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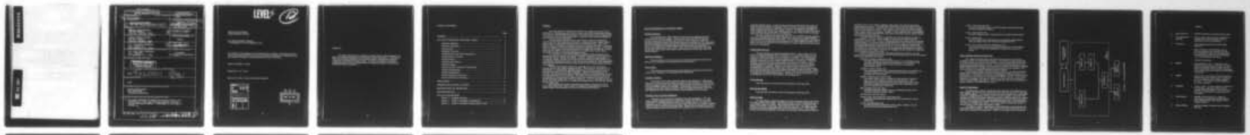

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The report describes the second three months activity in the development of a fully self-contained automated near field antenna measurement facility. A description of the system is included.

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LEVEL II

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NEAR FIELD ANTENNA MEASUREMENT SYSTEM

SECOND QUARTERLY REPORT
1 DECEMBER 1977 TO 28 FEBRUARY 1978

The objective of this program is the development of a complete, self-contained system which will automatically probe the near field amplitude and phase of an antenna aperture and compute and display far field antenna patterns and related data.

Contract DAAB07-77-C-0587

Prepared by A. E. Holley

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ABSTRACT

This report describes the second three months activity in the development of a fully self-contained automated near field antenna measurement facility. The primary efforts have involved installation of the system computer, detailing of mechanical components and software functional design. Training of personnel on the system computer has been started including conversion of analysis software to operate with the Hewlett-Packard computers.

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PURPOSE

The measurement of antenna characteristics is a significant cost item in the development, manufacturing, and field use of many radar and communication systems. Such costs are particularly high for phased array radar systems where a large amount of information, such as beam position data, is required on each individual antenna in order to provide system calibrations.

The conventional approach to such requirements involves transporting the antennas and beam steering control equipment to a high performance outdoor pattern range, often at a considerable distance from the manufacturing site. Even if the pattern range is automated so that data acquisition is computer controlled, a relatively long test program is required to properly evaluate typical phased arrays. If problems arise, far field pattern measurements provide little insight into the difficulty--a single miswired phase shifter or an open connection in a complex array may be almost impossible to diagnose without dismantling the system.

In recent years a measurement technique called near field probing has been developed to the point where it can provide an effective alternate to the far field range. The National Bureau of Standards, Boulder, Colorado, and the Georgia Institute of Technology, Atlanta, Georgia, have pioneered in the development of the hardware and computational techniques necessary to make this approach practical. Both organizations have built and demonstrated systems which provide accurate measurements on typical array antennas.

The near field technique involves the sampling of the vector RF field on a periodic grid near the antenna radiating aperture. These data are converted to a far field pattern by a mathematical algorithm equivalent to the actual creation of the far field pattern in space from the field distribution. Although the sampling must be periodic, and approximately at half wavelength intervals, an absolute position reference to the antenna aperture is not required. This feature makes the technique extremely cost effective for measurements of phased arrays since many beam positions can be interlaced during a single scan of the near field probe. Fast RF switching may also be used to allow sum and difference or multiple beam antenna ports to be properly sampled during a single scan.

This program will develop the hardware and software necessary to provide a near field measurement system capable of meeting the requirements for measurements of planar array antennas such as the AN/TPQ-36 and AN/TPQ-37.

STATUS OF INDIVIDUAL FUNCTIONAL AREAS

Computer Hardware

The Hewlett-Packard 1000 computer system and all peripherals have been received and are fully operational. The Real-Time Executive (RTE III) software operating system has been installed and except for minor problems arising from missing documentation updates this software functions as anticipated. Prior experience with Hewlett-Packard operating systems has helped in learning the RTE characteristics; however, the manuals and training materials are adequate for any programmer to quickly understand how to use the system. Many of the RTE subsystems such as the file manager will be particularly useful in the development and operation of the NFP system software.

Microwave Equipment

There has been no activity in this area during this reporting period since the delivery of the equipment is not expected until the next quarter.

Laser System

There has been no activity in this area during this reporting period except for receipt of all components of the subsystem other than cables.

Positioner Structure

The design of the primary structural frame of the positioner is complete and bids have been received from a number of vendors for this fabrication. The selected vendor has suggested some minor changes which will delay formal award until drawing and documentation changes are completed. Design details of the drive mechanism, traveling arm and other smaller structure items has begun and purchase orders have been initiated for most of the stock hardware and components for the structure.

Positioner Drive and Control Equipment

Alternative drive and control techniques have been investigated. The wide range of speeds combined with the requirement to position the probe in very small increments is a difficult problem for either DC or stepper motors. DC motors are inexpensive and can readily provide the speed range required but will require a complex software system to properly position the probe. Stepper motors simplify the software control problem but may not be available with enough torque to drive the system at the maximum required speed. A vendor (Control Systems Research) has been found who makes a DC motor/encoder unit together with a controller unit which is designed for direct computer interfacing. Motor speed, number of revolutions (in increments of 1/200 revolution) and direction are digitally selected. The relatively high cost of these units is offset by the reduced effort in designing the control software and two identical units have been ordered for the X and Y axis drives.

The drive system for the horizontal plane has been modified from the originally proposed combination chain and cable system due to concern over possible tilting of the traveling arm arising from cable stretch. The modified design involves an identical chain drive at the top and bottom of the traveling arm coupled together through a drive tube at one end of the structure which will allow the relative displacement of the top and bottom to be minimized.

Antenna Mount Structure

The basic design of the antenna mounting structure, which includes a rotary base for aligning the antenna under test parallel to the xy positioner plane and a rail system for moving the antenna in the z direction, is complete. This unit has been designed to have considerably more load capability than required for FIREFINDER antennas without the use of any special design bearings or components. Fabricated sections are simple structures using standard steel sections to minimize costs. Mounting adapters for the antennas to be tested will utilize as much of the antenna system hardware as possible. Rotation of the antenna about the vertical axis is accomplished by a handcrank driving a gear which is integral with the main bearing for coarse movement and screw drive vernier adjustment for final trimming. Tilting of the antenna under test is not provided by the near field system antenna mount but is an integral part of FIREFINDER antennas. Movement of the antenna along the z-axis is provided by a lead screw located between the mounting rails.

System Housing

There has been no activity in this area during this reporting period.

Interface and Cabling

There has been no activity in this area during this reporting period.

Software Design

The initial phase of software design has used the functional design specification to create a software flow outline. Each functional item has been translated into one or more software items to be coded. Each of these software items is organized in the software flow outline to show their relationship and hierarchy. The outline may then be used to provide the design details for each of the software items. These details include operator dialog interface, parameter characteristics and limitations, data file and table access, error situation handling, input/output, and required specialized utility software elements. The design effort forms the basis for all software development and considerable time will be spent to insure an operational and efficient design prior to most coding of the system. The outline format is being used to take advantage of the computer system providing the capability of rapid update and ease of maintenance of the software design document; thus, more time can be spent with the software design document production turnaround.

In parallel with this software design effort two specific program sections are in development. The first is actual coding of a broad control program that will initiate each software item. This is in keeping with good top-down structured programming techniques. The second involves coding and checkout of the lowest level software elements interfacing with the instruments and devices for taking the measurements. It is important that this latter effort take place now so that the hardware-software interface problems be worked out, and device control limitations and sequences be analyzed. Once these lower level software elements are debugged and operational their integration with the software items will be easier.

Besides the software program, subroutine organization, and flow, the data structures are being specified to meet the real-time and storage data access requirements. The primary data tables will include:

TCONFIG--Antenna Configuration Table
This table contains the specific characteristics of a particular antenna. From this information particular test parameters are calculated. The data collection routines will use these values for controlling the measurement devices.

GLOBALT--System Global Table
The system global table stores calculated values that are associated with a specific antenna such as frequency and physical probe movement increments for measurement.

MSEQT--Measurement Sequence Table
This table provides a specific sequence of parameters of frequency, beam, port, and Y distance used for each measurement. This sequence will currently be generated by hand and will provide a rapid and simple method of taking measurements without significant calculation or looping software constructs.

MDT--Measurement Data Table
This table is the most dynamic and it accommodates storage of the measured amplitude and phase values.

The data files used will include:

H and V Files--Horizontal and Vertical Data Files
These files will contain the collected data for horizontal and vertical polarization.

I File--Test Information File
This file contains the information used to setup, initialize, and run the test for the current antenna under test.

T File--Transferred Data File
This file contains the results of transforming the collected (raw) data to a form required for analysis.

A File--Analyzed Data File
This file contains the data resulting from the complete analysis phase.

R File--Results File
This file contains data resulting from processing the analyzed data in order to display it and draw conclusions regarding the test.

X File--Test Antenna Parameter Configuration File
This file contains the necessary characteristics data for each antenna to be tested, or different configuration of apariticular antenna to be tested.

Control and Data Collection Programming

The original functional design specification has been used as a basis for creating an outline of a functional flow diagram. This outline is being expanded and re-worked to depict the various measurement and control requirements as they will be encountered during program execution. As requirements and parameters for the different subsystems are defined, they are added to the outline so that when completed, it will contain all of the information necessary to generate the flow diagrams, and serve as a basis for writing the individual program modules.

Various programming techniques have been explored, and it has been decided that the most practical method of program development and generation will be on a modular basis. This allows for generation and debugging of individual tasks and interfaces without the involvement of a long and tedious software system. As the various modules are completed, they will be available to a master executive routine in the form of directly callable subroutines. This technique has been used successfully on a control routine for the synthesized RF source.

Analysis Programming

The NBS analysis software package has been loaded onto the Hewlett-Packard 3000 computer and several of the routines have been converted from CDC terminology to the HP3000 language. The program conversion requires changes in all input/output commands, graphic displays, and some of the control commands. Most of the NBS routines have sufficient comments imbedded to permit an understanding of the program functions down to the loop level. Several unidentified test and/or experiment points, however, are included in the programs and NBS consultation will be very beneficial in correcting or modifying these points. An overview of the principle NBS routines is shown in Figure 1 and a short description in Table 1.

Two Hughes computer routines have been developed that may be used for one dimensional pattern analysis. Both routines use the fast Fourier transform (FFT) to solve for the computed far field pattern. LINPAT is a straight forward routine that

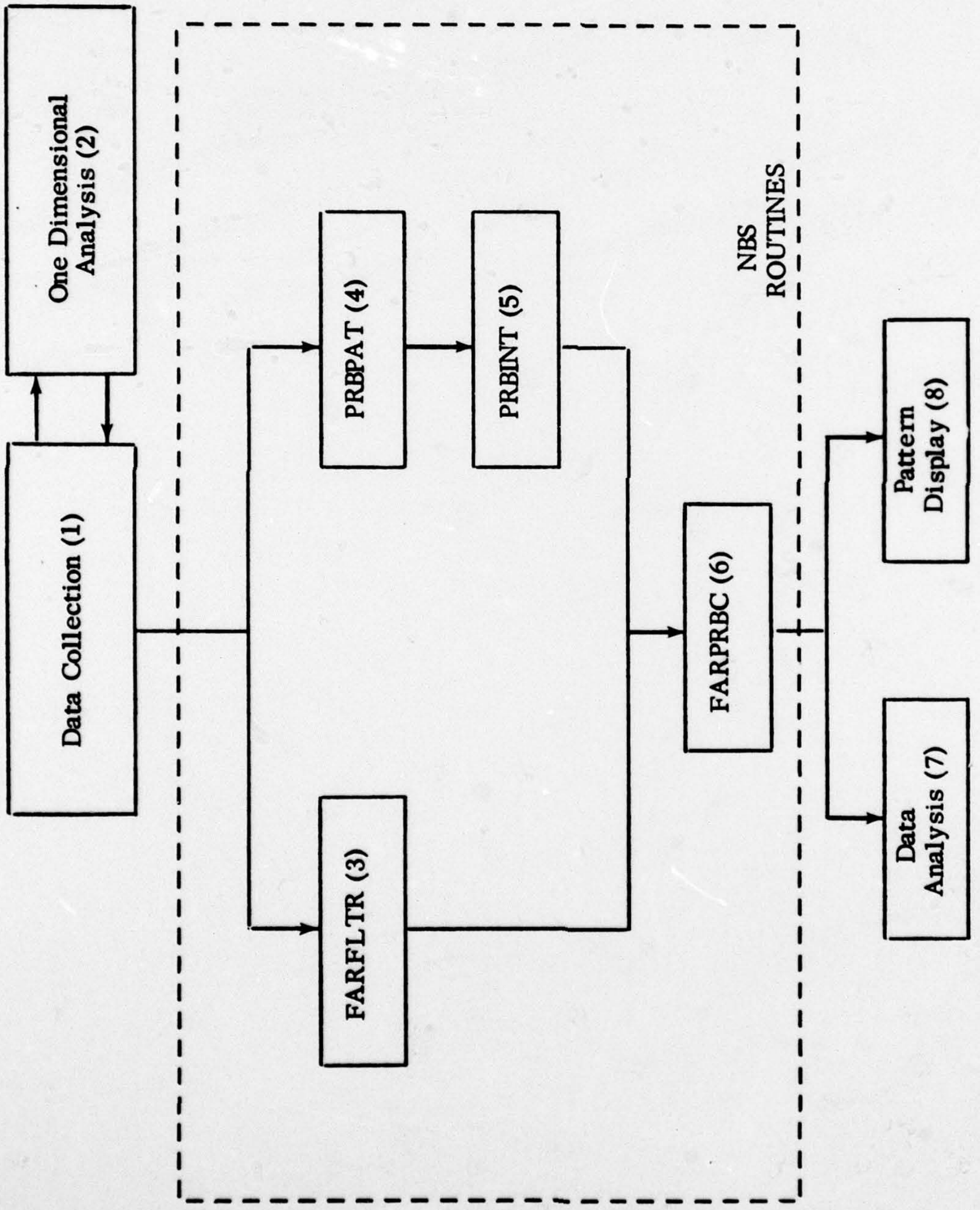


FIGURE 1 – ANALYSIS OVERVIEW

TABLE 1

1.	Data Collection	– amplitude and phase as measured by the probe.
2.	One Dimensional Analysis	– use line source pattern routine (LINPAT) to compute pattern of column data as data is measured to verify test operation.
3.	FARFLTR	– reads normalized data and computes $D(\underline{K})$ using FFT. – filters out center section of $D(\underline{K})$, inverse Fourier transforms this section, zero pads the resulting near field, and transforms again to obtain the high resolution far field patterns over a limited region in k_x and k_y. – computes antenna gain.
4.	PRBPAT	– reads nominal R- and L- components of far-field data produced from probe pattern measurements and combines them to produce two new files of actual right and left circular components of the probe pattern correcting for source antenna polarization.
5.	PRBINT	– reads R and L components of the probe patterns (PRBPAT) which are equally spaced in theta and phi and interpolates them to equal spacing in k_x and k_y. These data are then the input for the probe correction.
6.	FARPRBC	– reads R- and L- or linear spherical comments of far-field data produced by FARFLTR and combines them with PRBINT to produce two new tape files of right and left or linear spherical components.
7.	Data Analysis	– included in this category are routines to determine pattern parameters such as beam width, beam pointing, and sidelobe level or computed pattern.
8.	Pattern Display	– graphics package to display desired computed patterns.

computes the complete line source pattern with one call to the FFT. Zero padding of the input amplitude data is used to provide no error high resolution patterns. CHIRP-Z is a line source pattern computing routine that is used to compute pattern segments with very high resolution. CHIRP-Z permits the computation of a pattern with the computed points spaced at an arbitrary constant spacing over an arbitrary angle of view. CHIRP-Z is a more complex routine than LINPAT since three calls to the FFT subroutine are required for the pattern computation.

To obtain good sidelobe resolution requires approximately five to six computed data points per sidelobe. Good resolution of difference pattern null characteristics might require on the order of 20 computed points over an interval equivalent to the sidelobe width. For an array of N elements the pattern computation time using LINPAT is proportional to

$$T_{\mathrm{LINPAT}} \propto RN \log_2 RN \qquad (1)$$

where T is computation time
R = pattern resolution (number of computed points per sidelobe).

The pattern resolution is achieved by zero padding the amplitude data to make the N element array appear to have RN elements. For the CHIRP-Z program

$$T_{\mathrm{CHIRP\text{-}Z}} \propto 3(N+P) \log_2 (N+P) \qquad (2)$$

where P is the total number of computed points in the pattern.

Very high resolution over a narrow sector of the pattern (i.e. two lobes of difference pattern) can be achieved with $P \sim 100$.

For comparison of LINPAT and CHIRP-Z assume $N = 128$ elements and $R = 5$. Then for computation of the whole pattern

$$T_{\mathrm{LINPAT}} \propto 640 \log_2 640$$
$$\sim 6000$$

and for equivalent resolution over the whole pattern using CHIRP-Z

$$T_{\mathrm{CHIRP\text{-}Z}} \propto 3(128+640) \log_2 (128+640)$$
$$= 2304 \log_2 768$$
$$\cong 22000$$

For this example CHIRP-Z requires approximately 3.5 times more CPU time and slightly more core region than LINPAT.

For very high resolution over a narrow sector of the pattern assume $R = 20$. Then

$$T_{\mathrm{LINPAT}} \propto 2560 \log_2 2560$$
$$\sim 30k$$

while $T_{\mathrm{CHIRP\text{-}Z}} \propto 3(128+100) \log_2 (128+100)$

$$\sim 5.4k$$

For this example CHIRP-Z uses only one-fifth of the time and one-twentieth the core region required by LINPAT. Thus LINPAT is more efficient for computing whole patterns while CHIRP-Z is more efficient for narrow pattern sectors requiring high resolution.

As a check of the computer program sample radiation patterns computed using the CHIRP-Z transform, shown in Figures 2 and 3, were computed for a 256 element line source array with half wavelength spacing with a tapered difference distribution. The two patterns illustrate the flexibility of using arbitrary computation increments over an arbitrary field of view of the view of the radiation pattern. Figure 2 uses about the maximum increment which still shows excellent resolution of the sidelobe structure. Figure 3 uses an equal number of increments with one-tenth the increment size of the previous figure. This figure magnifies the difference pattern null and main beam characteristics but does not show much of the sidelobe performance.

Display Programming

There has been no activity in this program area during the reporting period.

System Alignment Procedures

There has been no activity in this program area during the reporting period.

Test and Evaluation Procedures

There has been no activity in this program area during the reporting period.

FIGURE 2 – CHIRP-Z TRANSFORM – 256 ELEMENTS

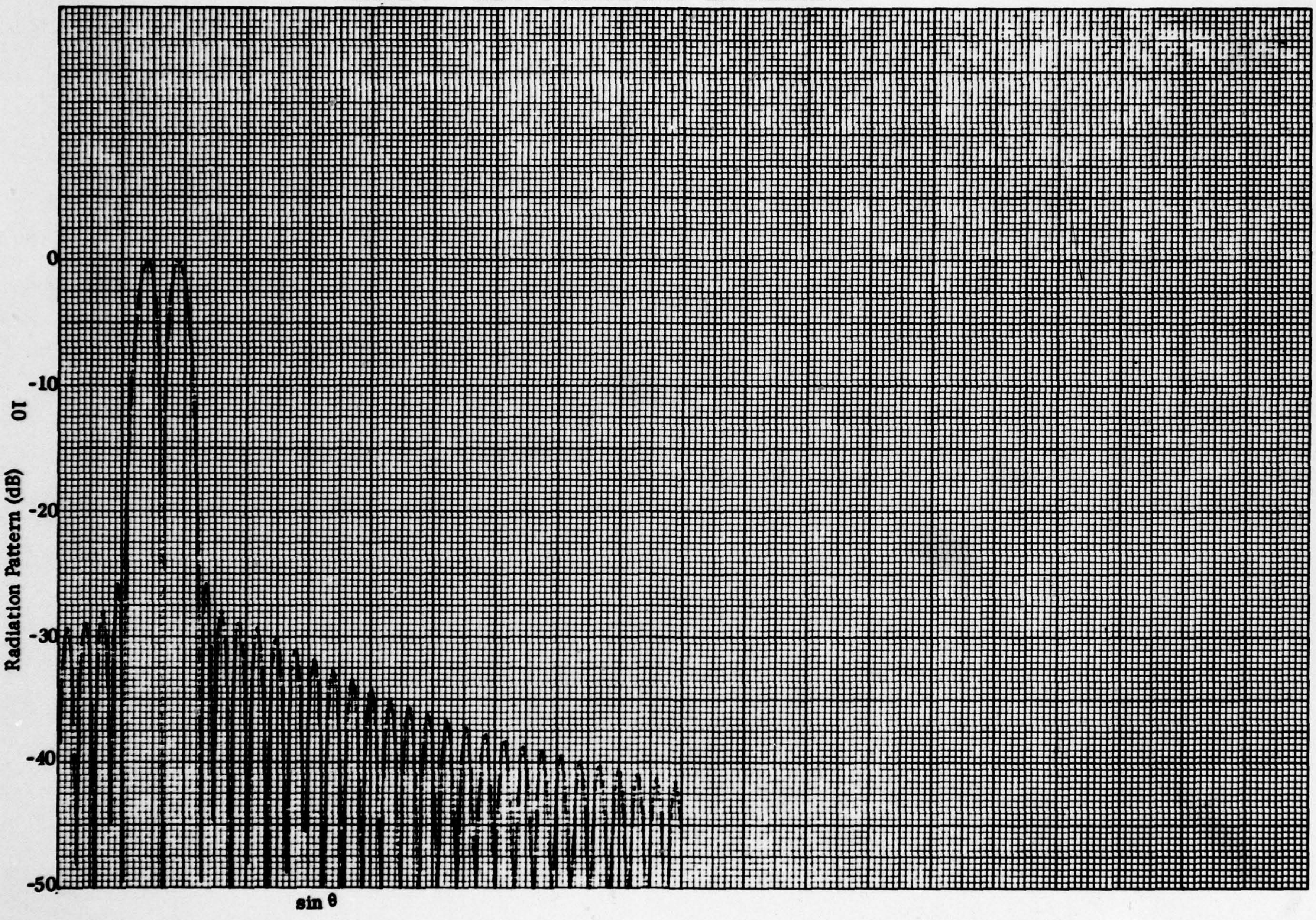
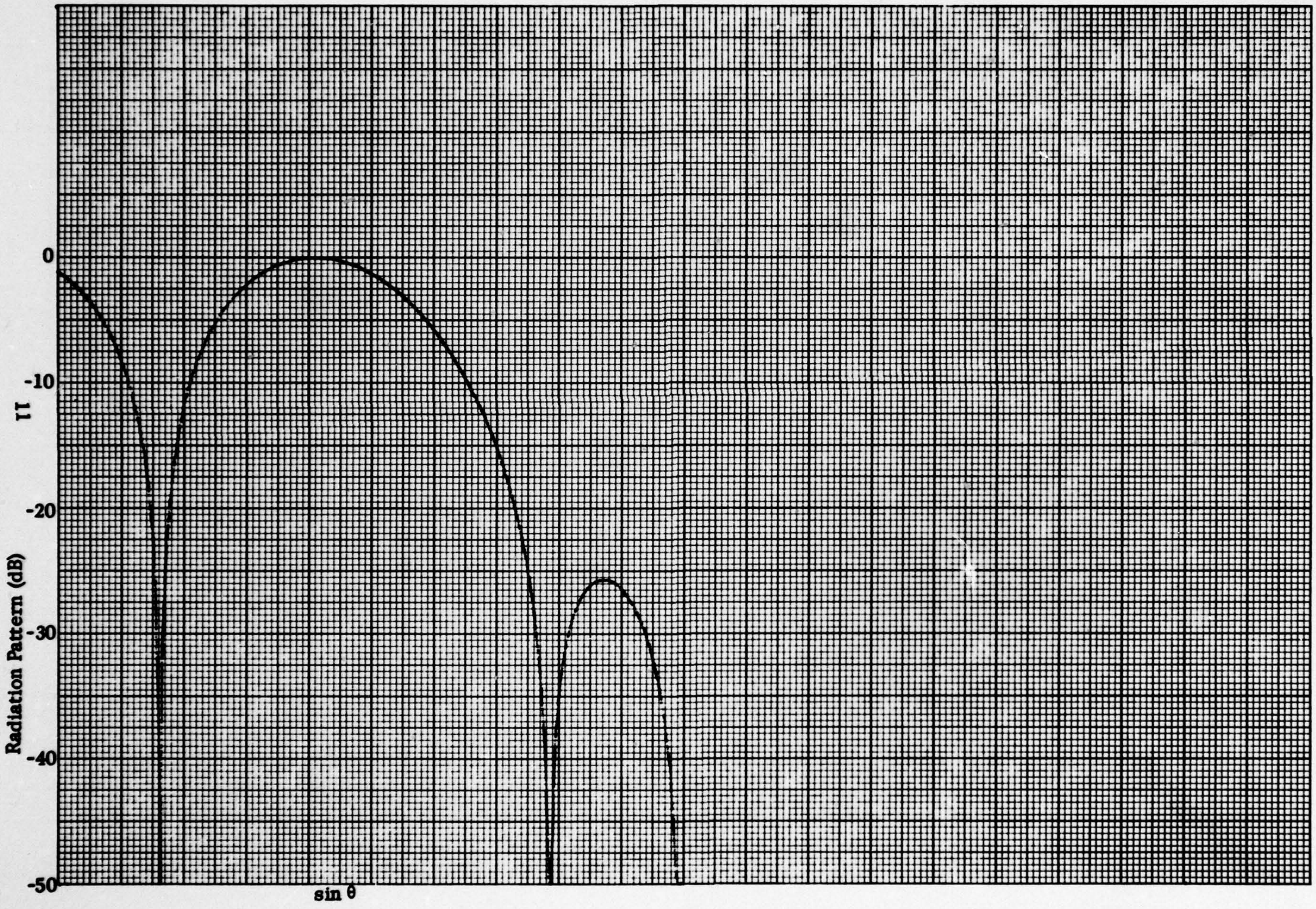


FIGURE 3 – CHIRP-Z TRANSFORM REDUCED FIELD OF VIEW



CONCLUSIONS

At this point in the development program no technical problems have arisen which have not been resolved as part of a normal design process. The program activities at Hughes Aircraft Company are progressing as expected. Almost all orders for vendor supplied equipment have been placed and drawings of structural items are being released for bid and fabrication. The consultant contract to the National Bureau of Standards has not been released due to problems with the wording of terms and conditions.

PROGRAM FOR THE NEXT QUARTER

During the third quarter the primary program activity will involve the completion of design of mechanical details. Software design and programming will be proceeding however actual coding of control and data collection software will await hardware completion. Analysis software conversion will continue and use of the system computer (HP1000) for actual system programming will begin.

IDENTIFICATION OF TECHNICIANS

Listed below are the primary technical personnel working on this program, their areas of responsibility, and the time spent during this reporting period.

- Alan E. Holley--Program Manager
- R. W. Howard--Computer hardware, microwave equipment, laser system, control and data collection programming (264 hours)
- D. J. Mecham--Software design, display programming (138 hours)
- R. L. Cummings--Positioner structure, positioner drive and control equipment, antenna mount structure system housing (155 hours)
- W. L. Lange--Analysis programming, test and evaluation procedures (208 hours)

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