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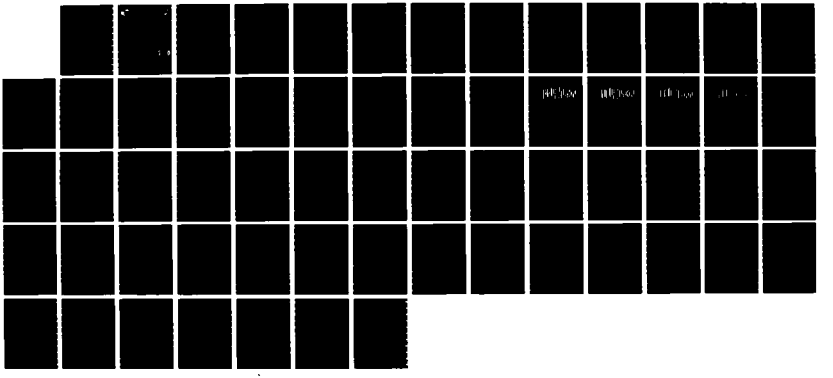

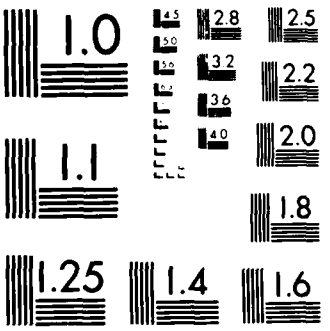

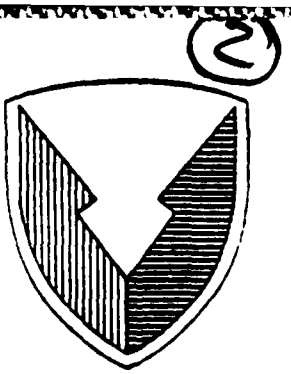

AD NO. _____

TECOM PROJECT NO. 7-CO-RD4-EP1-001

PUBLICATION NO. USAEPG-FR-1289

METHODOLOGY INVESTIGATION

COMPACT ANTENNA RANGE ANALYSIS

BY

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JANUARY 1986

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1. REPORT NUMBER: TRMS No. 7-CO-RD4-EP1-001	2. GOVT ACCESSION NO.: AD-A172556
3. RECIPIENT'S CATALOG NUMBER:	
4. TITLE *(and Subtitle)*: Methodology Investigation Final Report Compact Antenna Range Analysis	5. TYPE OF REPORT & PERIOD COVERED: Methodology Investigation Final Report Sep 84-Sep 85
	6. PERFORMING ORG. REPORT NUMBER: (Monitor) USAEPG-FR-1289
7. AUTHOR(s): R.W. Moody, ES&ST Div, MTD, USAEPG O.D Asbell and E.B. Joy, Georgia Tech Research Institute	8. CONTRACT OR GRANT NUMBER(s): DAEA18-84-C-0050 (P00002)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Georgia Tech Research Institute Atlanta, Georgia 30332	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 1T665702D625
11. CONTROLLING OFFICE NAME AND ADDRESS: U.S. Army Test and Evaluation Command ATTN: AMSTE-TC-M Aberdeen Proving Ground, MD 21005-5055	12. REPORT DATE: January 1986 13. NUMBER OF PAGES: 53
14. MONITORING AGENCY NAME & ADDRESS *(if different from Controlling Office)*: U.S. Army Electronic Proving Ground ATTN: STEEP-MT-EF Fort Huachuca, AZ 85613-7110	15. SECURITY CLASS. *(of this report)*: Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT *(of this Report)*

Unlimited

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

Unlimited

18. SUPPLEMENTARY NOTES

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

Antennas
Antenna Measurement
Antenna Patterns
Compact Antenna Test Range
Test Methodology
Methodology Investigation

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

This preliminary design study (methodology investigation) established the feasibility and cost of the reflector for an outdoor compact range with 50 foot diameter quiet zone. The U.S. Army at Ft. Huachuca, Arizona would use the range to measure patterns of microwave antennas mounted on vehicles and aircraft. Considerations included reflector configuration, size, focal length, surface accuracy, edge treatment, feed, quiet zone quality, manufacturing technology, erection, alignment and cost.

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FOREWORD

The US Army Electronic Proving Ground was responsible for the execution of this report. Mr. Richard W. Moody, Field Engineering Branch, was the Project Officer. The preliminary design and feasibility study was performed and the report was prepared under a contract with the Georgia Tech Research Institute (GTRI). In addition to the cited GTRI authors, Dr. Richard C. Johnson, of GTRI, who built the first compact radar range, provided guidance on reflector sizing, edge design, focal length selection, illumination design and surface accuracy specification. In addition, Johanna Eisenberger and Gene Rhoades of the Electronic Space Systems Corporation (ESSCO), Concord, Massachusetts, shared their knowledge of reflector fabrication techology. A technical paper covering the results of this investigation was presented at the Seventh Annual Conference and Symposium of the Antenna Measurements Techniques Association held in Melbourne, Florida, October 29-31, 1985.

SECTION 1. SUMMARY

1.1 Background

The U.S. Army Electronic Proving Ground, Ft. Huachuca, Arizona, currently uses an arc range to measure the effective gain of vehicle mounted antennas. The vehicle is rotated on a ground level turntable, while a horn antenna is swept in a large vertical arc centered on the vehicle. This range is considered inadequate for measuring pattern changes caused by reflections or obstructions from vehicle areas distant from the antenna. An earlier study by Rome Research Corporation (RRC) identified a compact range as a solution to the measurement problem. The technical and cost feasibility of a large, precision compact range reflector was not established in RRC study.

1.2 Objectives

The feasibility of the reflector for a new compact range at Ft. Huachuca was investigated by GTRI using the following guidelines. This range would be designed to operate at frequencies from 6 to 150 GHz, although use at frequencies above 90 GHz would be perhaps 10 years in the future. The main function of the range would be to measure patterns of antennas mounted on military vehicles and aircraft, determining whether antenna/vehicle interactions were degrading system performance. The reflector design should permit the range to be upgraded to measure the patterns of high frequency, high gain antennas.

The design study sought to make preliminary determinations of the following:

a. Reflector configuration.

b. Reflector size.

c. Surface accuracy.

d. Environmental effects on surface accuracy.

e. Edge treatment.

f. Fabrication and alignment techniques.

g. Reflector cost.

h. Field quality/measurement accuracy relationship.

i. Feed configuration.

j. Frequency range and quiet zone.

1.3 Summary of Procedures

The "state of the art" of large, accurate reflector fabrication was accessed by surveying the radio telescope and satellite communications antenna technical literature, and by talking to antenna manufacturers. The range measurement requirements were analyzed, and basic reflector design criteria were established. Several reflector configurations (offset fed paraboloid, center fed paraboloid, parabolic cylinder, dual crossed parabolic cylinders) were evaluated in light of fabrication and design criteria. The selected configuration (offset fed paraboloid) was developed into a preliminary design. A preliminary technical specification was written, and preliminary technical proposals and cost estimates were sought from several antenna manufacturers. Information from the responses was used to refine the design and to estimate the cost of both an offset fed paraboloid and dual crossed parabolic cylinder reflectors.

1.4 Summary of Results

The preliminary design is described below:

A circular, offset fed paraboloid, with a 110 foot focal length and 70 foot diameter was the reflector configuration choice.

The surface accuracy, under the most benign environmental conditions, should be .010 inch RMS over the central 56 foot diameter. Careful design

can achieve this accuracy with conventional materials, fabrication and alignment techniques.

Thermal distortion can be limited by reflector orientation, shading, matching coefficients of thermal expansion, matching thermal time constants, coatings, and landscaping. Wind distortion can be limited by controlling structure stiffness.

A serrated edge can limit diffraction effects, and is much less expensive than a rolled edge.

The reflector would be assembled from many precision panels mounted on a back structure. A dual theodolite coordinate measuring system would be used to align each panel individually. Photogrammetric studies would confirm the reflector's shape and measure environmental distortions.

Reflector fabrication cost would be about 2.2 million 1987 dollars. This figure includes detailed mechanical design, tooling, shipping, foundation, installation and alignment by an antenna manufacturer.

To measure the -10dB level of an antenna pattern with the desired -3dB accuracy requires that the total stray radiation level be -21dB. The depths of deep (-30 to -40dB) nulls will be measured less accurately with this level of stray radiation.

A candidate feed would be a dual port, low gain, corrugated conical horn.

The frequency range is limited by the number of feeds supplied, antenna surface accuracy (high frequency limit), and edge diffraction (low frequency limit). The expected quiet zone is a 50-foot diameter cylinder.

1.5 Analysis

The result of this investigation is a preliminary design for a large outdoor compact range reflector, and a cost estimate for this reflector.

The design was based on careful consideration of specific requirements and an examination of the current state of the arts of reflector manufacture and compact range design. Computer simulations of pattern measurements showed the relationship between field quality and measurement error. Further simulations have laid the groundwork for optimizing the selection of feeds and reflector focal length.

The crucial issues related to the mechanical design are manufacturability and thermal stability. Several vendors have expressed confidence that the reflector can be built to tolerance. Vendor data relating gain changes to thermal instability suggest that the preliminary design would have adequate stability. A detailed look at the nature of deformations of a panel is necessary to assure low enough stray radiation levels.

The overall performance of the range should be determined by a complete simulation, as suggested in Section 1.7. The willingness of established, competent antenna manufacturers to commit themselves to building the reflector to the Specification (see Appendix B) is evidence of the project's feasibility.

1.6 Conclusions

This preliminary design study documents the feasibility of the reflector for a large (50-foot diameter quiet zone) outdoor compact range, designed to measure the patterns of vehicle mounted antennas. The reflector can be built by an established antenna manufacturer, using conventional techniques. The estimated cost, about 2.2 million 1987 dollars, is within the range expected for a reflector of this size and accuracy.

1.7 Recommendations

The establishment of the feasibility of the reflector clears the way for additional range and reflector design work. The following are major areas requiring investigation by computer modeling, hardware measurement, or detailed design analysis.

1. Specification of the required quality of the quiet zone field based on the measurement mission. Co-polarized and cross polarized stray radiation levels must be specified over the desired range of frequency of operation.
2. Specification of the best reflector size. The reflector size is a tradeoff between cost, edge configuration, and quiet zone quality.
3. Specification of the reflector edge geometry. The edge should be either rolled or serrated with performance and cost as key tradeoffs.
4. Evaluation of various feed types for applicability to compact range application. Feeds should be ranked on the basis of uniformity of field and cross-polarization in the quiet zone, bandwidth, and power handling capability. An optimum feed should be recommended by the contractor for the USAEPG application. Note that this item has been funded and that work is under way.
5. Specification of the feed support, feed enclosure, and feed positioner. This system should allow easy access for aiming, aligning, rotating, and changing feeds. Below ground surface mounting should be considered for reduction of feed scattering, back radiation, and ground illumination.
6. Specification of the RF source. The required power level and frequency stability of the source or sources must be specified.

7. Specification of a ground reflection suppression technique. The reflector lower edge and the feed antenna pattern must be modified to achieve an acceptable ground reflection level.

8. Specification of the RF receiver. The RF measurement receiver must be specified to accommodate the anticipated low RF levels received by the antenna under test. Consideration must be given to receiving systems which allow time averaging of the received signal and noise.

9. Specification of the axial location of the quiet zone. The best axial location of the quiet zone must be specified as a trade-off among feed antenna back radiation, feed antenna scattering, edge scattering, and reflector aperture field diffraction.

10. Specification of the range certification and alignment technique. The recommended quiet zone field measurement and Fourier analysis technique must be implemented. A field probe must be moved through the quiet zone field, measuring and recording the amplitude, phase, and polarization of the field. A procedure for range alignment based on the measurements must be specified.

11. A Final Technical Specification, including drawings, must be written. The Specification would reflect the results of the above items.

12. The Final Technical Specification would be sent to potential vendors for quotes.

13. A reflector vendor must be chosen.

14. A final design must be generated by the vendor and the range's prime contractor. The design process would include detailed analysis of thermal and wind induced deflections, erection procedures and alignment procedures.

SECTION 2. DETAILS OF INVESTIGATION

2.1 Electromagnetic Preliminary Design

2.1.1 Introduction

This section presents the results of a preliminary electromagnetic design for a large compact range for the measurement of far field patterns of vehicle mounted antennas. This was a preliminary effort, and much detailed engineering and analysis remains.

2.1.2 Compact Range Concepts

Four compact range reflector concepts were investigated: (1) the point source, center fed paraboloid, (2) the point source, offset fed paraboloid, (3) the line source, parabolic cylinder, and (4) point source, dual crossed parabolic cylinders. The chosen concept, the offset fed paraboloid, offers the highest performance, at a price lower than all others except the center fed paraboloid.

The center-fed paraboloid was rejected for the following reasons:

1. The feed point is approximately 40 feet above ground. This height causes difficulty in changing and aligning feed antennas. The RF power transmission path is long unless the RF power amplifier is mounted near the feed antenna. This would increase feed blockage.
2. The feed blocks, diffracts and scatters the range field. The feed and feed supports cause significant blockage at both low frequency, where the feed antenna is physically large, and at high frequency, where the feed supports become the dominant scatterer. The distance from feed to quiet zone required to reduce feed blockage effects at 100 GH_z for a 1 foot diameter blockage would be 1000 feet. The residual amplitude ripple at 1000 feet is 1 dB. Lower ripple levels would require greater distance.

3. The feed support system, which must rigidly support the feed while creating minimum blockage, is a serious design problem.

The line source parabolic cylinder was rejected because of cost. The cost of the reflector is only slightly less than that of the paraboloid, but the line feed antenna is very expensive, narrow band, and physically large. Narrow bands mean that many of these feeds are required to cover the frequency range of interest.

The point source, dual crossed parabolic cylinder (DCPC) compact range concept was rejected because of high cost and inferior performance. GTRI estimates the cost of a DCPC reflector to be 150% that of an offset paraboloid. Performance is inferior because of surface accuracy. Each reflector of the DCPC system must have better accuracy than the single paraboloid to achieve equal performance. However, solar thermal problems will make the DCPC reflectors less accurate. The DCPC concept is discussed at more length later in this report.

All four compact range concepts can be configured for free space testing (the usual case) or for ground reflection testing. The only ground reflection compact range known to the authors of the report is the "Big Ear" radio telescope at Ohio State University. The ground reflection configuration is limited to vertical polarization only and does not significantly reduce the size of the required range reflector.

2.1.3 Shape of Quiet Zone

The traverse shape of the quiet zone is dictated by the shape of the reflector. There are two reasons for choosing a circular shape: (1) a circular reflector has the greatest ratio of aperture area to aperture edge, and (2) any antenna under test when rotated throughout a complete sphere requires a circular shaped quiet zone.

For best use of the available RF energy the feed antenna should illuminate the reflector with little spill over past the reflector surface.

2.1.4 Ratio of Reflector to Quiet Zone Dimensions

Optically, the reflector size would be equal to the quiet zone size, regardless of geometry of the reflector surface. The scattering from the edge of the reflector and the diffraction of the finite size aperture field, however, require that the reflector surface be larger than the quiet zone. Five factors have great impact on the size and quality of the quiet zone: (1) feed antenna pattern, (2) focal length to diameter ratio of the reflector, (3) edge geometry, (4) the distance between the reflector and the quiet zone, and (5) reflector size. The feed antenna pattern, F/D ratio, and the distance between the reflector and the quiet zone have minimum cost impact, while the edge geometry and reflector size have large cost impact. Thus, for a given quiet zone field quality, a tradeoff between edge geometry and reflector size can be undertaken with the feed antenna pattern, F/D ratio, and the location of the quiet zone as parameters. The preliminary design shown in Figure 1 shows a 50 foot diameter, circular quiet zone with a 70 foot diameter circular aperture reflector, where the edge geometry is low cost serrations with minimum edge lengths of 2 feet.

2.1.5 Quiet Zone Quality

The quality of the quiet zone is specified by the ratio of stray radiation to direct optical radiation within the quiet zone. Stray radiation produces amplitude and phase tapers and ripples in the otherwise constant fields in the quiet zone. Stray radiation is produced by the following mechanisms:

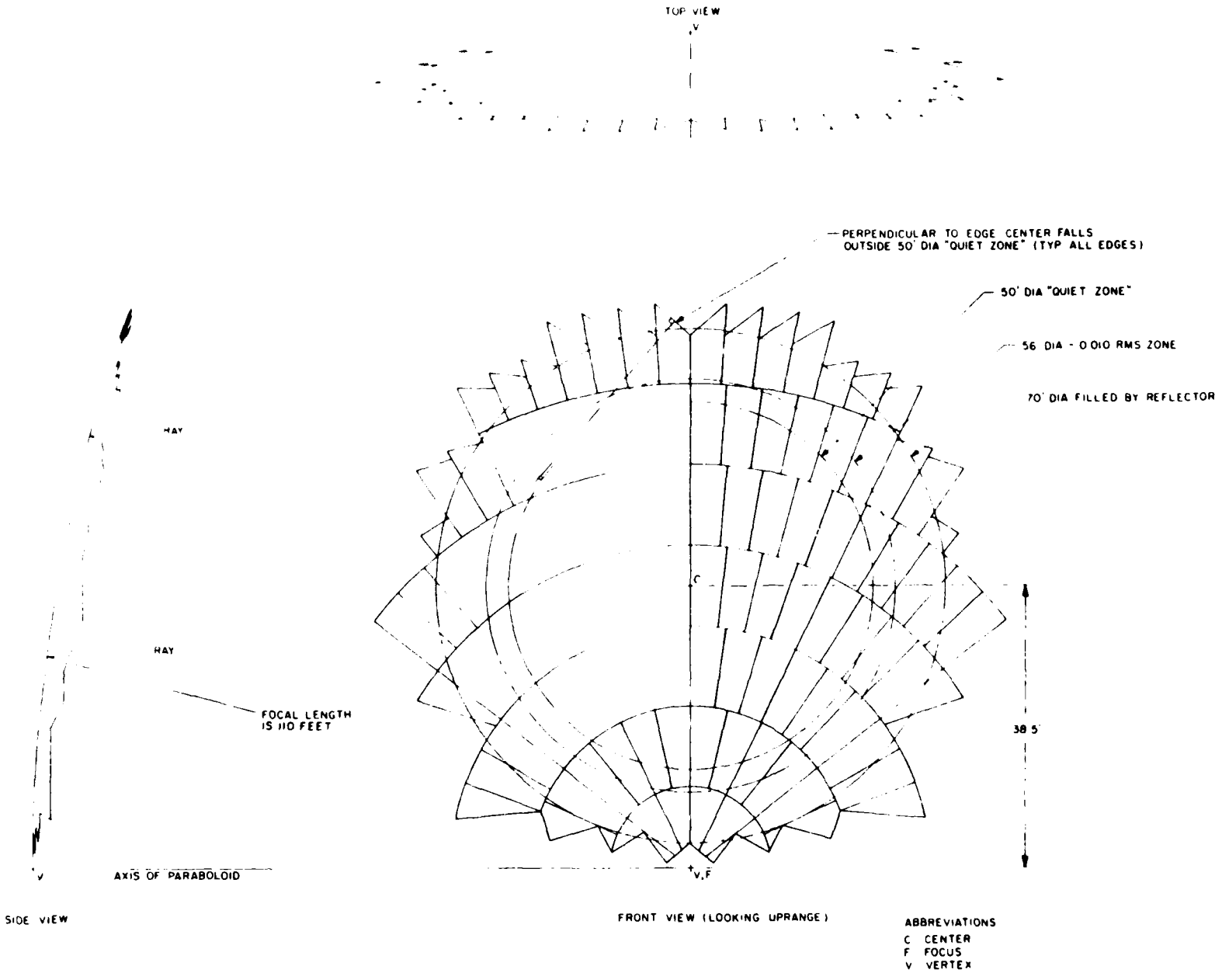


Figure 1. Preliminary Design

1. Scattering of the direct optical field as it passes over the feed antenna and feed antenna support.
2. Scattering from the edges of the reflector surface.
3. Back radiation from the feed antenna.
4. Ground reflection.
5. Scattering from reflector surface roughness.

Each of these sources of stray radiation must be assessed and controlled to produce the required quiet zone quality. The preliminary design calls for an offset feed configuration, which places the feed antenna outside the quiet zone area and calls for a very low gain and physically small feed antenna. Absorbing material will be used to reduce scattering from the feed support. The preliminary reflector design calls for serrated edges with minimum edge length of 2 feet, with each edge directed so the normal to the edge falls outside the quiet zone area. The serrated edge was selected over the rolled edge or absorber edge due primarily to its lower cost of manufacture. The tooling for the rolled edge is very expensive because no two sections of the outer reflector edge for a circular aperture offset paraboloid are identical. Thus a large number of forms would be required for the manufacture of the rolled edge. A detailed trade-off between these two edge concepts has not been performed.

The stray reflection from the feed antenna is reduced by designing for low back radiation, and by increasing the distance from the feed antenna to the quiet zone area. Absorber chokes and collars can also be used near the feed antenna to absorb back radiation. Ground reflections will redirect feed energy falling on the ground up and onto the reflector surface and into the quiet zone. This ground reflection can be reduced by absorbing feed radiation with absorber or lowering the feed assembly below ground

level and using metal deflectors to direct feed energy away from the reflector. Some scattering from the lower edge of the reflector may also be directed into the quiet zone by ground reflection. The lower edge geometry must direct edge scattering so it does not fall into the quiet zone directly or by ground reflection. This can be accomplished by directing scattering to the sides, as the preliminary design serrations will do.

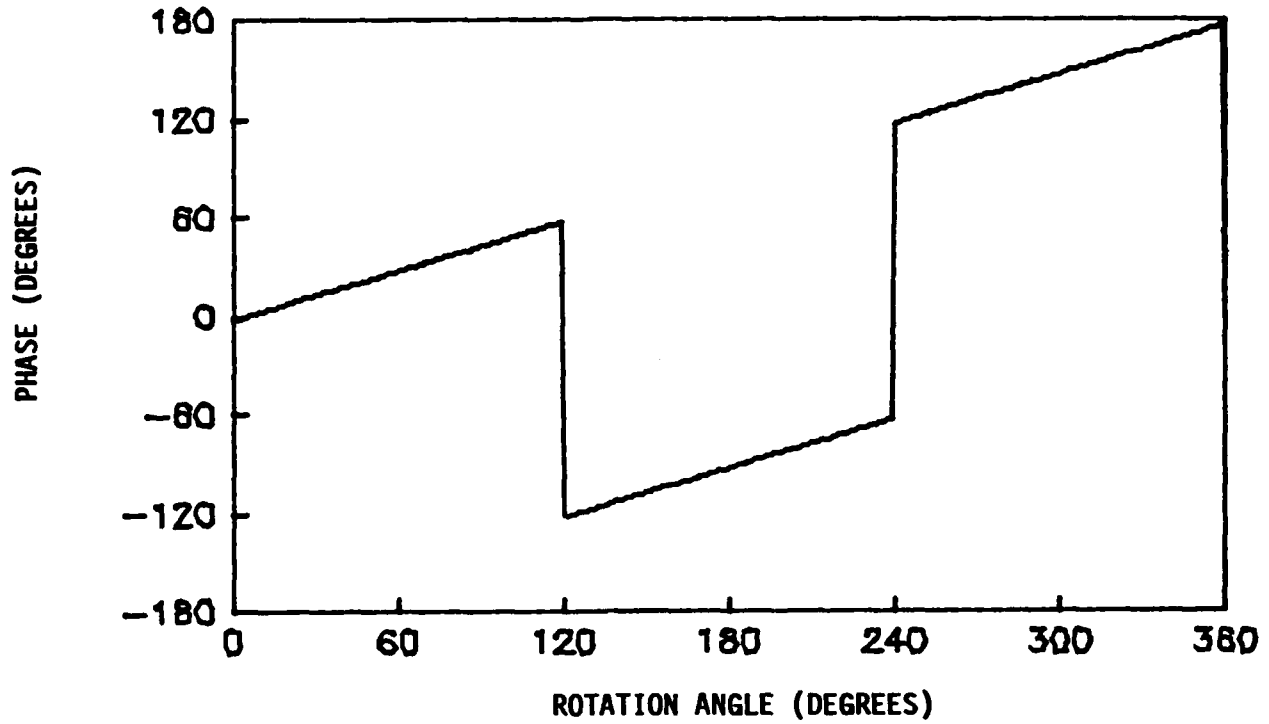
The surface quality of the reflector is specified by the magnitude and spatial frequency of the roughness. Given the size and distance of the quiet zone from the reflector, a maximum spatial frequency can be specified beyond which surface roughness scattering will be directed away from the quiet zone area. Conventional compact range design calls for a RMS surface smoothness of one-hundredth of a wavelength for all spatial frequencies of periods greater than three wavelengths.

Table 1 shows the effect of stray radiation (called measurement system reflectivity level in the table) on the accuracy of measuring an antenna pattern level. The table shows that a desired accuracy of -3 to +3 dB for a measurement of the -10 dB level of an antenna pattern requires that the stray radiation must be respectively -20.69 and -17.69 dB below the direct optical field level. Thus the total stray radiation of the measurement system should be less than approximately -21 dB. Smaller compact range measurement systems are routinely designed for total stray radiation levels below -40 dB, much better than the current mission requires.

Figure 2 shows the far field antenna pattern of a low gain antenna pattern with deep nulls. This pattern is typical of a free space measurement of a low gain antenna without any distortion or interference due to a mounting structure. Figure 3 shows the far field pattern of a

Table 1. REQUIRED MEASUREMENT SYSTEM REFLECTIVITY LEVEL (DECIBELS WITH RESPECT TO DIRECT MEASUREMENT FIELD) VERSUS DESIRED PATTERN ACCURACY

Pattern Level / Accuracy	0dB	-5dB	-10dB	-15dB
-1/+1dB	-19.27 -18.27	-24.27 -23.27	-29.27 -28.27	-34.27 -33.27
-2/+2dB	-13.74 -11.74	-18.74 -16.74	-23.74 -21.74	-28.74 -26.74
-3/+3dB	-10.69 - 7.69	-15.69 -12.69	-20.69 -17.69	-25.69 -22.69
-4/+4dB	- 8.66 - 4.66	-13.66 - 9.66	-18.66 -14.66	-23.66 -19.66
-5/+5dB	- 7.18 - 3.18	-12.18 - 7.18	-17.18 -12.18	-22.18 -17.18



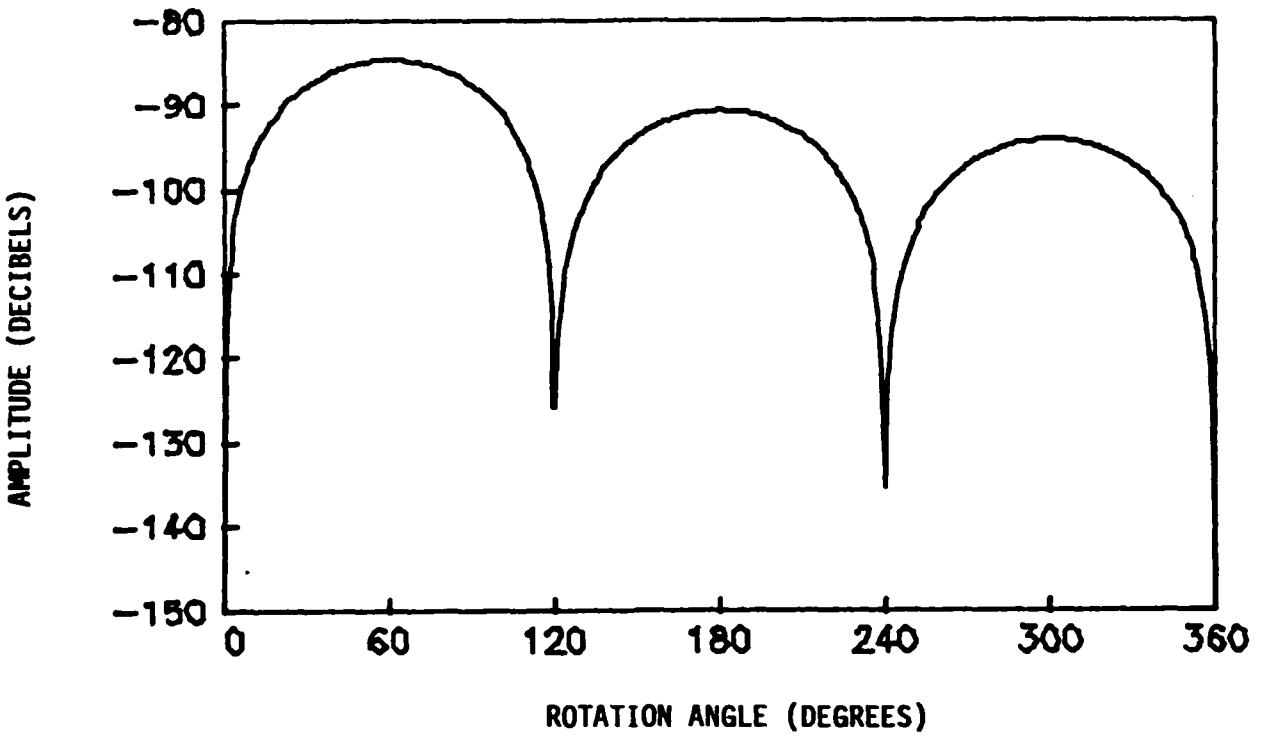


FIGURE 2. FAR FIELD PATTERN OF LOW GAIN ANTENNA

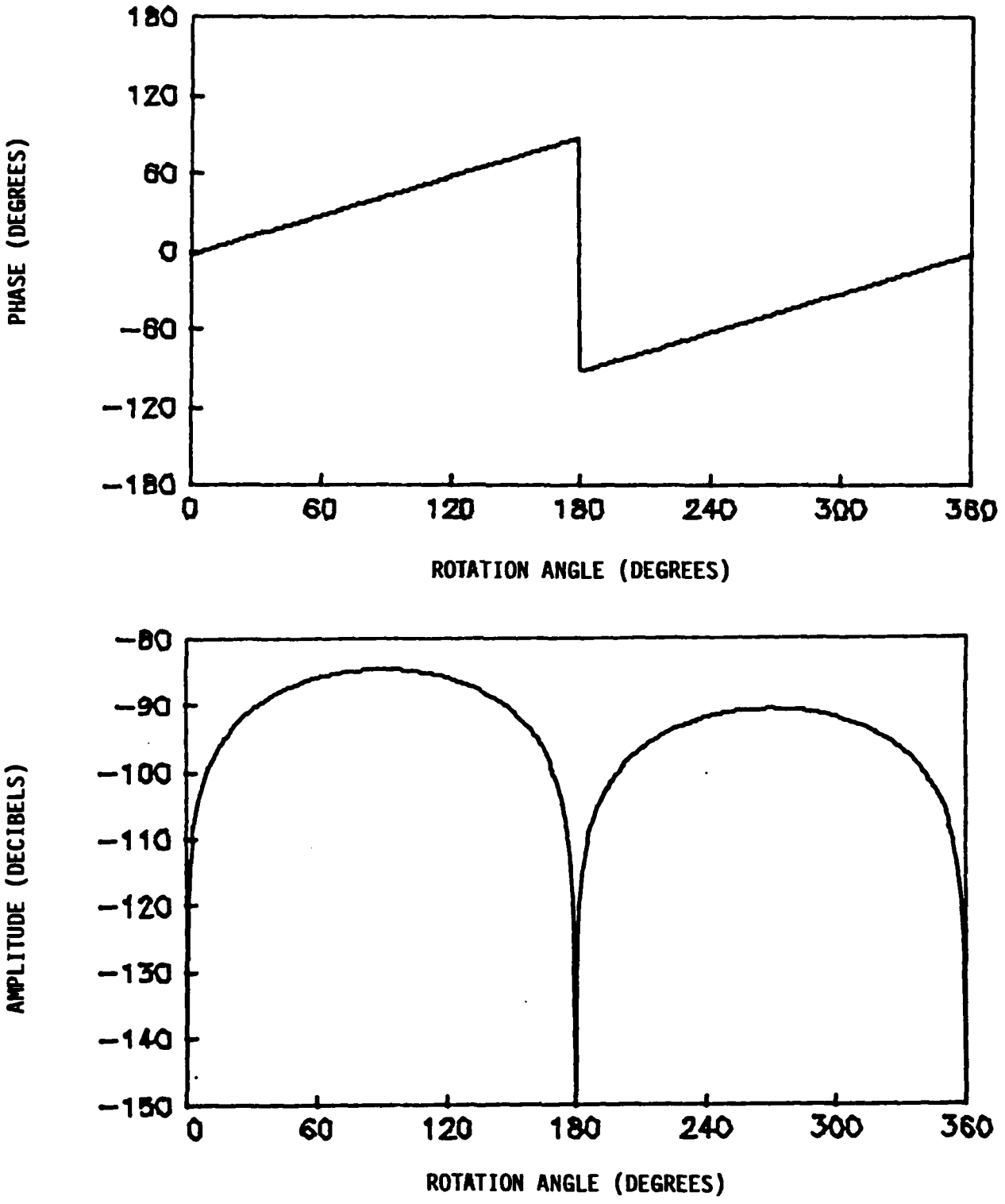


FIGURE 3. SCATTERED FAR FIELD PATTERN OF SIMPLE REFLECTOR

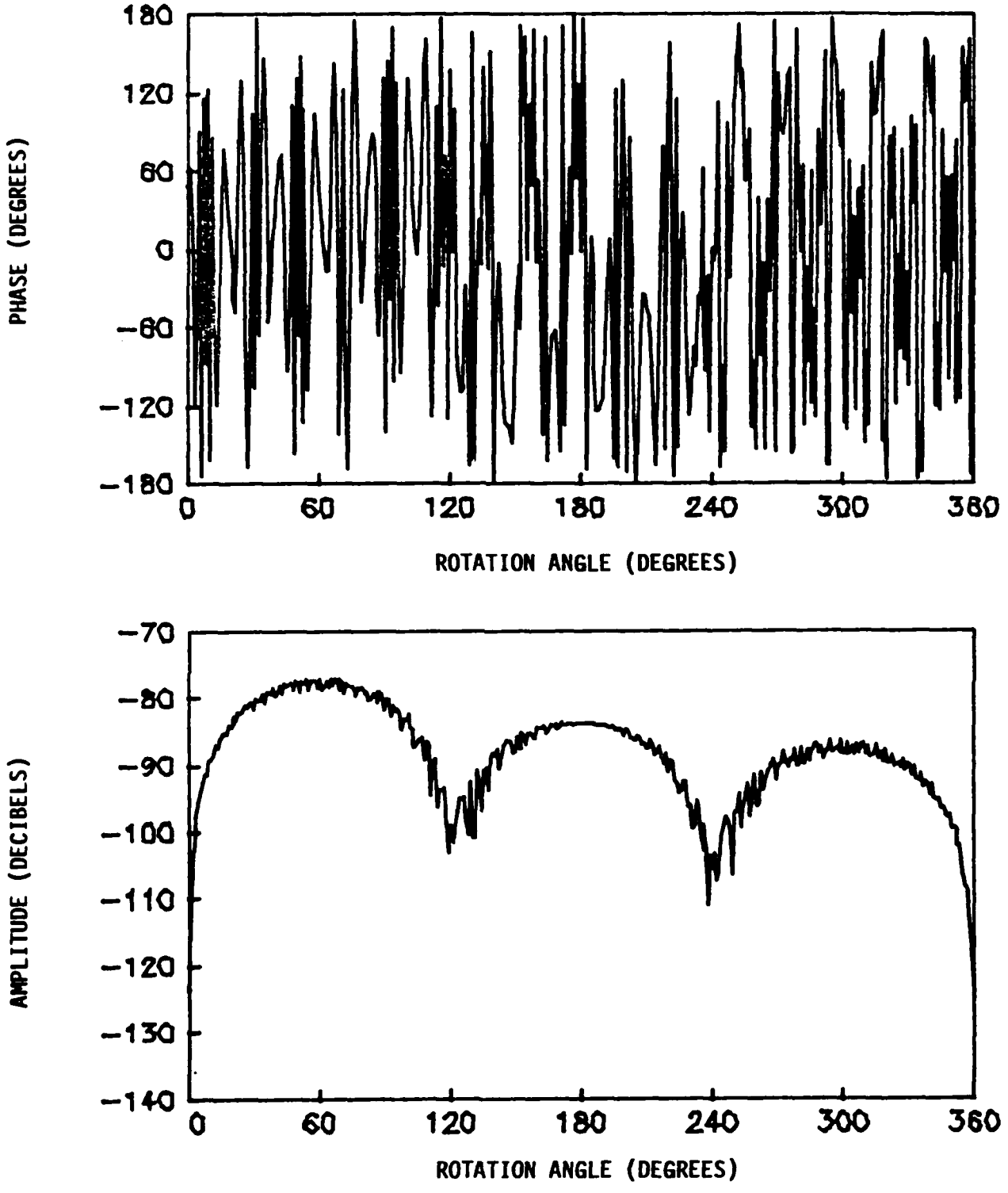


FIGURE 4. INTERFERENCE OF FAR FIELD ANTENNA PATTERN AND PATTERN OF SIMPLE SCATTERER FOR 30 WAVELENGTH SEPARATION

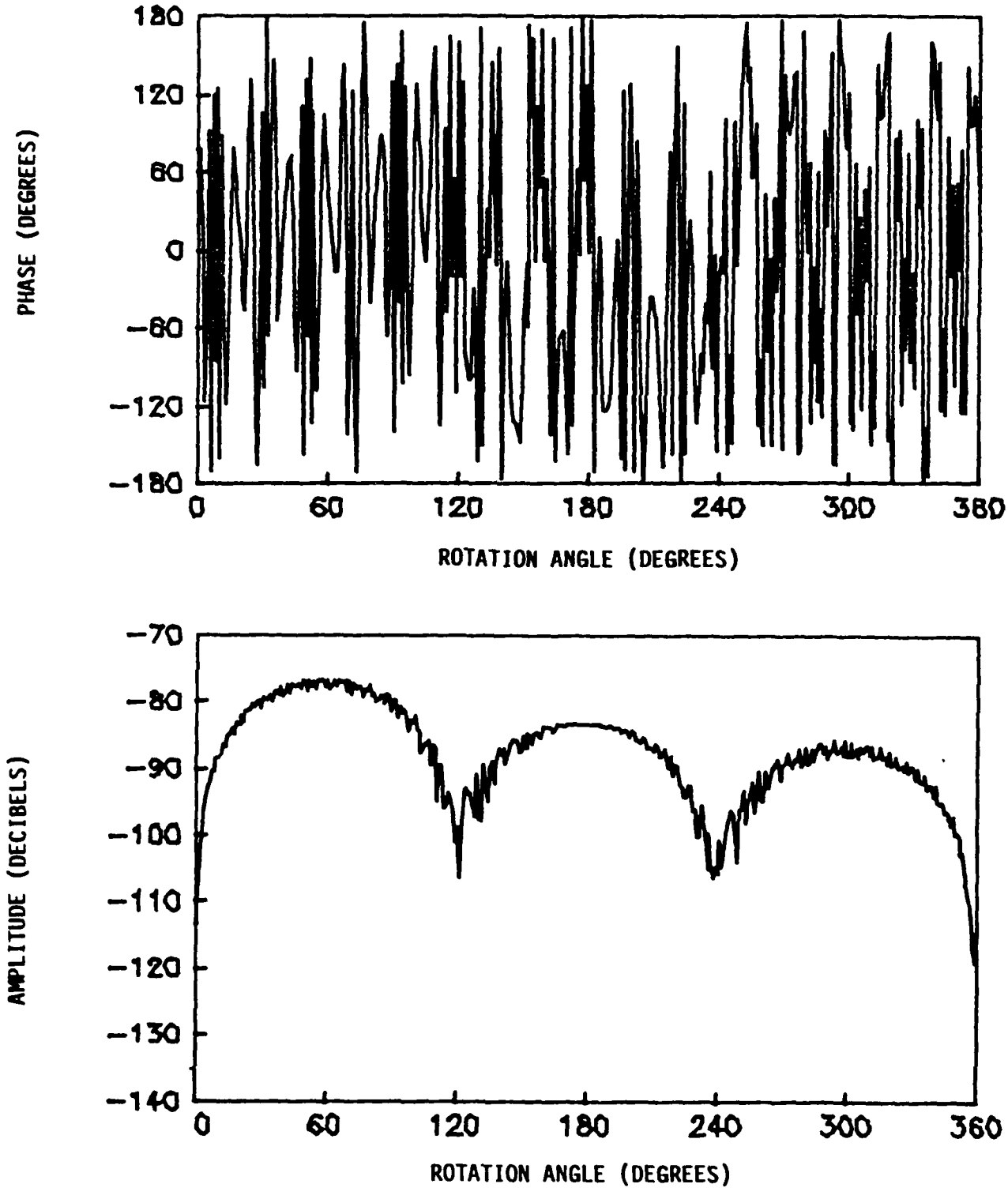


FIGURE 5. MEASURED VEHICLE MOUNTED ANTENNA PATTERN USING COMPACT RANGE WITH -20 dB STRAY RADIATION LEVEL

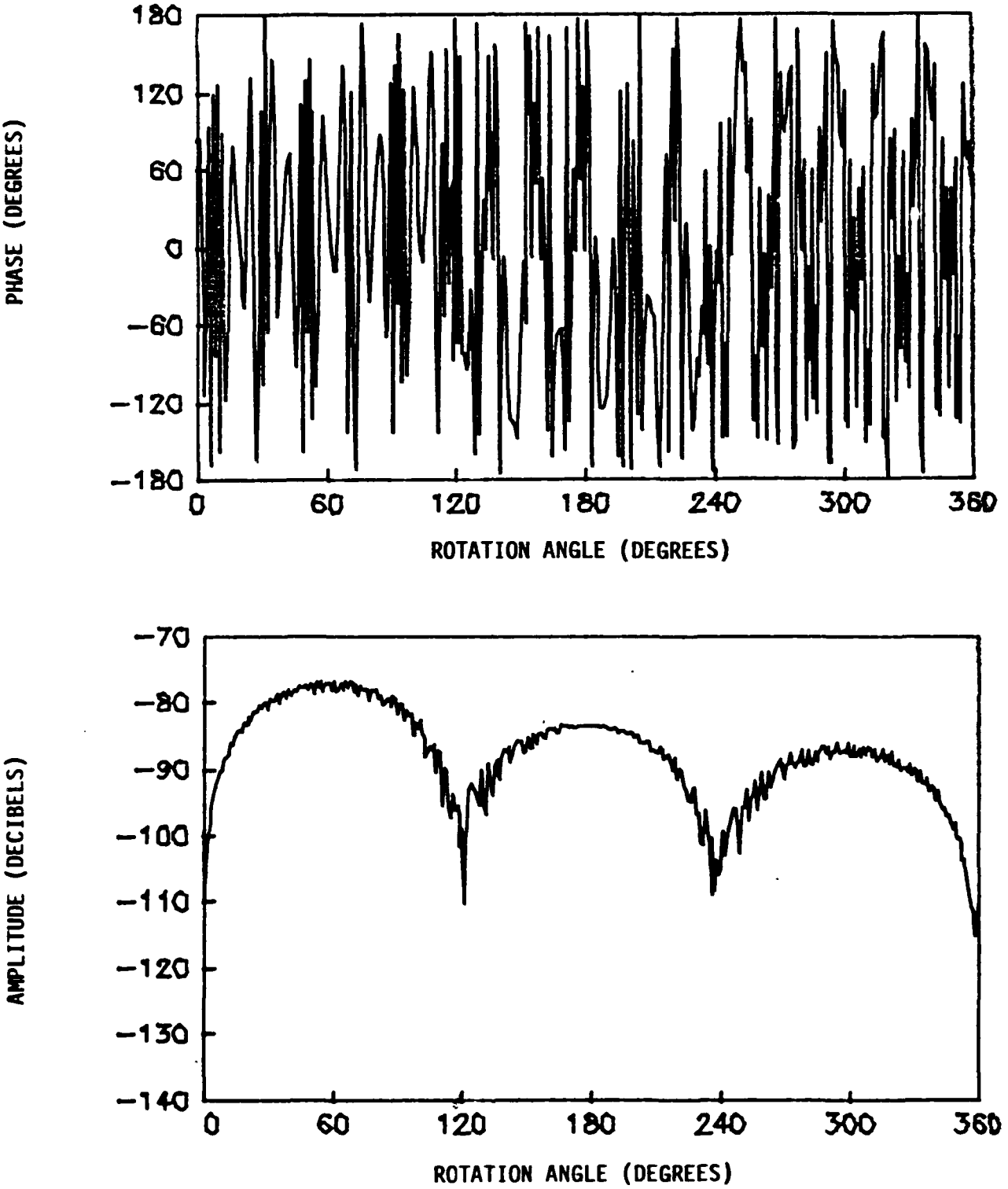


FIGURE 6. MEASURED VEHICLE MOUNTED ANTENNA PATTERN USING COMPACT RANGE WITH -15 dB STRAY RADIATION LEVEL

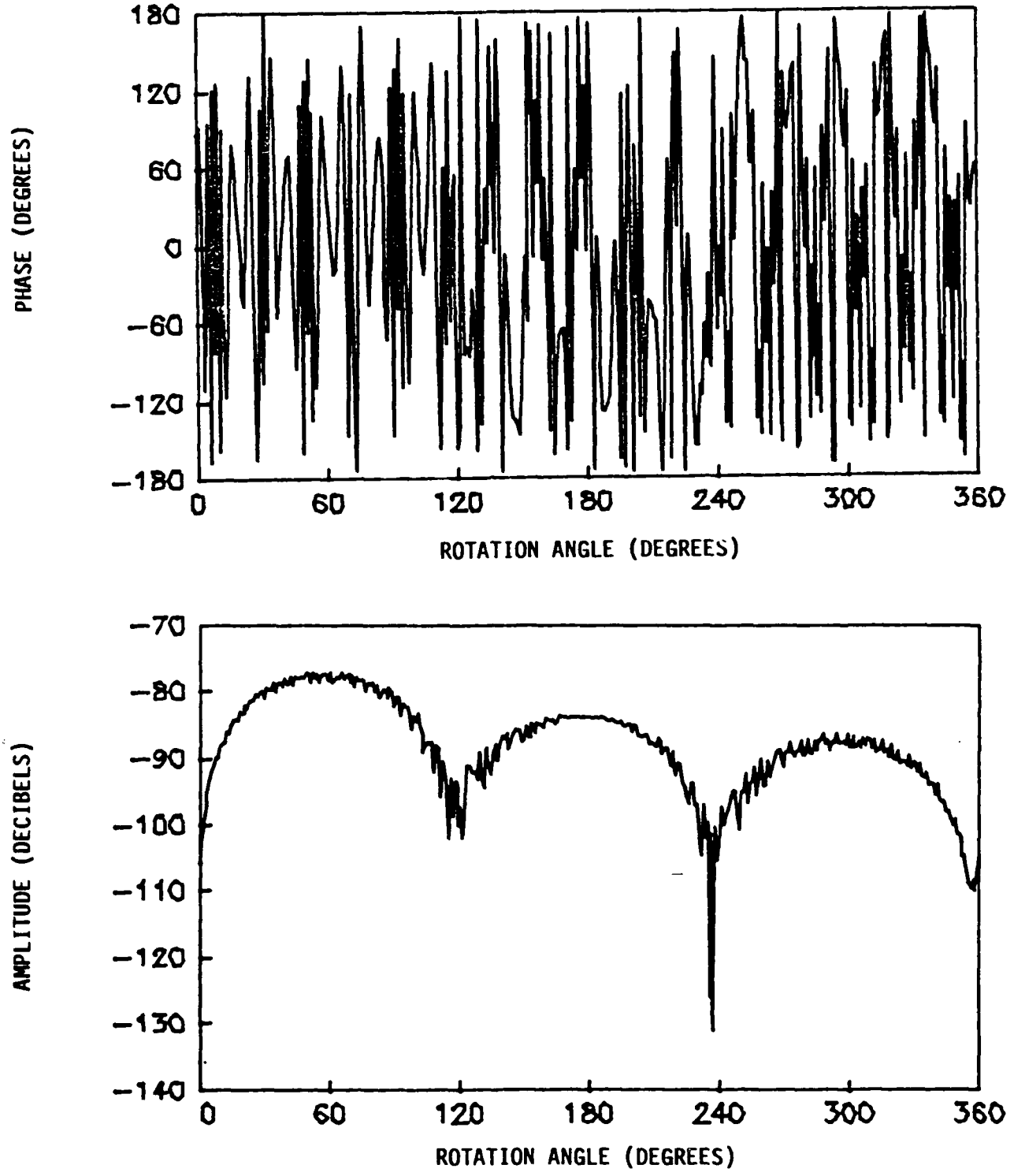


FIGURE 7. MEASURED VEHICLE MOUNTED ANTENNA PATTERN USING COMPACT RANGE WITH -10 dB STRAY RADIATION LEVEL

simple low gain antenna which in the example will represent the far field radiation pattern of a simple structure such as an airplane stabilizer, support strut, or wing edge when illuminated with a simple spherical wave produced by the antenna pattern in Figure 2. Figure 4 shows the pattern of Figure 2 modified by the presence of the scattering of Figure 3. The antenna is separated from the simple scatterer by 30 wavelengths and the peak of the scattering pattern is 20 dB below the peak of the antenna pattern. This figure shows the rapid modulation of the antenna pattern due to the presence of the scatterer. This simple model shows an effect of mounting a low gain antenna on a vehicle. Figures 5, 6, and 7 show computer simulated measurements of the vehicle mounted low gain antenna as shown in Figure 4 using a compact range with -20 dB, -15 dB, and -10 dB stray radiation levels, respectively. These simulations show little error in pattern measurement for the highest 10 dB levels of the pattern due to the stray radiation levels simulated, but show increasing errors for the lower pattern levels. Null depths of 30 and 40 dB will be measured less accurately with stray radiation levels of -10 dB, -15 dB, or -20 dB.

2.1.6 Feed Antenna Design Criteria

The feed is the second most important part of the compact range. Some say it is the most important part and must be designed and measured first and then the F/D and reflector geometry designed to best fit the feed performance. Computer studies[1] showed that the feed and feed location will set the overall performance of the quiet zone and very little can be done in the design of the reflector to compensate for a poor feed. The computer

[1]R. C. Johnson, "Some Design Parameters for Point-Source Compact Ranges," to be published in IEEE Transactions AP, May-June, 1986.

simulation showed that an F/D ratio of approximately 0.7 is optimum for a quiet zone taper of -0.5 dB using a simple broadband feed antenna. Table 2 shows a list of the factors which must be considered in the design of a feed antenna for a point source compact range. The table also shows the preliminary design specification for the feed. A candidate feed is a dual port, low gain, corrugated conical horn. This type horn with a 0.7 F/D reflector should provide the desired quiet zone amplitude and phase tapers over ± 30% bandwidths.

2.1.7 Feed Antenna Mounts and Positioning System

The feed antenna positioning system should be designed to perform two functions. The first is the aiming and alignment of the feed to produce the desired quiet zone. The phase center of the feed must be at the focal point of the reflector. The second possible function of the positioning system is to move the feed with an orbital motion around a circle of three wavelength diameter. The resulting pattern averaging may greatly reduce the effects of stray radiation with periods smaller than three wavelengths. The final design of the feed mounting and positioning system must determine the best location of the feed system with respect to ground level. It may be better to put the feed system slightly below ground level to reduce feed scattering and ground reflection.

2.1.8 Compact Range Cross Polarization

There are four main sources of cross polarization coupling for a point source paraboloidal reflector compact range. These are (1) the feed, (2) the reflector surface, (3) reflector edge diffraction, and (4) the offset feed geometry. Preliminary analyses of these four sources of cross polarization radiation show that the cross polarization levels will be more

TABLE 2. FEED ANTENNA DESIGN CRITERIA

- WIDE BANDWIDTH

  20% - HIGH PERFORMANCE
  50% - MAXIMUM

- REFLECTOR ILLUMINATION (CENTRAL PORTION)

  -1/2 dB TAPER

- EDGE ILLUMINATION

  -1 dB MINIMUM

- LOW CROSS-POLARIZATION

  -40 dB

- SPHERICAL PHASE FRONT

  5^0

- LOW VSWR

  1.1

- LOW BACK RADIATION

  -30 dB

- LOW GROUND REFLECTION

- TYPICAL: LOW GAIN CORRUGATED CONICAL HORN

than 30 dB below the co-polarized fields, which is acceptable. The cross polarization performance of the range can be enhanced by using a hybrid mode conical horn feed and using only a small central portion of the feed pattern to illuminate the reflector. A large F/D ratio facilitates this and improves the uniformity of reflector illumination. Roughness of the reflector surface, and especially reflector seams, are sources of cross polarized fields. The final design must more fully address the cross polarization effect of the seams.

Reflector edge scattering will contain cross polarized components. These can be reduced by reducing all edge scattering and by directing the scattering away from the quiet zone. The serrations must also be designed to uniformly disperse the cross polarized fields. The offset fed reflector geometry produces a cross polarized field, which is greatly reduced by a large F/D ratio. The preliminary F/D ratio of 0.7 should bring the cross polarized field to well below the 30 dB goal.

2.1.9 Frequency Range

Table 3 shows three factors which limit the usable range of frequencies. The feed antennas operate over basically waveguide bandwidths. A set of feed antennas, one for each waveguide bandwidth, is needed to cover a large range of frequencies.

2.1.10 RF Power Requirements

Table 4 shows the factors which determine the RF power requirements of the preliminary design compact range. The factors are: the gain of the feed antenna (low), the focal length of the reflector (large), the gain of the antenna under test (unfortunately small), and the sensitivity of the receiver required for maximum dynamic range. The Scientific Atlanta

TABLE 3. FREQUENCY RANGE LIMITS

1. Feed Performance

   20% Bandwidth Feeds: 17 feeds cover 5-110 GHz

   50% Bandwidth Feeds: 8 feeds cover 5-125 GHz

2. Reflector Edge: Low Frequency Limit

   Serration Length > 3λ

   Rolled Edge Half Ellipse > $5\lambda \times 2\lambda$

3. Reflector Surface Accuracy: High Frequency Limit

   RMS Error < $\lambda/100$ (high performance compact range)

   Spatial Period Average > 3λ

TABLE 4. RF POWER BUDGET

- FEED ANTENNA GAIN: 7 dBi
- FOCAL LENGTH PATTERN SPREADING: $1/F^2$
- GAIN OF ANTENNA UNDER TEST: 5 dBi
- FREQUENCY
- -30 dBm MAXIMUM SIGNAL AT RECEIVER MIXER (FOR MAXIMUM DYNAMIC RANGE)
- $P_r = P_t\ G_F\ G_{AUT}(\frac{\lambda}{4\pi F})^2$

EXAMPLES:

5 GHz	100 GHz
$\frac{P_r}{P_t} = (5)(3)(\frac{.197'}{4\pi\ 110'})^2$	$\frac{P_r}{P_t} = (5)(3)(\frac{.0098'}{4\pi\ 110'})^2$
$= 3.05 \times 10^{-7}$	$= 7.6 \times 10^{-10}$
For P_r = -30dBm	For P_r = -30dBm
P_t = 3.3KW	P_t = 1.3MW
For P_r = -60dBm	For P_r = -60dBm
P_t = 3.3W	P_t = 1.3KW

receiver requires an RF signal strength of approximately -30 dBm for maximum dynamic range of measurement. The compact range power coupling equation is also shown in Table 4 where F is the focal length of the range. Four examples of the required RF power are shown, two for each of two frequencies, 5 GHz and 100 GHz. The table shows that for full dynamic measurement range 3.3 kW are required at 5 GHz and 1.3 MW are required at 100 GHz. These power levels are very large and at 100 GHz are totally impractical. The power levels may be lowered to 3.3 W at 5 GHz and 1.3 kW at 100 GHz with a corresponding 30 dB reduction in dynamic range. Time averaging can increase dynamic range with limited power. If a receiver performs N independent samples of a fixed signal in random noise, the average of the N samples will provide an N fold increase in signal to noise ratio. Thus an N = 1000 average sample would yield a 30 dB signal to noise ratio improvement at the expense of measurement time. Note that this analysis is very pessimistic in the high frequency case. For this case, the gain of both the antenna under test and the feed (which need illuminate only the central part of the range reflector) would be much higher than the assumed values.

2.1.11 Electrical Certification and Alignment

There are two techniques in common usage to assess and certify the stray radiation level on a compact range. These are measurement of the quiet zone field along transverse cuts of the quiet zone and a pattern comparison technique in which far field pattern measurements are performed at several locations throughout the quiet zone and then compared with one another.

These two techniques can assess the level of stray radiation but only one can be used to align the compact range and can determine the direction

of stray radiation propagation, thus pinpointing its source. This technique is the amplitude and phase quiet zone measurement technique. Figure 8 shows a computer simulated measurement of the transverse cut of the quiet zone of a compact range. The phase shows an approximate maximum phase taper of 25° and shows an amplitude ripple of approximately ± 0.5 dB and a phase ripple of a few degrees. Standard nomographs would indicate that this quiet zone ripple corresponds to a reflectivity level of approximately -26 dB. Figure 9 shows the results of a new technique, a windowed, probe-compensated, Fourier transformation of the quiet zone field. Notice the main range radiation at 0° and a stray radiation source at -30°, 26 dB below the main radiation. The Fourier transform correctly assesses the range stray radiation level, and found it was from a source located 30° down from the quiet zone longitudinal axis. This technique is recommended for assessment, alignment, and improving the performance of the compact range.

2.1.12 Upgrade Capability

A range utilizing the preliminary design reflector could be upgraded to perform precision pattern measurements on high frequency, high gain antennas. A new feed and partial realignment of the reflector would be required. The new feed would have higher gain, and would therefore illuminate only the central portion of the reflector. This portion would be realigned to reduce surface errors. Measurement errors of both theodolite and photogrammetric techniques are proportional to the size of the object being measured, so higher alignment accuracies would be possible over the central area. The panels themselves would be manufactured with a 0.001-0.002 inch RMS tolerance. The central panels are better protected from direct insolation, and therefore thermal deformation, than the

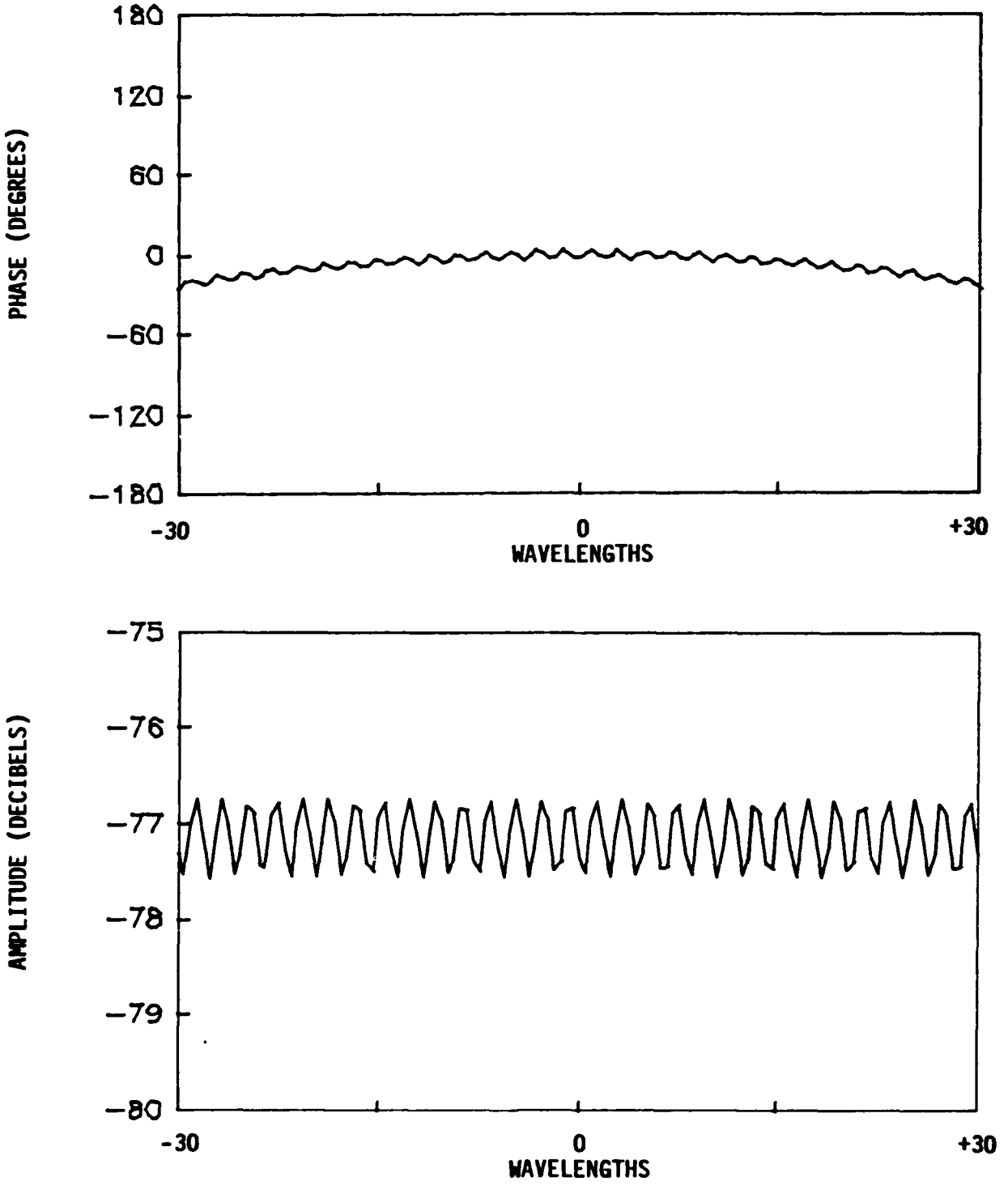


FIGURE 8. VERTICAL CUT OF QUIET ZONE FIELD

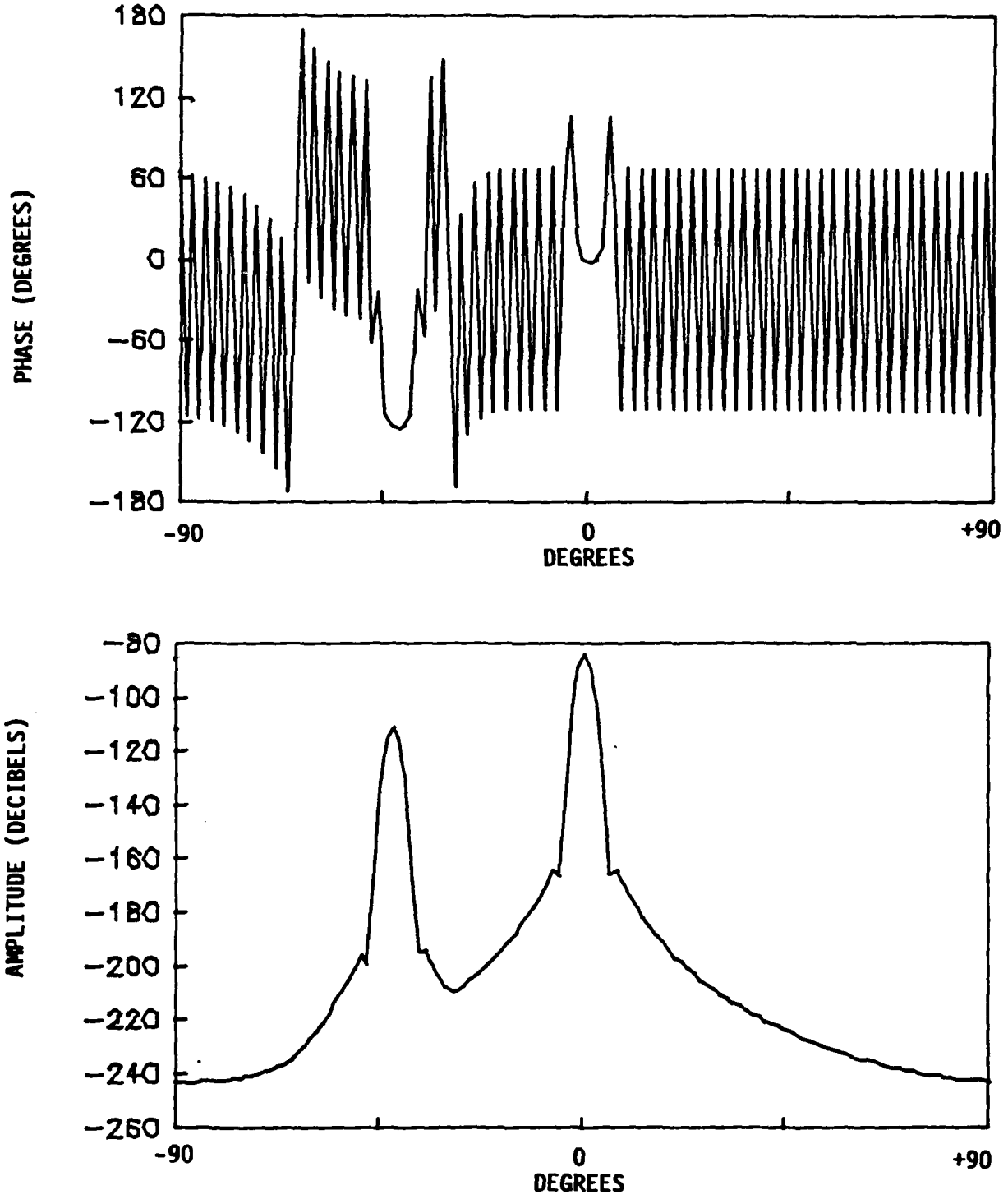


FIGURE 9. PLANE WAVE SPECTRAL COMPONENTS OF QUIET ZONE FIELD

peripheral panels. The mounting stiffness for the central panels would be higher, reducing wind deflections. The overall result would be a reflector with negligible edge effects (since the edge would not be illuminated) and a surface error of about 0.005 inch RMS over the illuminated zone (0.001-0.002 if only one panel is illuminated). Note that using a high gain feed and testing a high gain antenna resolves the high frequency transmitter power problem.

2.2 Mechanical Preliminary Design

2.2.1 Introduction

The following section addresses the feasibility of the primary design concept. Information was developed by GTRI, working with several antenna manufacturers, most notably, ESSCO.

The reflector is a fixed 70 foot diameter, high precision, offset paraboloid, mounted outdoors, without weather protection. The focal length is 110 feet. The reflector surface is made up of 110 precision formed aluminum panels, shaped as shown in Figure 1. This geometry keeps each panel within reasonable handling size, and limits the number of tools required to seven. Each of the seven rows is composed of up to 20 panels, identical except for truncations which create the reflector's serrated edge. The total surface area is about 4400 square feet.

2.2.2 Back Structure

The back structure is an aluminum space frame which holds the panels in precise alignment. The panels are joined to the back structure by adjustable attachment mechanisms. The back structure is supported from the rear, at three points, by the mount. The back structure's configuration matches the panel layout. The completed structure has radial parabolic beams joined by short beams arranged circumferentially.

2.2.3 Mount

The mount supports the back structure. A simple, massive space frame of structural steel is anchored in reinforced concrete pads.

2.2.4 Surface Accuracy

The tolerance of the 56 foot diameter central area is 0.010 inch RMS maximum. The tolerance of the zone bounded by 56 foot and 70 foot circles is 0.060 inch RMS. The tolerance of the zone outside the 70 foot circle is 0.125 inch RMS. These tolerances are referenced to the calculated best fit paraboloid defined by measured points in the 56 foot diameter central area. Measurements are made on the fully assembled and aligned reflector, under optimum conditions (no wind, night time, low rate of temperature change).

2.2.5 Panels

ESSCO has proposed to manufacture all the panels to a surface tolerance of 0.001-0.002 RMS. This high accuracy would add little to panel cost, while creating some room in the error budget for alignment, thermal, and wind errors. Most importantly, under the best ambient conditions the surface tolerance, limited only by panel and alignment accuracy, would be much better than 0.010 RMS.

ESSCO panels consist of a thin surface sheet that is bonded to and supported by an array of C-shaped grillage members. No surface rivets are used and all components are made, typically, from 0.040 inch thick aluminum. The panel is assembled on a precision male mold using a vacuum hold-down system during bond cure. Surface deflections under various loading conditions are controlled by varying surface sheet and grillage member thickness, grillage depth and transverse grillage spacing. Typical reflector panel size is 10-12 feet long by 3-4 feet wide.

2.2.6 Alignment and Final Inspection

The mount and back structure are assembled and adjusted to the required geometry, measurements being made with a dual theodolite coordinate measuring system. Each panel attachment point is adjusted to its proper, precalculated position. The panels are installed, with an optical target (small stick-on disc) over each attachment point. Final adjustments are made using the dual theodolite system, during a period of optimum thermal stability (overcast day or night, stable temperature). The central reflector zone alignment accuracy is expected to be better than .005 RMS. Photogrammetric studies, under various environmental conditions, confirm the accuracy of the final adjustment and reveal the magnitude of wind and thermally induced deformations.

2.2.7 Environmental Requirements

The reflector is to be erected in the Arizona desert, south of Tucson, at 31.5° north latitude, facing true north. A radome over the reflector would cause high frequency reflection problems, while enclosing the entire range would require a huge building and vast quantities of radar absorber. The reflector is therefore unprotected.

2.2.7.1 Wind

The reflector assembly is designed to withstand a 100 MPH wind from any direction without damage. Reflector surface panels are designed for maximum elastic deflections of 0.020 inch, relative to the panel support points, when loaded by a 20 MPH wind. The reflector back structure is designed for maximum panel support point deflections relative to the mount, when loaded by a 20 MPH wind, as listed below:

Inside 56 foot diameter central circle - 0.020 inch

Between 56 and 70 foot circles - 0.125 inch

Outside 70 foot circle - 0.250 inch

2.2.7.2 Temperature

The ambient temperature range is approximately 10-110°F, with maximum diurnal swings of 40°F. The reflector must withstand these conditions without damage or degradation.

2.2.8 Thermal Design

Control of thermal deflections is achieved by using one material (aluminum) in the reflector structure, and by limiting temperature differences in the structure. To the extent that temperature differences can be eliminated, thermally induced stresses and deviations from the parabolic shape will be eliminated. Temperature differences may arise from several sources:

a. Insolation, or heating by direct or indirect radiation from the sun.

b. Ambient temperature spatial variations.

c. Ambient temperature changes, with various structural members lagging by different amounts.

d. Radiation cooling of the reflector face at night. The shrouded back structure cools more slowly.

The measures discussed below limit temperature differences.

The reflector faces true north. The geometry of the offset feed reflector resembles a slightly dished circular plate, tilted 10° down from vertical. The sun will seldom strike the reflector face directly. It will never touch the face between the autumnal and vernal equinoxes. On August or April 21, the sun strikes the edges of the dish face with glancing rays for about 1.5 hours at either end of the day. On the summer solstice, the time of illumination reaches its maximum of three hours.

The back of the back structure is shrouded by non-structural sheet metal with insulation. This shades the back structure. Normally, then, neither the reflector face nor the back structure will receive direct sun.

The area around the reflector is planted with grass, which is watered and maintained. The grass, by its optical properties and transpiration, limits ground temperature and reflected solar radiation.

The reflector surface finish is selected for high reflectivity and low emissivity. This reduces the thermal load from direct and reflected solar radiation, and reduces the rate at which the reflector face cools by reradiation at night.

Each member of the back structure is sized to have a ratio of exposed surface area to mass similar to that of the reflector panels. The result is a structure which uniformly lags the changing ambient temperature.

The back side of the back structure is sheathed with sheet aluminum, with a layer of thermal insulation between the sheath and the inner space. The inner space is well ventilated.

The mount interfaces with the back structure at three points, approximating a 40 foot equilateral triangle with the center of the reflector at its centroid. The center point of the triangle is down. The interface between the mount and back structure is designed so differential expansion will not generate large stresses.

There are no expansion gaps between the panels. The face and back structure expand and contract together. The shroud on the back of the back structure is attached to allow differential expansion. The mount/back structure interface also allows differential expansion, by use of controlled stiffness joints.

2.2.9 Cost, Vendor Responses, Accuracy and Size

Vendor responses to the Request for Preliminary Proposal and Cost Estimate were evaluated to produce ballpark costs and performance/cost tradeoffs for the reflector.

ESSCO and Vertex were queried on the relationship between reflector surface accuracy and price. ESSCO said that relaxing the .010 RMS tolerance would allow some savings on panel inspection and alignment, but would not alter their manufacturing process. Vertex estimated that going from .010 to .030 RMS could save $50,000, while going from .010 to .060 RMS could save $150,000. The high frequency limit of the reflector is inversely proportional to the surface error. If a 0.010 RMS reflector provided acceptable performance at 150 GHz, 0.060 RMS would be good only to 24 GHz. Reducing surface accuracy is an ineffective cost control measure which greatly compromises performance.

Achieving surface accuracy much better than 0.010 RMS will be extremely difficult and expensive. Alignment errors, wind and thermal distortions are the most intractable problems. An air conditioned radome would be needed to significantly reduce thermal and wind distortions. An elaborate alignment procedure involving highly redundant photogrammetric studies and adjustments of calibrated panel mount mechanisms could reduce alignment errors.

Reflector price will be proportional to the 2 to 2.5 power of reflector diameter. The following table assumes 2.5 power scaling.

Diameter (feet)	Relative Price (%)
60	68
65	83
70	100
75	119
80	140

2.3 Dual Crossed Parabolic Cylinder (DCPC) Concept

2.3.1 Introduction

GTRI considered the DCPC reflector, Figure 10, and rejected it in favor of the offset fed paraboloid reflector. The performance of the two reflectors should be quite similar, provided that the focal lengths and edge treatments are similar, and that the surface error of each DCPC reflector is 71% of the single paraboloid error. The DCPC concept was rejected on surface error and cost grounds.

2.3.2 Surface Errors

The singly curved reflectors of the DCPC range cannot be constructed significantly more accurately than the doubly curved reflector of the single paraboloid range. ESSCO has built five doubly curved reflectors, ranging from 7 to 13.7 meters in diameter, with aggregate surface panel errors of .0016 to .00088 RMS. Alignment and wind errors, much larger than these panel errors, would be identical for either concept. Thermally induced errors, however, would be much worse for the DCPC reflectors. The single paraboloid is protected from direct solar radiation by its north facing orientation. It is impossible to face both DCPC reflectors north, so one or both of them will suffer major thermal distortions. For comparable performance the DCPC reflectors need better surface accuracy, yet will achieve worse. The single paraboloid should therefore perform better.

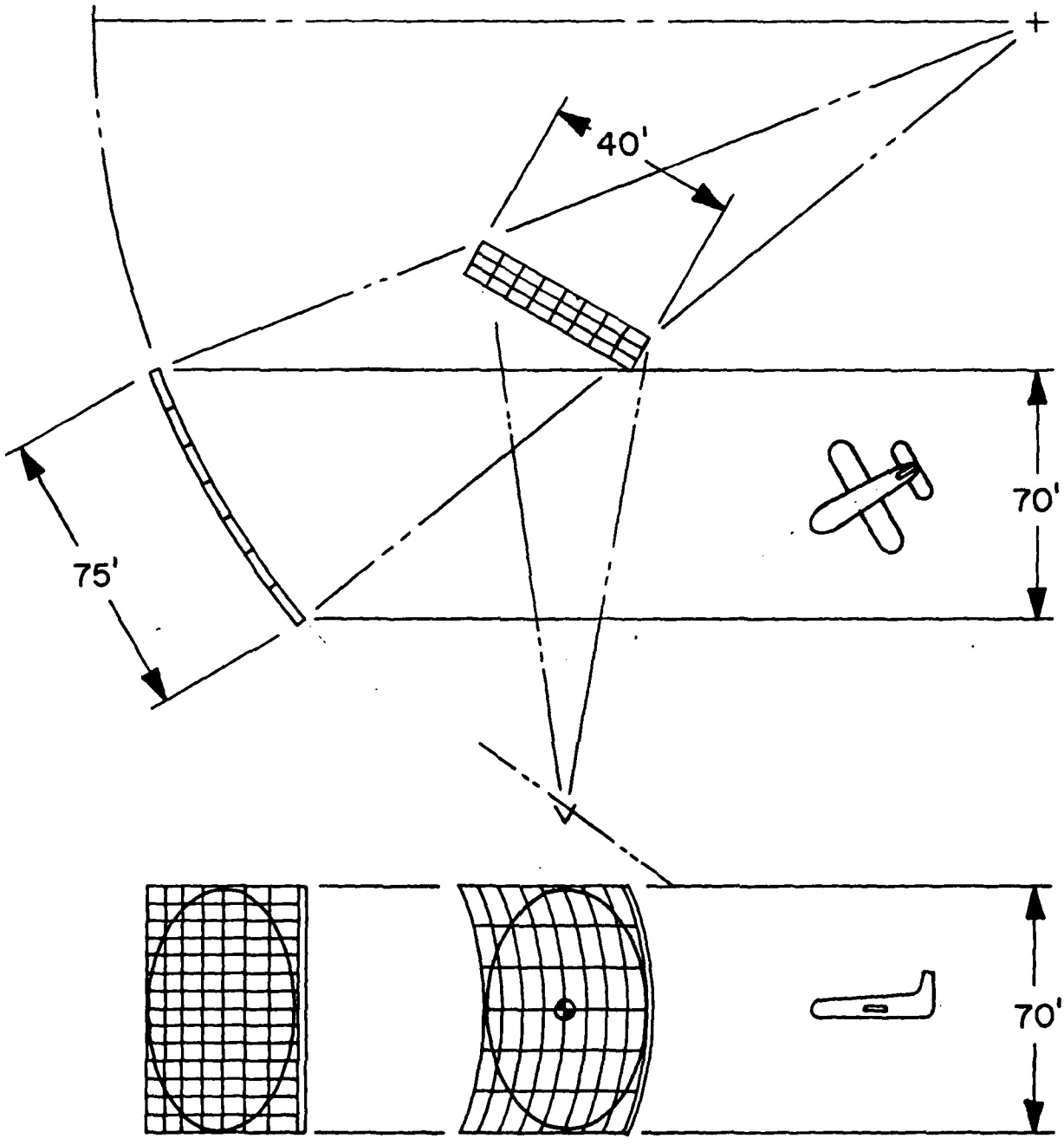


Figure 10. Dual Crossed Parabolic Cylinder Reflector

2.3.3 Cost

Singly curved reflectors are frequently assumed to be much cheaper than doubly curved ones. This assumption is not valid for large, very accurate, outdoor reflectors. Several categories of expenses are discussed below and tabulated in Table 5. The total cost of a single paraboloid is assumed to be unity, and all other figures are in relation to that. GTRI estimates that a DCPC reflector would be 1.5 times as expensive as an offset paraboloid.

Design and Management

Each singly curved reflector is simpler than the paraboloid, but since antenna manufacturers have much less experience with them, some manufacturing research would be required. The design and management cost for each singly curved reflector is assumed to be 75% of that for the paraboloid.

Tooling

High accuracy panels of any shape must be manufactured on precision tooling. The tooling is machined under numerical control, hand finished, and inspected. ESSCO believes that large tools for either type reflector panel would cost about the same. The single paraboloid would require seven tools, while the DCPC reflector would require ten.

Panel Manufacture and Inspection

ESSCO says that panel manufacturing and inspection costs are proportional to area, and would be about the same for doubly or singly curved panels. Since the techniques for fabricating doubly curved panels are so well-established, singly curved panels are treated as special cases of doubly curved panels. The DCPC reflectors have 1.66 times the area of the paraboloid.

Backstructure Fabrication

All the backstructures would be of equal height. The costs are assumed to be proportional to reflector area, with the singly curved reflector cost per square foot 70% that of the paraboloid. This accounts for the relative simplicity of the singly curved structure.

Mount and Foundation

Total panel weight and wind load vary with area, so mount costs are assumed to do likewise.

Packaging and Shipping, Assembly and Alignment

These costs vary with reflector area.

TABLE 5

Relative Costs of Offset Paraboloid and DCPC Reflectors

CATEGORY	COST[1]	
	PARABOLOID	DCPC[2]
Design and Management	0.15	0.23
Tooling	0.18	0.26
Panel Manufacture and Inspection	0.29	0.48
Backstructure Fabrication	0.19	0.22
Packaging and Shipping	0.09	0.15
Assembly and Alignment	0.08	0.13
TOTAL	1.00	1.50

Notes:

[1] - Total cost of the paraboloid is assumed to be 1.00.
[2] - Dual crossed parabolic cylinders.

APPENDICES

DEPARTMENT OF THE ARMY
U.S. ARMY COMMUNICATIONS COMMAND
ACQUISITION MANAGEMENT & CONTRACTING ACTIVITY
FORT HUACHUCA, ARIZONA
Post Office Box 748

July 31, 1984

Automation and Research and
Development Division

GEORGIA TECH RESEARCH INSTITUTE
Administration Building (ATTN: Duane Hutchison)
Georgia Institute of Technology
Atlanta, Georgia 30332

Gentlemen:

The Government is interested in including a Preliminary Design Study in Contract No. DAEA18-84-C-0050. The work is to include the following:

a. Analysis of size, fabrication and installation techniques, materials and tolerances required for the reflector.

b. Analysis of frequency range and quiet zone expected of the reflector.

c. Analysis of environmental effects on the compact range.

d. Analysis of defraction techniques, feed configuration, data averaging techniques and amplitude distribution for given frequencies, feed horn designs, and surface tolerances.

e. Cost analysis.

f. Results of above analysis will be presented in a study report. The report will be prepared as a methodology investigation final report and will be formatted in accordance with TECOM Regulation 70-12, Appendix D.

g. This effort will be completed in 6 months.

Appendix A

Letter of Direction

Please provide a Cost Proposal to accomplish this effort by 10 August 1984. If there are any questions, contact Lyn Raymond at (602) 538-1036.

Sincerely,

Billy Merrell

Billy Merrell
Contracting Officer

Appendix B

PRELIMINARY TECHNICAL SPECIFICATION

Compact Range Reflector
Project A-3922-007

1. Introduction

The Georgia Tech Research Institute (GTRI) is currently generating a preliminary design and cost estimate for a compact radar range. The reflector will be a fixed 70 foot diameter, high precision, offset paraboloid, mounted outdoors, without weather protection. This specification defines the requirements and design concept for the reflector. A fabrication contract award in late 1986 or 1987 is anticipated.

2. Purpose of Range

The compact range will be used primarily to measure radiation patterns of low gain antennas mounted on vehicles and aircraft. The frequency range is 6-150 GHz.

Compact ranges use a large reflector to generate a plane wave near the reflector. This plane wave is equivalent to that in the far-field of a smaller reflector. One may therefore accomplish far-field range type measurements at close range.

3. Reflector Requirements

Refer to Drawing A3922-702-M4, "Reflector, Offset Fed, Concept for Panel and Edge Configuration."

3.1 Geometry

The reflective surface is an offset fed paraboloid of 110 foot focal length. The front view (looking up range) shows a 70 foot diameter circle, centered 38.5 feet above the paraboloid's axis, filled by the reflector.

3.2 Edge Treatment

Special edge treatment is required to control diffraction effects. Well designed

serrations prevent excessive amplitude ripple in the "quiet zone." The particular pattern illustrated is not the only acceptable one. The design requirements are twofold. First, each edge must be at least two feet long. Second, in the front view, a perpendicular line through the center of each edge must fall outside of a 50 foot diameter "quiet zone" centered on the reflector. The construction of such a perpendicular is illustrated.

3.3 Surface Quality

3.3.1 Tolerances

The tolerance of the 56 foot diameter central area shall be 0.010 inch RMS maximum. The tolerance of the zone bounded by 56 foot and 70 foot circles shall be 0.060 inch RMS. The tolerance of the zone outside the 70 foot circle shall be 0.125 inch RMS. These tolerances shall be referenced to the calculated best fit paraboloid defined by measured points in the 56 foot diameter central area. Measurements are to be made on the fully assembled and aligned reflector, under optimum conditions (no wind, night time, low rate of temperature change).

3.3.2 Panel Gaps and Rivets

If there are gaps between adjacent panels, the area of such gaps must not exceed 0.05% of the total reflector area. Electrical continuity across the gaps is not required. Gap treatments must be environmentally stable. For example, metallized tape which would peel in two years would not be acceptable.

Rivet heads must be flush with the reflecting surface.

3.4 Environmental Requirements

The reflector will be erected in the Arizona desert, South of Tucson, at 31.5° North latitude. It will face true North. There will be no enclosure or radome for weather protection.

3.4.1 Temperature

The ambient temperature range is approximately 10-110°F, with maximum diurnal swings of 40°F. The reflector must withstand these conditions without damage or degradation.

Surface accuracy degradation due to thermal and moisture effects shall be minimized. Neither radomes nor active temperature control are permissible. Encouraged techniques include, but are not limited to, reflector orientation, shading, insulation, use of materials with similar thermal coefficients of expansion, careful design of connections between structures with different coefficients, control of thermal time constants of structural elements, ground cover plantings, and finish choice. Exotic, controlled expansion materials, such as graphite-epoxy composites, will be considered on a cost vs. performance basis. The goal is for the reflector to retain its paraboloidal shape and surface tolerance over a wide range of temperatures, and during changes in ambient temperature. Partial failure to meet this goal will restrict use of the reflector at high frequencies to periods of optimum thermal stability, thus reducing the productivity of the range.

3.4.2 Wind

The reflector assembly, including the panels, shall be designed to withstand a 100 MPH wind from any direction without damage.

Reflector surface panels shall be designed for maximum elastic deflections of 0.020 inch, relative to the panel support points, when loaded by a 20 MPH wind. The reflector back structure shall be designed for maximum panel support point deflections relative to the mount, when loaded by a 20 MPH wind, as listed below:

Inside 56 foot diameter central circle - 0.020 inch
Between 56 and 70 foot circles - 0.125 inch
Outside 70 foot circle - 0.250 inch

3.4.3 Corrosion, Erosion, and UV Radiation

Materials and finishes shall be chosen to resist atmospheric corrosion, erosion by wind

borne particles, and UV solar radiation. Selection shall conform to the requirements of MIL-STD-889B, 7 July 1976 or latest revision, "Military Standard, Dissimilar Metals." The corrosion environment is mild. There is precipitation, but the climate is generally dry. There is no salt or strongly alkaline material in the air.

4. Design Concept

This section describes GTRI's current concept for meeting the requirements of Section 3. Alternative approaches are acceptable and encouraged.

4.1 Panels

The reflector surface is made up of many precision formed aluminum panels, shaped as shown in Drawing A3922-702-M4. These panels are stretch or draw formed, trimmed, and stiffened on precision tooling. Stiffening ribs are epoxy bonded to the back of the panels. Tooling is NC machined, or generated by sweeping plaster or epoxy with multiple templates. Attachment points are installed at precise locations in the panel back corners.

Panels forming the reflector edge are truncated in various ways to create the required serrated edge. This work is done manually. A considerable loss of surface precision is permissible for these panels.

4.2 Back Structure

The back structure is an aluminum space frame which holds the panels in precise alignment. The panels are joined to the back structure by adjustable attachment mechanisms. The back structure is supported from the rear, at three points, by the mount.

The back structure's configuration matches the panel layout. The completed structure has radial parabolic trusses joined by short, straight trusses arranged circumferentially (trusses are radially or circumferentially oriented about the axis of the paraboloid). The structure could be assembled from long, parabolic trusses and short circumferential trusses. Another approach would use modules, shaped like the panels. Each module would have precision machined interfaces for joining to adjacent modules. This approach would simplify on-site assembly by reducing the size of the

largest elements. However, the resulting structure would have many more members.

Each member of the back structure is sized to have a ratio of exposed surface area to mass similar to that of the reflector panels. The result will be a structure which uniformly lags the changing ambient temperature.

The back side of the back structure is sheathed with sheet aluminum, with a layer of thermal insulation between the sheath and the inner space. The inner space is well ventilated.

The mount interfaces with the back structure at three points, approximating a 40 foot equilateral triangle with the center of the reflector at its centroid. The center point of the triangle is down. The interface between the mount and back structure is designed so differential expansion will not generate large stresses.

4.3 Mount

The mount supports the back structure. The mount consists of a simple, massive space frame of structural steel, anchored in reinforced concrete pads. It is strong and stiff enough to permit the reflector assembly to meet the 100 MPH survival requirement.

4.4 Thermal Considerations

Control of thermal deflections is achieved by using one material (aluminum) in the reflector structure, and by limiting temperature differences in the structure. To the extent that temperature differences can be eliminated, thermally induced stresses and deviations from the parabolic shape will be eliminated. Temperature differences may arise from several sources:

a. Insolation, or heating by direct or indirect radiation from the sun.

b. Ambient temperature variations in space, for example, high temperatures near the ground.

c. Ambient temperature time variations, with various structural members lagging by different amounts.

d. Radiation cooling of the reflector face at night. The shrouded back structure cools more slowly.

The measures discussed in the following paragraphs limit temperature differences.

The reflector faces true North. The geometry of the offset feed reflector resembles a slightly dished circular plate, tilted 10° down from vertical. The sun will seldom strike the reflector face directly. It will never touch the face between the autumnal and vernal equinoxes. On August or April 21, the sun will strike the edges of the dish face with glancing rays for about 1.5 hours at either end of the day. On the summer solstice, the time of illumination reaches its maximum of three hours.

The back of the back structue is shrouded by non-structural sheet metal with insulation. This shades the back structure. Normally, then, neither the reflector face nor the back structure will receive direct sun.

The area around the reflector is planted with grass, which is watered and maintained. The grass, by its optical properties and transpiration, limits ground temperature and reflected solar radiation.

The reflector surface finish is selected for high reflectivity and low emissivity. This reduces the thermal load from direct and reflected solar radiation, and reduces the rate at which the reflector face cools by reradiation at night.

The thermal time constants of the reflector face panels and back structure members are similar, so all elements lag ambient temperature variations together. The time constant of a simple thermal system is:

$$T = \frac{mc}{hA} \quad \text{where}$$

T = time constant
m = element mass
c = heat capacity
h = surface heat transfer coefficient
A = heat transfer area

Since the reflector surface and back structure are aluminum, c is constant. The interior of the back structure is well ventilated, so the interior and ambient temperatures are similar. The heat transfer coefficient for the face is somewhat higher than for the back structure, because of wind and vertical orientation. Therefore, T may be held constant by holding m/A approximately constant. In other words, the ratio of weight to surface area for back structure elements should be somewhat less than the ratio for the face panels, to compensate for differing surface heat transfer coefficients. This is accomplished by fabricating the back structure from open section shapes (angles, channels, Z sections) of appropriate thickness.

There are no expansion gaps between the panels. The face and back structure expand and contract together. The shroud on the back of the back structure is attached to allow differential expansion. The mount/back structure interface also allows differential expansion, by use of controlled stiffness flexures.

4.5 Alignment and Final Inspection

The mount and back structure are assembled and adjusted to the required geometry, measurements being made with a dual theodolite coordinate measuring system. Each panel attachment point is adjusted to its proper, precalculated position. The panels are installed, with an optical target (small stick-on disc) over each attachment point. Final adjustments are made using the dual theodolite system, during a period of optimum thermal stability (overcast day, nightime, stable temperature).

Several photogrammetric studies, under various environmental conditions, confirm the accuracy of the final adjustment and reveal the magnitude of wind and thermally induced deformations.

Appendix C

REQUEST FOR PRELIMINARY PROPOSAL AND COST ESTIMATE
Project A-3922-007

1. Purpose of Request

The Georgia Tech Research Institute (GTRI) is seeking technical input and budgetary pricing information for the reflector described in "Preliminary Technical Specification, Compact Range Reflector." This information will be used to generate a Final Technical Specification, and to arrange funding for a reflector fabrication contract. A contract award date in late 1986 or 1987 is anticipated.

2. Preliminary Proposal

GTRI solicits a Preliminary Proposal solely to guide development of a Final Technical Specification. A simple presentation, perhaps in letter format, is perfectly adequate. The information described below is requested.

2.1 Requirements Feasibility

Are the surface tolerance specifications achievable by techniques within your experience? Do you have any experience indicating the level of surface thermal stability achievable by the techniques described in the Preliminary Technical Specification?

2.2 Design Concept

How do you propose to approach the requirements of the Preliminary Specification? This discussion should generally parallel the "Design Concept" section of the Specification, and may reference that section.

3. Preliminary Cost Estimate

The budgetary cost estimate should assume a contract award at the end of 1986. Costs should be broken down as follows:

a. Reflector Design

b. Panel Manufacture and Inspection

c. Back Structure Fabrication

d. Shipping (including Mount)

e. Mount (including Foundation and Installation)

f. Reflector Assembly and Installation (inlcuding alignment and all on-site work except that included under "Mount")

GTRI will arrange for final inspection.

GEORGIA TECH RESEARCH INSTITUTE
GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA 30332

GTRI

13 May 1986

CMDR, USAEPG
Attn: STEEP-MT-EF
Mr. Richard W. Moody
Ft. Huachuca, Arizona 85613

Reference: Phone call of 29 April 1986

Dear Mr. Moody:

Here are our responses to the following questions:

Q. Will there be procedures to periodically check the reflector alignment?

A. I do not believe routine alignment checks are needed. A check 12 months after initial alignment, plus checks when special circumstances (questionable performance, possible damage) dictate, should be adequate. The procedure would be the same as that used to confirm the initial alignment, i.e. a photogrammetric survey. If the photogrammetric targets are left in place after initial alignment verification, a repeat survey should cause virtually no downtime. Results would be available in one week. The cost would be $5000-$10,000. GSI, in Melbourne, Florida, can provide this service.

Q. How often (estimate) would realignment be required and how long would it take?

A. There is nothing inherent in the preliminary design which should require periodic realignment. Hopefully, we should be able to align the reflector just once, occasionally checking to verify that alignment remained satisfactory. If required, realignment would be a major job. There will be about 100 panels, each with six adjustable mount points. If all needed adjustment (unlikely), the effort might take 100 hours, with a crew of three. It might be necessary to work at night to maximize accuracy.

Q. Will there be procedures to monitor the purity and uniformity of the quiet zone during operation?

A. No. To monitor the purity and uniformity of the quiet zone requires a totally different set up than that required for normal operation.

Q. What will be required to monitor the quiet zone and how much time will be required?

A. The monitoring of the quiet zone will require a field probe with enough movement to move over the entire zone. The probe will have to be set up and

aligned. The measured data will be processed to show the uniformity of the zone. This effort would take a crew of two or three approximately four days to obtain the measurements.

If you need any additional information on these questions, please do not hesitate to give me a call.

Sincerely,

Henry P. Cotten
Project Director - A-3922

dmr

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