

GEORGIA INSTITUTE OF TECHNOLOGY

Engineering Experiment Station

PROJECT INITIATION

Date: Feb. 7, 1969

Project Title: Development of a C-Band Parabolic Reflector Scanning Antenna

Project No.: A-1142

Project Director: Mr. R. M. Goodman, Jr.

Sponsor: Vitro Services Div., Vitro Corporation of America

Effective 1-2-69 Estimated to run until: ~~XMAS~~ 1-1-70

Type Agreement: Standard Industrial Agreement Amount: \$ 196,550

Reports: Monthly Progress Reports
Final Technical Report

Contact Person: Technical Matters
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Vitro Corporation of America
Ft. Walton Beach, Florida 32548

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Assigned to Electronics Division
Radar Branch

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GEORGIA INSTITUTE OF TECHNOLOGY
Engineering Experiment Station

PROJECT TERMINATION

Date 12/28/71

PROJECT TITLE: Development of a C-Band Parabolic Reflector Scanning Antenna
PROJECT NO: A-1142
PROJECT DIRECTOR: Mr. R. M. Goodman, Jr.
SPONSOR: Vitro Services Division; Automation Industries, Inc.; Fort Walton Beach, Fla.
TERMINATION EFFECTIVE: 1/2/72
CHARGES SHOULD CLEAR ACCOUNTING BY: Project inactive - no charges allowable.

Contract Closeout Items Remaining: None

Electronics (Sensor Systems) Division

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GEORGIA INSTITUTE OF TECHNOLOGY
EXPERIMENT STATION

225 North Avenue, Northwest · Atlanta, Georgia 30332

25 March 1969



Vitro Corporation of America
Vitro Service Division
Ft. Walton Beach, Florida 32548

Attention: Mr. Walter F. Keating

Subject: Monthly Progress Report 1, Project A-1142
"Development of a C-Band Parabolic Reflector Scanning Antenna"
Covering the Period from January 1 to February 1, 1969

Gentlemen:

At the request of the sponsor, Vitro Services, technical work was started during the first week in January 1969 on the subject antenna system. This work effort has been designated as Georgia Tech Project A-1142. Mr. R. M. Goodman, Jr. is the Project Director and Mr. R. A. Moore, the Assistant Project Director.

Prior to receipt of a contract with Vitro Services, Georgia Tech developed, in house, an X-Band breadboard model of the feed scanning mechanism. The model consisted of a circular ring of probes illuminated by a waveguide horn. Those probes directly in front of the horn aperture receive energy. As the horn is rotated the succeeding probes around the ring are illuminated. Energy is coupled out of the circular ring of probes by coaxial cables of equal length. These cables feed a linear array of probes. The spacing between these probes was designed to provide a radiation pattern of the proper beamwidth for the illuminated array of probes to illuminate a paraboloidal reflector. As the waveguide feed in the circular ring is rotated the phase center of the energy radiated by the linear array moves in a straight line along the array. It is this type of motion of the phase center of a feed illuminating a paraboloidal reflector that is necessary to scan the energy reflected off the reflector.

Preliminary measurements using this breadboard scanner were taken to prove the feasibility of the system. The results of these measurements indicated that the phase center did scan in a smooth fashion along the linear array and the radiation pattern was reasonable for the illumination of a paraboloidal reflector.

Several problem areas were evident in the initial scanner design. Probably of most importance is the amount of astigmatism (displacement of the E-plane and H-plane phase centers) in the feed array. The magnitude of this problem area, as to pattern degradation, will not be known until measurements of far field radiation patterns are made with the scanner positioned to illuminate a reflector.

The other major problem area is the power handling capability of the coaxial cabling. Investigation and laboratory tests will be required to determine the power handling limits of the type of coaxial cable to be used.

A visit was made to Vitro Services Division, Ft. Walton Beach, Florida on 20 January by R. M. Goodman, Jr. and H. L. Baker of Georgia Tech. These men met with Vitro personnel, Walter Keating and others, to discuss contractual matters on the subject system.

The anticipated work to be conducted during the next report period will be as follows: The X-Band scanning Feed will be mounted in front of a 4-foot paraboloidal reflector with an f/D ratio of 0.33. Far field radiation patterns will be measured. Work will also be conducted in the design of the feed array in an effort to reduce the amount of astigmatism present and also to smooth the feed radiation patterns. This work effort in the feed array design is necessary to provide a more efficient illumination of the paraboloidal reflector.

Respectfully submitted:

R. M. Goodman, Jr.
Project Director



GEORGIA INSTITUTE OF TECHNOLOGY
EXPERIMENT STATION

225 North Avenue, Northwest · Atlanta, Georgia 30332

25 March 1969

Vitro Corporation of America
Vitro Services Division
Ft. Walton Beach, Florida 32548



Attention: Mr. Walter F. Keating

Subject: Monthly Progress Report 2, Project A-1142
"Development of a C-Band Parabolic Reflector Scanning Antenna"
Covering the Period from February 1 to March 1, 1969

Gentlemen:

Work covered under the subject contract during this report period, February 1 to March 1, 1969 has been concerned primarily with the testing of a breadboard X-Band (10 GHz) feed horn and scanning mechanism.

The initial feed design had considerable undesired currents along the length of the aperture. These currents were the cause for undesired ripples in both the phase and amplitude of the feed pattern. Serrating the aperture, producing a toothed type structure, helped to smooth the H-plane feed pattern in phase and amplitude. The E-plane feed pattern also has undesired ripples, but recent measurements indicate that these ripples can be eliminated by the addition of a set of choke blinders. The H-plane beamwidth of the feed pattern is not as wide as desired for efficient illumination of the planned 4-foot paraboloidal reflector, which has an f/D ratio of 0.33. A paraboloid with a longer focal length (0.4 f/D ratio) will be used; this will be an efficient reflector for the feed illumination.

Far field radiation patterns have been made for the scanning feed mechanism (without E-plane blinders) and a 4-foot paraboloidal reflector with an f/D ratio of 0.33. The required scan limits and side lobe level were achieved in the plane of scan (H-plane), although the -3dB beamwidth is wider than desired. The beamwidth and side lobe level in the plane orthogonal to the plane of scan (E-plane) are not acceptable at present. This degradation of the E-plane pattern is most likely the combined result of astigmatism in the feed horn and poor E-plane reflector illumination.

The anticipated work to be conducted during the next reporting period will be to modify the E-plane aperture of the X-Band feed horn. This modification will be the addition of choke blinders and shortening of the

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Project A-1142
Page 2

horn to reduce the amount of astigmatism in the E- and H-plane phase centers. It is also anticipated that far field radiation patterns will be measured using the X-Band feed and a 4-foot paraboloidal reflector with a 0.39 f/D ratio. An effort will be started to determine the peak power limitations of 5/8 inch coaxial cable and the methods available for increasing these limits, such as pressurization, high dielectric strength gases and precision fabrication.

Respectfully submitted:

R. M. Goodman, Jr. ✓
Project Director



GEORGIA INSTITUTE OF TECHNOLOGY
EXPERIMENT STATION

225 North Avenue, Northwest · Atlanta, Georgia 30332

11 April 1969

Vitro Corporation of America
Vitro Services Division
Ft. Walton Beach, Florida 32548



Attention: Mr. Walter F. Keating

Subject: Monthly Progress Report 3, Project A-1141
"Development of a C-Band Parabolic Reflector Scanning Antenna"
Covering the Period from March 1 to April 1, 1969

Gentlemen:

A summary of the work done on the subject contract for the report period 1 March to 1 April 1969 is contained herein.

The X-Band breadboard scanning feed mechanism was re-packaged in a configuration which simulated more accurately the desired package. This scanner feed was then mounted in front of a 46.25 inch paraboloidal reflector, which has an F/D ratio of 0.39, and far-field radiation patterns were measured. The radiation patterns indicate that the required specifications on radiation patterns and scan limits were achieved. The E-plane secondary pattern, which has the proper -3 dB beamwidth, begins to broaden at approximately the -6 dB region. This boardening is strictly due to astigmatism of the phase centers, i.e., the E-plane phase center not being at the focal point of the paraboloidal reflector. The H-plane secondary pattern has the proper -3 dB beamwidth throughout the scan limit. This beam at the center of scan position is a pencil beam with a maximum side-lobe level of -23 dB. The coma-lobe at the limit of scan (approximately 5 degrees off axis) is -12.5 dB. Measurements of radiation patterns for small increments of scan indicate that there is no measurable scalloping of the beam as the system scans.

A redesign of the X-Band linear array feed is in the drawing phase. This design incorporates a modified E-plane aperture to reduce the astigmatism and E-plane choke blinders. Laboratory tests on a mock-up of this design indicate that this feed should provide a better illumination of the paraboloidal reflector than obtained in the present X-Band array and also, should reduce the phase center astigmatism approximately 65-70 percent (reduce astigmatism from 0.7 inch to 0.25 inch). This redesigned array is anticipated to be



GEORGIA INSTITUTE OF TECHNOLOGY
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225 North Avenue, Northwest · Atlanta, Georgia 30332

3 July 1969



Vitro Corporation of America
Vitro Services Division
Ft. Walton Beach, Florida 32548

Attention: Mr. Walter F. Keating

Subject: Monthly Progress Report 4, Project A-1142
"Development of a C-Band Parabolic Reflector Scanning Antenna"
Covering the Period from 1 May to 1 July 1969

Gentlemen:

No work was done on the referenced contract during June 1969.

Further work will be undertaken as required by the sponsor.

Respectfully submitted:

R. M. Goodman, Jr.
Project Director

RMG:mo



GEORGIA INSTITUTE OF TECHNOLOGY
EXPERIMENT STATION

225 North Avenue, Northwest · Atlanta, Georgia 30332



Vitro Corporation of America
Vitro Services Division
Ft. Walton Beach, Florida 32548

Attention: Mr. Walter F. Keating

Subject: Monthly Progress Report 5, Project A-1142
"Development of a C-Band Parabolic Reflector Scanning Antenna"
Covering the Period from 1 July to 1 August 1969

Gentlemen:

No work was done on the referenced contract during July 1969.

Further work will be undertaken as required by the sponsor.

Respectfully submitted:

R. M. Goodman, Jr.
Project Director

RMG:mo



EXPERIMENT STATION

225 North Avenue, Northwest • Atlanta, Georgia 30332

8 May 1969



Vitro Corporation of America
Vitro Services Division
Fort Walton Beach, Florida 32548

Attention: Mr. Walter F. Keating

Subject: Summary Progress Report on Project A-1142
"Development of a C-Band Parabolic Reflector
Scanning Antenna"

Gentlemen:

This report is primarily oriented to the work covered under the subject contract during this report period, April 1, 1969 to April 30, 1969. Since, at the request of Vitro Services Division, the work effort on the subject contract was to stop by April 30, 1969, this report will contain a summary of the work effort from January 1, 1969 to April 30, 1969.

The X-Band linear array feed design incorporating E-plane choke blinders and a modified E-plane aperture was fabricated and tested. Results of the R.F. measurements on this redesigned feed indicate that the feed functions satisfactory. The E-plane choke blinders, designed using data from a past study at Georgia Tech, ⁽¹⁾ performed as expected in reducing off-angle E-plane radiation from the field. Serration of the H-plane aperture surface to reduce the current flow on this surface was required. These currents were producing standing-waves over the aperture surface, which were the cause for undesired ripples in the feed's amplitude and phase radiation characteristics. The modified E-plane aperture flare angle had the desired effect of reducing the E-plane and H-plane astigmatism. Phase center measurements made using the redesigned feed indicate that the E-plane phase center is approximately 0.25 inches in front of the H-plane phase center. On the prior feed there was approximately 0.7 of an inch separation between the phase centers.

The linear array feed radiation patterns included as Figure 1 and Figure 2 are E-plane and H-plane cuts, respectively. Although, these radiation patterns are for the center of scan position, they are typical of any position along the array aperture. Indicated on these patterns is the 126° included angle of the 46.25 inch diameter paraboloidal reflector with a 0.39 f/D ratio. For

this 126° included angle of the reflector it is necessary to add 2.5 dB space attenuation at the reflector edges, thereby making the illumination function (feed amplitude radiation level) about 22 dB down at the reflector edges relative to the level at the reflector center. It can be seen in Figure 1 and 2 that the feed illumination for the E-plane and H-plane are essentially the same. The VSWR of the X-Band linear array and rotating scanner system, excluding the reflector, is approximately 3:1, looking into the system at the rotating scanner. This VSWR does not vary appreciably as the ring-feedhorn is rotated. Since this X-Band breadboard system was to be primarily used for radiation pattern measurements, where the 3:1 VSWR would not degrade performance, no attempt was made to improve the impedance match. The VSWR of the X-Band breadboard is not indicative of the VSWR that would be associated with a C-Band proto-type system. In the C-Band proto-type the system VSWR would be the complete system, i.e.; feed and reflector combination. Any impedance matching required would necessarily have to be done using this complete system.

The described linear feed array and rotating scanner system were packaged in a container which simulated the desired aperture blockage. This container was then positioned in front of the 46.25 inch diameter paraboloidal reflector on struts of appropriate spacing and size. The photographs included as Figures 3, 4, 5 and 6 show the X-Band breadboard model at various aspect angles. The coaxial cable feeding the scanner, visible in Figure 6, was necessary to allow manual positioning of the rotating scanner assembly. On the C-Band proto-type, waveguide and a rotary joint would replace this coaxial cable. In the photographs a Styrofoam (Dow Chemical Co. trade-made) radome is shown covering the linear array feed.

The far-field antenna radiation patterns included in this report were measured on an antenna range having 700 feet of separation between the transmitting antenna and the test receiving antenna. These data were obtained using a measurement frequency of 10 GHz.

Due to the astigmatism present in the feed system an accurate evaluation of the antenna's performance required a series of antenna pattern measurements with the feed located at various positions along the focal line axis. The feed positions utilized in the tests were such that the reflector system focal point coincided with the feed's (1) E-plane phase center, (2) H-plane phase center, (3) and at several compromise positions between these phase centers.

The initial tests indicated that feed positioning was very critical and that only a slight movement of the feed (on the order of $1/64$ of an inch) produced a considerable difference in the radiation patterns. This was the result of energy being re-radiated from the reflector apex back into the feed, thereby mismatching the feed and resulting in the sensitive position dependence of the feed. A piece of R.F. absorbing material, slightly smaller than the area

of feed aperture blockage, was placed at the reflector apex to reduce the energy returned to the feed. This eliminated the critical positioning associated with the feed and reflector. The placement of the absorbing material at the reflector apex should not degrade the system's radiation performance, as this area of the reflector contributes very little to the radiation characteristic due to the associated feed aperture blockage. On the C-Band prototype, if this type of impedance matching is required, a metallic apex-matching plate (center portion of reflector raised approximately a quarter wavelength) would be utilized in lieu of the absorbing material.

The feed position which provides the best overall performance as to E-plane and H-plane side-lobes and pencil-beam shape is when the H-plane phase center is located slightly behind (away from the reflector) the focal point. The radiation patterns included as Figures 7 through 30 are system far-field radiation patterns for this feed position with the absorber apex-matching plate. The H-plane radiation patterns, Figures 7 through 27 are a plot of relative amplitude in dB versus azimuth angle of rotation in degrees, with the appropriate azimuth scale indicated on the pattern. The H-plane patterns versus scan angle were obtained by rotation of the illuminating feed-horn in the ring array. Each successive H-plane scan pattern is for an approximate $16\frac{1}{3}$ degrees of angular rotation of the ring array feed-horn and is indicated on each pattern by "Ring-feed rotation." The two probes, diametrically opposite the center of scan position of the ring feed-horn are terminated in loads. This condition reduces the interference pattern generated by simultaneous illumination of each end of the linear array.

The E-plane radiation patterns presented Figures 28, 29 and 30, are for the center of scan, plus $3\frac{1}{2}$ degrees and minus $3\frac{1}{2}$ degrees of scan position, respectively. These E-plane patterns do not change appreciably with scan and therefore may be considered typical for any position in the scan sector.

The scanning composite pattern shown by the radiation pattern of Figure 31 was obtained by successive angular rotation of the ring array feed-horn. This plot was started at the center of scan position with step intervals of approximately 8 degrees of the ring array feed-horn, for one-half of the scan sector. These pattern data and other measurements indicate that there is no measurable scalloping of the main beam as the system scans. The slight rise in the amplitude, approximately $\frac{1}{4}$ dB, toward the end of the scan sector is possibly due to a modification of the aperture blockage, as a function of the reflector illumination when the system approaches the ends of scan. A change in the impedance match of the linear array feed and reflector combination, as a function of scan, could also produce this type of increase.

The curves of Figure 32 are a summary of the included antenna radiation patterns Figures 7 through 30. These curves present the worst case side-lobes (including coma lobes) for the H-plane and E-plane radiation patterns as a

function of scan angle. It is seen from these data that the side-lobe and coma-lobe rise of 9 dB, i.e.; -20 dB at center of scan to -11 dB at the two beamwidth or 4 degrees of scan angle position, is in agreement with the measurement data report by the Naval Research Laboratory for scanning characteristics of the paraboloidal reflector.² This NRL referenced report shows measured data on a paraboloidal reflector, with an f/D ratio of 0.5, fed by a simple feed-horn (minimal aperture blockage) that provides a 20 dB tapered illumination at the edge of the paraboloid. When this feed horn was at the focal point of the reflector the measured side-lobes were 25 dB below the peak of the main beam. As the feed horn was displaced from the focal point, to simulate scanning in the H-plane, a distance equivalent to two beamwidths of scan angle, the coma-lobe increased to a level of 17 dB below the peak of the main beam. This is generally the same slope and amplitude rise of the side-lobes versus scan that was measured on the X-Band breadboard antenna. If the differences in aperture blockage of these two antenna systems (NRL and X-Band breadboard) are considered, the -11 dB coma-lobe at a two beamwidth scan angle may be approaching the theoretical limit for the X-Band breadboard aperture blockage configuration.

Calculations were made to determine the theoretical value of center of scan side-lobes and gain for the specified scale feed and strut blockage. The theory for performing these calculations is described in reference 3. If a paraboloidal reflector has an aperture illumination that is 20 dB down at the reflector edge the first side-lobe level will be 30.5 dB below the peak of the main beam, assuming no strut blockage or feed blockage. For the same aperture illumination and specified strut blockage and feed blockage the first side-lobes will increase to a value of 19.8 dB below the peak of the main beam. This value of side-lobe is approximately the value measured on the X-Band breadboard model.

A reduction in antenna gain of approximately 0.7 dB is calculated for the specified aperture blockage. The theoretical gain for the 46.25 inch diameter aperture at 10 GHz, excluding aperture blockage and considering a 60 percent aperture efficiency, will be 39.5 dB above an isotropic source. Considering the aperture blockage gain reduction and a small loss in the feed system the specified system antenna gain of 37 dB should be obtainable without difficulty on a C-Band proto-type.

The X-Band breadboard model has a measured gain of 35.5 dB at 10 GHz. This gain measurement, although valid, is not representative of the gain that would be obtained on a C-Band proto-type antenna. The reason for this lower gain can be attributed to the 3:1 VSWR, which accounts for a 1.2 dB loss and an approximate 1.5 dB loss in the feed system associated with the usage of the small size coaxial cable and connectors.

The mechanical design associated with the C-Band proto-type antenna design is approximately 50 percent complete. No great problems are foreseen in the

area of packaging in the specified configuration. A clutch and braking breadboard has been fabricated and tested. The breadboard performed very well and no problems are anticipated in this area of the C-Band proto-type design.

Calculations have been performed to determine the feasibility of constructing a coaxial cable to meet the following conditions:

- 5/8 inch inside diameter
- 2.0 Mega-Watts peak power
- 2.0 Kilo-Watts average power
- Maximum load VSWR of 1.5:1

These calculations indicate such a cable is feasible; however, after temperature and load effects are considered, the cable will only handle 230 kW peak power when filled with dry air at 1 atmosphere absolute pressure. Successful operation with 2 MW peak power required pressurization, use of gases having high dielectric strength, or both. Two of the more common suitable gases would be SF₆ or "Freon-12". Either of these gases at 2 atmospheres absolute pressure will increase the breakdown of the coaxial cable to an acceptable level. Final choice of a suitable dielectric gas will probably be determined by the compatibility of the gas and its decomposition products with other materials in the system. There will be approximately 0.88 Watts per inch of cable length dissipated (in heat) for the specified operating conditions. This heating may present a thermal problem which may require some form of forced-air cooling at the cables. Phelps-Dodge Electronics, a company which deals in the design and manufacture of coaxial cable, is in concurrence with these findings.

In accordance with our mutual agreement, no further work will be done on the contract at this time.

Respectfully submitted:

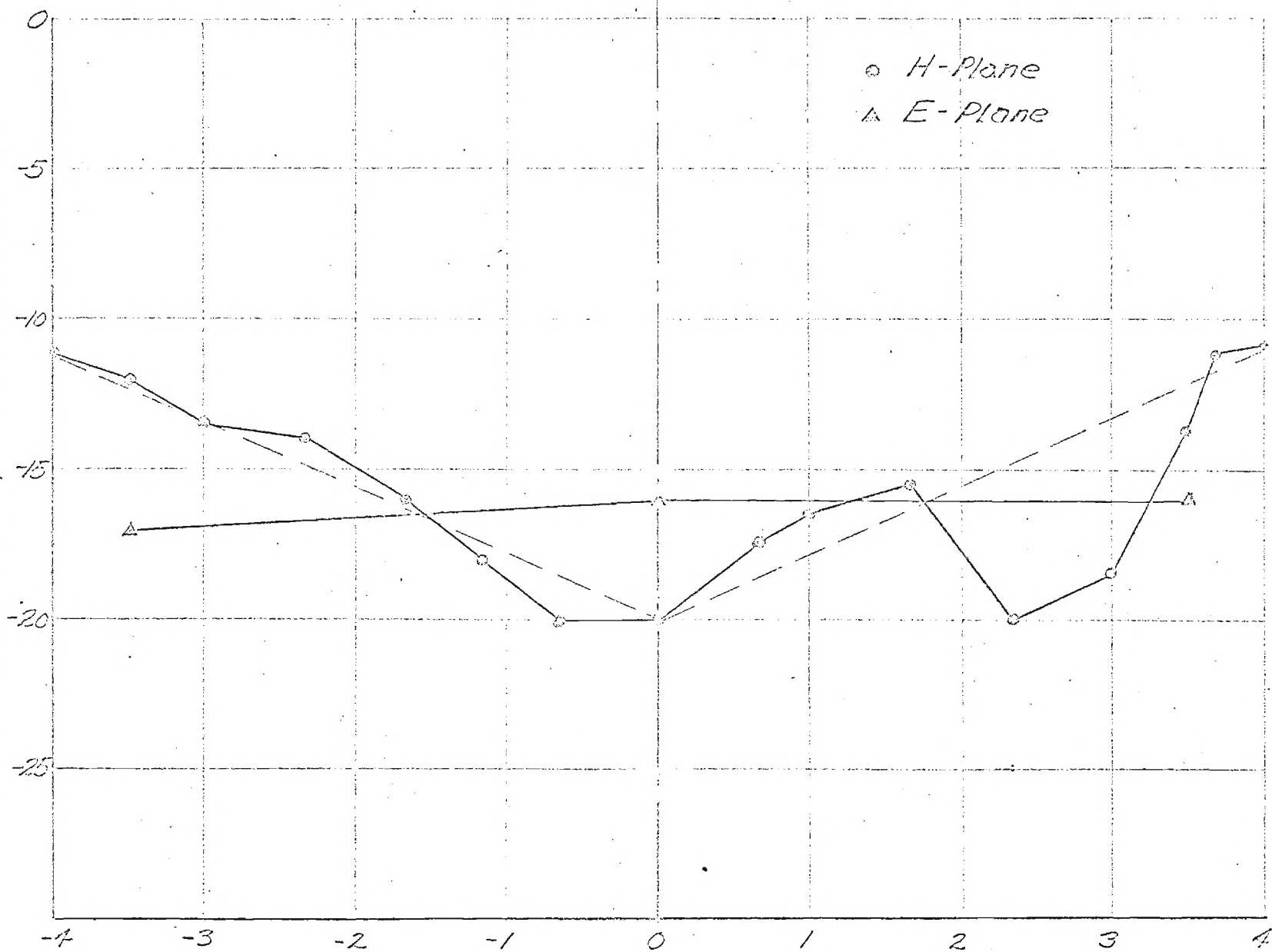
R. M. Goodman, Jr.
Project Director

RMG:sp

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1. "Improved Radiation Characteristics of Shipboard Radar Antennas", F. L. Cain and R. C. Johnson, Final Report Volume II, Contract No. N0bsr-91070, Georgia Institute of Technology, 1 March 1966.
2. "Off-Axis Characteristics of the Paraboloidal Reflector", K. S. Kelleher and H. P. Coleman, Naval Research Laboratory, 31 December 1952.
3. "Estimating the Effect of Feed Support Member Blocking on Antenna Gain and Side-Lobe Level", C. Larry Gray, The Microwave Journal, March, 1964, pages 88-91.

MAXIMUM SIDE-LOBE
in dB relative to peak of main beam



SCAN ANGLE ~ degrees

FIGURE 22