce the 0.5-inch display cell to the 0.011-inch carriage stepping increment. For a focal length of 58 mm, the image and object distances are 59.3 mm and 2670 mm (8.8 feet), respectively, for the given magnification ratio. The relatively long object distance of 8.8 feet was accomodated by a plywood light-tight tube, 8.0 feet long. In a finished model a shorter object distance can readily be obtained by the use of a shorter focal-length lens system without degradation of the optical characteristics.

2.9.2 Test Results

Figure 6 summarizes the series of tests that were performed to evaluate the dynamic velocity characteristics of the incremental drive system. This figure is a record of the step response of the carriage as a function of the amount of viscous damping. These photographs were obtained by opening the camera shutter while the CRT spot was being deflected at a linear rate to provide a time base. The image of the CRT trace was focused onto the film surface perpendicular to the direction of carriage motion.

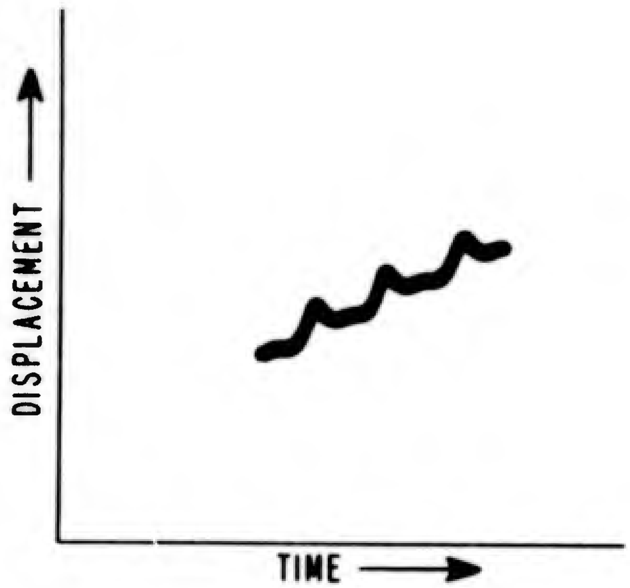
Figure 6A is a record of the carriage dynamic response for the case in which damping was supplied by the greased guide ways only. It is clearly evident from the large overshoot that occurs at each step that the system is under-damped. The addition of the variable viscous damper was necessary to reduce the overshoot to an acceptable level as illustrated in Figure 6B.

As the stepping rate of the film carriage was increased, the dwell time between each step became shorter. At 80 steps per second (Figure 6C) the carriage velocity approached zero between drive pulses, but at 100 steps per second the carriage did not come to rest. The nearly straight sloping line of Figure 6D indicates that the carriage velocity was nearly constant.

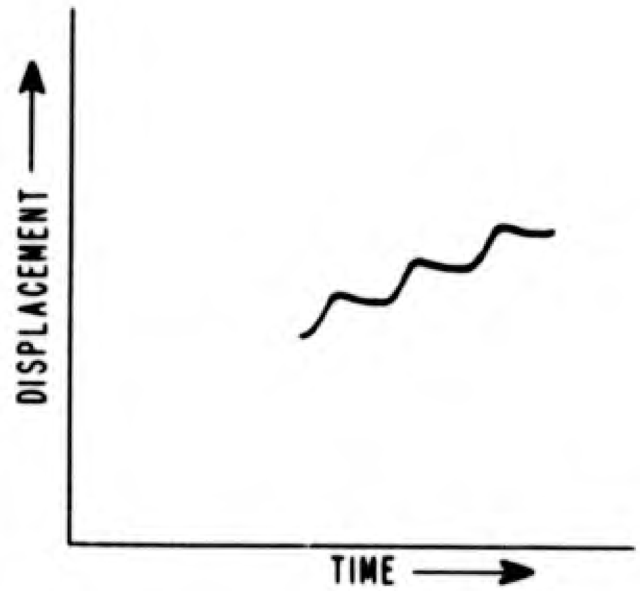
Figure 7 is a reproduction of the test results in which the number "10" was formed on the CRT in synchronism with the drive pulses to the stepping motor. Because the character-generator circuit did not have the capability of changing numerals during a single run, the CRT was blanked during alternate steps of the motor to ensure that there was no carry-over of the image between frames.

The numbers in Figure 7A were recorded at a step rate of 40 per second. There was no blurring of the characters from motion of the carriage, because at this stepping rate the carriage is essentially at rest during exposure. The writing rate on the cathode-ray tube was adjusted to form the two characters in 1.0 millisecond.

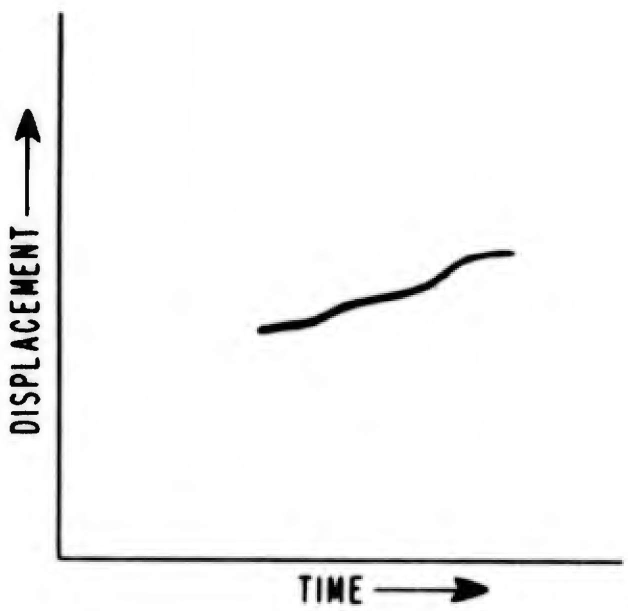
The numbers in Figure 7B were obtained with a writing time of 125 micro-seconds per character. The rate of 130 steps per second was too fast to permit



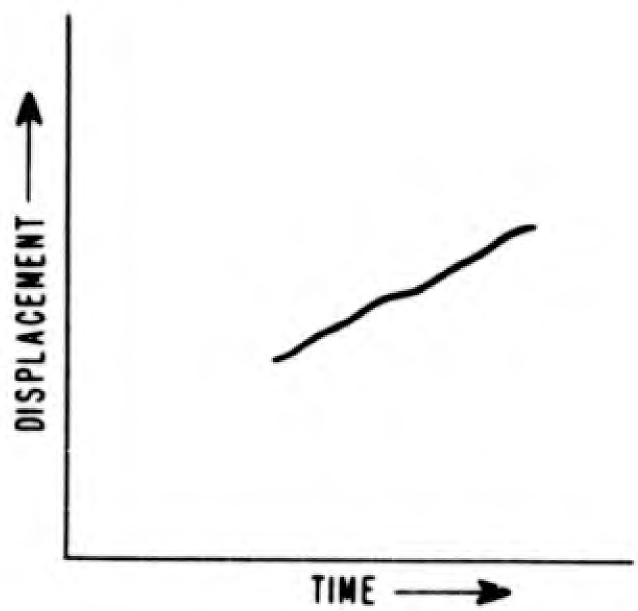
A. 50 Steps per Second
No Damping



B. 40 Steps per Second
Viscous Damping

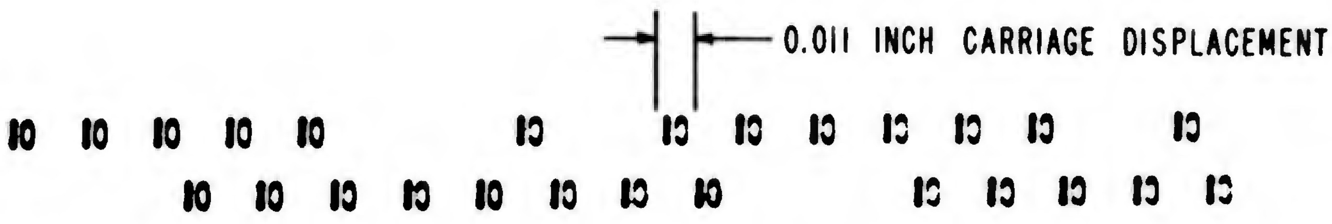


C. 80 Steps per Second
Viscous Damping

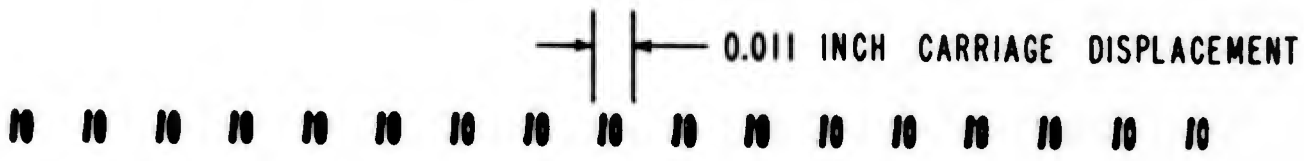


D. 100 Steps per Second
Viscous Damping

Figure 6. Step Response of Film Carriage



A. 40 Steps per Second Carriage Velocity



B. 130 Steps per Second Carriage Velocity

Figure 7. Reproduction of Photographs Obtained with Experimental High-Speed, Three-Dimensional Recorder

the film carriage to come to rest between steps. However, at a rate of 130 steps per second, the carriage moved only 0.00018 inch in 125 microseconds. This amount of movement is insignificant when one considers that the line width of a character on the film is approximately 0.002 inch. The uniformity of the spacing of the two-digit groups confirmed that the carriage velocity is nearly constant.

2.9.3 Conclusions

The tests conducted with the experimental radiation distribution recorder were for the purpose of determining the feasibility of the proposed system, and for investigating associated mechanical, optical, and photographic problems. The experimental recorder was not intended to represent the optimum design for a prototype model. Experience gained in the present study program and the selection of a stepping motor that is better suited for this requirement should lead to a recorder with improved dynamic performance. The positive results of the tests show that the proposed system is feasible, and that a recording rate of 100 or more samples per second is practicable.

The photographic reproductions indicate that the line width exposed on the negative is somewhat greater than desired. It does not appear that the resolution is limited by the grain size of the photographic emulsion or the optics of the system. Rather, it appears that the negatives have been exposed to a density greater than that required for maximum resolution in order to get satisfactory contrast. Additional attention is being given to the problem of obtaining better resolution while retaining good contrast.

During the fourth quarter of this study, consideration will be given to the circuitry for integrating the radiation distribution recorder into the antenna measurement system, the optimum print-out format, and methods for obtaining on-site printed enlargements.