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DESIGN OF A FACILITY FOR MEASURING ANTENNA PATTERNS AND RADAR CROSS SECTIONS

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Winnipeg, Manitoba

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DEFENCE RESEARCH ESTABLISHMENT SUFFIELD, RALSTON, ALBERTA

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DESIGN OF A FACILITY FOR MEASURING ANTENNA PATTERNS AND RADAR CROSS-SECTIONS

FINAL REPORT
FOR

DEFENCE RESEARCH ESTABLISHMENT
SUFFIELD ALBERTA

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BY

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1 REPORT REVIEW

1.1 INTRODUCTION

This report presents results of a study towards the design of a facility for measuring the antenna radiation pattern of antennas and the radar cross-section (RCS) of targets. The report is set out in five sections along with an appendix. This section describes the report organization and presents an executive summary. Section 2 lists the desired system requirements, presents the design strategy and describes the basic elements of the designed facility, the anechoic chamber, the needed building and required instrumentation and positioning equipment. Also included are the methods to verify the chamber performance and establish confidence in the accuracy of the RCS measurements. The section concludes with a costing of the different possible design options for the facility.

In section 3 the background information for the instrumention design is given and then it deals with the various candidate types of RCS radar instruments and their features and concludes with a development of relevent range and instrumentation design equations. Section 4 presents two basic instrumentaion system designs. One design, base option 1, is capable of indoor RCS measurements and indoor/outdoor antenna measurements over the frequency range 3 to 18 GHz and is expandable to both lower and higher frequency ranges through a set of sub-options. The second design, base option 2, allows indoor and outdoor measurements of both antenna patterns and RCS target values. These instrumentation options are fully described, representative components are provided along with costs and an estimate of system performance is included.

The details of the anechoic chamber design are presented in section 5. This section begins with a discussion of chamber types then presents results of a computer evaluation of two candidate anechoic chamber systems on which the final chamber selection is made. Amplitude and phase distributions in the chamber quiet zone and reflectivity levels over a wide frequency range are included. Appendix A to section 5 reviews th basics of chamber design with topics on absorber material, chamber types and performance evaluation procedures.

1.2 EXECUTIVE SUMMARY

1. A 20 ft high, 30 ft wide and 30 ft long anechoic chamber lined with 24 inch thick absorber is selected for the facility. One end of the chamber is 'openable' through a foam weather wall to permit indoor/outdoor type measurements.
2. The building to house the chamber is recommended to be a 24 ft high, 32 ft wide and 50 ft long structure. The end of the building containing the anechoic chamber is equiped with a weather door to allow the chamber to be 'opened'.
3. A Scientific Atlanta positioner system is selected as the representative system for the antenna and target positioning.
4. Items 1, 2 and 3 above are basic to all the instrumentation systems designed and form a base cost for the facility totalling $483,924.00.

5. Two basic instrumentation systems are described in the report. The first system is the lowest cost system which can meet the fundamental desired measurement requirements. It allows indoor RCS measurements and indoor/outdoor antenna measurements, both limited to the frequency range 3 to 18 GHz. The cost of this system, base option 1, is $202,713.00. (The base cost from item 4 must be added to obtain the total cost.)

6. A number of instrumentation and software sub-options can be added to base option 1 to expand its capabilities and frequency range.

7. The second instrumentaion system, base option 2, addresses adding an outdoor RCS measurement capability to the facility. The total cost of the base option 2 complete facility is $1,145,167.00. (Much of the instrumentation forming base option 1 is common to base option 2.)

2 GENERAL FACILITIES DESIGN

2.1 INTRODUCTION

2.1.1 DESIGN GOALS

The desired performance capabilities of the combined antenna and RCS measurement facility are summarized as follows:

1. The facility should allow antenna pattern measurements over the frequency range 0.5 to 40 GHz.
2. Allow measurement of the composite antenna pattern of an array of antennas mounted on a vehicle with size contained within a 5 meter sphere.
3. The facility should be capable of making RCS measurements on the frequency range 1 to 40 GHz. The initially designed system may cover a smaller frequency range but with allowance for progressive future expansion to greater frequency coverage.
4. Be capable of determining the RCS of a class of targets up to 0.5 m overall extent in an indoor facility.
5. Be capable of determining the RCS of a class of objects contained within a sphere of 5 meter diameter in a combination indoor-outdoor facility.
6. Allow bistatic (up to 30 degrees) RCS measurements on a class of objects up to 0.5 meter in overall extent in an indoor facility.
7. The RCS is to be measured as a function of both frequency and target position (orientation).

2.1.2 DESIGN STRATEGY

Since the overall facility needed to perform RCS measurements is much more complex and demanding on instrumentation as compared to that required for antenna measurements, the design carried out in this report is primarily focused on satisfying the goals for RCS measurments. However, at all stages of the design process the dual role of the facility is considered when selecting components of the facility such as the anechoic chamber or range layout or instrumentation. Generally it can be stated that if the selected system is capable of RCS measurements over a specified frequency range on a class of target sizes then the system can be readily re-configured to permit antenna measurements over the same frequency range on a class of antennas of size similar to the targets. Therefore, no detailed antenna system design is presented in this study although the RCS systems presented are capable of being re-configured to satisfy the antenna measurement goals.

In regard to bistatic measurements it was found in site visits to the facilities at Ohio State University and the Georgia Technical University that systems capable of this type of measurement are rare, complex and costly. Limited bistatic measurements could be undertaken in an indoor chamber using the monostatic setup but the effects of offsetting the source and receive antennas off the chamber axis would have to be assessed. Bistatic measurements were considered beyond the scope of this study and are not addressed in the presented designs.

One important underlying requirement is that the range is to be low cost. Since many of the above desired capabilities are not consistent with a low cost facility, a hierarchy of subsets of the above listed capabilities will be considered each chosen in a manner to allow future expansion to an RCS facility which has the full set of capabilities. An instrumentation system will be designed for each subset of capabilities, called an equipment option. The instrumentation design and equipment options are presented in detail in report section 4. These equipment options are selected on a basis which allows the same instruments to be used for antenna pattern measurements with minimal hardware additions or modifications.

This criteria somewhat limits the choice for RCS instrumentation although it minimizes system cost by sharing instruments between the two range functions. The strategy of the instrumentation design will be to choose a combination of equipment able to first meet the basic subset of specified capabilities while secondly minimizing cost at the expense of standard RCS performance measures. The standard performance measures taken into account are RCS sensitivity, dynamic range, measurement time and accuracy. Furthermore, ease of operation was given some consideration. Some equipment options possess additional features including possible future expansion beyond the specified capabilities and these will be noted as additional considerations.

The full 1 to 40 GHz desired operating bandwidth of the RCS range is divided into three sub-ranges for the purposes of this report; 1 to 2 GHz, 2 to 26.5 GHz and 26.5 to 40 Ghz. Each range will be described by representative frequencies of respectively, 1.0 GHz, 10.0 GHz and 40 GHz. Distinct classes of equipment and range options are suggested on the basis of their operation in one or more of the three bands. Furthermore, this division of the operating bandwidth is compatible with current literature on RCS measurements. Most of the attention will be directed towards the microwave frequency range represented by 10 GHz since it is expected that this will be the most heavily used band.

2.1.3 RANGE SIZE

A detailed discussion of range types is presented in report section 5 where an anechoic chamber size and outdoor range configuration is selected to meet the desired performance goals. The use of a compact range was briefly examined which would allow indoor measurements on both large and small targets. However, because of the large cost of such a facility it was eliminated from consideration. The selected RCS range facility is described as follows:

1. Indoor range.
   The range length needed for the specified target extent is at least 8 meters and the primary function of this range will be to measure the RCS of small targets (0.5 meter) at 1 Ghz and 10 Ghz with the potential to measure smaller targets (0.2 meters) at 40 Ghz.
2. Outdoor range.
   This range length is selected to be 1 km. The targets under test (TUT) will be of large extent (maximum of 5 meters) and measurements will be at 1 Ghz and 10 Ghz.

2.2 FACILITIES DESCRIPTION

The RCS/Antenna facility which has been designed to meet the specified measurement requirements consists of the following basic elements:

1. An electromagnetic anechoic chamber with movable end walls that can be configured for either indoor or indoor/outdoor operation of the facility.
2. A building to house the anechoic chamber, house the majority of the system instrumentation and provide operations and work space.
3. Instrumentation to perform the RCS and antenna measurements including software to process the data.
4. Turntables inside the anechoic chamber to mount test antennas and targets and a pedestal mounted polarization unit for source antenna mounting.
5. For the outdoor portion of the range, a tower for source antenna mounting in the case of antenna measurements and for RCS measurements a pylon or tower suspension system for large target mounting.

Figure 2.1 depicts the overall RCS/Antenna system which has the capability of making measurements over the frequency range 1 to 40 Gz on antennas and targets up to 4 meters in maximum dimension. Each of the elements of this system are now described in detail beginning with the anechoic chamber.

2.2.1 THE ANECHOIC CHAMBER

The design details for the proposed electromagnetic anechoic chamber are presented in section 5 of this report.

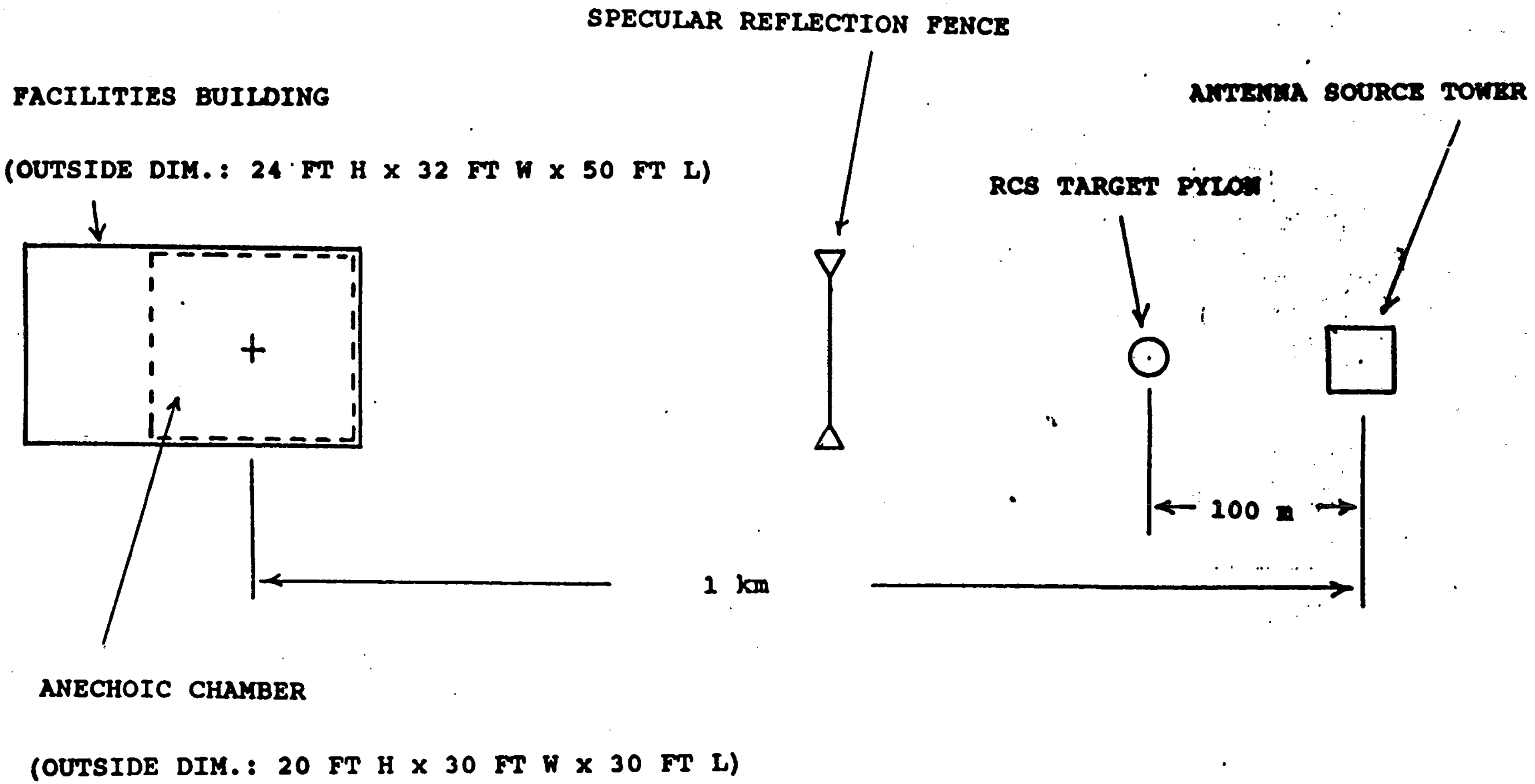


FIGURE 2.1 GENERAL RCS/ANTENNA MEASUREMENT FACILITY.

A ray tracing method was used to evaluate the reflectivity level along the axis of the chamber at a number of frequencies over the range 1 to 10 Ghz. Also, the variation of the amplitude and phase of the total field along a vertical and horizontal radius from the chamber centre for a number of points along the axis was calculated. This was done for two rectangular chamber dimensions using 1 foot thick absorber material. These results lead to the selection of a chamber with outside dimensions of 20 ft height, 30 ft width and 30 ft length. A 2 ft thick electromagnetic wave absorber lines the chamber. However, the absorber on the two ends of chamber must be mounted on movable panels so that the chamber can be configured for use as an indoor facility or an indoor/outdoor facility.

Figure 2.2 depicts the anechoic chamber setup and shows the electromagnetic transparent foam weather wall needed when the system is configured for indoor/outdoor measurements. This wall should be constructed from a low density, low loss foam of six to eight inch thickness. A wind loading study should be carried out on this foam wall to determine the safe wind conditions for operation. The absorber panels at the transparent wall end of the chamber are removed to the storage area of the building for this configuration.

The reflectivity performance of the chamber is poorest at the lowest operating frequencies, 500 Mhz for antenna measurements and 1 Ghz for RCS measurements. At 500 Mhz (60 cm wavelength) the 2 ft (61 cm) thick pyramidal absorber is close to 1 wavelength in thickness and presents a reflection attenuation of about -30 dB at normal incidence and about -20 dB at 50 degrees incidence.

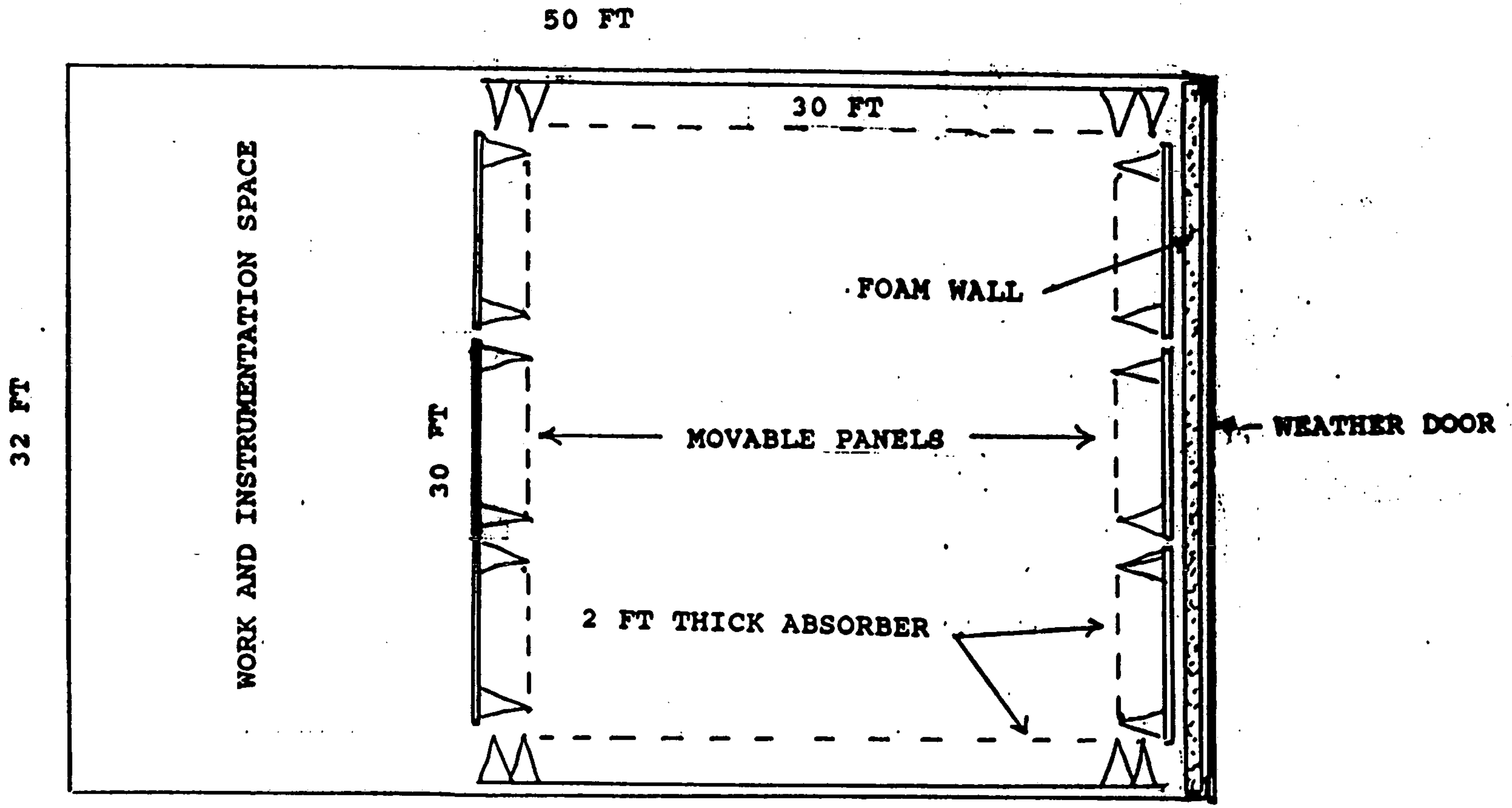


FIGURE 2.2 ANECHOIC CHAMBER GENERAL LAYOUT.

At 1 Ghz the absorber is about 2 wavelengths in thickness with normal incidence attenuation of about -40 dB and 50 degree incidence attenuation about -30 dB. The chamber is expected to perform at a reflectivity level in its quiet zone of -20 dB at 500 Mhz, -30 dB at 1 Ghz and -40 dB at 3 Ghz (6 wavelengths of absorber thickness), see [1]. The performance for frequencies above 3 Ghz will be lower than -40 dB. It should be noted that a chamber reflectivity level of -20 dB translates into a measurement uncertainty of 2 dB (±1 dB from a nominal recorded value) while a -40 dB level corresponds to an uncertainty of 0.2 dB (±0.1 dB), also see [1].

For indoor antenna measurements the chamber configuration is depicted in figure 2.3. The distance from the source antenna to the test antenna in the quiet zone is about 20 ft (6 m) so that antennas up to about 1.5 m in major dimension can be tested at 500 Mhz but no more than 15 cm diameter at 40 Ghz. This is based on the criteria that

$$D^2 = R\lambda/2 \tag{2.1}$$

where D is the antenna major dimension and R is the range length. These size restrictions generally apply to RCS targets except that measurements are taken over a band of frequencies and the range criteria applies to the highest measurement frequency.

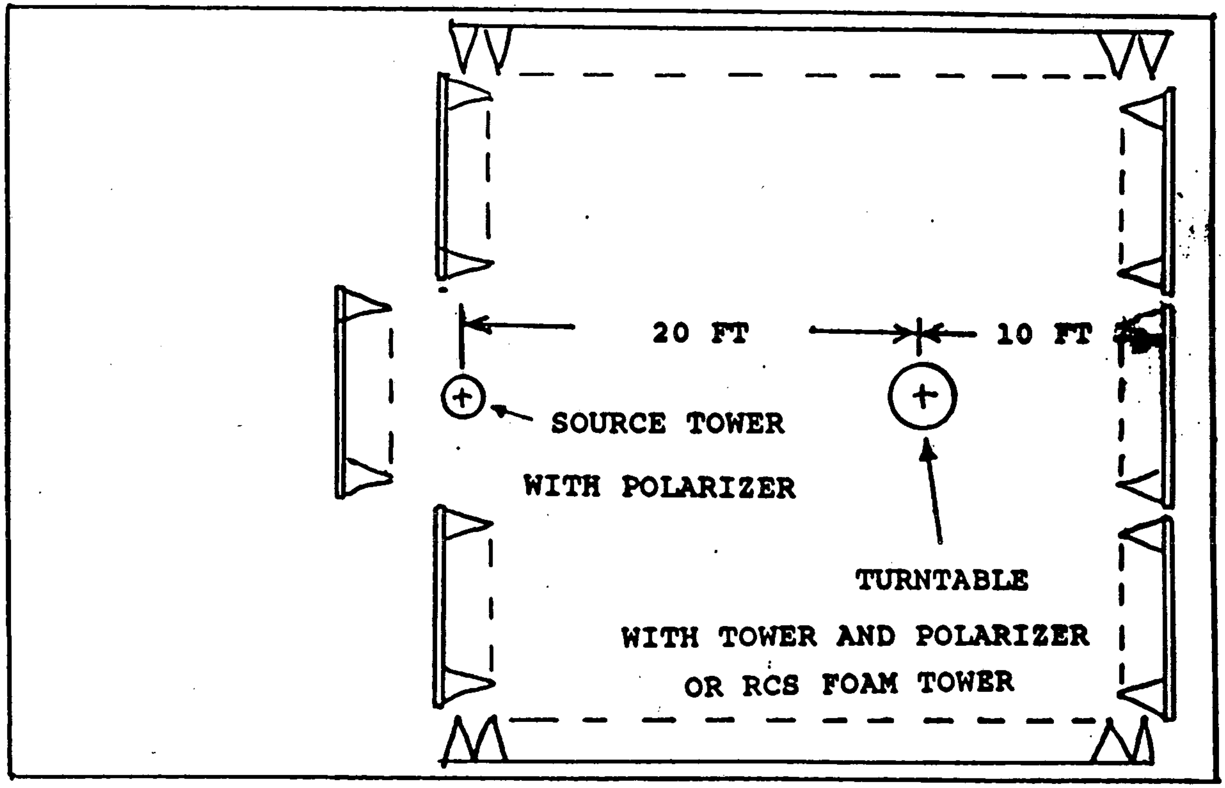


FIGURE 2.3 INDOOR RCS/ANTENNA CHAMBER CONFIGURATION.

The indoor/outdoor operation of the chamber requires that the absorber panels next to the transparent foam weather wall be moved to the work space area, the building weather door opened and the back wall absorber panels (panels adjacent to the work space area) arranged to provide maximum reflectivity attenuation. For antenna measurements the remote piloted vehicle and its antenna are mounted on the large turntable centered in the chamber. The source tower to provide plane wave illumination of the chamber is 1 km distant along the axis of the chamber. This arrangement permits the measurement of antenna structures of 4 meter maximum dimension up to a frequency of 10 Ghz. At 40 Ghz the maximum aperature size is restricted to about 2 meters.

Details of the source tower height and its relationship to a specular reflection fence which must be place about midway between the chamber and the source tower are provided in report section 5.

To perform indoor/outdoor RCS measurements the chamber is configured in exactly the same way as for antenna measurements. The transmit/receive antenna system is mounted centrally in the chamber. If separate transmit and receive antennas are used the transmit antenna can be mounted outside the facilities building to provide better isolation between it and the receive antenna. The RCS target is mounted on a pylon located about 900 meters down the chamber axis and 100 meters from the tower used for antenna measurements. Hardware gating eliminates background signals from the source tower. This RCS configuration enables measurements on targets with size and maximum measurement frequency restriction as follows: 4 meters (9.4 Ghz), 2.7 meters (20 Ghz) and 1.9 meters (40 Ghz).

If a pylon system is not used to support the target then a tower suspension system as shown in figure 2.4 is recommended for consideration. The towers of this system are located so that the hardware gating can isolate the tower returns and target/tower interactions when a gating cell of up to 8 meters is utilized.

2.2.2 FACILITIES BUILDING

In order for the laboratory building to house an anechoic chamber with outside dimensions of 20 ft height, 30 ft width and 30 ft length a building size of at least 24 ft height, 32 ft width and 50 ft length is recommended (see figure 2.2). The end portion of the building, beyond the end wall of the chamber, consists of a space of approximately 16 ft length by 32 ft width which can be used to house instrumentation, provide operator space and a work area for model assembly.

External to the building the terrain should be cleared of trees and large shrubs in the direction towards the large source tower for a clear line of sight to it and the RCS target pylon. The target pylon itself should be mounted on a small mound to provide additional elevation. As well, the foundation pad for the building should be layed so that it is elevated above the local terrain by at least 2 ft but preferably 5 ft. The landscaping on the weather door side of the building should taper off to the local terrain level fairly abruptly (in about 10 to 20 ft depending upon the pad elevation).

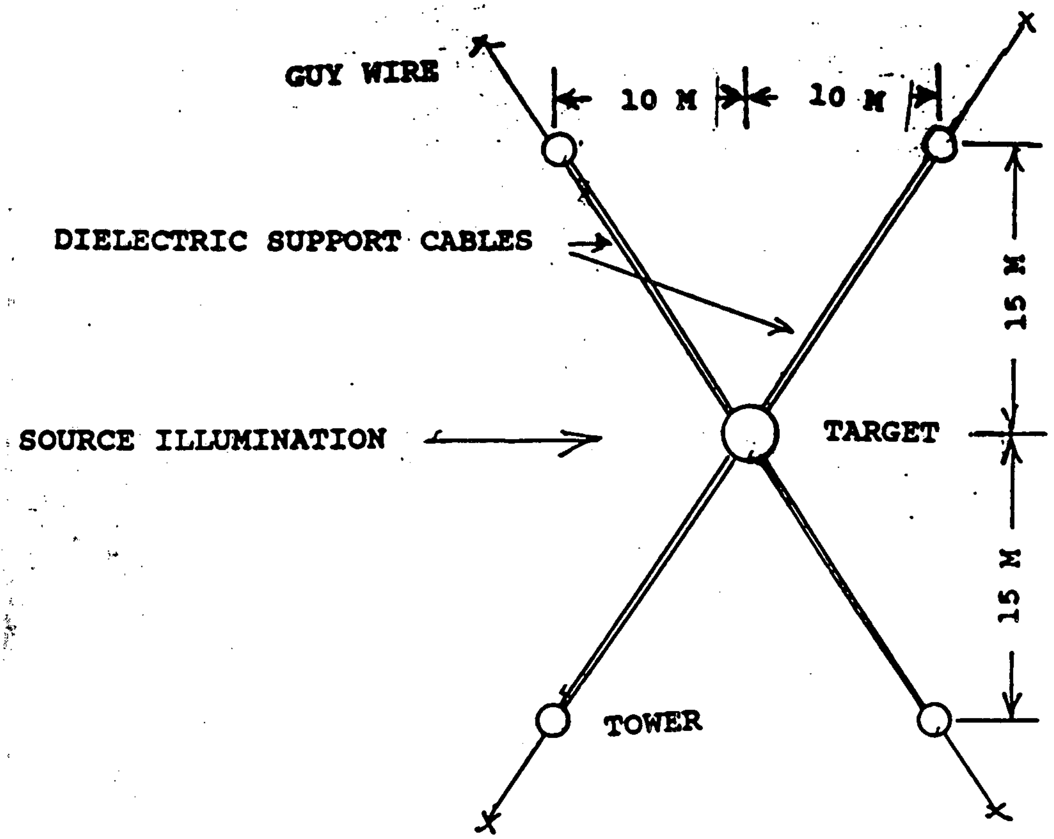


FIGURE 2.4 RCS LARGE TARGET SUSPENSION SYSTEM.

This will help to reduce ground reflections into the open chamber end as well as help to prevent snow build-up at the weather door.

A number of modular rigid frame column type structures were examined as potential candidate buildings, such as those manufactured by Armco Building Systems and Robertson Building Systems. However, these structures are generally unsuitable since the module widths are in the order of a minimum 50 ft width in order to provide a building height suitable to house a 20 ft high anechoic chamber (an external building height of at least 24 ft is needed). Therefore, it is believed that a custom built structure is the more economical solution.

2.2.3 INSTRUMENTATION

The instrumentation design is thoroughly covered in report sections 3 and 4. There are six instrumentation options and sub-options presented in such a way that a basic system can be selected to match the immediate technical needs and budget constraints of DRES and yet allow for future growth of the facility. The options range from a basic indoor only system for testing small antennas and targets over the frequency range 3 to 18 Ghz (expandable down to 1 GHZ and up to 26 GHz and 40 GHz) through to a full indoor/outdoor system with hardware gating as well as software gating for testing larger antennas and targets over the full frequency range of 1 to 18 Ghz. The intermediate options build on the basic system with instrument and software additions (substitutions in some options) to increase the system capabilities.

When selecting an instrumentation option attention should be given to the possibility of using frequency and antenna or target scaling in future planned experimental studies. If scaling is applied to an RCS target the target dimensions in wavelengths must remain fixed along with the permeability, permittivity and surface impedances,then σ/λ^2 is also fixed [2]. Thus, if the scaled frequency is k times the actual frequency the target size is reduced by k and the range distance is also reduced by k. However, the RCS level at the scaled frequency is reduced by k^2 and the instrumentation sensitivity may be challenged. As an example: suppose the real radar cross-section σ_R of a 50 cm diameter target is required at 5 Ghz and a target reduction factor of 2 is used then the scaled target is 25 cm in diameter and the scaled radar cross-section σ_S must be measured at 10 Ghz. The real radar cross-section is determined from $\sigma_R = 4 \times \sigma_S$.

2.2.4 CHAMBER TURNTABLES AND POLARIZERS

In order to rotate antennas or targets about a desired axis the indoor system configuration uses a light weight turntable with a tower and small polarizer (or for RCS work a foam tower). The turntable must be located so that when the antenna or target is mounted it is positioned in the chamber quiet zone. Also, a source tower mounted with a polarizer is positioned near the wall furthest from the quiet zone. Figure 2.3 shows the layout of this part of the system.

For the indoor/outdoor configuration a heavy duty turntable is placed centrally in the chamber. The large antennas are placed on this turntable. These units are computer controlled through a controller and programmer. Two companies supply instrumentation of this type, Scientific Atlanta Corporation and Orbit Advanced Technologies. Two example systems have been assembled which could serve the needs of the facility. One system is based on instrumentation available from Scientific Atlanta and a block diagram of the setup is shown in figure 2.5 while the second system is based on Orbit instrumentation and is depicted in figure 2.6.

Both the Scientific Atlanta and Orbit systems consist of the following basic elements:

1. A light weight azimuth over elevation turntable.
2. A tower placed on top of the turntable and mounted with a polarizer for antenna measurements or in place of the tower a foam column or low radar cross-section pylon for mounting targets.
3. A source tower mounted with a polarizer.
4. A heavy duty turntable located centrally in the chamber for indoor/outdoor antenna measurements.
5. A power unit to drive the axis of each turntable and polorizer (Scientific Atlanta Positioner Controller or Orbit Power Control Unit).
6. A unit to provide digital control of the power drive unit and interface with the system computer (Scientific Atlanta Position Programmer or Orbit Position Controller Programmer).

7. Cables which must be custom assembled once a final system is decided upon.

EQUIPMENT LIST FOR THE SCIENTIFIC ATLANTA TURNTABLE/POLARIZER SYSTEM

UNIT	MODEL	COST
Heavy Duty AZ/EL turntable	53152B	28 420.00
Roll Tower	5028A	11 590.00
Polarizer	56060	6 020.00
Position Controller	4181-1	18 235.00
Position Programmer	2012A	16 100.00
Digital Indicator	1844	8 390.00
Cable System	custom	est 5 000.00
	Total	US $ 93 755.00
Note: 1US$ = 1.6 CN$		CN $150 008.00
OPTION		
Light Duty AZ/EL Turntable	5023A	23 345.00

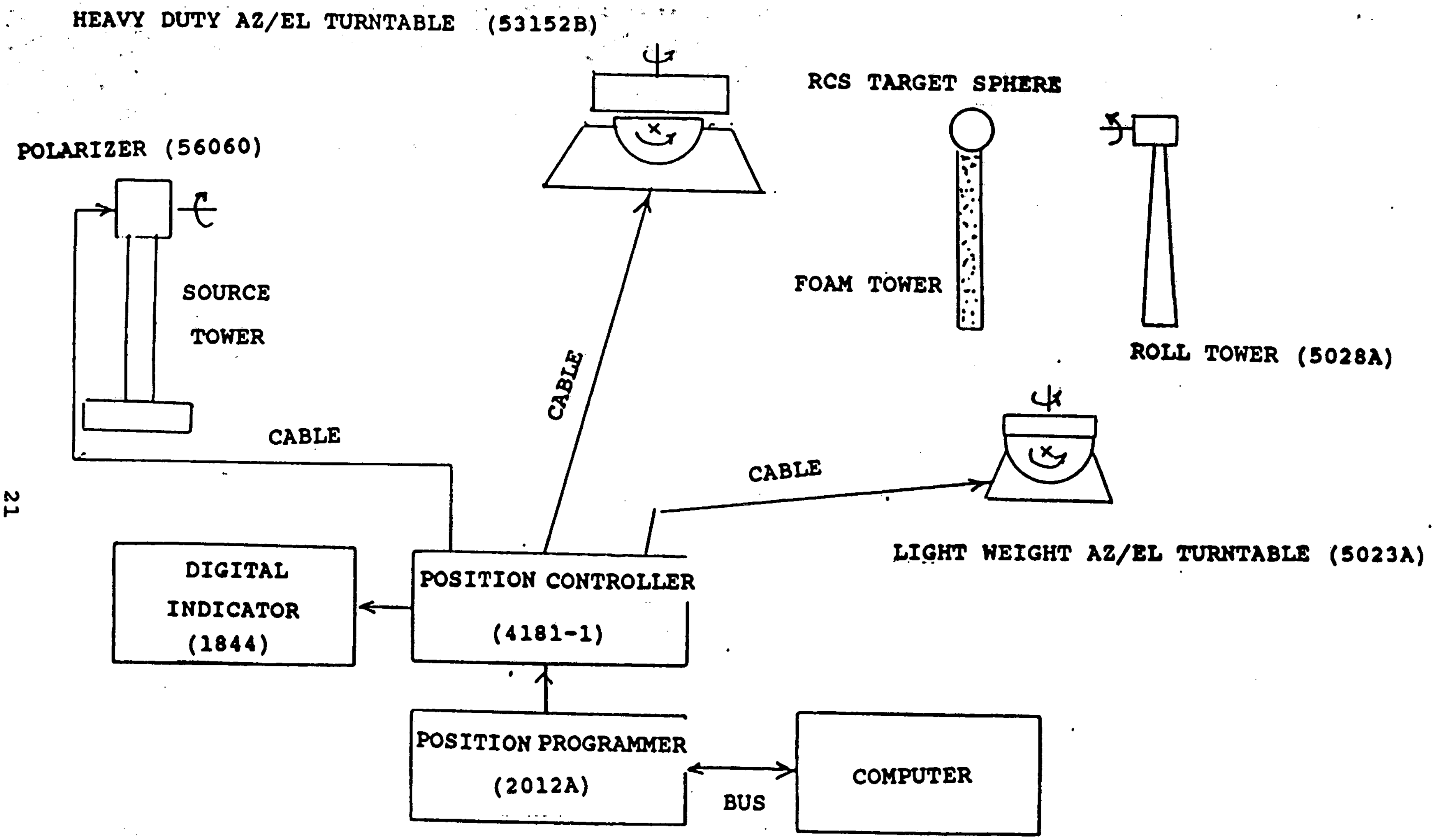


FIGURE 2.5 SCIENTIFIC ATLANTA TURNTABLE/POLARIZER SYSTEM.

EQUIPMENT LIST FOR ORBIT TURNTABLE/POLARIZER SYSTEM

UNIT	MODEL	COST
Heavy Duty AZ/EL Turntable	AL-4373-1	18 550.00
Model Tower	AL-4810-1	15 800.00
Polarizer	AL-360-1P15	est 6 000.00
Power Control Unit	AL-4103-2-6A	17 000.00
Position Programmer	AL-4006-3A	14 500.00
Cable System	custom	est 5 000.00
FOB Israel, Total		US $ 76 850.00
Note: 1US$ = 1.6 CN$		CN $122 960.00
OPTION		
Light Duty AZ/EL Turntable	AL-4370-1	10 800.00

It should be emphasized that these are example systems as the manufacturers carry a wide range of turntables and polarizers and the final units must be selected based on maximum antenna and target torque loads.

The small turntable is used for indoor measurements. To perform antenna measurements the tower and polarizer are placed on the turntable and the test antenna mounted on the polarizer. This provides three axis rotation of the antenna. For RCS measurements a foam tower can be mounted on the turntable and the target placed at its top. The turntable can be used to rotate the target azimuthly.

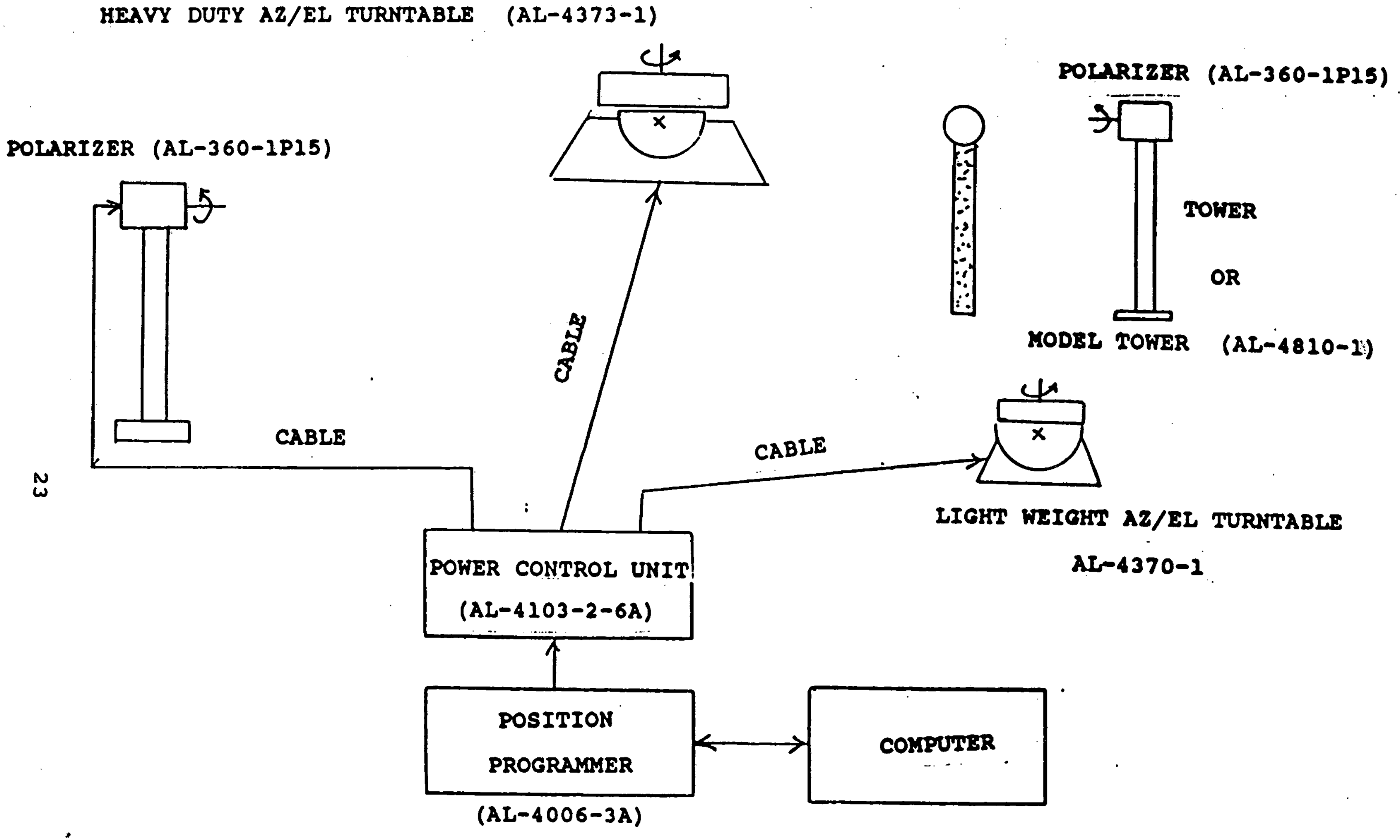


FIGURE 2.6 ORBIT TURNTABLE/POLARIZER SYSTEM

Alternatively a low radar cross-section pylon can be mounted on the turntable, but the pylon must then contain an azimuth rotator at its top in order to rotate the target. The pylon has a wing shaped variable cross-section and its vertical axis leans towards the source end of the chamber. It cannot be rotated so the pylon must have a drive motor at its top to rotate the target.

In the case of indoor/outdoor antenna measurements the centrally located large turntable is used for mounting large antenna units. A suitable wood tower can be constructed and placed on the turntable to vertically offset the antenna into the quiet zone of the chamber. Only the azimuth axis is used in taking a pattern, however, the elevation axis can be used for tilt adjustment to boresight the antenna towards the source antenna. For RCS indoor/outdoor measurements the large turntable can be used as a platform for setting up the transmit/receive antenna system.

Consideration should be given to a setup which uses only one heavy duty turntable. In this setup the turntable is mounted on a track system bolted to the floor and the turntable is moved to the chamber center for indoor/outdoor operation or near the end wall for indoor operation. The turntable must be securely clamped to the track during operation. This single turntable setup requires further equipment re-arrangement to convert between the two types of operation.

2.2.5 OUTDOOR TOWER AND TARGET PYLON

Since DRES already has a tower suitable for mounting the source antenna for antenna testing no further design is provided for this portion of the system except for the tower location. Report section 5 gives information as to the location of a fence to reduce specular reflections. The position and height of the fence is related to the mounting height of the source antenna on the tower. The tower will require a small room or enclosure to house the source instrumentation. As well, a digital bus is required between the tower and the chamber computer to enable control of the source. This bus can be realized through a modem system and a telephone line or laser link system or other means.

A 15 ft high pylon with rotator is available from Scientific Atlanta for supporting large targets, model 5551-1(15). The price of this unit is US$147,000.00 (CN$235,280.00 based on a 1.6 conversion factor). The pylon is ogive shaped and has a rotator at the top with a 1500 lb capacity. Backscatter from the pylon is below -30 dBsm at 2 GHz to -49 dBsm at 18 GHz. A 25 ft high pylon is available from Scientific Atlanta but at a considerable higher cost.

A tower suspension system as described in section 2.2.1 is a low cost alternative to the pylon. The rotation of the target is difficult with the suspension system and it also does not provide a support system for the target which is as stable as the pylon.

2.3 PERFORMANCE VERIFICATION

Test procedures which can be used to verify the performance of the facility are presented in this section of the report. The procedures to be described fall into two classes of measurement; the tests needed to evaluate the reflectivity in the quiet zone of the of the anechoic chamber when it is configured both as an indoor chamber and also when it is configured as an indoor/outdoor chamber, and tests to evaluate the RCS performance of the system again for each of its two configurations. Two basic articles serve as the basic technical reference for these procedures [2, 3].

2.3.1 ANECHOIC CHAMBER PERFORMANCE

Elaborate test methods could be invoked to completely characterize the chamber performance, such as a complete field probing of the quiet zone. However, for a reasonable expenditure of time, effort and cost it is standard to establish an average reflectivity level for points within the quiet zone. This reflectivity level is defined [3] as 'the average ratio of reflected power density to direct transmitted power density at points within the quiet zone under conditions of one-way energy propagation between transmitting and receiving antennas of stated directivity'. The antenna pattern comparison technique is the widely accepted method of evaluating quiet zone reflectivity. Report section 5 presents the theory behind the technique. The details are summarized as follows:

1. The chamber is illuminated with a transmitting antenna aimed along the axis of the chamber and a receiving antenna (with sufficient gain, 15 to 20 dB) is located on axis at the back of the quiet zone furthest from the transmitting antenna. The receiving antenna is mounted for azimuthal pattern measurements and a radiation pattern recorded.
2. The turntable with mounted receiving antenna is then moved a fraction of a wavelength laterally towards one of the side walls and the radiation pattern measurement

taken again. This process is repeated a number of times until the sidelobe patterns show a full constructive and destructive perturbation by the chamber wall reflections; i.e., the sidelobe region of the radiation pattern will be bounded by a maximum and minimum envelope of recorded signal levels.

3. The average reflectivity R(dB) in the region of the quiet zone probed while taking these pattern measurements is calculated from the maximum signal deviation D(dB) at a conveniently selected sidelobe level G(dB). The calculation is made using the equation

$$R = -20 \log \frac{(d+1)}{(d-1)} + G \tag{2.2}$$

   where d is the peak to peak deviation as a ratio (D = 20 log d). For example, if the pattern peak to peak deviation at the -25dB sidelobe pattern level is 1.1dB then the reflectivity level is -49dB.

4. The turntable and receiving antenna are next moved further laterally to the sidewall edge of the quiet zone and pattern sets obtained to measure the average reflectivity in this region of the quiet zone.

5. This process is repeated for a number of selected regions of the quiet zone, generally including the quiet zone center and front center regions. To probe the top or bottom portions of the quiet zone the receiving antenna must be offset vertically from the quiet zone central axis.

The above procedure applies to average reflectivity measurements for the chamber when it is configured for either indoor or indoor/outdoor antenna measurements. For the indoor/outdoor chamber configuration the quiet zone center shifts to the middle of the chamber over the large turntable.

The reflectivity levels expected for the indoor chamber configuration are best for parts of the quiet zone closest to the chamber center. The reason for this field behaviour is the smaller angle of incidence for the wall specular illumination and therefore greater absorber attenuation for points closer to the source antenna. Therefore, the most detailed probing needs to be done in the quiet zone back wall region. However, for the indoor/outdoor chamber configuration the front end of the quiet zone (portion closest to the open wall) needs the more detailed probing because of the field scattering from the periphery of the open chamber end and the foam weather wall.

2.3.2 RCS PERFORMANCE EVALUATION

The performance level of RCS facilities is generally evaluated through measurements on standard targets, usually conducting spheres although flat plates and corner reflector targets are sometimes used. The procedure is very basic and is thoroughly described in [2.3]. Generally, RCS measurements are undertaken on a set of spheres of different diameter over a wide frquency range. The relative differences between measured cross-section values for the different spheres can be compared with theoretical differences in absolute cross-section. The comparison of several diferent calibration targets is recommended to establish confidence in the measurement accuracy.

Analytic data is available for other targets, plates and corner reflectors, which can be used to further increase measurement credibility, although carefull allignment procedures must be used with these types of targets.

2.4 FACILITIES COSTING

2.4.1 BUILDING COST

The external dimensions of the building needed to house the anechoic chamber and provide work and instrumentation space are 32 ft width, 50 ft length and 24 ft height. Therefore, the needed building area is 1600 sq ft. The only special feature of the structure is the large weather door located on the wall to which the anechoic chamber must 'open'when it is configured for indoor/outdoor operation. Also, suitable heating and air conditioning must be provided to give a stable temperature environment for the computer and instrumentation.

An engineering consulting firm was approached for information on typical construction costs of hangar or wharehouse type buildings. The estimate obtained was near $100 per sq ft of building area when no special foundation or building features are needed. On this basis the basic building cost is estimated to be $ 160 000.00. To account for additional costs of the weather door, air conditioning, the high building roof (minimum 24 ft) and possible site preparation (fill to elevate the structure slightly above the local terrain) a further 20 percent is added to the basic cost.

TOTAL ESTIMATED BUILDING COST $ 192 000.00

2.4.2 ANECHOIC CHAMBER COST

The anechoic chamber costs fall into three categories: absorber and adhesive cost; foam weather wall cost and chamber fixed absorber support walls (ceiling, two side walls) and movable absorber support panel costs; and related installation and construction costs. Details of the estimates is provided below.

TOTAL ESTIMATED CHAMBER COST $ 141 916.00

1. ABSORBER AND ADHESIVE COST

The absorber is placed on a surface area (two walls, ceiling, floor and two sets of end panels) of approximately 3600 sq ft of the 30 ft wide, 30 ft long and 20 ft high chamber. It should be noted that the absorber does not need to cover the complete inside surface area of the chamber walls since the absorber is 2 ft thick. Specially mitered absorber pieces need to be ordered from the manufacturer for the corners of the chamber. The intallation of the absorber needs to be carefully planned along with its mounting on the panel sections. A quotation was obtained from Keene Corporation Advanced Absorber Products for 24 inch thick pyramidal absorber (coverage 2 ft by 2 ft) and adhesive.

742 units	AAP-24		51 724.00
272 units	AAP-24-1M		19 747.00
24 units	AAP-24-2M		1 838.00
105 gallons	8013.0018		2 889.00
		US$	76 198.00
	(1.6 conv.)	CN$	121 916.00

2. FOAM WEATHER WALL AND SUPPORT WALL AND PANEL COST

These estimates were based on a rough estimate of required foam material, wall studs and beams and plywood paneling.

$ 10 000.00

3. ABSORBER INSTALLATION AND CONSTRUCTION COST

Again, only a rough estimate can be made of the installation and construction cost and it is taken to equal the material cost.

$ 10 000.00

2.4.3 POSITIONER SYSTEM COST

The positioning system from Scientific Atlanta is selected as the representative equipment for the facility. The cost details for this equipment was provided in report section 2.2.4.

TOTAL POSITIONER SYSTEM COST $150 008.00

2.4.4 BASIC SYSTEM COST

The building, anechoic chamber and positioner system are basic elements which must be included along with any of the instrumentation options or sub-options selected for the initial system to be installed.

Building Cost	$ 192 000.00
Anechoic Chamber Cost	$ 141 916.00
Positioner System Cost	$ 150 008.00
BASIC SYSTEM COST	$ 483 924.00

2.4.5 COST TO IMPLEMENT BASE OPTION 1

SUMMARY OF FEATURES:

1) FREQUENCY RANGE, 3 TO 18 GHz.
2) INDOOR/OUTDOOR ANTENNA MEASUREMENT CAPABILITY.
3) INDOOR RCS MEASUREMENTS.
4) HP-8510B/8511A RECEIVER SYSTEM WITH TIME DOMAIN GATING.
5) IBM-AT COMPUTER SYSTEM.
6) SCIENTIFIC SOFTWARE PACKAGE, McMILLAN ASYST.

Base Option 1 Equipment Cost (See report section 4)	$ 202 713.00
Basic System Cost	$ 483 924.00
BASE OPTION 1 SYSTEM COST	$ 686 637.00

7) SUB-OPTION FOR FLAM & RUSSELL RCS SOFTWARE WITH MicroVAX II COMPUTER.

Add Cost for F&R Software and MicroVAX	$ 168 000.00
Subtract Cost of IBM-AT, ASYST software & Printer/Plotter	$(16 860.00)
BASE OPTION 1 WITH SUB-OPTION 1A	$ 837 777.00

8) SUB-OPTION FOR POWER AMPLIFIER TO IMPROVE RCS SENSITIVITY.

Add Cost of Power Amplifier	$ 11 329.00
BASE OPTION 1 WITH SUB-OPTIONS 1A & 1B	$ 849 106.00

9) SUB-OPTION FOR ANTENNAS TO EXTEND FREQUENCY DOWN TO 1.0 GHz.

Add Cost of Antennas	$ 10 732.00
BASE OPTION 1 WITH SUB-OPTIONS 1A, 1B & 1C	$ 859 838.00

10) SUB-OPTION FOR MILLIMETER WAVE OPERATION TO 26 GHz AND 40 GHz.

Add Cost of MMWave Equipment (See section 4)	$ 57 962.00
BASE OPTION 1, WITH SUB-OPTIONS 1A, 1B, 1C & 1D	$ 917 800.00

2.4.6 COST TO IMPLEMENT BASE OPTION 2

SUMMARY OF FEATURES:

1) FREQUENCY RANGE, 1 TO 18 GHz.
2) INDOOR/OUTDOOR ANTENNA MEASUREMENT CAPABILITY.
3) INDOOR/OUTDOOR RCS MEASUREMENTS.
4) HP-8510B/EXTERNAL MIXER RECEIVER SYSTEM.
5) CUSTOM TRANSMIT/RECEIVE SWITCH SYSTEM BY FLAM & RUSSELL.
6) HARDWARE GATING SUB-SYSTEM BY FLAM & RUSSELL.
7) FLAM & RUSSELL MIXER SUB-SYSTEM.
7) MicroVAX II COMPUTER SYSTEM.
8) ANTENNA/RCS SOFTWARE BY FLAM & RUSSELL.
9) TWT POWER AMPLIFIERS.

Base Option 1 with Sub-options 1A, 1B & 1C and Basic Equipment Cost	$ 859 838.00
Add Base Option 2 Cost (See Report Section 4)	$ 275 329.00
Add Target Suspension System Cost (see 2.2.5)	est. $ 10 000.00
BASE OPTION 2 SYSTEM COST	$ 1 145 167.00
OPTION Scientific Atlanta Target Pylon (see 2.2.5)	$ 235 280.00

2.5 REFERENCES

[1] B. F. Lawrence, 'RF Anechoic Chamber Test Facilities,' Second ESTEL Spacecraft EMC Seminar, Noordwijk, May 1982 (Also published as a technical note by Keene Corporation).

[2] R. B. Dybdal, 'Radar Cross-section Measurements,' Proc. IEEE, V75, N4, April 1987, p. 498.

[3] E. F. Buckley, 'Outline of Evaluation Procedures for Microwave Anechoic Chambers,' Microwave Journal, August, 1963.

3 INSTRUMENTATION DESIGN

3.1 INTRODUCTION

Radar cross-section measurements are inherently more difficult to perform than antenna radiation pattern and gain measurements. A number of factors contribute to the difficulty of RCS measurements, such as the large two way signal path attenuation, the close proximity and coupling between transmit and receive antennas (particularly in the monostatic setup) and the relatively large contribution to the total received signal of the range background signals.

For the proposed facility the instrumentation setup must be capable of being configured to perform the dual measurement role of antenna radiation pattern measurements and target RCS measurements. Because of the more specialized instrumentation required and extensive signal processing needed for RCS measurements the basic instrumentation system is first designed and configured to perform RCS measurments. When the facility is needed for antenna measurements the instrumentation is readily re-configured for this purpose. The receiving portion of the system will have more than adequate sensitivity and dynamic range for pattern measurements. Separate software is of course needed to process the antenna measurement data. Therefore, the instrumentation design is primarily focused on meeting the RCS requirements.

Two base RCS measurement setups have been designed and these are described in detail in report section 4. The first setup described is labelled Base Option 1 and is the most basic system with limited frequency coverage and restricted target size capabilities. In total six options and sub-options are presented with Base Option 2 being the most extensive setup with the most sophisticated hardware and software for signal processing and largest target handling capability.

The remaining portion of this report section deals with the basics of RCS measurements and forms the background for report section 4 which describes each of the instrumentation options.

3.2 RCS RECEIVED SIGNAL COMPONENTS

The general task presented in radar cross-section measurements, regardless of the type of range facility, is to measure the power scattered from an illuminated target as a function of various properties of the incident radiation; such as the angle of incidence, the polarization and the frequency. The basic function of the instrumentation is to illuminate the target with suitable radiation and to extract the RCS from the returned signal. The return signal P_R is composed of a number of components only one of which is the desired echo return from the target, P_E. The measurment system must have the processing capability to extract the desired target echo from the composite return signal. The total received power is given on a dB basis by

$$P_R = P_E + P_{CA} + P_{CS} + P_{CM} + P_{CC} \tag{3.1}$$

where P_{CA} is the power coupled externally from the transmitting antenna to the receiving antenna, P_{CS} is the power coupled internally by the receiver from the transmitter circuits, P_{CM} (target cell clutter) is the power received due to reflections from the target support structure and P_{CC} (range clutter) is the power received due to reflections from the range itself (background echos). The distinction between these two clutter terms is necessary as the mechanisms for removal of each from the measured data is different. The background return from the chamber can be minimized by proper chamber design through prudent use of absorbing material or by appropriate signal conditioning and processing. Discrimination between the target echo and the remaining terms in (3.1) is the responsibility of the signal processing software installed with the instrumentation.

3.3 SYSTEM PERFORMANCE CRITERIA

The following list of performance criteria based on Tavormina [1] is invoked as a measure of the desired overall capabilities of the RCS system.

1. Frequency coverage.
   The present state of development of source and receiver instrumentation generally determines the possible maximum system frequency coverage.
2. Range coverage.
   This is the allowable range in distance between the receive/transmit antennas and the target point. In the case of an outdoor range, the maximum distance between the target and instrument antennas will be limited either by the sensitivity of the radar receiver (the receiver's noise floor) or by the transmitter to receiver coupling (P_{CA}). The minimum target/antenna separation will be limited by gating times and T/R switching times.
3. Measurement capability.
   Types of RCS measurements:
   a) RCS versus target position (orientation).
   b) RCS versus frequency.
   c) RCS versus transmit and receive polarization including

cross-polarization.

d) RCS versus range.

e) RCS versus cross range (imaging).

4. Measurement accuracy.

This quantity applies to the RCS values measured.

5. Measurement dynamic range.

This is the ratio of the maximum to minimum value of a particular RCS type measurement.

6 Measurement sensitivity.

This quantity refers to the smallest cross-section that may be reliably measured for a given range. Measurement integration time and receiver sensitivity are strongly related and should be considered together when evaluating the RCS sensitivity.

7. Range resolution.

The range resolution of any system is assessed primarily on the basis of its clutter rejection and the target cell must be adequately resolved amongst the various sources of clutter.

8. Measurement time.

This quantity refers to the total time required to acquire a single data point for a particular measurement type. The time required to complete an entire measurement program is difficult to specify since there may be considerable overhead time in acquiring a complete set of data; such as computation time, data transfer time, equipment setup time, settling time, disk access time, etc.

9. Ease of operation.

This can include the amount of set up time, physical effort in configuring the system, operator skill, etc.

10. Cost.

This quantity is an estimate of the equipment costs only and does not include installation or operator training costs.

3.4 CLASSES OF RCS INSTRUMENT

Three distinct classes of RCS instrument radar exist and these are described as follows:

1. The continuous wave (CW) radar in which the incident signal is continuous although its frequency may be stepped or modulated by a continuous time varying function. Radar capabilities and performance are determined by the type of modulation employed.
2. The low bandwidth gated-CW radar which uses high speed switches to gate the transmitter on and off in order to achieve clutter rejection; notably for the terms P_{CA} and P_{CC} in equation (3.1). This class of radar is characterized by low transmitter power and use of a narrow-band receiver (the bandwidth being much smaller than that of the gating waveform).
3. High power pulse radars that are modulated by very short pulses. This radar class can resolve the clutter terms P_{CC} and P_{CM} as well as specific scattering centers within the target. Very high bandwidth receivers are employed in such systems (the receiver bandwidths being equal to or greater than the spectral bandwidth of the pulsed waveform).

The third class of radar, the high power pulsed radar, is employed for very long outdoor ranges. The receivers have very large bandwidths that allow the intercept of all the energy contained in one return pulse resulting in quick acquisition of data. The response resolution of these systems is excellent, however, they face minimum range distance limitations due to the speed of the T/R switches and are therefore unsuitable for short outdoor ranges or for indoor ranges.

Therefore, the short pulse class of radar is eliminated from further consideration in this study as it is incompatible with the requirements that the radar instrumentation be used for both indoor and outdoor measurements as well as for antenna pattern measurements. This class of radar would be suitable for a high performance outdoor range but additional equipment would be required to perform the other types of measurements.

The remaining two classes of instrumentation shall be considered, namely, the CW and gated-CW radar. The CW radar is suited for indoor measurements and for short (10's of meters) outdoor ranges that are particularly free of clutter hence this class of radar will be examined as a candidate for the indoor range system. Available literature and consultations with manufacturers suggest that the non-gated (that is, software gating only) CW systems can not be reliably applied to long outdoor range measurements so that only the gated-CW radar class will be considered for this application.

3.5 TYPES OF CW RCS RADAR INSTRUMENTS

The CW radar class may be further subdivided into three types of instrument and a description of each type follows:

1. The CW radar.

These instruments transmit a continuous signal at a single frequency and simultaneously receive a reflected signal from the target. The received power due to chamber reflections (P_{CC}) is minimized through chamber design while target cell clutter and transmitter/receiver coupling is minimized through vector background subtraction. With the target removed, a sample of the outgoing transmitter signal is added to the receiver input and adjusted in phase and amplitude so that the total received signal is nulled. Hence, this procedure subtracts the background clutter from the received signal when the target is in place. A high stability (frequency and amplitude) transmitter is required as well as a stable transmit sample bridge. The inherent stability of the equipment together with the external isolation available between the receive and transmit antenna configuration determines the ultimate sensitivity of the system. In practice the sample signal and receive signal summation may be performed at the intermediate frequency of the phase amplitude receiver. Although this type of receiver will represent a large capitol investment, it allows the signal sample bridge to be used over a wide range of operating frequencies.

The CW radar performs RCS measurements one frequency at a time and the the transmit signal sample system must be readjusted for each frequency point at which the RCS measurement is desired. Although extremely slow and cumbersome this method has been demonstrated to provide RCS versus target position data for reasonably small targets (down to -20 dBsm) in an indoor range of the order of 10 meters in length. Disadvantages to this system include a range limitation imposed by the transmit/receive antenna isolation, the need for a highly skilled operator to perform these measurements, extreme difficulty in obtaining RCS versus frequency data and the inability to perform range and cross range measurements.

2. The stepped CW radar.
These systems are built around a sensitive receiver capable of accurately measuring the phase and amplitude of a signal on one or more input channels with respect to a reference channel. The target is illuminated at a number of selected frequencies over a bandwidth for each angle of target position desired. The phase and amplitude of the received signal is measured at each sample frequency to form the discrete frequency domain data. The frequency domain data is then transformed into the time domain by the fast Fourier transform which results in data giving the reflected signal level as a function of time (which in turn translates into the distance to the scattering centre which produces a particular reflection). Suitable processing is employed to isolate the various reflections from their respective clutter. Only returns within a particular time window will correspond to the target cell echoes, hence the transmit/receive coupling and chamber echoes can be eliminated. By applying a time domain window to this data (values outside the window are set to zero) and transforming back into the frequency domain, the target cell RCS versus frequency can be obtained. The removal of all but the target cell clutter in this manner is referred to as software gating.

The target cell clutter may be removed by vector background subtraction as in the case of the CW radar. In a stepped CW system this procedure involves measuring the target cell return signals (phase and amplitude) both with and without the target present and then recording the difference. As with the CW radar, this system requires a stable transmitter and stable target supports, however, less demand is placed on the stability of the inter antenna coupling components as these are removed by the software gating. The fundamental difference between background subtraction methods as employed in the CW and the stepped CW technique is that in the former, the subtraction is performed with hardware while in the latter the process is performed in software.

The response resolution of the radar is a measure of its ability to separate two distinct points of reflection within its target cell. The minimum discernible distance between any two scattering points in the cell is inversely proportional to the interrogating bandwidth (that is resolution increases as the band of frequencies over which the target is interrogated increases). This suggests that an arbitrarily high resolution may be obtained by increasing the bandwidth. Although there are bandwidth limitations in practice, the resolution for modern equipment may be increased to the order of centimeters allowing the possibility of range and cross range measurements which may be used to construct radar images of the target.

The primary attraction of the stepped CW radar lies in the flexibility with which the system can be developed. The system's ability to cover various frequency ranges and range sizes can be expanded by appropriate equipment additions to a core system consisting of a broadband receiver, computer and software capable of performing the required time/ frequency domain transformations. The transmitter output power must be kept below the level which causes saturation of the receiver. Such limitations imposed by the hardware must be adhered to if the software gating is to operate effectively.

3. FM-CW radar.

This type of radar illuminates a target with a signal that is swept (usually linearly) over a frequency band. A homodyne receiver generates a baseband signal from the product of the transmit and receive signals. This modulation process results in a baseband signal consisting of spectral components determined by the sweep rate, the sweep frequency range (bandwidth) and the target range. The baseband signal is sent for Fourier analysis (real-time) where the RCS amplitude as a function of range can be extracted. A discrete Fourier transform results in the division of the test range into a number of cells with the RCS of each cell determined independently. A prior knowledge of the target distance can be employed along with the range resolution to remove range clutter outside the cell containing the target. The RCS versus frequency may be obtained by transforming back into the frequency domain after the target cell is identified and bracketed in the time domain. This type of radar has the potential to generate high resolution images of a target through RCS measurements as a function of range and position followed by processing with appropriate software. The RCS of the target cell is that of the target itself and the target support structure (the reflected power term P_{CM} in (3.1)). The target cell clutter may be removed by vector background subtraction as mentioned previously. The response resolution is inversely proportional to the swept bandwidth and is equivalent to the total bandwidth covered in the stepped CW case [1]. The maximum transmit power is limited by the attainable inter-antenna coupling (P_{ca} in (3.1)) and the maximum allowable signal before receiver saturation occurs.

3.6 LOW BANDWIDTH GATED RADAR INSTRUMENTS

All of the CW radar instruments described above may be hardware gated in order to convert them to a low bandwidth pulsed system. Hardware gating involves turning the receiver off (that is isolating it from the receive antenna) except for that interval of time in which the receiver must accept reflected power from the target cell. The transmitter is also hardware gated to produce a suitable target illumination pulse and then is switched off during the time the reflected signal is being accepted by the receiver. The bandwidth of the receiver is smaller than the spectral width of the pulsed waveform so that only a fraction of the energy from any given pulse is captured. In order to overcome this signal loss, a continuous train of pulses (each being representative of the target cell RCS) is delivered to the receiver and treated as if they formed a non-gated signal. It is for this reason that the receiver must be gated off during the periods of pulse transmission, otherwise the transmitter coupling would add power to the RCS signal and invalidate the measurement. The pulsed transmit power is reduced relative to the CW transmit power by its duty cycle. This loss can be made up again by signal integration and averaging.

The gating is accomplished by switching the appropriate antennas on or off with high speed RF switches. The timing systems and gate waveform generators are separate systems that must be added to the CW radar instrument. Hence, the hardware gating feature is convenient to add as a retrofit to a CW radar instrument should the capabilities of such a system be required in the future.

The principle reason for adding hardware gating to a system is to allow longer range measurements such as those required with an outdoor range. The hardware gating circumvents the transmitter power limitations due to the transmit/receive antenna coupling of CW radars thereby allowing the use of high transmit powers to overcome the large path losses of long ranges. Furthermore, such ranges possess high levels of clutter which may not be easily removed by only software gating due to the receiver saturation limitations discussed previously (especially with the high power transmitters). A further advantage over CW radars is a speed increase in the overall measurement process as fewer frequency points are required to cover the range (since software gating need only be applied in the vicinity of the target cell).

3.7 SUMMARY

The stepped-CW radar type is selected as the primary instrument for consideration out of the three types of CW radar. With the addition of hardware gating the stepped-CW instrument is converted to a low bandwidth pulsed radar instrument capable of outdoor RCS measurements.

The CW radar is eliminated from consideration as it is severely limited in its ability to reliably perform the types of RCS measurements required (particularly RCS versus frequency measurements) in a reasonable length of time and readily allow expansion of the system to cover a wide range of frequencies both for indoor and outdoor measurements.

Furthermore, the CW range is by its nature custom designed for each experiment performed and requires experienced engineering staff to set up and operate the RCS range leading to very high operating costs.

The FM-CW radar can meet the requirements for RCS measurements, however, instrumentation is not easily integrated into an antenna pattern measurement range. For this reason it was likewise eliminated from further consideration.

The wide bandwidth, high power, short pulse instrument is incompatable with the requirements of use for indoor RCS measurements or for antenna pattern measurements, therefore, it also is eliminated as a candidate system.

3.8 INSTRUMENTATION DESIGN EQUATIONS

In RCS measurements the instrumention minimum detectable RCS (RCS sensitivity), resolution and clutter rejection are of principle concern. Methods for obtaining resolution and clutter rejection are unique to each type of radar instrument, therefore, each type must be evaluated independently. RCS sensitivity on the other hand is limited primarily by constraints inherent in the range design and by the performance of components employed in the receiver/transmitter system. Hence, all of the radar types considered face the same sensitivity limit. The dependence of RCS sensitivity on instrumentation parameters will be summarized first and then its dependence on range parameters will be considered.

The basic radar equation which gives the power in the received target signal is

$$P_R = \frac{P_T G_T G_R \lambda^2 \sigma}{(4\pi)^3 R^4 L} \tag{3.2}$$

where P_R is the received power, P_T is the transmitted power, G_T and G_R are the transmit and receive antenna gains, respectively, λ is the wavelength, R is the distance between the transmit and receive antennas and the target, L represents cable and switch losses and σ is the target radar cross-section. This expression may be written as

$$P_R = P_T F_P \sigma \tag{3.3}$$

where F_P is a range performance factor

$$F_P = \frac{G_T G_R \lambda^2}{(4\pi)^3 R^4 L} \tag{3.4}$$

Since the maximum permissable transmit and receive antenna gains, G_T and G_R, as well as the range distance, R, are pre-determined by the largest target size to be measured on the range while L is established by the length of cable runs we see that F_P is fixed by these range quantities and establishes an upper bound for RCS sensitivity improvemement.

The manner in which the range parameters effect the performance factor F_P will now be discussed. The range length will be assumed known at this point so that the maximum allowable antenna gains need to be determined in terms of the desired target sizes.

Target sizes are generally specified by target extent (E). The minimum allowable separation distance between the instrument antennas and the target is fixed by the extent of the largest target expected to be measured in the range. In order to maintain the phase taper across the target to within $\frac{\lambda}{8}$ when it is illuminated by a spherical wave the range distance R must be greater than

$$R > \frac{2E^2}{\lambda} \tag{3.5}$$

If this restriction is relaxed at the expense of RCS accuracy the maximum allowable target extent is

$$E < \sqrt{\lambda R} \tag{3.6}$$

Also, in order to guarantee that the beamwidth of the antenna is such as to illuminate the target with less than a 1 dB amplitude taper across the extent of the target the maximum gain of either the transmit or receive antennas is constrained by

$$G_{MAX} < \left(\frac{R}{E}\right)^2 \tag{3.7}$$

The maximum usable transmitter power P_T is limited in practice by the external isolation obtainable between the receive and transmit antennas in a CW system. In the case of gated systems this isolation includes gate isolation.

During gated-CW operation the transmit signal has a duty cycle so that a number of successive measurements n need to be taken and the results integrated to yield an RCS whose absolute magnitude depends linearly on sample time. The receiver bandwidth will limit the rate at which the absolute magnitude of this signal increases. The integrated noise will be removed from each measurement sample so that there will be no net increase in noise with increasing n. Hence, the signal to noise ratio will increase by a factor of two (3 dB) for each doubling of the number of measurements taken. Imperfections within the integration process are taken into account by the integration efficiency, ϵ. Therefore, the effective noise level for a receiver is given by

$$N = \frac{kT_S B}{n\epsilon} \tag{3.8}$$

where k is Boltzman's constant ($1.38\text{x}\ 10^{-23}$ J/K), B is the bandwidth and T_S is the system temperature. T_S may be expressed in terms of the receiver noise figure (F) as

$$T_S = T_0(F-1) \tag{3.9}$$

where T_0 is the reference temperature (usually 290 K).

For a signal power equal to the receiver noise floor, i.e., $P_R = N$ for S/N=1, equations (3.3) and (3.8) yield the relationship for the minimum detectable cross-section σ_{MIN} which on a dB basis is

$$\sigma_{MIN} = 10\log\left(\frac{kT_S B}{n\epsilon}\right) - P_T - F_P \tag{3.10}$$

The receiver sensitivity is usually quoted by the manufacturer as that input signal level which results in unity S/N at the point of detection, i.e., when

$$S = 10\log(kT_S B) \qquad (3.11)$$

The equation giving the RCS sensitivity in terms of receiver sensitivity is then

$$\sigma_{MIN} = S - F_P - P_T - 10\log(n\epsilon) \qquad (3.12)$$

In this expression the performance factor F_P is determined by the range parameters, while the receiver sensitivity S and transmitter power level P_T are determined by equipment specifications.

In report section 4 the RCS sensitivity is calculated using (3.12) after S has been determined from (3.11) and F_P from (3.4) for the particular option considered.

3.9 REFERENCES

[1] Tavormina, J., "Instumentation Radars Fulfill Role in RCS
Measurement", Microwave System News and Communications Technology, Feb. 1985, pp 75-96

4 EQUIPMENT SYSTEM DESIGN

4.1 INTRODUCTION

The instrumentation required for a stepped CW type RCS measurement system is presented in this section. Several possible equipment options exist for this type of radar instrument ranging from a completely in-house designed and assembled system using readily available technology and off-the -shelf components to turn-key systems which can be obtained from at least two manufacturers. Moreover, several hybrid options exist where sections may be assembled in-house or managed through consultants while remaining sections could be provided by manufacturers to complete the system.

Two basic equipment options with a number of sub-options is presented in the following portions of this report. Each of these two base options is comprised of a system assembled from representative components which are readily available from manufacturers and generally represent the current state-of-the art in terms of component performance. In most cases there are alternatives to the selected components, however, since this study is not intended to provide a final design but only serve as a guide for planning and budgetary purposes towards obtaining such a facility, the selections are representative and not necessarily optimum on a technical or economic basis.

The first base option is further divided into sub-options which are are extensions of the basic option. A sub-option involves the addition or change of equipment or software which results in an expansion of the basic system capabilities and facilitates a gradual facility expansion (these extensions can usually be added to an functioning system without seriously disturbing system operation). Once a base option and appropriate sub-options are selected the system's capabilities are limited by that choice. Moving from base option 1 to base option 2 requires a major change of equipment as opposed to a simple equipment addition. Hence, the base option should be chosen with the future system in mind.

Both base options require a receiver that is capable of amplitude and phase measure of the RCS signal relative to a reference transmit signal. A computer is needed to acquire the data and perform a fast Fourier transform (FFT) to obtain the frequency response of the range and target. The functions of range gating, target cell clutter rejection and RCS calculations are all performed in either the frequency or time domain as appropriate. The role of the receiver may be filled by either a vector network analyzer or a phase amplitude range receiver. Both receiver types are fully compatible with the instrumentation needs of an antenna pattern measurement range. The performance requirements of frequency coverage, measurement accuracy, RCS sensitivity and measurement speed may determine the choice of receiver. In base options 1 and 2 a network analyzer is utilized as the receiver and although other choices exist (Wiltron analyzer and possibly EIP analyzer) the Hewlett Packard HP-8510B is selected as the receiver.

The computer chosen must be capable of acquiring all the data generated by a target measurement program and must be fast enough to perform the needed FFT's in a reasonable amount of time. The facility performance requirements such as target cell and chamber clutter rejection, measurement speed and ease of operation determine the choice of computing facilities and software requirements.

4.2 BASE OPTION 1

SUMMARY OF FEATURES:

1) FREQUENCY RANGE, 3 TO 18 GHz.
2) INDOOR/OUTDOOR ANTENNA MEASUREMENT CAPABILITY.
3) INDOOR RCS MEASUREMENTS.
4) HP-8510B/8511A RECEIVER SYSTEM WITH TIME DOMAIN GATING.
5) IBM-AT COMPUTER SYSTEM.
6) SCIENTIFIC SOFTWARE PACKAGE, McMILLAN ASYST.
7) SUB-OPTION FOR FLAM & RUSSELL RCS SOFTWARE WITH MicroVAX II COMPUTER.
8) SUB-OPTION FOR POWER AMPLIFIER TO IMPROVE RCS SENSITIVITY.
9) SUB-OPTION FOR ANTENNAS TO EXTEND FREQUENCY DOWN TO 1.0 GHz.
10) SUB-OPTION FOR MILLIMETER WAVE OPERATION TO 26 GHz AND 40 GHz.

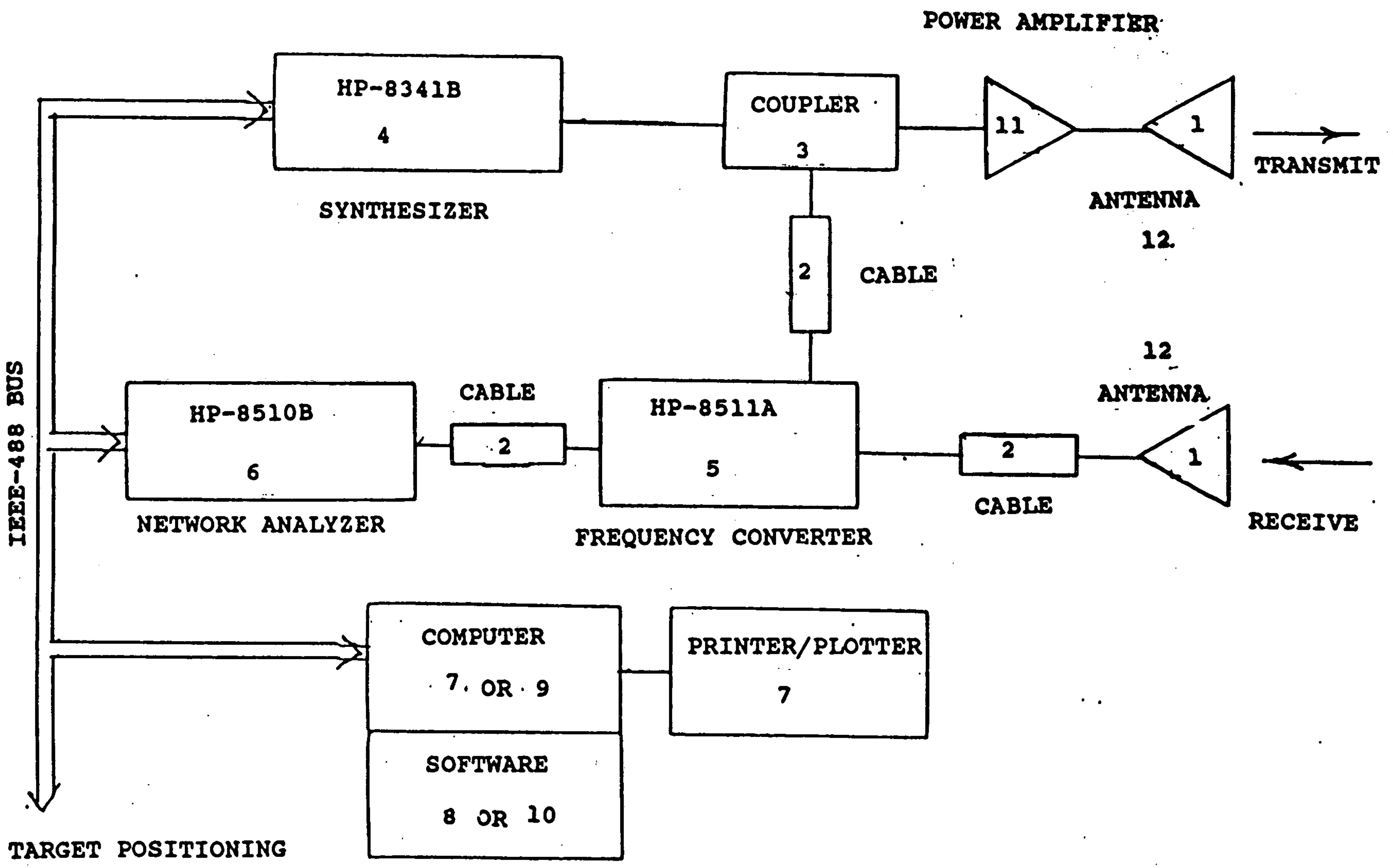
DESCRIPTION

Figure 4.1 depicts the representative instrumentation for base option 1 built around an HP-8510B vector network analyzer. This basic system operates over the frequency range 3 to 18 Ghz. The analyzer and signal source are located together at the base of the transmit/receive antenna tower and are connected to the computer from this operating location by an IEEE-488 bus using bus extenders if necessary. Associated with the HP-8510B is an HP-8511A frequency converter which has four input channels although only two channels are utilized in the depicted system. The two channels are necessary for the basic measurements as described in this report, however, the potential exists for taking simultaneous measurements of more than one quantity such as two polarizations or more than one antenna position (bistatic measurements). The ability to take simultaneous measurements can represent a considerable saving in overall measurement time although additional equipment such as antennas may be required.

Base option 1 uses in house designed software and modest computing hardware. Most of the needed signal processing software is available on the HP-8510B leaving the tasks of overall instrument orchestration and data presentation to the external computer. General purpose scientific software packages such as ASYST are available that allow IEEE-488 bus control and complex user written macros to perform various tasks relating to data collection and processing. This allows an initial cost saving at the expense of in-house software development. The overall cost of this development including manpower will be highly dependent on the resources available at DRES.

It is assumed that with the base option 1 set-up, the transmission lines connecting equipment and antennas can be under 4 meter in length. This assumption underlies the estimate of transmission line losses appearing in a table later in report section 4.11.

The transmitter consists of a laboratory grade frequency synthesizer which provides power for both the reference channel power and target illumination. The synthesizer output is expected to be in the order of 10 dBm which should provide for reasonable performance without the need for a high power amplifier.



4.1 EQUIPMENT FOR BASE OPTION 1

Separate antennas are employed for both the receive and transmit channels thereby providing front end isolation to prevent receiver saturation. The antennas recommended for RCS work are of the diagonal horn type [1] due to their sidelobe performance, pattern consistency with frequency and pattern symmetry, all specifications superior to the counterpart conventional horn antenna type. The use of such antennas also provides at least 50 dB isolation between the receive and transmit antennas.

Section 4.3 lists the representative equipment for base option 1. This basic system is expected to provide performance measures and face limitations as follows:

1. <u>Frequency range</u>: The frequency range is limited on the low end to 3 GHz by the antennas and on the high end to 18 GHz by the frequency synthesizer.
2. <u>Range type</u>: The configuration is intended for indoor range measurements only. The system source power level and receiver sensitivity together with only a software gating system for clutter rejection, make any outdoor RCS measurements with this system impossible. However, outdoor antenna measurements are most adequately handled by base option 1.
3. <u>Sensitivity</u>: Section 4.12 presents a table which lists the RCS sensitivity for the various system options including base option 1 and its sub-options. These calculations are made assuming a receiver sensitivity based on S/N=1 which may compromise accuracy. Hence, if better accuracy is desired the RCS sensitivity should be based on S/N>1 which will give a sensitivity value greater than that listed in the table.

4. Dynamic range: The dynamic range of the HP-8510B is specified by the manufacturer to be 80 dB when using the HP-8511A frequency converter as the front end. Other references [2] state that this dynamic range may be increased by the use of external frequency converters to as much as 100 dB. Hence the 80 dB specification is not a hard limit and can be improved. The 80 dB dynamic range signal operation is between the noise floor of the analyzer and the 1 dB compression point of the frequency converter. In practice, the usable dynamic range is considered to be 20 dB less than this value resulting in the published dynamic range specification [3] of 60 dB.

5. Clutter rejection/range resolution: Range clutter rejection is obtained by resolving the range into a number of cells, one of which contains the target. As with linear FM radar, the range resolution or target cell size is on the order of the speed of light divided by twice the band of frequencies sampled [2, 4, 5]. For target cells of 1 meter in extent, the bandwidth is on the order of 100 MHz. Less than 20 frequency samples would be required to cover the indoor range. The HP-8510B can acquire up to 801 frequency points [2] over the entire frequency operating range, hence, it is more than adequate to isolate any target extent that will be tested in the indoor range. Target imaging could be applied by simply increasing the frequency span and taking more frequency samples. Providing the clutter returns do not exceed the overload limit of the receiver front end, range clutter may be successfully removed by the software gating features of the HP-8510B.

   Target cell clutter may be ignored if the target support structure has a RCS that is significantly smaller then that of the target. For indoor targets which are small and lightweight, low density foam supports and prudent choice of support geometry [6] should yield support clutter as low as -40 dBsm which should allow measurement of target RCS values in the order of -30 dBsm. Flam and Russell provide target supports which exhibit an RCS of less than -45 dBsm over the 1 to 18 GHz frequency range.

For the measurement of lower target RCS levels, vector background subtraction may be employed to remove the target cell clutter. Manufacturers that provide background clutter subtraction systems [2] and research workers reporting on this subject [7] suggest improvements of 30 dB in RCS sensitivity over that available with uncorrected target cell clutter. Systems built around the HP-8510B have demonstrated target cell clutter levels of -65 dBsm after background subtraction.

Initially, the RCS range could be assembled without target cell clutter rejection and such features added at a later date if enhanced performance is desired. This would not involve further hardware development. Software development could continue over time without disturbing the day to day operation of the system.

6. <u>Measurement</u> <u>time</u> : An estimate of data acquisition time is given in the table in section 4.12. This value is the time required to acquire the phase/amplitude information for a single target position and does not include time overhead involved in the display and presentation functions. The estimate is based upon a 50 msec data acquisition time per frequency point plus 900 msec of setup time.

7. Other considerations: Additional advantages of the system built around a network analyzer such as the HP-8510B include:

a) The availability of commercial RCS software packages, such as the Flam and Russell FR-8003. These packages, when combined with the HP-8510B provide for a complete turnkey system with all of the features mentioned above including background subtraction, target imaging, multiple measurement channels and complete target positioner control.

b) The network analyzer based RCS system can perform both antenna and pattern measurement with no additional hardware beyond additional cabling and the use of bus extenders.

c) The network analyzer and its associated front end constitute the basic hardware requirements and provide most of the needed software within the analyzer itself. Performance is enhanced with the addition of external software which could be developed in stages without disturbing the ongoing operation of the system. Furthermore, the software can be custom designed for the facility.

d) The analyzer based system could even perform high target resolution imaging if such a capability is desired in the future.

e) The network analyzer can be made available for other work such as microwave circuit testing when not required for RCS and antenna measurements.

4.3 EQUIPMENT FOR BASE OPTION 1

EQUIPMENT AND SOFTWARE LIST
ITEM - REFER TO FIGURE 4.1

ITEM	DESCRIPTION	TYPE	COST
1	Diagonal Horns, 3 to 12 GHz	FR-6414, 2 rqd	US$ 6000.00
1	Diagonal Horns, 12 to 18 GHz	FR-6415, 2 rqd	US$ 6400.00
2	Cables, 4 meter length	Storm 421-014, 3 rqd	US$ 1332.00
3	Coupler, 1 to 18 GHz	Narda, 4222-16	$ 818.00
4	Synthesized Generator	HP-8341B	$65930.00
5	Frequency Converter	HP-8511A	$27997.00
6	Network Analyzer	HP-8510B, Opt 010	$69137.00
7	Computer, Note 1	IBM-AT Equivalent	$ 7420.00
8	Scientific Software	ASYST, McMillan	$ 2497.00
7	Graphics Printer	HP-2227A	$ 787.00
7	Plotter	HP-7550A	$ 6156.00
Note: 1 US$ = 1.6 $Canadian		TOTAL	$ 202713.00

Note 1. IBM -AT equivalent system with the following options: 640 K, EGA graphics, 40 Mb hard drive, 12 MHz clock speed, 20287 co-processor, serial/parallel ports, IEEE interface card.

4.4 SUB-OPTION 1A - FLAM AND RUSSELL SOFTWARE

In this sub-option the RCS measurement software and computer system is replaced by a commercial package, Flam and Russell FR-8003. The advantages of installing such a package are: the software has a dual antenna amd RCS measurement data processing capability, no software development is required by DRES, software support is available from the manufacturer, higher speed processing of the data over the in-house developed system is likely, further software options such as that for cross-range imaging are available and expansion to include an outdoor facility is more readily accomplished. This sub-option is a highly recommended addition to base option 1. Also, the computer needed to operate this system is fairly substantial with multi-user capability and could be made available for other computational uses.

SOFTWARE REPLACEMENT LIST
ITEM - REFER TO FIGURE 4.1

ITEM	DESCRIPTION	TYPE	COST
9	Computer	MicroVAX II	US$55000.00
10	Antenna/RCS Software	Flam & Russell FR-8003	US$50000.00
Note: 1 US$ = 1.6 $Canadian		TOTAL	$ 168000.00

4.5 SUB-OPTION 1B - POWER AMPLIFIER

This sub-option consists of adding a power amplifier to base option 1 in order to achieve greater RCS sensitivity with short measurement times (i.e., down to a single measurement). This approach is recommended by Flam and Russell in order to increase the sensitivity so that vector backgroung subtraction can be applied to take advantage of the clutter rejection capabilities of the HP-8510B.

The target signal levels at microwave frequencies in base option 1 are all well above the clutter background level expected in the target cell. However, in order to fully exploit the cell clutter rejection capabilities of the HP-8510B the measured clutter signals should be above the noise floor of the receiver. In order to accomplish this a wideband power amplifier needs to be added. This amplifier increases the RCS sensitivity by a factor of 10. As well, increased averaging can be utilized.

Alternatively, integration may be employed (increasing n) to obtain sensitivities of about the same order using the 10 dBm source power levels, however, the measurement times will be increased accordingly (by a factor of 20 for a 10 dB increase in sensitivity, assuming an integration efficiency of 50%). In practice, it becomes difficult to achieve performance improvements with integration factors over 1000 as the integration efficiency decreases, usually due to range instability. Most of the signal processing facilities are incorporated within the HP-8510B, hence, the computer is relieved of the computationally intensive tasks of performing the FFT, time domain windowing, smoothing, etc.; leaving only the tasks of positioner control and data presentation.

SUB-OPTION 1B - POWER AMPLIFIER (CONTINUED)

EQUIPMENT ADDITION LIST
ITEM - REFER TO FIGURE 4.1

ITEM	DESCRIPTION	TYPE	COST
11	Medium Power Amplifier	HP-8349B	$11329.00
Note: 1 US$ = 1.6 $Canadian		TOTAL	$ 11329.00

4.6 SUB-OPTION 1C - LOW FREQUENCY ANTENNAS

This sub-option extends the system low frequency bound to 1 GHz by adding a wideband horn capable of 1 to 3 GHz operation.

EQUIPMENT ADDITION LIST
ITEM - REFER TO FIGURE 4.1

ITEM	DESCRIPTION	TYPE	COST
12	Horn Antennas, 1 to 3 GHz	AEL-H1734, 2 rqd	$10732.00
Note: 1 US$ = 1.6 $Canadian		TOTAL	$ 10732.00

4.7 SUB-OPTION 1D - MILLIMETER WAVE EXTENSION

This sub-option is shown in figure 4.2 and provides for a frequency expansion to millimeter waves using in-house selected equipment although Flam and Russell can also custom design a millimeter wave extension to their external mixer option. It is recommended that consultation with this manufacturer take place before the initial system design if expansion to a millimeter wave is highly likely.

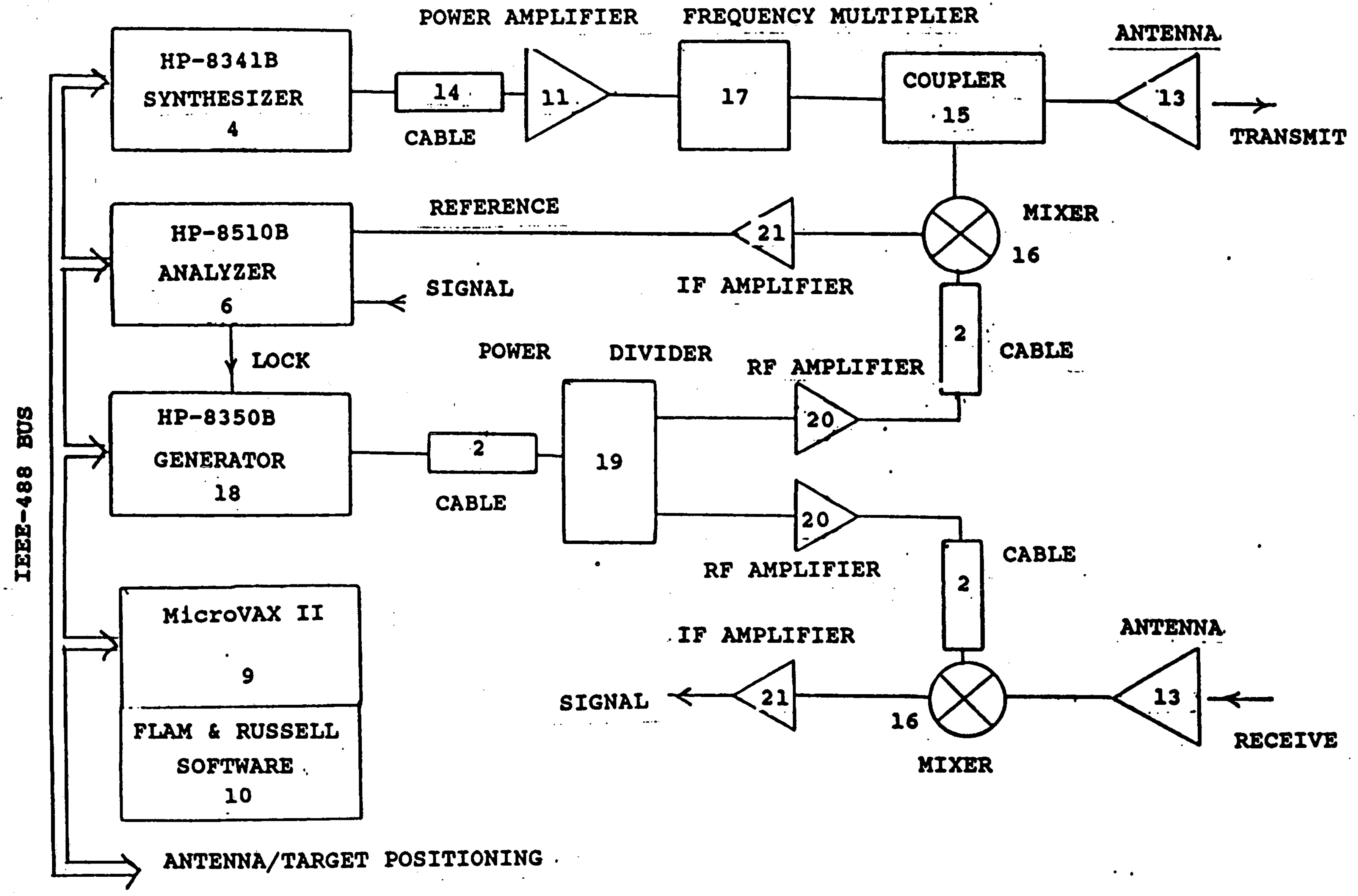
EQUIPMENT ADDITION LIST
ITEM - REFER TO FIGURE 4.2

ITEM	DESCRIPTION	TYPE	COST
13	Diagonal Horns, 18 to 26 GHz	FR-6413, 2 rqd	$ 4000.00
13	Diagonal Horns, 26 t0 40 GHz	FR- , 2 rqd	$ 4000.00
14	Cable	Storm 421-014	US$ 444.00
15	Coupler, 18 to 26 GHz	HP-K752C	$ 1331.00
15	Coupler, 26 to 40 GHz	HP-R752C	$ 1436.00
16	Harmonic Mixer, 18 to 26 GHz	HP-11970K, 2 rqd	$ 4834.00
16	Harmonic Mixer, 26 to 40 GHz	HP-11970A, 2 rqd	$ 4994.00

CONTINUED ON NEXT PAGE

EQUIPMENT ADDITION LIST (CONTINUED)
ITEM - REFER TO FIGURE 4.2

ITEM	DESCRIPTION	TYPE	COST
17	Frequency Multiplier, 18 to 26 GHz	Spacek Labs, K-2X,2 rqd	US$ 800.00
17	Frequency Multiplier, 26 to 40 GHZ	Spacek Labs, Ka-2X,2 rqd	US$ 960.00
18	Phased-locked Generator	HP-8350B with HP-83525A	$27616.00
19	Power Dividers,		
	0.5 to 2 GHz	Narda 4321-2	US$ 422.00
	2 to 8 GHz	Narda 4324-2	US$ 492.00
20	Amplifiers,	Avantek AWT-2042	$ 1711.00
	1 to 18 GHz	Avantek AWT-8032	$ 2701.00
21	IF Amplifiers, 20 MHz	Avantek UTC-543 2 rqd	$ 351.00
Note: 1 US$ = 1.6 $Canadian		TOTAL	$ 57962.00



4.2 SUB-OPTION 1D: MILLIMETER WAVE SYSTEM

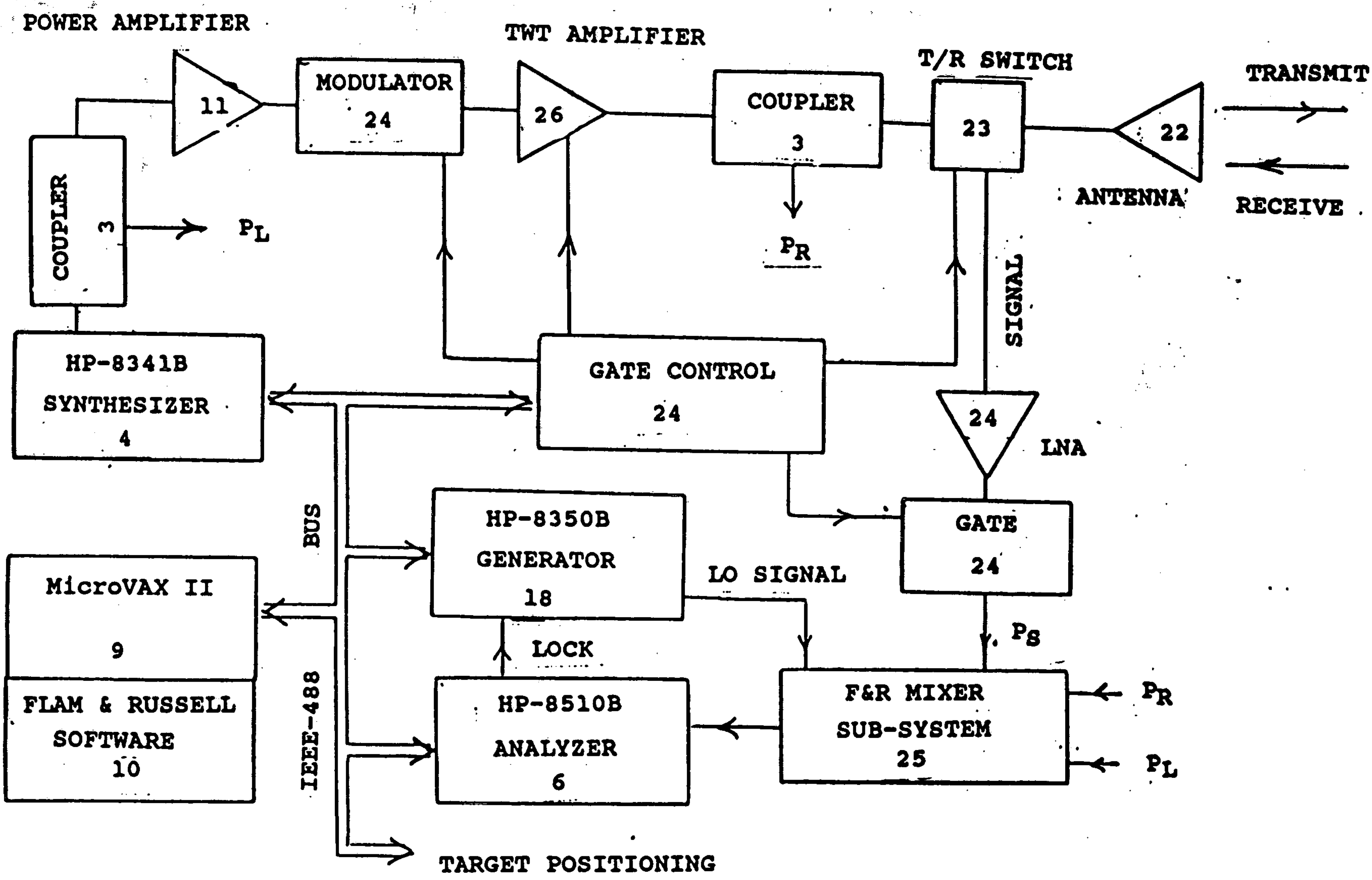
4.8 BASE OPTION 2

SUMMARY OF FEATURES:

1) FREQUENCY RANGE, 1 TO 18 GHz.
2) INDOOR/OUTDOOR ANTENNA MEASUREMENT CAPABILITY.
3) INDOOR/OUTDOOR RCS MEASUREMENTS.
4) HP-8510B/EXTERNAL MIXER RECEIVER SYSTEM.
5) CUSTOM TRANSMIT/RECEIVE SWITCH SYSTEM BY FLAM & RUSSELL.
6) HARDWARE GATING SUB-SYSTEM BY FLAM & RUSSELL.
7) FLAM & RUSSELL MIXER SUB-SYSTEM.
7) MicroVAX II COMPUTER SYSTEM.
8) ANTENNA/RCS SOFTWARE BY FLAM & RUSSELL.
9) TWT POWER AMPLIFIERS.

DESCRIPTION

This section describes base option 2 which is the instrumentation setup needed in order to perform outdoor long range RCS measurements. Figure 4.3 is a block diagram of the setup. The key element of this setup is the hardware gating scheme. The design of the hardware gating system goes beyond the simple selection of off the shelf components, hence, it is not suitable for an in-house development program. Hardware gating is usually supplied with a packaged RCS system that includes at least the RCS software.



4.3 EQUIPMENT FOR BASE OPTION 2.

The representative system selected is the Flam and Russell FR-8003 system. This system includes the RCS measurement software with a MicroVAXII computer. Also selected is the hardware gating from Flam and Russell, system FR-8105, which includes the diode switch gate delay and timing subsystems, isolators and filters.

A software option to run the hardware gating subsystem is included as an upgrade to the software at no additional cost. Therefore, no software development is required by DRES and software support is available from the manufacturer. Also, options such as cross range imaging software can be added.

Much of the information presented regarding base option 1 applies to base option 2. However, the HP-8511A frequency converter is replaced by an external mixer system along with an external local oscillator. The external mixers have advantages over the frequency converter as follows:

1. They generally exhibit better sensitivity and greater dynamic range as compared to the frequency converter.
2. They can be conveniently placed at the antenna terminals thereby reducing the transmission losses. This results in a further increase in RCS sensitivity as well as greater flexibility in designing a physical equipment layout for a given experiment.
3. Their frequency range can readily be expanded beyond 18 GHz by adding new mixers to the system.
4. They are an essential component for outdoor RCS operation.
5. It results in a more flexible system providing more performance selection (sensitivity, dynamic range, etc.) through appropriate mixers.

The external mixers and associated components are a commercially available subsystem. The system employs an external mixer subsystem manufactured by Flam and Russell as an option to their FR-8003 RCS system. Although the customer is responsible for providing the network analyzer, synthesized main source and phased locked LO source, the company will provide the necessary installation and acceptance tests in addition to the software and options specified above. Moreover Flam and Russell provides training for up to four people over a period of three days. This results in a complete turn key system for RCS measurement in the frequency range 1 to 18 GHz.

An additional advantage of this sub-option lies in the extra channels (single extra channel in the outdoor case and two channels in the indoor case) that are available in the Flam and Russell options. These additional channels may be used for the measurement of two quantities simultaneously such as both receive polarizations.

Dual polarization antennas have been used in the sample system which could take advantage of this feature. Although the cross polarization measurements were not originally required of this RCS range, dual polarization antennas are a worthwhile investment for antenna pattern measurements. The polarization of the transmit antenna can be changed without physically moving the antenna during pattern measurements of cross polarized signals (and risking loss of boresight).

The local oscillator chosen is a laboratory grade signal source capable of phase locked operation with the network analyzer. Frequency stability is then provided by the main synthesized source. The use of an external local oscillator precludes the use of the swept frequency mode of the synthesizer (the stepped mode only is allowed) in order to speed up the measurements. This restriction results from the need to switch bands and mixer harmonic numbers during the course of the sweep.

It should be noted that a three mixer signals are required since three signals are now processed; one mixer is needed to provide a continuous phase lock reference from the main source, one mixer for the output (after gating) amplitude reference and finally the mixer for the received signal itself.

A high power amplifier is required to overcome the large path losses incurred by the long outdoor range. A set of travelling wave tube (TWT) amplifiers which provide 10 watts of power is selected for the representative system. The TWT amplifier is driven by a wideband power amplifier which also can serve as the drive amplifier for frequency multipliers needed for possible expansion to the millimeter wave band. A diode switch is included in order to improve isolation between the transmitter and receiver as well as input and output isolators (as recommended by manufacturers of gated ranges) and a power sampler which extracts a sample of the output power for level correction.

A Flam and Russell T/R switch has been selected which allows a single antenna to perform both receive and transmit functions. This switch can supply the necessary isolation between the receive and transmit ports and operates fast enough to allow for successful gating for outdoor RCS measurements. Besides the possible economic advantagesover a two antenna system there is a considerable set up time saving with the use of only one antenna as the critical boresighting procedures are eliminated. An exact price for this option is difficult to provide as it is a custom designed feature and can only be designed after the basic range design is completed. The cost provided is based on the previous development of a system similar in make-up to the one presented here.

A considerable cost saving may result from the use of solid state power amplifires rather than the TWT amplifiers. The outdoor range design is complex with many factors to be considered, therefore, the representative system can only provide a rough guide as to the costs involved.

4.9 EQUIPMENT FOR BASE OPTION 2

EQUIPMENT ADDITION LIST
ITEM - REFER TO FIGURE 4.3

ITEM	DESCRIPTION	TYPE	COST
3	Coupler, 1 to 18 GHz	Narda 4222-16	$ 818.00
22	Antenna, Dual-Polarized,	AEL APX-1318	$ 7203.00
	1 to 12 GHz		
22	Antenna, Dual-Polarized,	Scientific	US$ 7000.00
	12 to 18 GHz	Atlanta,	estimated
	Feed/Reflector	28-12/4, 22-4/A	
23	T/R switch module	Flam & Russell	US$ 10000.00
	1 to 18 GHz	Custom Design	estimated
24	Hardware gating system	FR-8105	US$ 60000.00
25	Mixer Sub-assenbly	FR-8505RM	US$ 27500.00
26	10 Watt TWT amplifiers,	Logimetrics	
	1 - 2 GHz	A230/L	$ 26000.00
	2 - 4 GHz	A230/S	$ 26516.00
	4 - 8 GHz	A230/C	$ 24716.00
	8 - 18 GHz	A230/IJ	$ 23694.00
	(Includes input/output isolators and 30 dB sampler)		

Note: 1 US$ = 1.6 $Canadian TOTAL CN$ 275329.00

4.10 POWER BUDGET CALCULATIONS

RCS SYSTEM PERFORMANCE CALCULATIONS

OPTION	FREQ (GHz)	L (dB)	G (dB)	Fp (dB)	S (dB)	Pa (dBm)	RCSmin (dBsm)	TIME (ms)
1	10	3.0	16	-71	-90	10	-29	3500
	Note:1,2,3							
1A	10	3.0	16	-71	-90	10	-29	1900
	Note:1,2,4							
1B	10	3.0	16	-71	-90	20	-39	3500
	Note:1,2,3							
1C	1	1.0	10	-60	-90	10	-40	3500
1C	2	1.0	11	-65	-90	10	-35	3500
1C	10	3.0	16	-71	-90	10	-29	3500
	Note:1,2,3							
1D	1	0.0	10	-58	-121	20	-83	3500
1D	2	0.0	11	-63	-121	20	-78	3500
1D	18	0.0	16	-65	-121	20	-76	3500
1D	20	0.0	16	-69	-100	16	-47	3500
1D	26	2.0	16	-76	-100	8	-32	3500
1D	40	2.0	16	-82	-98	8	-24	3500
	Note:1,2,5							

CONTINUED ON NEXT PAGE

OPTION	FREQ (GHz)	L (dB)	G (dB)	Fp (dB)	S (dB)	Pa (dBm)	RCSmin (dBsm)	TIME (ms)
2	1	6.0	23	-123	-120	40	-37	3500
2	2	6.0	29	-117	-120	40	-43	3500
2	10	6.0	42	-105	-120	40	-55	3500
2	18	6.0	43	-108	-120	40	-52	3500
	Note:1,5,6							

NOTES

1. For S/N=1 at receiver.
2. Single measurement only (n=1).
3. Stepped frequency mode, 51 points.
4. Ramp (swept frequency) mode, 500 msec sweep rate.
5. Stepped frequency mode only, 51 points: swept measurement mode is not available on the external mixer systems.
6. Assumes 64 samples taken at 200 microsecond intervals which is completed before the 50 msec data transfer time. The averaging is necessary to compensate for gating losses. The gate duty cycle is taken to be 2.5 %.

4.11 TRANSMISSION LINE LOSSES

TABLE OF LINE LOSSES

FREQUENCY (GHz)	T/R SWITCH INCLUDED	FUNCTION	DESCRIPTION	LOSS (dB)
1	No	Receive	4 meter cables	1.0
2			with HP-8510B	1.0
10				3.0
26				4.0
1	No	Receive	External mixer	0.0
2			located at antenna	0.0
10				0.0
20				0.0
1	Yes	Receive/	T/R system loss	6.0
2		Transmit		6.0
10				6.0
18				6.0

4.12 REFERENCES

[1] Foti,S.J., McGahey,D.D., "Diagonal Horn Improves Anechoic Chamber Measurements", Microwaves and RF, March 1984, pp 105-110

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[5] Mensa, D.," Wideband Radar Cross Section Diagnostic Measurements", IEEE Trans. Instrumentation & Measurement, Sept. 1984, pp 206-214

[6] Ratte, Gilles, Delisle, Gilles, Lecours, Michel, "Experimental Techniques for the Radar Cross Section of Complex Structures", ?????, pps 163-168

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5 THE ELECTROMAGNETIC ANECHOIC CHAMBER

5.1 CHAMBER DESIGN

The required anechoic chamber is intended to test both small antennas and those mounted on an RPV. It will also be used for RCS measurements. Since the required test zone is about 5m in diameter, the far field measurement distance cannot be achieved within a standard chamber environment two possible solutions therfore exist. Use a compact range within the chamber to generate the plane wavefront, or one may use an open chamber. Here, we describe briefly both systems and provide chamber dimensions that can accommodate both.

The compact range is the most advanced method of measuring both antenna patterns and RCS returns. It is compact and can be located inside a moderately small chamber and as such provides an accurate and convenient system for all tests. It can be calibrated and function at all times, regardless of environmental conditions. However, it is an expensive sytem to set-up. Currently, three different designs are available: 1) an offset paraboloid, 2) a dual cyldrical parabolic system, and 3) a dual paraboloid or shaped system. The offset paraboloid is the simplest system to operate. It consists of a single parabolid surface, which when illuminated by a feed at its focal point generates equi-phase wavefronts at the reflector aperture. However, because the surface is paraboloidal, it is difficult to fabricate. Consequently, high performance compact ranges with this system have upper frequency limits due to the surface tolerance. At low frequencies, one may use part of an existing large paraboloid to construct a low cost range. Commercially Scientific Atlanta manufactures this class of compact ranges. The dual cylindrical parabolic compact range utilizes two parabolic reflectors that are curved only in one plane.

They are consequently easier to fabricate and maintain higher surface tolerances. Their main drawbacks are: 1) difficulty in alignment, since it is a dual optical system, and 2) the necessity for two large reflectors. Their performance however is more superior in aperture field uniformity and low cross-polarization. Because the reflector surface is curved in one plane the fabrication of this system does not require special tools and can be made using planar sheets mounted on parabolic ribs. March Microwave of Netherland supplies a commercial system of this type. The most advanced, but most difficult to fabricate is the dual shaped system. Here, two nearly paraboloid surfaces (shaped) are used in a Cassegran or Gregorian form to generate plane wavefronts. Harris Corporation of U.S.A. manufacturers such a system. Due to shaping the aperture field uniformity can be high and the spillover power can be reduced significantly. The latter is an important feature for improving the RCS measurements. For reference a sample of these compact ranges are shown in Figures 2-1 to 2-3. No additional design details are provided, since we assume that, due to the cost, the compact range solution is not required by DRES.

To enable testing large antennas or those mounted on an RPV, we propose an open anechoic chamber design. Here, one of the chamber walls is made of low loss commercial foams to allow the signal transmission. The system allows the measurement of both small and large units. To achieve this, it contains separate transmit and receive towers, as well as all measurement instrumentations. One set of transmit and receive towers are located at two opposite ends of the chamber and may be used for testing of small antennas or radar reflectors. In addition, a heavy duty turntable is located at the centre of the chamber. This turntable will be used in testing large antennas or those mounted on an RPV. In this case, the transmit antennas is located outside the chamber to generate the plane wavefront inside the chamber. In this mode of operation the radiation field of the transmit antenna penetrates through the foam wall and illuminates the test unit. The transmit tower is selected to be at an approximately 1.0 km distance from the chamber, where a small instrument room should be located to house the signal source. Fig. 4 and 5 show the chamber cross-section and the location of the towers. To eliminate the ground reflections a wooden fence at an appropriate distance must also be installed.

For design a rectangular chamber is selected. To accommodate RPV's. Its dimensions are selected to be 20 ft (height) × 30 ft × 30 ft. Using the data available for commercial absorbing material the reflectivity of such a chamber is investigated and shown in Chapter 3. It shows that, within a quiet zone of 6 ft and with an absorber thickness of 1 ft the reflectivity level can be below 26 dB. We therefore propose to use absorbers with 2 ft thickness to reduce the chamber reflectivity below 40 dB range.

5.2 CHAMBER REFLECTIVITY

Performance evaluation of the anechoic chamber was carried out employing the ray tracing method. The chamber considered in the present study is a rectangular chamber with one side open end, as shown in Fig. 1. The reason for selecting one side open end is to make use of the same chamber for in-door as well as for out-door measurements. In general for different types of measurements, it is necessary to use different criteria to assess the figure of merit of the chamber. Several figures of merit namely reflectivity level, termination VSWR, equivalent cross section, amplitude and phase uniformity etc. are found in the literature. However, we have selected the reflectivity level in the quiet zone as the performance index. Reflectivity level is defined as the ratio of the sum of all reflected waves to direct radiation.

Reflectivity level at an observation point inside the chamber is a function of its dimensions, absorber characteristics, transmitting antenna specifications and frequency of operation. In our evaluation, 1ft thick ECCOSORB-VHP-NRL-8 absorber lining is assumed over the inner side of the walls. Performance of the absorbers is sensitive to the angle of incidence, frequency of operation and the polarization of the incident wave. Tables 1 and 2 give reflection coefficients of the absorber for incident angles of 50°, 60° and 70°. For other angles of incidence the reflection coefficient is estimated by linear interpolation/extrapolation of the available data. In the first set of results, the chamber dimensions are taken as 20ft × 20ft × 30ft (Fig. 1). An x-polarized wide band horn located on the axis of the chamber, at a distance 5ft from the open end of the chamber, is used as the transmitter. Details of the horn are provided in Table 3.

Utilizing ray optics, specular reflections are assumed from the absorber lining, i.e. from the inner surface of the chamber. Zero phase change is assumed on reflection. Second bounce rays and the presence of the supporting structures of the transmitter and the test antenna are ignored. The vector sum of the five reflected waves - two from side walls and one each from the floor, ceiling and front wall, provides the net reflected signal. While calculating the reflected field from each wall, the incident field has to be decomposed into perpendicularly polarized and parallely polarized components. Then appropriate reflection coefficient, obtained through Tables 1 and 2, was used for each part of the incident field component. Addition of the two reflected wave components due to the incident field components yields the effective reflected field. Since principal polarization is selected along the x-direction, both the reflected and the direct fields at the point of observation are resolved along the x-direction for calculating the reflectivity level.

Extensive computations were carried out with a grid size 1ft × 1ft × 1ft between z = 6ft and 20ft observation planes. A sample set of the results for the operating frequencies 1, 4 and 10 GHz are enclosed. From the computed data the highest reflectivity level in a 6ft × 6ft × 6ft observation region situated as shown in Fig. 2 is identified. Reflectivity levels as a function of frequency are given in Table 4. From these results it is clear that the figure of merit of the anechoic chamber shows improvement as the frequency of operation increases. However, this improvement is bound to be negligble after reaching a particular frequency. In the present example an improvement of 20 dB is noticed, when the frequency is raised from 1 GHz to 4 GHz. Further increase in frequency to 10 GHz has produced hardly 5 dB additional improvement in reflectivity level. An examination of these results also indicate that for any selected frequency of operation, reflectivity level deteriorates as the distance between the transmitter and the observation plane increases. For instance, a deterioration of 8-10 dB is noticed when the 6ft × 6ft × 6ft observation region is moved from 10ft to 19ft.

However, the reflectivity level is only a measure of interference of the unwanted reflected waves with the direct wave, but doesn't provide information about the maximum allowable size of the antenna that can be tested inside the chamber. The amplitude and phase variations of the total field in the plane of observation decides the maximum allowable size of the antenna. Therefore, the total field on several observation planes was computed. Figs. 3 and 4 depict the amplitude and phase variations, respectively. The field variations shown in the plots are along the principal cuts (x,y-axes) on the planes of observation, for the frequencies of operation 1, 2, 3, 4, 5 and 10 GHz. From these illustrations, it is seen that the total field variation is almost the same along the x and y directions. This is due to the square cross section of the chamber and the reasonable circular symmetry in the transmitting radiation pattern.

Limitation on the size of the test antennas is obvious from these illustrations of the total field. The maximum allowable size D of the test antenna is given by Friss transmission formula $D = \sqrt{R\lambda/2}$, where λ is the wave length and R is the range, i.e. the distance between the transmitter and the test antenna. For a range of 20ft the maximum allowable size at different frequencies of operation are given in Table 5.

Since there exists a limitation on the size of the antenna that can be tested inside the anechoic chamber, the open range measurement procedure is resorted to for the large antennas. The test antenna is positioned at the center of the chamber. The transmitting antenna now is a pencil beam antenna, which is placed at the far-zone of the test antenna, is used as the transmitter. The scheme is as shown in Fig. 5. A range of 1000m, for a 4m, test antenna at an operating frequency 9.40 GHz is considered for illustration. Referring to Fig. 5, only the rays that are hitting the ground between the points A and B will be able to interfere with the direct radiation and cause a measurement error. A wooden fence, simulating a microwave reflector at an appropriate position, can block these intercepting bundle of rays. From simple trigonometric relations, the height of the wall CD and its location from the test antenna (i.e. from the open end of the chamber) were calcualted and provided in Table 6 as a function of transmitter height. Therefore, by having an open end, the advantage of utilizing the chamber both for the in-door and out-door has been brought out. The results shown in the next section are for a chamber with the dimensions 20ft × 30ft × 30ft (Fig. 6). The reflectivity levels given in Table 7 are very close to those of the 20ft × 20ft × 30ft chamber. For the sake of completeness, the amplitude and phase variations of the total field (Fig. 7, 8) and the sample computed data on reflectivity level are also included.

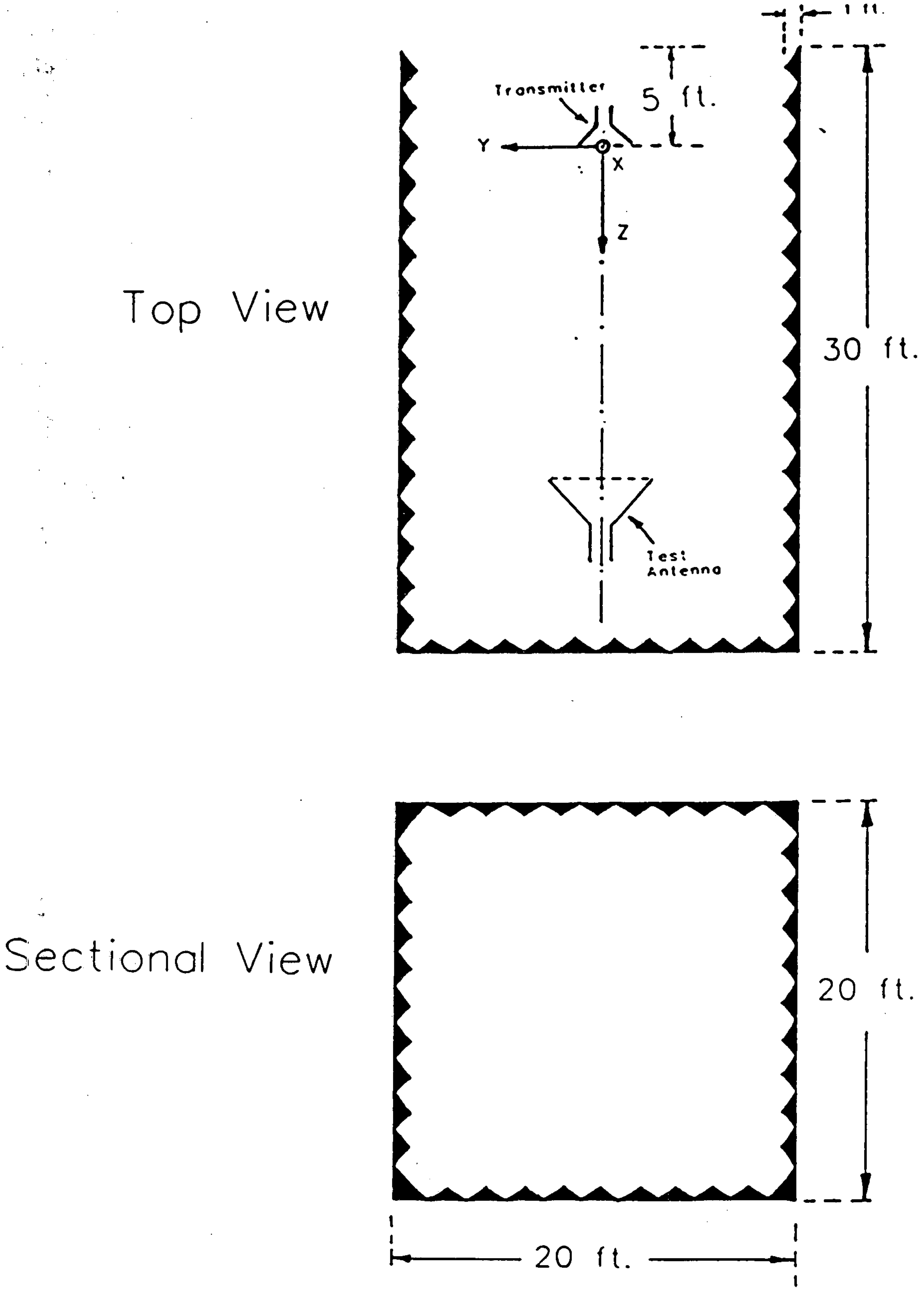


Fig. 1. Microwave Anechoic Chamber, 20' x 20' x 30'

Absorber Characteristics : VHP-NRL-8
(Emerson and Cuming, Inc.)

T = Absorber Thickness in Wavelengths

For a Perpendicularly Polarised Incident Wave : Table 1

Incident angle (Deg.)	Reflection Coefficient - (DB)								
	T=1.0	T=1.3	T=2.2	T=2.6	T=3.0	T=3.8	T=5.1	T=5.7	T=10.0
50	-22	-24	-29	-36	-41	-43	-46		-55
60	-15	-17	-23	-22	-34	-36	-34	-42	-48
70	-12	-11	-16	-15	-23	-24	-25	-33	-38

For a Parallel Polarised Incident Wave : Table 2

Incident angle (Deg.)	Reflection Coefficient - (DB)								
	T=1.0	T=1.3	T=2.2	T=2.6	T=3.0	T=3.8	T=5.1	T=5.7	T=10.0
50	-20	-27	-33	-30	-38	-40			
60	-17	-25	-31	-27	-28	-38	-33	-37	-42
70	-11	-19	-21	-20	-21	-27	-30	-28	-38

Table - 3 : Details of the Transmitting Horn used in the Evaluation of the Reflectivity Level of the Anechoic Chamber.

Make : American Electronic Laboratories Inc.

Horn Model No : H 1479	Bandwidth : 1 - 12.4 GHz.
Horn Model No : H 1498	Bandwidth : 2 - 18 GHz.

3-dB beamwidths of these two horns are same .

3 - dB Half beamwidth in E - Plane = 25 Deg.

3 - dB Half beamwidth in H - Plane = 22.5 Deg.

The electric field of an X - polarized transmiting horn with the above specified 3-dB beamwidths is simulated by

$$E(\theta,\phi) = (\cos\theta)^{3.52}\cos\phi\ \hat{\theta} - (\cos\theta)^{4.37}\sin\phi\ \hat{\phi}$$

Fig. 2.

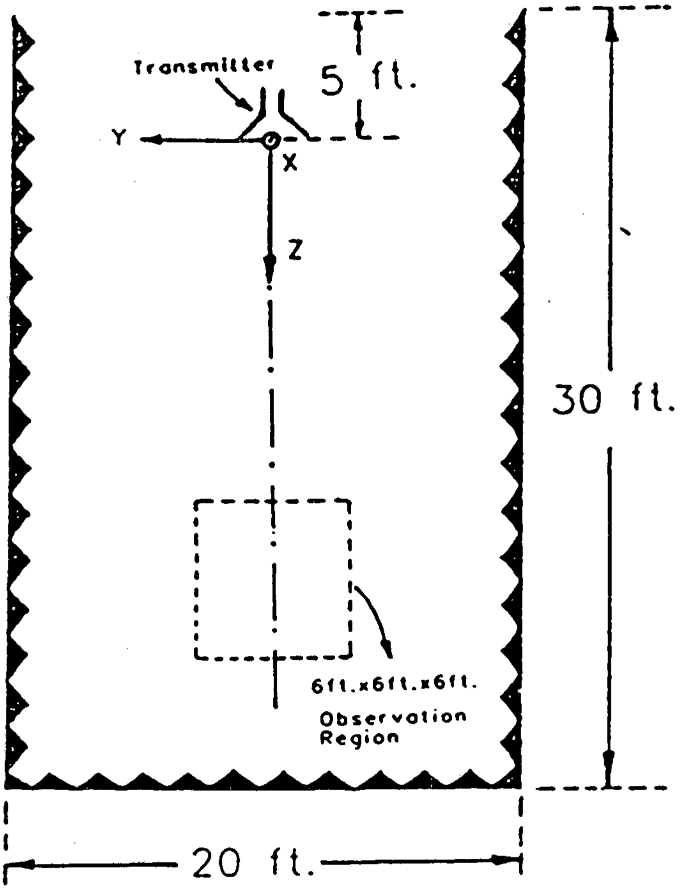


Table - 4

Location of the centre of the 6ftx6ftx6ft observation region on the z-axis	Reflectivity Level - (DB)						
	f = 1GHz.	f = 2GHz.	f = 3GHz.	f = 4GHz.	f = 5GHz.	f = 6GHz.	f = 10GHz.
10 ft.	-26.86	-34.76	-44.68	-47.01	-47.26	-47.08	-52.53
13 ft.	-23.36	-32.62	-42.41	-43.44	-45.34	-45.34	-49.61
16 ft.	-20.20	-28.95	-39.55	-41.93	-41.59	-41.59	-46.29
19 ft.	-17.65	-26.75	-36.51	-36.98	-39.71	-39.71	-44.43

Frequency = 1 G.Hz

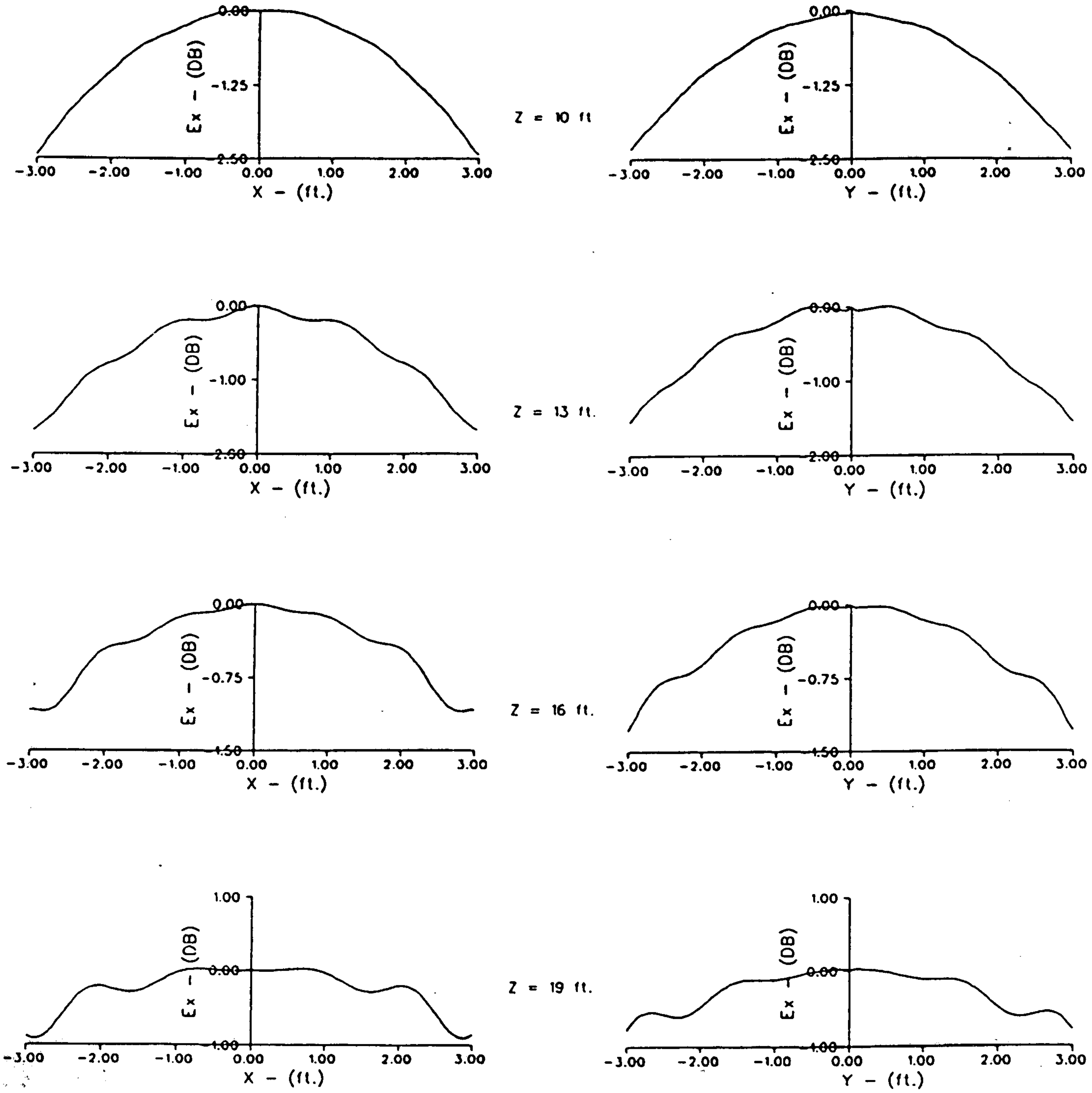


Fig. 3a. Amplititude variation, f = 1GHz

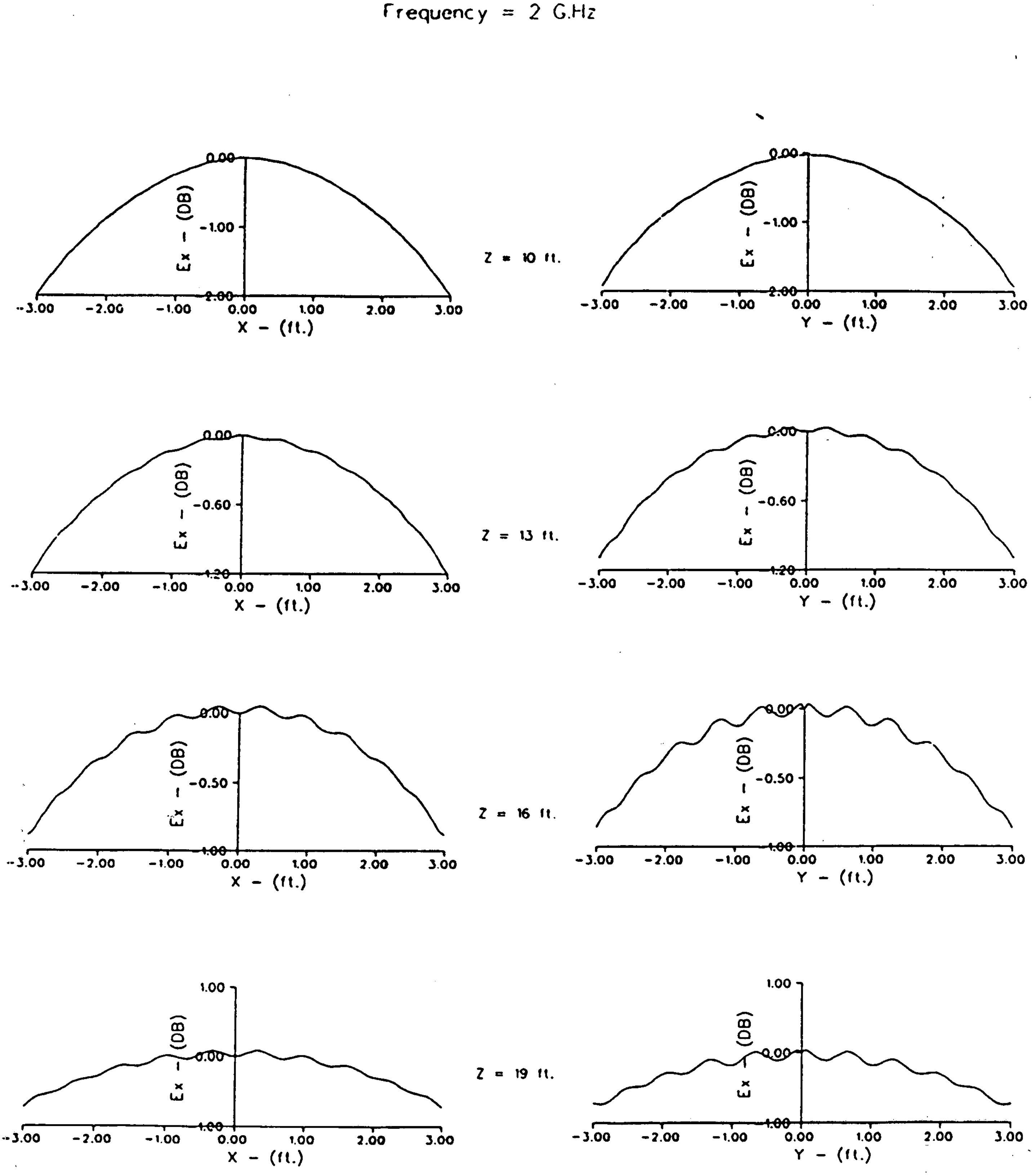


Fig. 3b. Amplitude variation, f = 2GHz

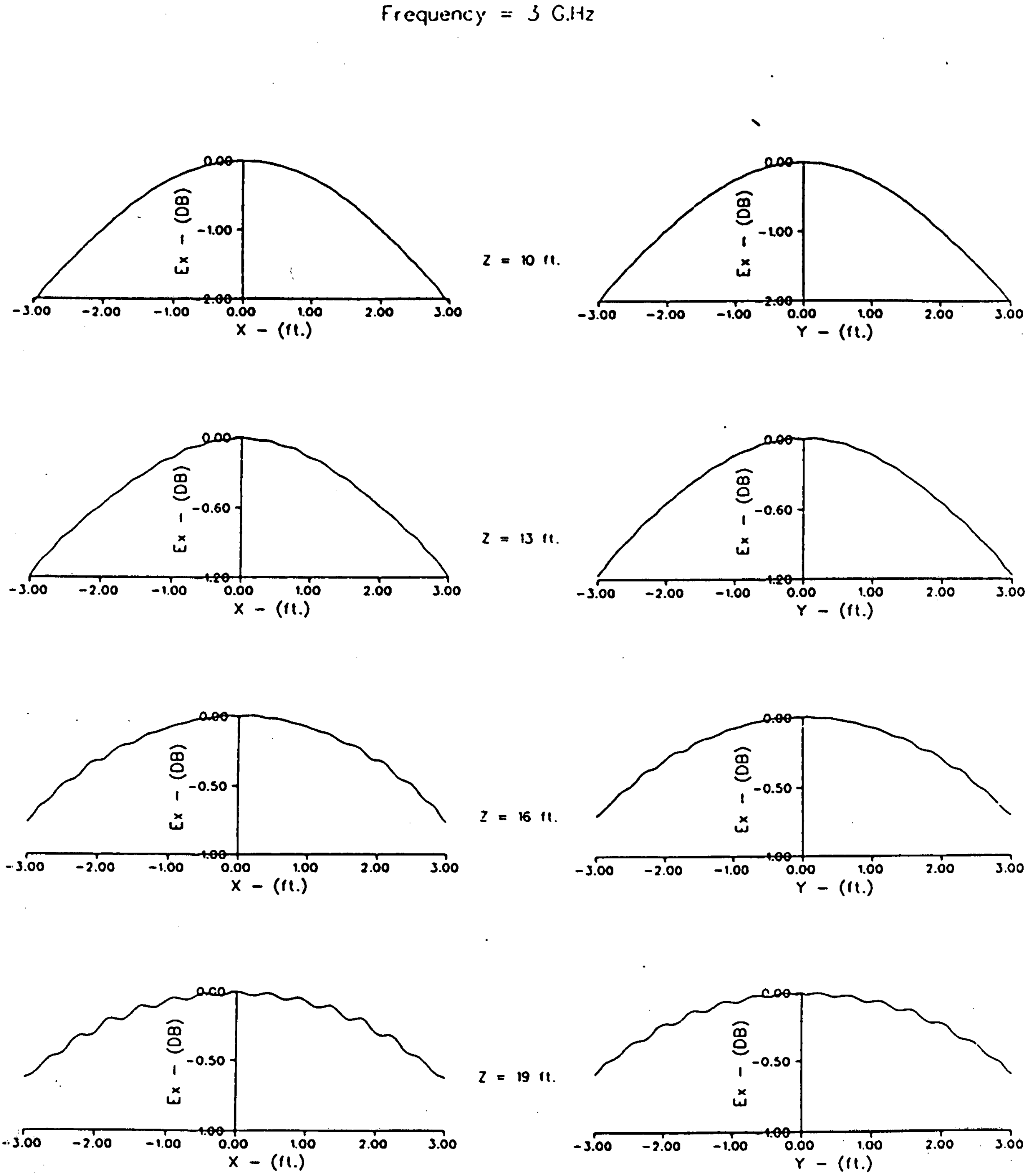


Fig. 3c. Amplitude variation, f = 3GHz

DESIGN OF A FACILITY FOR MEASURING ANTENNA PATTERNS AND RADAR CROSS-SECTIONS

FINAL REPORT
FOR

DEFENCE RESEARCH ESTABLISHMENT
SUFFIELD ALBERTA

PREPARED UNDER
CONTRACT NO. W7702-6-2111/01-SG

BY
E. BRIDGES, R. SMEGAL AND L. SHAFAI

EMWAVE TECHNOLOGY LIMITED
WINNIPEG MANITOBA

FEBRUARY 1988

Table of Contents

Frequency = 4 GHz

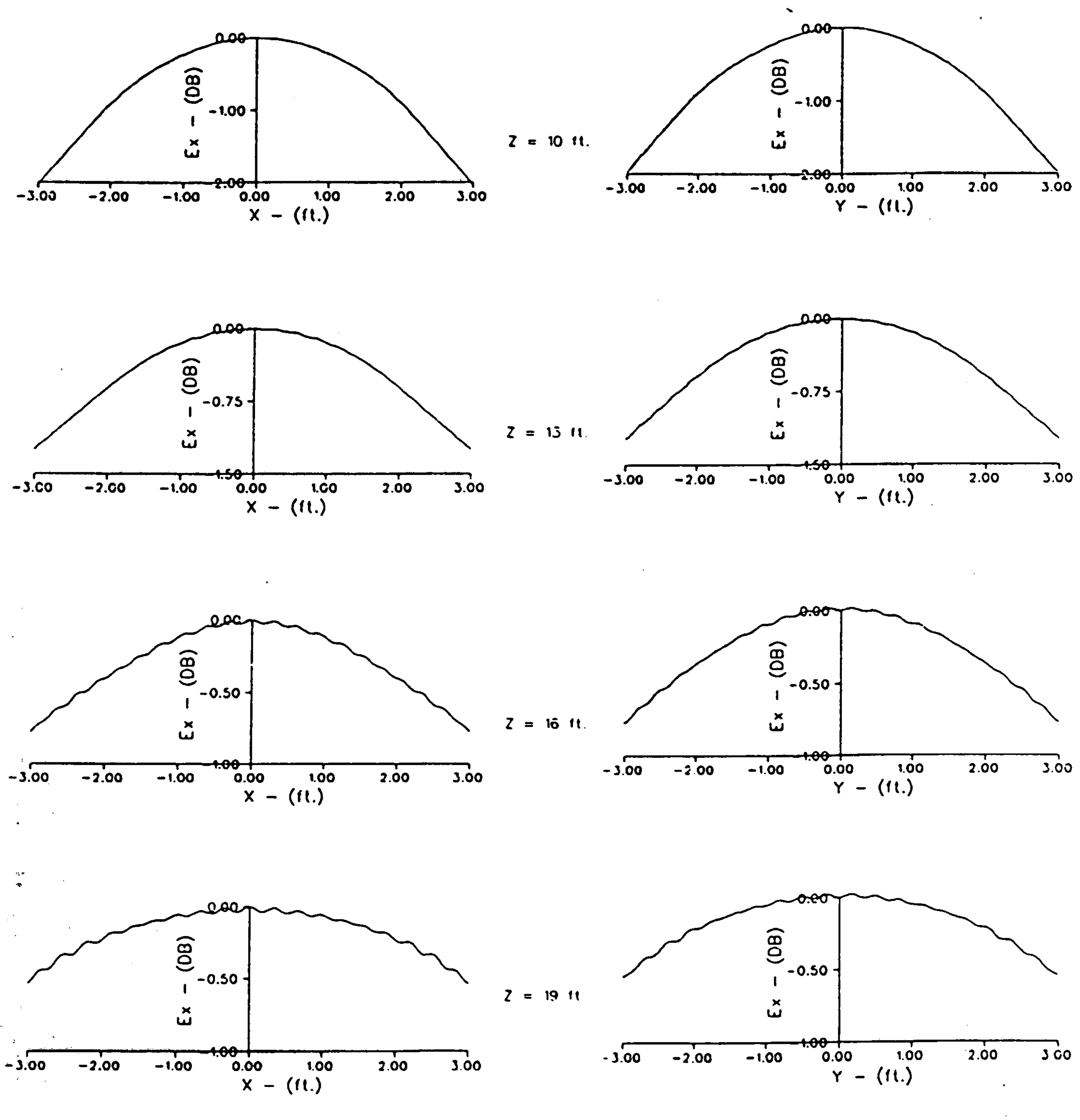
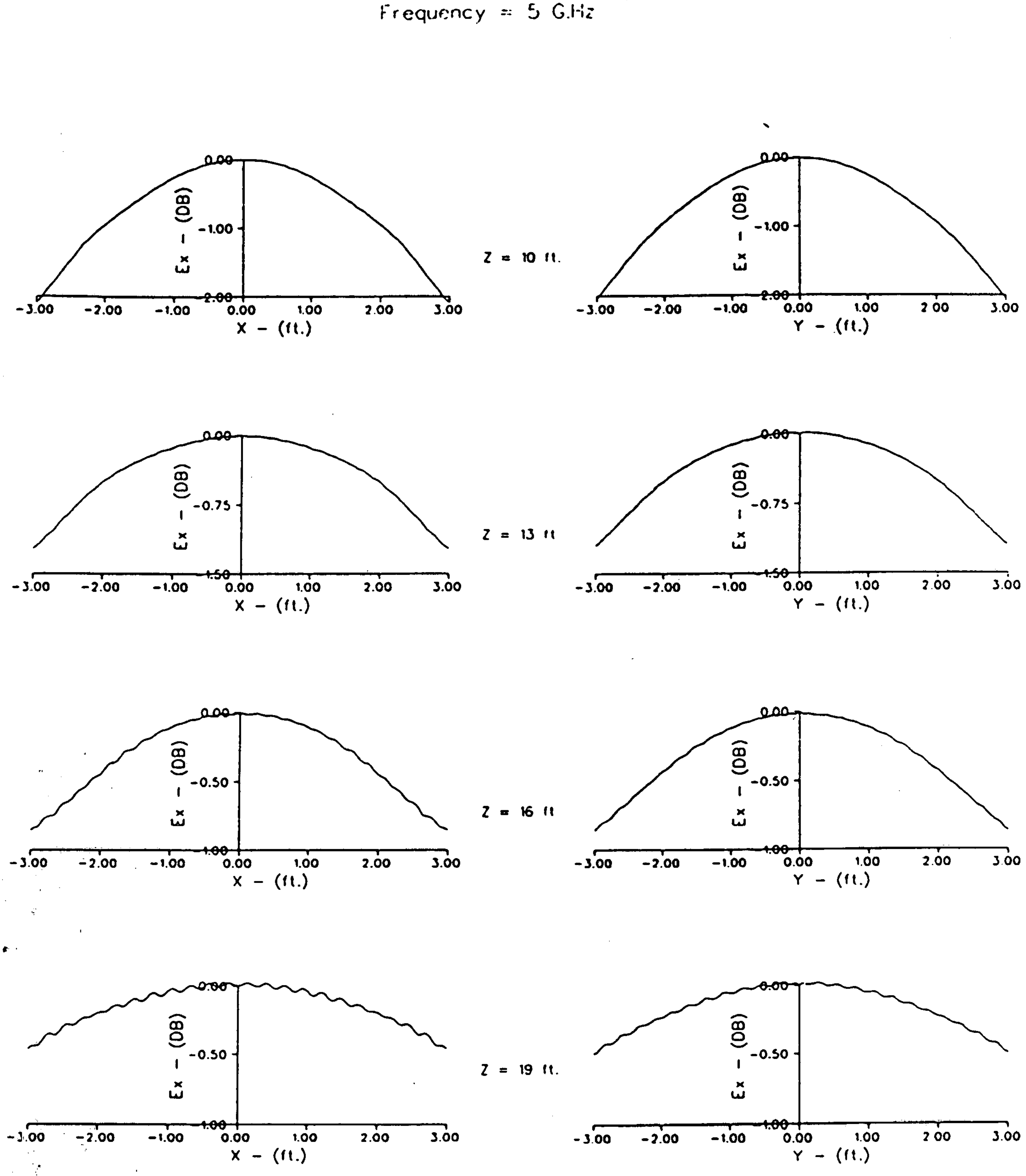


Fig. 3d. Amplitude variation, f = 4GHz



Frequency = 5 GHz

Fig. 3e. Amplitude variation, f = 5GHz

Frequency = 10 GHz

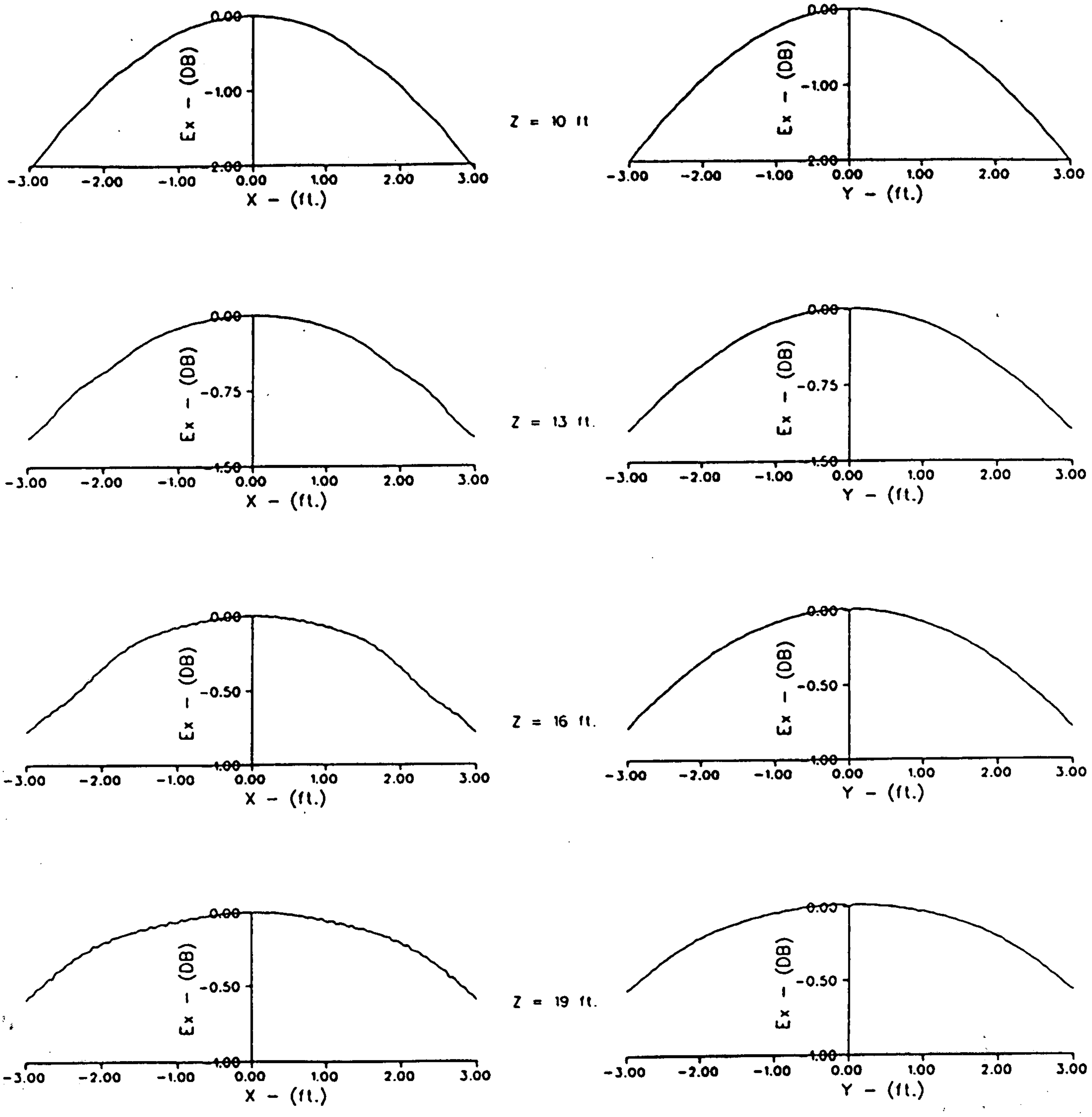


Fig. 3f. Amplitude variation, f = 10GHz

Frequency = 1 GHz

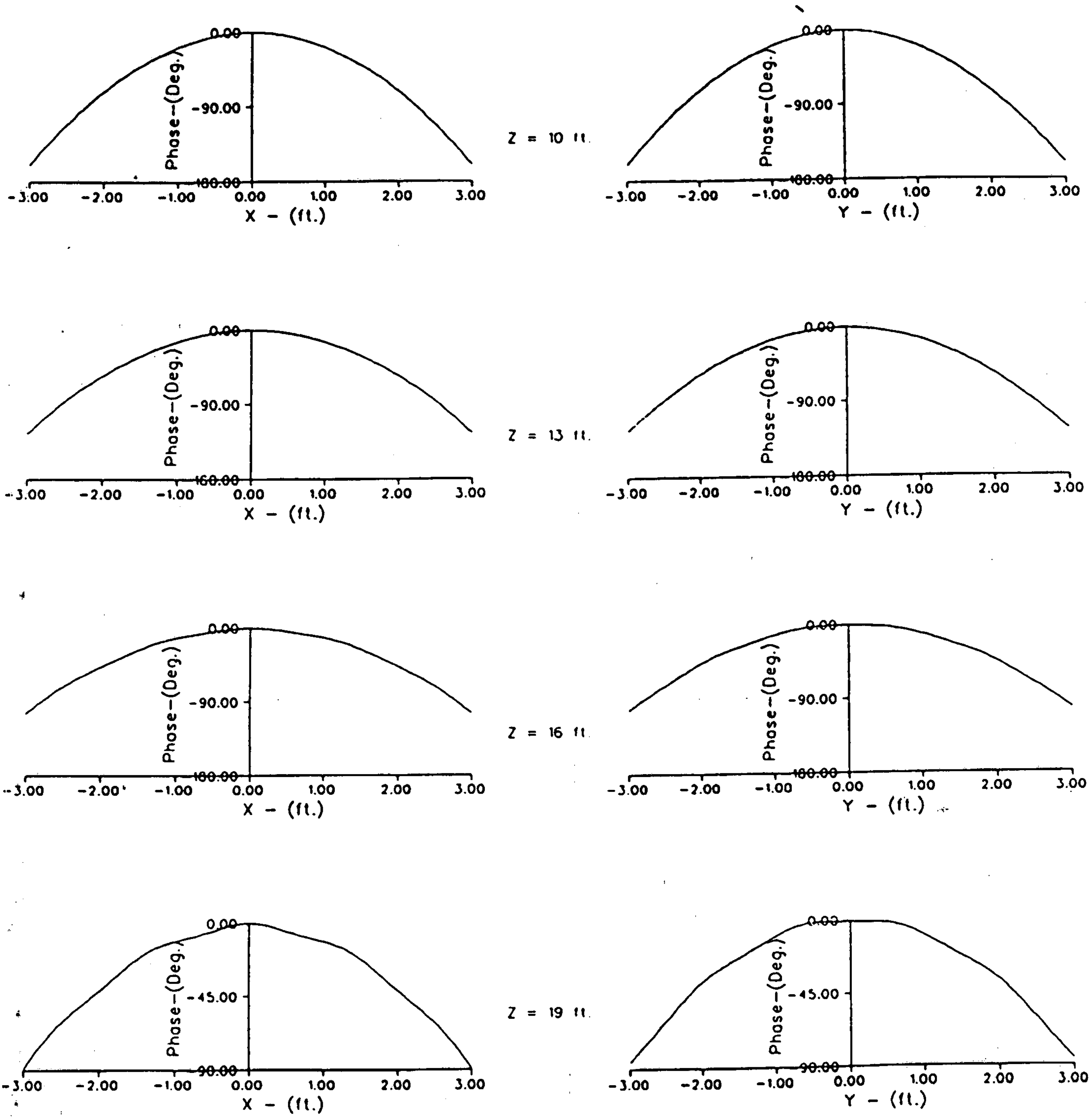


Fig. 4a. Phase variation, f = 1GHz

Frequency = 2 GHz

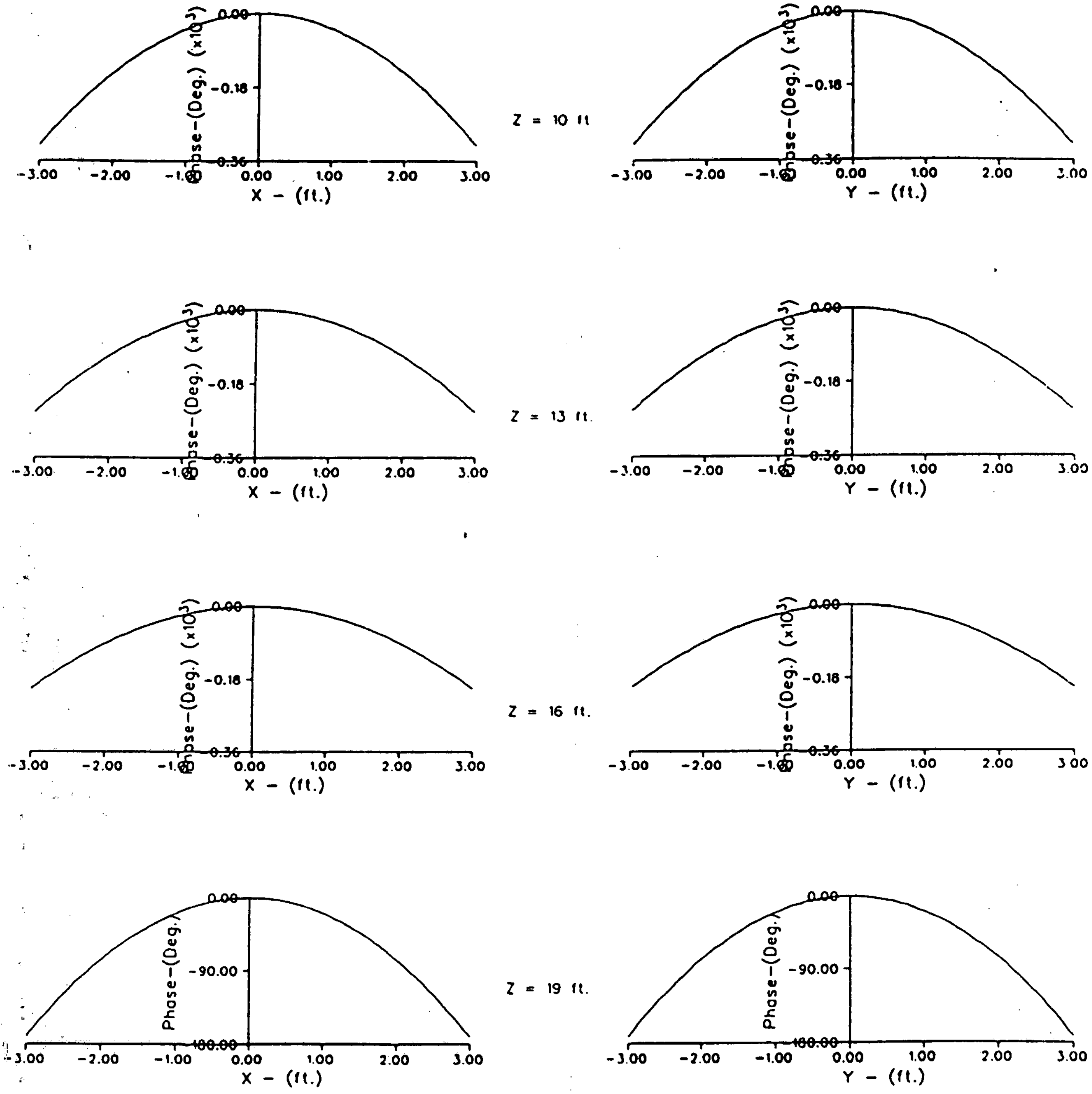


Fig. 4b. Phase variation, f = 2GHz

Frequency = 3 GHz

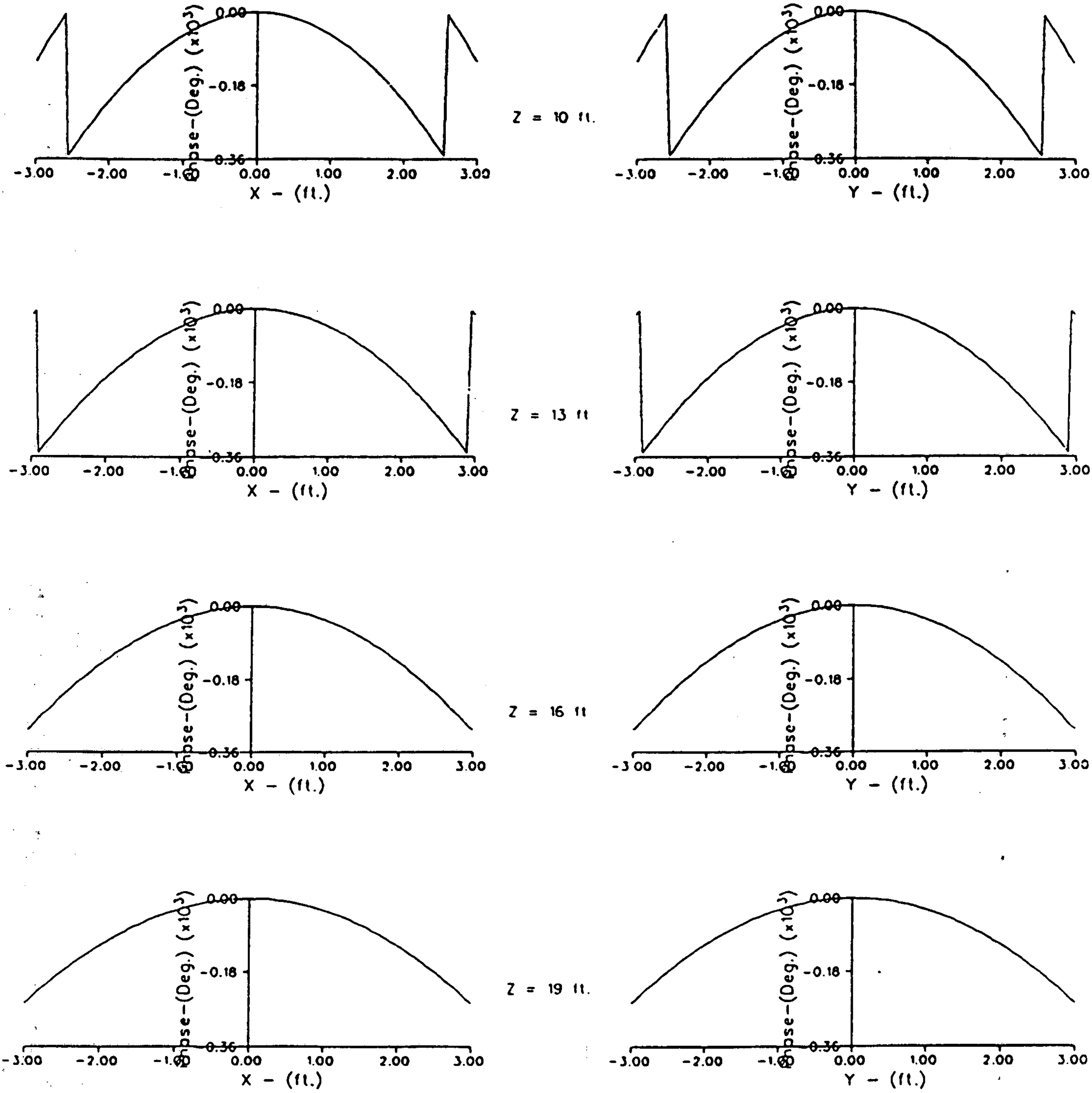


Fig. 4c. Phase variation, f = 3GHz

Frequency = 4 GHz

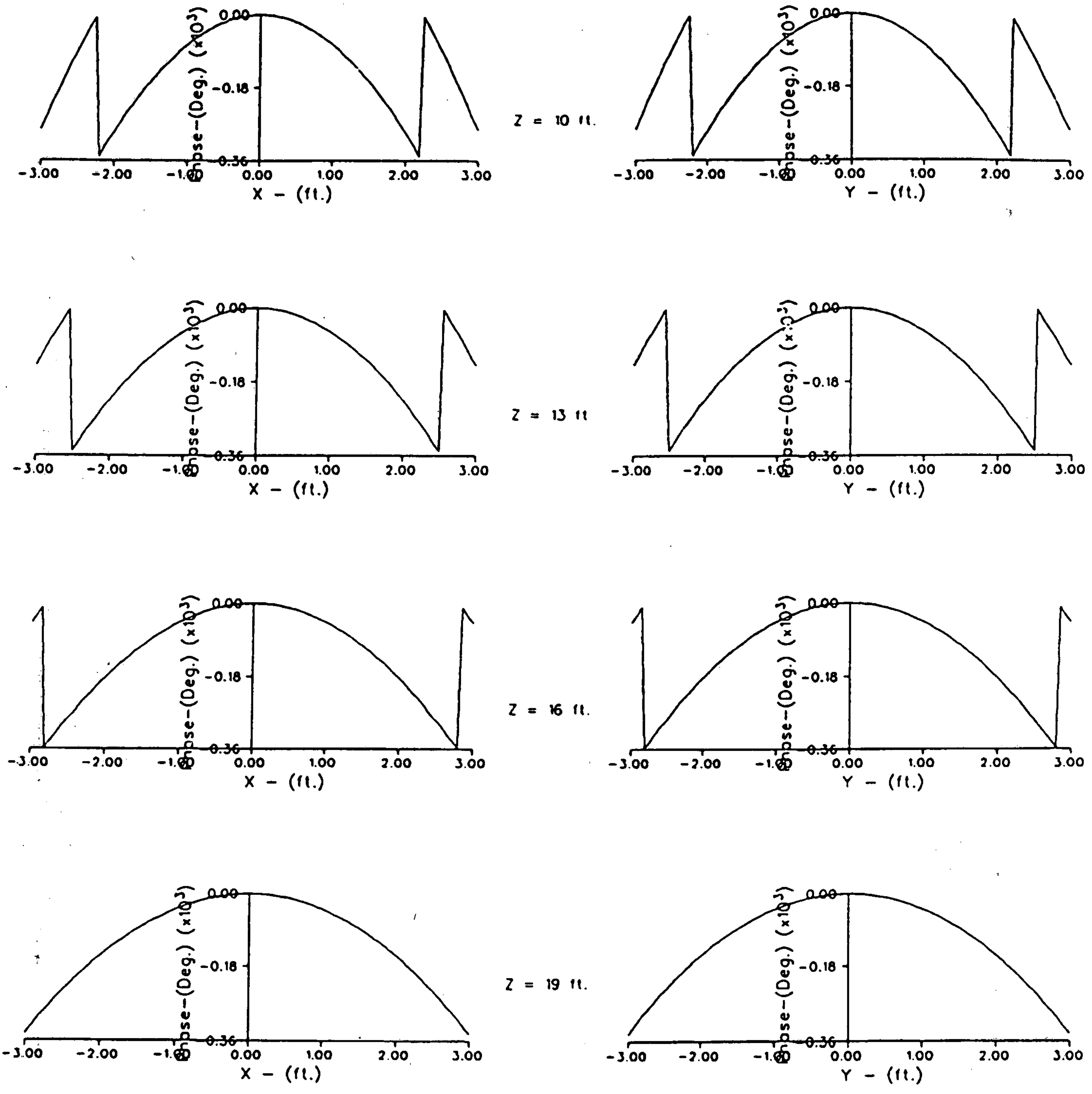


Fig. 4d. Phase variation, f = 4GHz

Frequency = 5 GHz

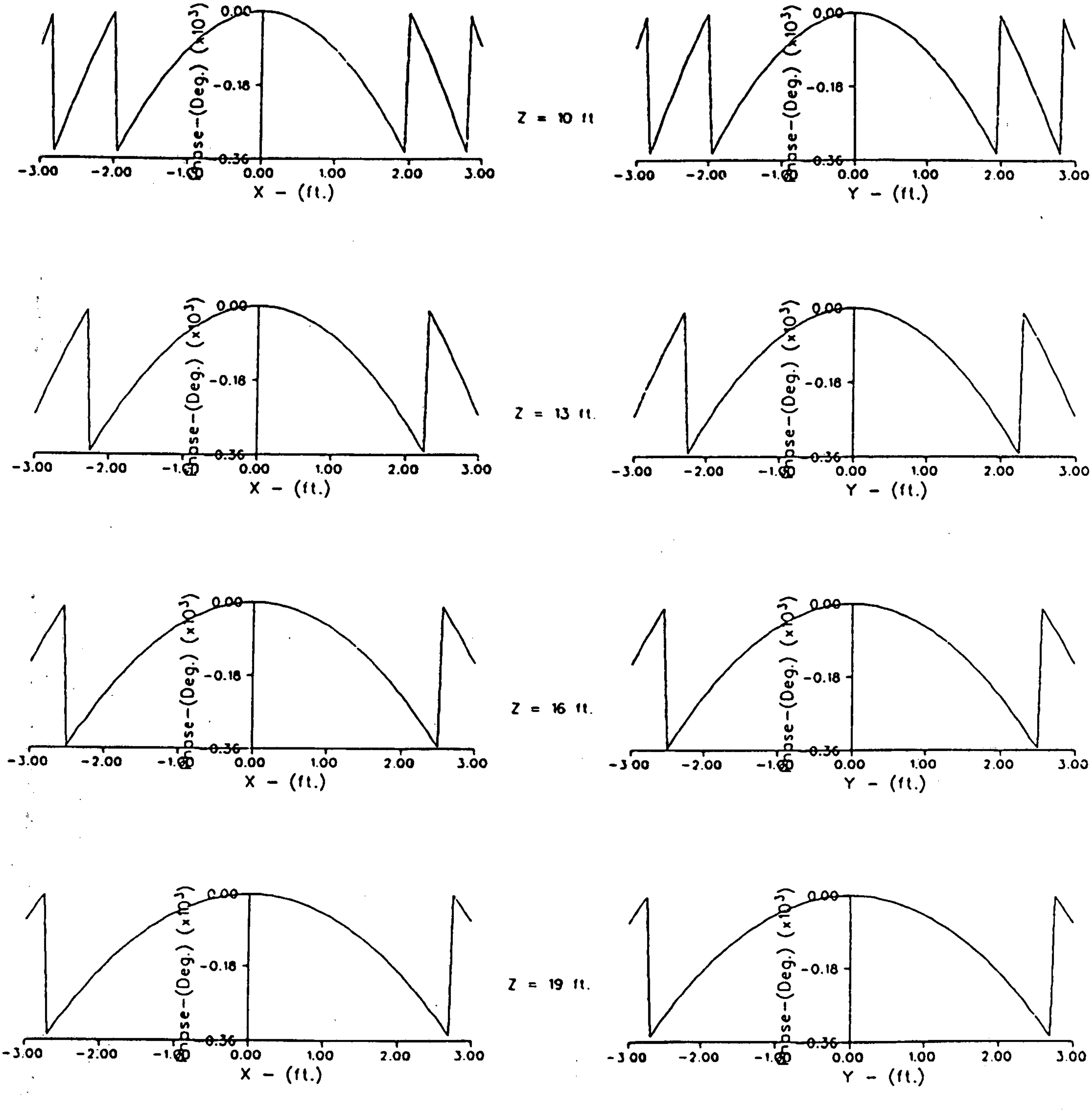


Fig. 4e. Phase variation, f = 5GHz

Frequency = 10 G.Hz

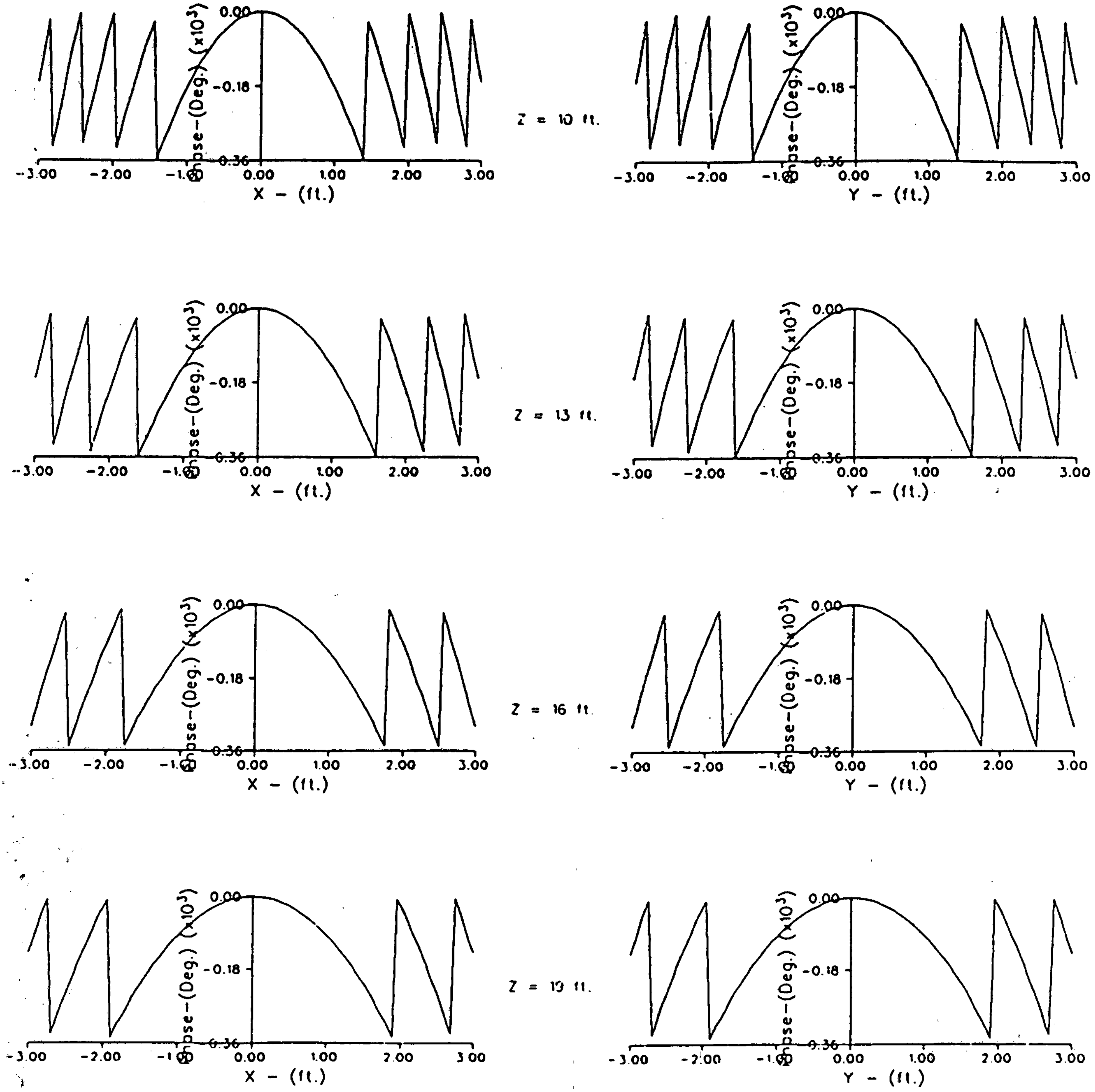


Fig. 4f. Phase variation, f = 10GHz

Table - 5

Frequency (GHz.)	λ (Cm.)	Maximum dimension (D) of the test antenna for a range R = 20 ft. $D = \sqrt{R\frac{\lambda}{2}}$ (Cm.)
1	30.00	95.62
2	15.00	67.62
3	10.00	55.21
4	7.50	47.81
5	6.00	42.76
6	5.00	39.04
7	4.285	35.14
8	3.75	33.81
9	3.333	31.87
10	3.00	30.24

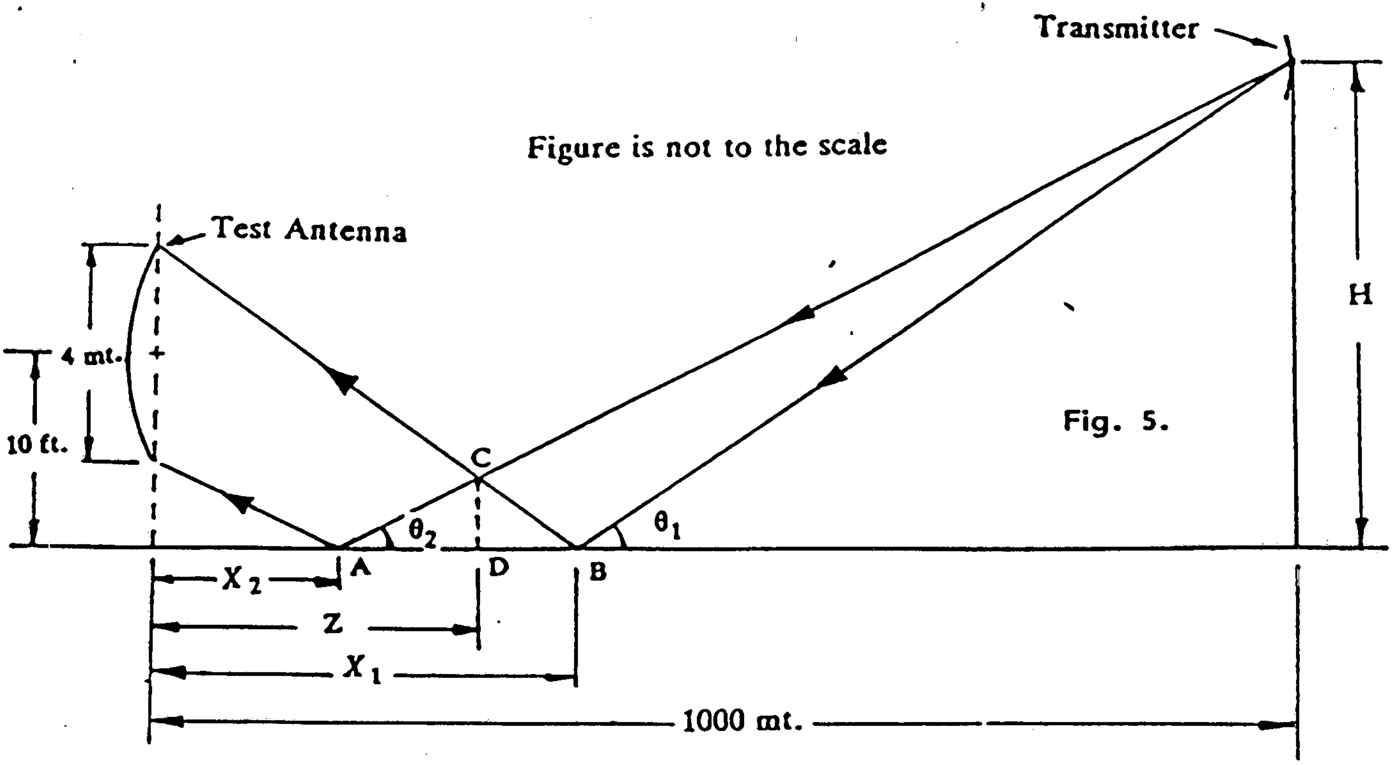


Figure is not to the scale

Fig. 5.

Table - 6

H (ft.)	Z (ft.)	CD (ft.)	X_1 (ft.)	θ_1 (Deg.)	X_2 (ft.)	θ_2 (Deg.)
90	328.08	5.90	509.90	1.86	120.73	1.63
85	345.35	5.87	535.01	1.77	127.55	1.54
80	364.54	5.83	562.71	1.68	135.20	1.46
75	385.98	5.79	593.44	1.60	143.81	1.37
70	410.10	5.74	627.72	1.51	153.61	1.28
65	437.44	5.68	666.20	1.42	164.83	1.20
60	468.69	5.62	709.71	1.34	177.82	1.11
55	504.75	5.55	759.29	1.25	193.03	1.02
50	546.81	5.47	816.33	1.16	211.10	0.933
45	596.52	5.37	882.63	1.08	232.89	0.846
40	656.17	5.25	960.65	0.988	259.69	0.759

Anechoic Chamber dimensions -20.0ft.X 20.0ft.X 30.0ft. 1.1

Transmitter location from the open-end of the Chamber - 5.0ft.

Frequency - 1.0GHz.

Z - 6.0ft. PLANE

X ---- (ft.)	Y ---- (ft.) 0	1	2	3	4	5	6	7
0	-37.30	-38.68	-36.92	-34.29	-31.11	-27.62	-23.94	-20.02
1	-36.65	-36.99	-35.89	-33.55	-30.53	-27.17	-23.60	-19.78
2	-34.80	-34.61	-33.59	-31.60	-28.93	-25.88	-22.58	-19.06
3	-31.99	-31.67	-30.64	-28.87	-26.54	-23.85	-20.87	-17.72
4	-28.53	-28.19	-27.21	-25.63	-23.60	-21.22	-18.48	-15.53
5	-24.70	-24.39	-23.49	-22.09	-20.34	-18.28	-15.72	-12.76
6	-20.82	-20.53	-19.69	-18.46	-17.03	-15.41	-13.17	-10.31
7	-17.15	-16.86	-16.04	-14.29	-13.74	-12.63	-10.94	-8.32

Z - 7.0ft. PLANE

X ---- (ft.)	Y ---- (ft.) 0	1	2	3	4	5	6	7
0	-35.77	-37.34	-36.06	-34.05	-31.45	-28.41	-25.16	-22.05
1	-35.29	-35.80	-35.16	-33.40	-30.92	-27.95	-24.73	-21.64
2	-33.50	-33.86	-33.25	-31.76	-29.50	-26.67	-23.55	-20.52
3	-31.79	-31.60	-30.92	-29.56	-27.50	-24.84	-21.86	-18.94
4	-29.16	-28.96	-28.31	-27.11	-25.25	-22.79	-29.03	-17.38
5	-26.25	-26.08	-25.55	-24.57	-22.95	-20.70	-18.29	-16.21
6	-23.13	-23.02	-22.67	-21.95	-20.52	-18.34	-16.18	-14.76
7	-19.77	-19.71	-19.53	-19.10	-17.78	-15.38	-13.15	-11.97

Z - 8.0ft. PLANE

X ---- (ft.)	Y ---- (ft.) 0	1	2	3	4	5	6	7
0	-34.41	-36.05	-34.98	-33.32	-31.21	-28.82	-26.23	-23.49
1	-34.06	-34.65	-34.22	-32.81	-30.86	-28.60	-26.14	-23.50
2	-33.05	-33.08	-32.66	-31.52	-29.86	-27.94	-25.87	-23.55
3	-31.46	-31.31	-30.75	-29.69	-28.29	-26.79	-25.26	-23.41
4	-29.39	-29.16	-28.48	-27.40	-26.13	-24.94	-23.78	-22.00
5	-26.92	-26.64	-25.83	-24.65	-23.40	-22.35	-21.23	-18.99
6	-24.17	-23.85	-22.53	-21.64	-20.39	-19.52	-18.58	-16.17
7	-21.34	-20.99	-20.01	-18.70	-17.58	-17.19	-16.94	-14.70

Z = 9.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-33.13	-34.83	-33.98	-32.69	-31.08	-29.23	-27.04	-24.35
1	-32.88	-33.53	-33.31	-32.23	-30.68	-28.79	-26.52	-23.83
2	-32.12	-32.22	-31.99	-31.10	-29.61	-27.61	-25.18	-22.49
3	-30.89	-30.83	-30.50	-29.67	-28.21	-26.09	-23.53	-20.90
4	-29.20	-29.13	-28.84	-28.14	-26.78	-24.64	-22.03	-19.74
5	-27.13	-27.12	-27.03	-26.66	-25.55	-23.48	-21.10	-19.43
6	-24.80	-24.90	-25.15	-25.27	-24.42	-22.20	-19.92	-19.12
7	-22.45	-22.67	-23.31	-23.87	-22.68	-19.65	-17.20	-16.65

Z = 10.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-32.12	-34.03	-33.66	-32.92	-31.67	-29.88	-27.92	-26.44
1	-31.79	-32.61	-32.86	-32.37	-31.30	-29.72	-28.00	-26.79
2	-30.89	-31.11	-31.29	-31.02	-30.28	-29.17	-28.08	-27.54
3	-29.57	-29.60	-29.54	-29.25	-28.73	-28.10	-27.64	-27.28
4	-28.04	-27.95	-27.67	-27.23	-26.74	-26.35	-25.97	-24.51
5	-26.38	-26.18	-25.63	-24.96	-24.42	-24.09	-23.40	-20.93
6	-24.45	-24.12	-23.33	-22.48	-22.02	-22.01	-21.43	-18.76
7	-21.91	-21.54	-20.67	-19.90	-19.87	-20.83	-21.12	-18.25

Z = 11.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-30.88	-32.44	-31.38	-30.02	-28.72	-27.54	-25.17	-24.12
1	-30.92	-31.49	-31.05	-29.87	-28.58	-27.33	-25.83	-23.68
2	-30.95	-30.98	-30.56	-29.53	-28.24	-26.81	-25.05	-22.81
3	-30.75	-30.62	-30.08	-29.08	-27.75	-26.17	-24.35	-22.34
4	-29.98	-29.83	-29.33	-28.40	-27.07	-25.50	-23.97	-22.76
5	-28.55	-28.50	-28.21	-27.42	-26.04	-24.47	-23.44	-23.53
6	-26.95	-27.05	-27.04	-26.25	-24.44	-22.52	-21.68	-22.36
7	-25.81	-25.96	-25.86	-24.40	-21.79	-19.56	-18.87	-19.54

Z = 12.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-30.16	-32.49	-33.16	-33.53	-32.56	-30.07	-27.15	-24.63
1	-29.62	-30.76	-31.96	-32.57	-31.91	-29.85	-27.25	-24.81
2	-28.31	-28.80	-29.74	-30.42	-30.19	-28.90	-27.09	-24.94
3	-26.86	-27.12	-27.72	-28.25	-28.17	-27.30	-25.93	-23.98
4	-25.73	-25.88	-26.25	-26.62	-26.58	-25.79	-24.26	-22.13
5	-24.97	-25.04	-25.25	-25.55	-25.66	-24.95	-23.10	-20.81
6	-24.19	-24.17	-24.23	-24.62	-25.20	-24.87	-22.80	-20.58
7	-23.21	-23.08	-23.03	-23.72	-25.09	-24.95	-22.01	-19.81

Z = 13.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-28.94	-30.23	-28.72	-27.45	-27.19	-28.00	-29.35	-32.45
1	-29.36	-29.72	-28.82	-27.68	-27.43	-28.22	-29.41	-31.34
2	-30.23	-30.07	-29.22	-28.15	-27.82	-28.37	-28.88	-28.56
3	-30.32	-30.10	-29.25	-28.17	-27.66	-27.85	-27.77	-26.48
4	-28.46	-28.39	-27.86	-26.95	-26.42	-26.56	-26.61	-25.37
5	-25.24	-25.36	-25.29	-24.71	-24.22	-24.37	-24.72	-23.77
6	-22.21	-22.48	-22.85	-22.64	-22.22	-22.39	-22.87	-21.87
7	-19.96	-20.34	-21.06	-21.26	-21.13	-21.71	-22.69	-21.40

Z = 14.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-28.25	-30.42	-30.12	-28.83	-26.66	-23.93	-22.13	-21.63
1	-27.75	-28.91	-29.64	-28.95	-27.02	-24.44	-22.86	-22.71
2	-26.51	-27.14	-28.20	-28.38	-27.11	-25.09	-24.22	-25.03
3	-25.78	-26.22	-27.04	-27.35	-26.54	-25.07	-24.81	-26.65
4	-26.86	-27.13	-27.40	-27.21	-26.44	-25.09	-24.71	-26.12
5	-30.20	-29.92	-28.48	-27.06	-26.19	-24.86	-23.97	-24.25
6	-33.32	-30.85	-26.96	-24.89	-24.25	-23.35	-22.55	-22.78
7	-27.16	-25.45	-22.60	-21.09	-20.93	-20.69	-20.45	-21.19

Z = 15.0ft. PLANE

	Y ---- (ft.)							
X ---- (ft.)	0	1	2	3	4	5	6	7
0	-27.53	-29.90	-29.75	-30.36	-34.35	-33.72	-28.03	-23.04
1	-26.88	-28.27	-29.32	-30.01	-31.66	-29.86	-25.86	-21.82
2	-25.22	-26.14	-27.57	-27.97	-27.28	-25.34	-22.75	-19.93
3	-23.93	-24.75	-26.19	-26.53	-25.58	-23.98	-22.03	-20.03
4	-22.87	-23.68	-25.16	-25.81	-25.54	-24.68	-23.44	-22.16
5	-21.64	-22.52	-24.24	-25.27	-25.35	-24.85	-24.22	-23.57
6	-22.12	-23.41	-26.32	-23.04	-26.26	-24.16	-23.49	-22.87
7	-25.36	-27.90	-35.16	-32.16	-24.88	-21.81	-21.33	-21.14

Z = 16.0ft. PLANE

	Y ---- (ft.)							
X ---- (ft.)	0	1	2	3	4	5	6	7
0	-26.15	-26.23	-23.76	-23.36	-24.27	-25.18	-27.87	-27.44
1	-28.09	-27.21	-25.01	-24.83	-26.24	-27.83	-31.00	-26.56
2	-32.27	-30.17	-27.34	-27.60	-30.45	-34.50	-31.30	-23.59
3	-32.80	-29.76	-26.42	-26.64	-29.79	-31.93	-26.84	-21.77
4	-26.97	-25.22	-22.88	-22.97	-25.03	-25.18	-22.26	-19.51
5	-23.52	-22.41	-20.80	-21.21	-23.40	-23.71	-21.45	-19.62
6	-22.05	-21.06	-19.78	-20.80	-24.01	-25.43	-23.46	-22.14
7	-21.04	-20.19	-19.33	-21.34	-26.80	-28.96	-23.43	-21.90

Z = 17.0ft. PLANE

	Y ---- (ft.)							
X ---- (ft.)	0	1	2	3	4	5	6	7
0	-26.06	-30.02	-30.33	-27.69	-24.04	-23.83	-27.22	-31.27
1	-24.11	-26.56	-29.16	-26.86	-23.27	-23.24	-26.00	-33.09
2	-21.80	-23.39	-25.82	-24.42	-21.69	-21.95	-24.17	-30.98
3	-22.93	-24.67	-27.27	-25.69	-22.95	-24.11	-29.25	-36.94
4	-27.15	-29.87	-31.23	-28.68	-25.54	-27.61	-34.89	-24.27
5	-27.48	-27.89	-25.90	-24.43	-22.59	-23.85	-26.82	-21.30
6	-22.21	-21.46	-20.03	-19.42	-18.72	-20.08	-22.46	-19.15
7	-19.61	-18.98	-18.03	-18.03	-18.15	-21.26	-26.66	-21.83

Z = 18.0ft. PLANE

				Y ---- (ft.)				
X ---- (ft.)	0	1	2	3	4	5	6	7
0	-25.22	-27.44	-26.38	-30.16	-31.54	-26.62	-22.75	-24.83
1	-23.86	-25.94	-27.25	-28.77	-26.21	-23.43	-20.85	-23.86
2	-21.63	-23.31	-25.32	-24.73	-22.27	-20.58	-19.02	-22.36
3	-21.58	-22.86	-24.15	-24.77	-23.42	-21.47	-19.94	-23.86
4	-21.42	-22.24	-22.91	-24.63	-24.53	-22.23	-21.07	-26.33
5	-24.01	-26.13	-28.40	-29.16	-25.09	-24.10	-25.00	-32.74
6	-24.75	-28.83	-33.74	-24.74	-20.99	-21.38	-22.83	-23.89
7	-18.58	-20.48	-21.85	-18.32	-16.52	-16.89	-18.56	-22.18

Z = 19.0ft. PLANE

				Y ---- (ft.)				
X ---- (ft.)	0	1	2	3	4	5	6	7
0	-23.70	-22.35	-20.20	-22.64	-25.04	-22.42	-19.08	-16.66
1	-28.45	-25.19	-22.85	-26.83	-31.71	-25.56	-21.22	-19.10
2	-36.06	-28.86	-25.57	-32.73	-48.22	-25.92	-21.87	-20.77
3	-25.64	-22.64	-20.76	-24.25	-26.54	-20.89	-18.13	-17.06
4	-22.25	-19.98	-18.59	-21.51	-23.32	-19.39	-17.46	-16.91
5	-24.96	-21.62	-19.97	-23.74	-27.43	-23.60	-21.21	-19.89
6	-31.02	-25.09	-23.00	-30.30	-42.82	-23.39	-22.40	-26.59
7	-24.39	-25.26	-24.43	-24.39	-20.77	-16.63	-17.57	-22.56

Z = 20.0ft. PLANE

				Y ---- (ft.)				
X ---- (ft.)	0	1	2	3	4	5	6	7
0	-23.47	-24.19	-22.29	-22.55	-23.70	-27.37	-20.40	-15.90
1	-22.35	-24.29	-24.10	-22.25	-22.76	-33.93	-23.95	-17.21
2	-21.27	-23.44	-24.18	-21.41	-21.81	-32.04	-25.49	-17.74
3	-26.03	-25.81	-24.00	-24.32	-26.56	-28.54	-20.67	-16.79
4	-24.21	-22.87	-21.30	-21.76	-23.48	-25.25	-18.67	-15.33
5	-18.65	-18.77	-18.28	-17.44	-18.69	-22.74	-17.26	-14.22
6	-19.70	-21.05	-21.15	-19.34	-21.93	-37.29	-22.03	-18.88
7	-24.37	-32.08	-34.14	-26.16	-33.22	-24.22	-20.28	-20.87

Z - 21.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-23.50	-35.96	-62.26	-26.10	-26.31	-26.32	-28.78	-20.92
1	-19.09	-23.47	-26.41	-20.31	-20.35	-23.12	-27.56	-17.89
2	-17.65	-20.82	-22.92	-18.60	-18.74	-21.31	-25.75	-17.30
3	-21.78	-26.63	-30.36	-23.80	-23.31	-23.04	-33.03	-21.89
4	-21.78	-27.67	-31.14	-21.76	-23.00	-28.73	-23.32	-16.81
5	-17.25	-20.17	-20.95	-16.75	-18.13	-22.74	-18.71	-14.09
6	-15.94	-18.56	-19.59	-16.21	-16.50	-18.62	-22.68	-15.16
7	-17.81	-20.46	-22.06	-19.52	-19.47	-21.78	-27.88	-19.71

Z - 22.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-22.11	-21.77	-21.41	-27.24	-20.45	-17.47	-21.69	-28.31
1	-20.93	-23.10	-24.57	-23.93	-20.87	-20.03	-32.55	-20.65
2	-19.74	-21.46	-22.85	-22.01	-19.58	-19.34	-37.03	-19.72
3	-19.76	-18.63	-18.86	-22.45	-17.81	-16.09	-21.60	-22.79
4	-24.57	-23.63	-24.27	-29.02	-22.38	-20.93	-25.00	-21.17
5	-21.88	-25.30	-27.13	-22.49	-20.67	-22.09	-30.62	-16.82
6	-16.13	-16.23	-16.75	-17.13	-14.31	-14.93	-23.11	-14.36
7	-18.30	-16.17	-16.60	-20.63	-15.51	-15.09	-19.70	-21.43

Z - 23.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-20.70	-17.86	-17.64	-23.30	-17.93	-15.54	-16.95	-30.41
1	-30.55	-22.72	-23.06	-35.20	-23.76	-20.08	-18.77	-23.93
2	-29.74	-22.01	-22.55	-40.98	-22.35	-19.69	-19.75	-24.07
3	-19.88	-16.24	-16.44	-21.78	-16.64	-15.02	-17.38	-25.35
4	-24.91	-19.78	-19.42	-23.18	-22.26	-17.55	-15.71	-25.27
5	-36.81	-23.92	-23.83	-29.92	-23.93	-20.71	-20.06	-20.88
6	-21.41	-17.13	-17.87	-23.99	-16.07	-16.13	-21.84	-19.10
7	-16.60	-13.91	-13.82	-16.31	-14.53	-12.12	-13.15	-23.20

Anechoic Chamber dimensions =20.0ft.X 20.0ft.X 30.0ft.

Transmitter location from the open-end of the Chamber = 5.0ft.

Frequency = 4.0GHz.

Z = 6.0ft. PLANE

	Y ---- (ft.)							
X ---- (ft.)	0	1	2	3	4	5	6	7
0	-57.33	-59.72	-57.85	-54.89	-51.82	-48.50	-44.94	-40.21
1	-56.67	-57.44	-56.59	-54.11	-51.08	-47.81	-44.62	-40.25
2	-54.88	-54.83	-54.02	-52.17	-49.45	-45.94	-43.02	-40.22
3	-52.31	-52.02	-50.94	-49.29	-47.39	-44.23	-40.90	-37.63
4	-48.80	-48.59	-47.61	-45.70	-44.86	-41.24	-38.72	-36.46
5	-44.79	-44.67	-44.27	-42.51	-41.18	-38.65	-36.41	-34.02
6	-40.82	-40.51	-40.12	-39.27	-37.60	-35.46	-33.52	-31.30
7	-37.88	-37.30	-35.91	-35.90	-33.73	-32.27	-30.67	-28.70

Z = 7.0ft. PLANE

	Y ---- (ft.)							
X ---- (ft.)	0	1	2	3	4	5	6	7
0	-55.75	-58.16	-56.84	-55.36	-52.97	-49.39	-46.10	-42.17
1	-55.36	-56.20	-55.85	-54.60	-52.17	-49.48	-45.68	-42.11
2	-53.98	-54.01	-53.68	-52.62	-50.07	-48.47	-45.37	-42.23
3	-51.50	-51.38	-50.95	-50.02	-47.67	-45.65	-42.88	-40.53
4	-48.78	-48.69	-48.51	-47.76	-45.59	-44.38	-42.07	-39.03
5	-46.17	-45.60	-44.84	-44.72	-42.27	-41.20	-39.10	-36.43
6	-43.33	-43.06	-41.82	-41.83	-39.37	-38.59	-36.80	-34.53
7	-40.74	-40.46	-38.85	-38.19	-36.82	-36.30	-34.57	-32.54

Z = 8.0ft. PLANE

	Y ---- (ft.)							
X ---- (ft.)	0	1	2	3	4	5	6	7
0	-54.44	-57.31	-56.33	-54.31	-51.79	-50.04	-46.10	-43.85
1	-53.93	-55.10	-54.96	-53.63	-52.17	-49.39	-46.62	-42.91
2	-52.50	-53.26	-53.03	-52.07	-51.77	-48.93	-47.23	-44.06
3	-51.51	-51.42	-50.96	-50.16	-48.85	-46.38	-44.68	-43.07
4	-49.64	-48.91	-47.81	-47.76	-46.63	-45.25	-42.73	-41.34
5	-46.93	-46.85	-45.77	-45.92	-43.88	-42.90	-39.89	-37.61
6	-45.45	-44.47	-42.73	-42.80	-41.84	-41.83	-38.91	-36.10
7	-42.54	-42.94	-40.31	-39.59	-38.80	-39.90	-37.89	-35.23

Z = 9.0ft. PLANE

				Y ---- (ft.)				
X ---- (ft.)	0	1	2	3	4	5	6	7
0	-53.06	-55.61	-54.19	-53.73	-52.14	-49.06	-48.33	-44.37
1	-53.48	-54.03	-53.92	-52.82	-51.14	-50.43	-47.49	-46.29
2	-52.81	-52.68	-52.53	-51.88	-51.03	-50.07	-48.82	-46.46
3	-50.95	-51.18	-50.46	-49.90	-49.80	-46.76	-45.39	-42.29
4	-49.25	-49.37	-48.19	-47.50	-47.25	-45.17	-44.78	-45.00
5	-47.84	-46.51	-45.64	-46.51	-45.29	-43.97	-40.57	-39.40
6	-44.63	-44.66	-42.94	-44.20	-42.22	-44.15	-40.43	-37.02
7	-43.42	-41.59	-40.57	-43.21	-38.78	-41.43	-40.97	-37.30

Z = 10.0ft. PLANE

				Y ---- (ft.)				
X ---- (ft.)	0	1	2	3	4	5	6	7
0	-52.00	-54.25	-52.88	-51.66	-52.87	-51.61	-50.05	-48.87
1	-51.95	-52.98	-53.54	-52.69	-51.38	-51.41	-50.32	-46.70
2	-52.08	-51.44	-51.79	-51.04	-51.46	-50.41	-45.96	-44.30
3	-51.31	-50.35	-50.26	-49.61	-49.56	-45.76	-45.79	-43.39
4	-47.86	-48.44	-47.40	-47.64	-47.42	-46.46	-46.06	-44.11
5	-45.90	-45.64	-45.42	-48.57	-44.75	-44.86	-41.29	-43.17
6	-43.76	-43.33	-45.79	-45.08	-42.15	-44.64	-41.83	-33.24
7	-41.11	-42.23	-44.17	-42.66	-41.01	-39.44	-41.82	-39.20

Z = 11.0ft. PLANE

				Y ---- (ft.)				
X ---- (ft.)	0	1	2	3	4	5	6	7
0	-51.00	-53.47	-51.35	-51.64	-53.35	-49.99	-45.42	-46.03
1	-50.49	-51.98	-52.31	-54.54	-51.06	-47.90	-47.35	-44.82
2	-51.98	-50.80	-51.01	-50.49	-49.27	-48.56	-46.07	-50.21
3	-49.53	-47.98	-49.26	-49.38	-48.37	-46.96	-50.57	-44.21
4	-46.93	-47.55	-48.85	-48.44	-47.02	-47.94	-42.89	-44.84
5	-46.50	-48.45	-47.66	-46.47	-44.45	-45.15	-45.96	-40.31
6	-48.84	-46.74	-45.71	-42.08	-47.15	-41.20	-42.83	-44.87
7	-44.09	-44.11	-40.55	-42.92	-41.69	-42.95	-37.92	-39.68

Z - 12.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-49.85	-50.80	-50.46	-51.91	-50.29	-50.87	-48.96	-45.98
1	-50.90	-51.29	-53.32	-53.41	-47.93	-48.81	-51.44	-43.24
2	-50.65	-48.46	-49.97	-48.61	-48.87	-51.31	-46.20	-43.66
3	-48.12	-47.01	-50.17	-49.23	-49.03	-47.44	-44.87	-46.27
4	-48.76	-50.41	-48.26	-46.73	-47.16	-46.00	-46.18	-43.04
5	-45.86	-45.96	-44.51	-46.35	-46.93	-44.60	-43.84	-43.64
6	-44.00	-42.91	-45.95	-47.48	-42.58	-44.97	-42.30	-40.23
7	-44.77	-47.69	-47.07	-40.85	-43.04	-39.70	-44.03	-40.45

Z - 13.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-48.73	-48.83	-51.32	-50.71	-56.69	-46.24	-46.41	-51.03
1	-51.87	-50.56	-52.21	-49.27	-50.53	-47.15	-50.07	-46.45
2	-48.26	-47.65	-49.47	-50.68	-49.15	-45.46	-54.44	-42.20
3	-47.99	-49.28	-47.28	-47.93	-46.47	-51.29	-44.13	-44.10
4	-44.26	-46.07	-46.18	-49.52	-47.13	-45.51	-44.93	-45.47
5	-48.34	-48.80	-49.35	-43.73	-45.68	-45.80	-44.08	-41.74
6	-44.65	-43.24	-41.60	-45.32	-46.12	-43.01	-43.93	-43.45
7	-40.59	-42.35	-46.55	-44.34	-41.26	-46.62	-40.18	-41.08

Z - 14.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-48.59	-55.15	-53.50	-52.39	-47.77	-47.76	-45.94	-51.35
1	-45.97	-49.10	-48.67	-50.30	-49.32	-48.77	-45.53	-50.44
2	-46.60	-48.93	-48.56	-46.36	-47.87	-48.98	-43.79	-43.84
3	-44.82	-46.64	-49.41	-48.38	-49.88	-43.70	-53.43	-41.03
4	-48.25	-46.46	-45.83	-44.32	-46.88	-49.69	-41.58	-50.34
5	-45.29	-44.35	-45.44	-51.15	-43.26	-44.96	-46.25	-40.82
6	-45.82	-46.12	-43.37	-40.96	-48.61	-42.92	-43.43	-42.95
7	-39.50	-40.18	-44.24	-51.81	-39.53	-45.78	-41.37	-42.80

Z - 15.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-47.03	-47.71	-47.05	-47.58	-45.88	-58.00	-45.78	-47.54
1	-49.00	-48.67	-48.71	-49.94	-45.56	-52.69	-45.89	-46.89
2	-47.78	-47.00	-48.41	-54.32	-47.27	-46.22	-44.69	-45.39
3	-47.14	-45.83	-44.04	-47.06	-48.19	-45.15	-46.31	-42.45
4	-49.99	-50.47	-48.08	-44.68	-45.64	-44.03	-44.45	-42.41
5	-41.67	-42.59	-44.02	-45.19	-46.82	-44.25	-42.74	-41.45
6	-47.41	-46.92	-44.59	-42.92	-41.42	-46.33	-42.64	-44.63
7	-40.76	-40.64	-42.05	-48.60	-41.94	-39.98	-41.65	-41.75

Z - 16.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-47.10	-52.76	-55.73	-50.30	-46.14	-47.73	-41.86	-51.47
1	-45.32	-47.99	-51.46	-48.72	-46.65	-48.83	-42.11	-48.16
2	-43.44	-44.48	-46.93	-45.69	-45.22	-50.38	-44.25	-42.63
3	-45.86	-45.95	-46.53	-46.13	-42.29	-45.91	-51.70	-40.14
4	-45.58	-46.34	-49.39	-51.46	-45.50	-40.45	-48.79	-46.86
5	-43.70	-42.98	-42.22	-45.36	-57.65	-44.58	-39.33	-47.05
6	-50.89	-49.70	-45.47	-40.76	-41.29	-57.66	-43.01	-39.71
7	-40.30	-41.44	-46.33	-52.47	-40.62	-38.18	-44.46	-41.60

Z - 17.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-45.08	-47.48	-45.86	-45.10	-49.82	-56.66	-47.07	-40.52
1	-45.19	-46.30	-45.63	-44.48	-47.86	-55.72	-48.66	-40.49
2	-45.90	-46.49	-46.21	-43.93	-44.28	-51.48	-49.75	-41.43
3	-47.47	-48.22	-48.99	-45.99	-42.47	-44.35	-50.31	-45.56
4	-43.71	-44.74	-48.03	-50.54	-45.48	-40.48	-44.31	-50.23
5	-39.93	-40.08	-41.25	-45.42	-52.64	-44.66	-37.78	-46.52
6	-44.32	-43.12	-40.57	-39.39	-43.45	-56.50	-43.35	-37.19
7	-43.50	-44.54	-48.11	-42.54	-37.21	-40.11	-47.96	-41.97

Z - 18.0ft. PLANE

X ---- (ft.)	Y ---- (ft.)							
	0	1	2	3	4	5	6	7
0	-44.73	-46.62	-44.19	-41.93	-42.08	-47.28	-43.53	-41.49
1	-45.52	-46.06	-44.36	-41.95	-41.65	-45.36	-44.17	-41.27
2	-48.55	-48.27	-46.10	-42.73	-41.02	-43.90	-46.59	-41.83
3	-53.45	-53.27	-51.09	-46.12	-41.84	-41.59	-47.48	-46.97
4	-47.33	-47.60	-48.01	-48.61	-45.74	-41.36	-41.64	-69.30
5	-41.93	-42.29	-43.12	-44.10	-47.13	-44.39	-37.63	-40.04
6	-39.92	-39.95	-40.23	-41.02	-44.76	-73.97	-43.10	-35.98
7	-44.54	-43.57	-41.18	-38.45	-37.45	-46.47	-46.30	-42.48

Z - 19.0ft. PLANE

X ---- (ft.)	Y ---- (ft.)							
	0	1	2	3	4	5	6	7
0	-44.91	-47.59	-46.29	-45.13	-43.49	-41.40	-45.72	-44.76
1	-45.23	-46.34	-46.25	-45.48	-43.82	-41.61	-45.97	-47.66
2	-45.40	-45.73	-46.04	-45.83	-43.95	-41.53	-45.93	-55.83
3	-44.62	-44.80	-45.22	-45.24	-42.74	-39.47	-41.55	-53.00
4	-44.85	-45.23	-46.53	-47.78	-44.52	-38.84	-37.61	-39.75
5	-42.80	-43.21	-45.53	-52.73	-56.84	-44.10	-38.63	-36.56
6	-39.66	-39.45	-39.94	-43.92	-51.25	-51.98	-42.69	-35.99
7	-40.25	-39.40	-37.92	-39.11	-44.80	-53.40	-41.30	-43.15

Z - 20.0ft. PLANE

X ---- (ft.)	Y ---- (ft.)							
	0	1	2	3	4	5	6	7
0	-44.54	-49.31	-53.24	-50.85	-45.82	-44.42	-40.17	-39.76
1	-43.41	-45.67	-49.34	-47.75	-44.11	-43.28	-39.96	-40.86
2	-41.36	-42.37	-44.65	-43.84	-41.09	-40.05	-37.48	-38.64
3	-41.63	-42.34	-44.36	-44.15	-41.04	-39.90	-36.82	-36.86
4	-45.07	-46.31	-49.84	-48.92	-44.06	-41.93	-37.58	-36.19
5	-43.78	-45.54	-50.31	-49.60	-44.03	-42.88	-38.65	-36.12
6	-42.66	-45.41	-54.80	-61.38	-47.75	-46.25	-43.12	-39.13
7	-38.16	-39.85	-45.51	-52.97	-45.18	-39.62	-37.18	-43.19

Z - 21.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-43.91	-51.57	-54.20	-50.58	-54.10	-46.71	-44.57	-41.05
1	-41.31	-44.55	-48.47	-46.14	-49.40	-44.13	-42.21	-38.21
2	-38.66	-40.37	-43.35	-42.30	-44.58	-42.41	-41.59	-37.81
3	-39.54	-41.38	-44.76	-43.59	-47.07	-44.04	-41.98	-38.20
4	-38.07	-39.64	-41.59	-40.38	-42.59	-41.34	-42.11	-40.59
5	-38.86	-40.73	-43.37	-41.57	-44.14	-43.21	-44.79	-42.94
6	-38.61	-40.47	-42.17	-39.23	-39.82	-38.88	-43.09	-57.59
7	-42.60	-45.69	-46.78	-39.70	-38.06	-35.63	-36.18	-41.22

Z - 22.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-43.21	-55.56	-58.35	-57.02	-55.44	-51.16	-54.60	-46.40
1	-39.15	-43.28	-47.44	-45.49	-47.87	-44.03	-44.47	-45.89
2	-36.98	-39.55	-42.40	-41.31	-43.08	-41.24	-41.87	-44.40
3	-37.88	-40.56	-41.84	-42.80	-43.30	-42.81	-41.39	-43.26
4	-36.56	-38.91	-40.05	-41.94	-42.80	-44.26	-43.58	-45.79
5	-36.63	-38.36	-38.42	-41.46	-40.48	-42.27	-41.07	-40.38
6	-36.77	-38.34	-38.48	-42.64	-40.83	-42.02	-41.45	-38.61
7	-35.28	-36.33	-36.85	-40.73	-39.56	-40.13	-41.45	-39.61

Z - 23.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-42.66	-47.31	-48.40	-43.28	-44.33	-43.29	-38.97	-35.01
1	-37.73	-42.16	-42.55	-38.99	-37.48	-37.60	-36.82	-35.95
2	-37.39	-41.38	-42.22	-39.43	-37.83	-38.06	-36.70	-34.41
3	-39.12	-43.83	-43.62	-42.44	-37.73	-36.76	-35.95	-34.57
4	-42.51	-52.82	-53.51	-49.47	-42.01	-39.91	-37.58	-35.21
5	-41.64	-48.91	-49.25	-45.55	-41.38	-41.81	-41.11	-37.61
6	-44.65	-47.97	-53.15	-48.05	-40.52	-39.37	-40.78	-39.57
7	-50.26	-48.45	-60.65	-49.78	-41.28	-38.47	-39.19	-40.80

Anechoic Chamber dimensions -20.0ft.X 20.0ft.X 30.0ft.

Transmitter location from the open-end of the Chamber = 5.0ft.

Frequency = 10.0GHz.

Z = 6.0ft. PLANE

X ---- (ft.)	Y ---- (ft.)							
	0	1	2	3	4	5	6	7
0	-62.39	-71.90	-69.43	-67.24	-64.47	-60.30	-56.65	-53.34
1	-61.63	-64.65	-66.32	-64.73	-62.06	-59.08	-56.07	-51.68
2	-59.95	-60.46	-61.29	-60.71	-59.01	-56.54	-53.65	-50.73
3	-57.17	-57.27	-57.13	-56.45	-55.06	-53.23	-51.02	-47.76
4	-53.49	-53.73	-53.18	-52.57	-51.14	-49.83	-47.48	-45.82
5	-50.13	-49.73	-49.62	-48.86	-47.35	-46.16	-44.52	-42.35
6	-45.81	-45.85	-45.34	-44.41	-44.06	-42.29	-41.03	-38.48
7	-42.11	-42.71	-41.45	-41.40	-39.53	-38.46	-38.15	-35.80

Z = 7.0ft. PLANE

X ---- (ft.)	Y ---- (ft.)							
	0	1	2	3	4	5	6	7
0	-60.69	-69.65	-69.18	-66.29	-64.64	-61.26	-57.51	-56.06
1	-60.34	-63.60	-65.36	-64.96	-62.74	-60.98	-56.91	-56.16
2	-59.00	-59.99	-60.74	-61.60	-60.34	-57.30	-56.12	-52.37
3	-56.94	-57.23	-56.98	-57.38	-56.17	-54.18	-53.00	-51.24
4	-53.93	-54.27	-53.94	-54.13	-52.78	-51.68	-49.22	-47.34
5	-51.20	-50.71	-51.49	-51.00	-49.59	-48.64	-46.82	-45.84
6	-48.38	-48.58	-47.20	-46.79	-47.65	-45.60	-44.37	-41.78
7	-44.44	-43.74	-44.73	-43.42	-43.65	-41.93	-42.08	-39.26

Z = 8.0ft. PLANE

X ---- (ft.)	Y ---- (ft.)							
	0	1	2	3	4	5	6	7
0	-59.63	-69.95	-66.85	-67.07	-64.61	-62.06	-60.83	-57.05
1	-58.63	-62.08	-65.07	-63.76	-62.66	-60.27	-58.86	-56.54
2	-58.23	-59.12	-60.23	-61.26	-61.32	-59.71	-57.52	-54.91
3	-56.58	-56.94	-56.85	-57.16	-56.97	-55.94	-55.20	-53.31
4	-54.69	-54.54	-53.93	-53.88	-53.42	-53.83	-51.36	-49.63
5	-52.42	-52.57	-51.89	-50.68	-50.49	-50.09	-50.20	-48.81
6	-48.65	-49.74	-47.97	-47.69	-47.97	-46.14	-45.63	-44.43
7	-45.45	-45.33	-46.07	-45.25	-44.95	-43.02	-42.98	-42.99

Z - 9.0ft. PLANE

	Y ---- (ft.)							
X ---- (ft.)	0	1	2	3	4	5	6	7
0	-58.27	-67.01	-66.22	-66.72	-64.83	-61.84	-60.19	-55.88
1	-58.01	-61.38	-63.97	-64.36	-62.32	-60.60	-59.95	-56.44
2	-56.79	-57.42	-59.95	-59.81	-60.18	-58.30	-57.60	-54.59
3	-55.47	-56.30	-56.85	-57.99	-57.80	-58.10	-55.07	-53.90
4	-54.62	-55.08	-53.80	-54.12	-54.21	-53.28	-52.29	-51.62
5	-53.06	-52.46	-51.67	-50.81	-51.05	-52.07	-50.71	-48.58
6	-51.06	-49.91	-49.62	-48.81	-50.08	-47.24	-47.46	-45.19
7	-49.53	-48.18	-47.49	-46.70	-48.11	-46.39	-45.73	-45.61

Z - 10.0ft. PLANE

	Y ---- (ft.)							
X ---- (ft.)	0	1	2	3	4	5	6	7
0	-56.95	-68.57	-68.31	-63.30	-62.67	-64.39	-59.44	-54.64
1	-56.19	-60.11	-65.29	-60.96	-63.14	-62.41	-57.87	-56.52
2	-55.77	-56.31	-59.01	-59.59	-60.99	-58.82	-57.81	-56.93
3	-55.51	-56.57	-55.92	-57.97	-58.18	-57.92	-55.99	-57.74
4	-54.05	-53.27	-54.27	-53.15	-53.74	-52.55	-55.99	-52.58
5	-50.79	-51.48	-53.09	-53.11	-54.69	-51.24	-52.27	-51.00
6	-50.35	-52.31	-48.74	-49.44	-48.01	-50.44	-47.92	-46.49
7	-51.52	-49.20	-47.44	-45.97	-49.13	-45.06	-45.94	-44.41

Z - 11.0ft. PLANE

	Y ---- (ft.)							
X ---- (ft.)	0	1	2	3	4	5	6	7
0	-55.46	-65.38	-70.59	-62.04	-64.60	-65.50	-59.59	-64.08
1	-55.08	-58.76	-64.17	-62.20	-61.03	-62.56	-57.93	-58.70
2	-54.39	-55.60	-58.75	-57.98	-59.87	-58.86	-53.87	-53.60
3	-54.44	-54.07	-56.14	-56.16	-57.08	-56.89	-55.55	-55.29
4	-54.11	-55.24	-52.90	-55.53	-56.06	-55.66	-53.28	-53.90
5	-50.31	-50.64	-54.14	-51.33	-51.23	-53.55	-50.19	-55.31
6	-52.51	-52.82	-48.59	-49.33	-48.83	-49.69	-48.85	-50.40
7	-46.20	-46.17	-52.27	-50.79	-51.25	-44.96	-47.57	-47.72

Z = 12.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-55.49	-68.82	-64.39	-59.59	-62.44	-67.31	-61.09	-56.14
1	-54.65	-58.32	-59.42	-63.97	-58.13	-57.77	-61.42	-58.54
2	-55.47	-56.45	-56.58	-61.37	-60.76	-56.11	-54.48	-59.28
3	-55.30	-54.03	-53.09	-57.58	-56.46	-56.11	-58.97	-57.64
4	-53.82	-54.84	-51.62	-56.60	-55.13	-56.01	-55.62	-53.68
5	-50.40	-52.55	-52.04	-53.88	-52.39	-53.71	-50.64	-51.33
6	-48.16	-48.07	-54.48	-48.79	-48.34	-52.88	-48.67	-56.70
7	-51.08	-47.95	-47.44	-45.86	-46.02	-50.84	-44.66	-47.01

Z = 13.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-53.22	-59.18	-59.60	-69.60	-58.17	-61.21	-65.45	-59.23
1	-55.11	-58.86	-62.55	-58.17	-69.07	-60.60	-60.52	-58.09
2	-55.41	-55.19	-55.28	-60.53	-57.42	-56.13	-55.72	-55.81
3	-52.53	-52.94	-52.56	-56.71	-57.82	-54.51	-56.80	-59.92
4	-52.00	-50.48	-52.49	-52.29	-56.77	-56.40	-58.37	-52.11
5	-50.91	-49.72	-51.93	-50.25	-52.65	-53.35	-50.20	-57.75
6	-49.40	-48.01	-49.04	-48.23	-49.32	-48.54	-49.79	-47.57
7	-50.52	-47.45	-47.28	-45.56	-46.66	-45.06	-56.22	-46.66

Z = 14.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-53.18	-59.62	-58.73	-66.74	-57.35	-63.70	-55.33	-58.82
1	-53.02	-56.86	-62.98	-59.66	-59.80	-53.61	-57.30	-57.51
2	-52.21	-51.98	-55.18	-60.75	-55.53	-59.22	-56.06	-55.84
3	-50.61	-52.29	-55.16	-53.92	-56.67	-55.15	-58.16	-64.06
4.	-54.27	-54.03	-51.07	-52.71	-52.27	-50.88	-50.97	-52.54
5	-51.96	-50.62	-49.15	-53.69	-53.28	-52.11	-53.65	-55.47
6	-48.67	-47.57	-49.50	-47.39	-53.67	-51.64	-48.57	-48.96
7	-45.48	-45.31	-52.78	-45.02	-46.08	-45.19	-51.24	-47.02

Z = 15.0ft. PLANE

X ---- (ft.)	Y ---- (ft.) 0	1	2	3	4	5	6	7
0	-51.28	-57.32	-56.81	-63.74	-56.26	-57.20	-55.64	-58.17
1	-52.72	-54.90	-54.87	-60.38	-57.30	-56.69	-54.73	-56.93
2	-53.31	-55.23	-55.61	-54.13	-64.50	-54.43	-54.64	-59.96
3	-49.93	-50.35	-53.61	-55.37	-53.28	-53.71	-57.72	-56.77
4	-51.88	-53.15	-51.40	-52.03	-53.31	-57.25	-56.24	-58.21
5	-49.49	-48.68	-49.98	-54.00	-50.42	-49.91	-48.63	-51.11
6	-47.54	-48.89	-54.71	-46.38	-47.66	-52.73	-50.46	-44.90
7	-54.52	-52.57	-45.16	-54.45	-47.12	-47.78	-55.54	-48.49

Z = 16.0ft. PLANE

X ---- (ft.)	Y ---- (ft.) 0	1	2	3	4	5	6	7
0	-51.43	-62.90	-71.43	-61.30	-53.08	-71.36	-52.83	-53.29
1	-50.27	-54.63	-64.39	-62.70	-54.55	-62.52	-57.86	-52.32
2	-48.85	-50.29	-54.81	-56.87	-55.38	-56.39	-57.81	-52.05
3	-49.61	-49.60	-51.49	-57.29	-51.17	-62.84	-54.17	-53.28
4	-55.03	-53.28	-49.16	-51.05	-52.69	-56.04	-54.01	-49.24
5	-46.64	-48.15	-53.02	-47.42	-55.16	-50.72	-49.54	-46.40
6	-50.18	-47.21	-45.79	-54.57	-47.02	-47.94	-48.62	-45.55
7	-46.03	-50.09	-51.75	-45.52	-46.32	-51.28	-51.93	-46.83

Z = 17.0ft. PLANE

X ---- (ft.)	Y ---- (ft.) 0	1	2	3	4	5	6	7
0	-49.28	-54.58	-55.62	-53.18	-69.04	-53.66	-54.58	-53.42
1	-51.21	-54.03	-60.25	-60.64	-56.74	-54.83	-54.49	-55.38
2	-48.99	-49.41	-54.03	-59.19	-54.78	-65.53	-51.40	-59.59
3	-48.89	-49.29	-52.77	-56.31	-49.41	-56.38	-52.71	-60.53
4	-47.20	-48.42	-49.95	-59.55	-49.65	-58.45	-48.52	-48.13
5	-51.30	-48.37	-46.76	-52.40	-47.45	-54.83	-47.75	-47.92
6	-54.39	-55.10	-49.46	-47.53	-50.33	-57.40	-48.73	-47.67
7	-44.11	-46.64	-54.64	-43.64	-62.20	-47.97	-46.15	-47.20

Z = 18.0ft. PLANE

				Y ---- (ft.)				
X ---- (ft.)	0	1	2	3	4	5	6	7
0	-49.84	-54.79	-52.26	-51.27	-52.59	-67.51	-51.03	-53.14
1	-47.92	-52.00	-54.25	-61.41	-53.34	-50.38	-53.80	-52.98
2	-53.25	-55.05	-57.11	-54.24	-50.59	-53.33	-53.20	-52.57
3	-55.34	-52.16	-52.39	-50.21	-52.23	-57.91	-52.69	-70.75
4	-53.94	-53.00	-51.28	-48.10	-53.45	-47.50	-52.40	-46.11
5	-52.93	-57.95	-50.21	-46.85	-56.28	-48.83	-53.64	-55.30
6	-49.55	-53.23	-50.97	-44.77	-54.10	-43.75	-51.18	-53.85
7	-46.78	-47.80	-57.20	-43.68	-55.02	-43.91	-44.29	-51.03

Z = 19.0ft. PLANE

				Y ---- (ft.)				
X ---- (ft.)	0	1	2	3	4	5	6	7
0	-48.23	-52.44	-52.91	-53.00	-52.78	-55.03	-65.04	-49.62
1	-49.08	-52.87	-57.82	-67.69	-57.80	-52.65	-54.52	-53.38
2	-49.24	-48.62	-50.83	-51.89	-54.23	-63.20	-53.42	-51.49
3	-46.91	-46.29	-49.60	-53.97	-56.66	-50.80	-54.32	-55.92
4	-48.84	-48.65	-52.00	-50.40	-48.18	-52.67	-48.49	-47.35
5	-53.05	-55.62	-52.98	-48.30	-48.19	-56.96	-47.14	-55.68
6	-51.95	-54.07	-49.07	-43.25	-48.87	-46.54	-52.26	-43.02
7	-55.70	-55.81	-45.69	-42.00	-61.60	-41.75	-52.99	-50.52

Z = 20.0ft. PLANE

				Y ---- (ft.)				
X ---- (ft.)	0	1	2	3	4	5	6	7
0	-46.39	-51.69	-51.26	-51.60	-54.52	-53.20	-54.05	-55.12
1	-48.06	-50.55	-51.12	-53.03	-52.08	-50.29	-51.08	-52.62
2	-50.16	-51.18	-53.26	-59.91	-51.36	-48.83	-49.77	-55.62
3	-45.80	-46.30	-46.04	-48.76	-49.43	-60.28	-52.00	-47.46
4	-47.83	-48.96	-50.56	-60.34	-52.80	-49.33	-49.72	-51.12
5	-52.34	-53.08	-51.65	-45.88	-47.05	-54.26	-51.73	-50.42
6	-45.90	-44.88	-43.95	-43.20	-52.77	-49.13	-47.71	-49.43
7	-41.77	-41.17	-41.63	-46.71	-51.92	-43.25	-60.63	-45.31

Z - 21.0ft. PLANE

X ---- (ft.)	Y ---- (ft.) 0	1	2	3	4	5	6	7
0	-51.03	-69.75	-59.15	-59.79	-59.94	-61.79	-53.51	-55.41
1	-49.88	-55.35	-68.15	-55.66	-79.07	-56.67	-58.72	-53.44
2	-44.43	-45.53	-49.05	-48.91	-51.48	-54.04	-56.20	-49.93
3	-45.14	-45.36	-47.02	-49.17	-48.14	-52.25	-54.03	-48.73
4	-45.35	-46.32	-50.14	-55.48	-52.50	-48.95	-45.54	-47.59
5	-46.63	-46.12	-45.24	-44.00	-43.69	-50.25	-66.07	-46.10
6	-41.37	-41.76	-42.62	-47.09	-71.72	-44.69	-46.74	-49.68
7	-45.16	-47.59	-55.50	-46.89	-42.36	-43.04	-53.92	-44.47

Z - 22.0ft. PLANE

X ---- (ft.)	Y ---- (ft.) 0	1	2	3	4	5	6	7
0	-45.01	-50.38	-49.72	-49.77	-47.56	-51.96	-48.48	-53.64
1	-46.19	-48.82	-51.03	-53.50	-51.36	-63.84	-47.82	-56.25
2	-47.19	-47.38	-48.87	-47.94	-45.90	-49.62	-45.41	-71.25
3	-45.19	-45.09	-46.33	-48.91	-47.50	-49.07	-44.43	-59.19
4	-52.56	-51.25	-53.25	-55.04	-53.94	-49.91	-50.31	-43.86
5	-42.61	-42.57	-44.69	-46.35	-45.80	-50.54	-55.46	-47.17
6	-59.82	-61.34	-58.83	-52.64	-46.28	-41.19	-46.59	-43.26
7	-40.56	-41.18	-40.58	-41.74	-44.16	-49.65	-43.78	-44.96

Z - 23.0ft. PLANE

X ---- (ft.)	Y ---- (ft.) 0	1	2	3	4	5	6	7
0	-44.51	-48.70	-50.45	-51.92	-54.84	-50.70	-54.33	-44.18
1	-46.26	-49.26	-51.14	-52.12	-51.54	-48.70	-50.58	-45.65
2	-44.45	-45.99	-48.43	-52.61	-50.61	-45.49	-49.19	-56.16
3	-41.53	-43.54	-44.33	-47.20	-48.88	-45.15	-48.22	-55.95
4	-41.75	-43.68	-44.25	-46.90	-49.75	-46.03	-46.76	-56.01
5	-52.23	-57.07	-73.86	-60.37	-55.08	-54.55	-52.16	-50.59
6	-41.58	-40.01	-40.60	-41.71	-42.41	-41.61	-47.00	-44.20
7	-61.33	-54.10	-54.73	-50.06	-44.39	-42.42	-39.85	-45.11

Top View

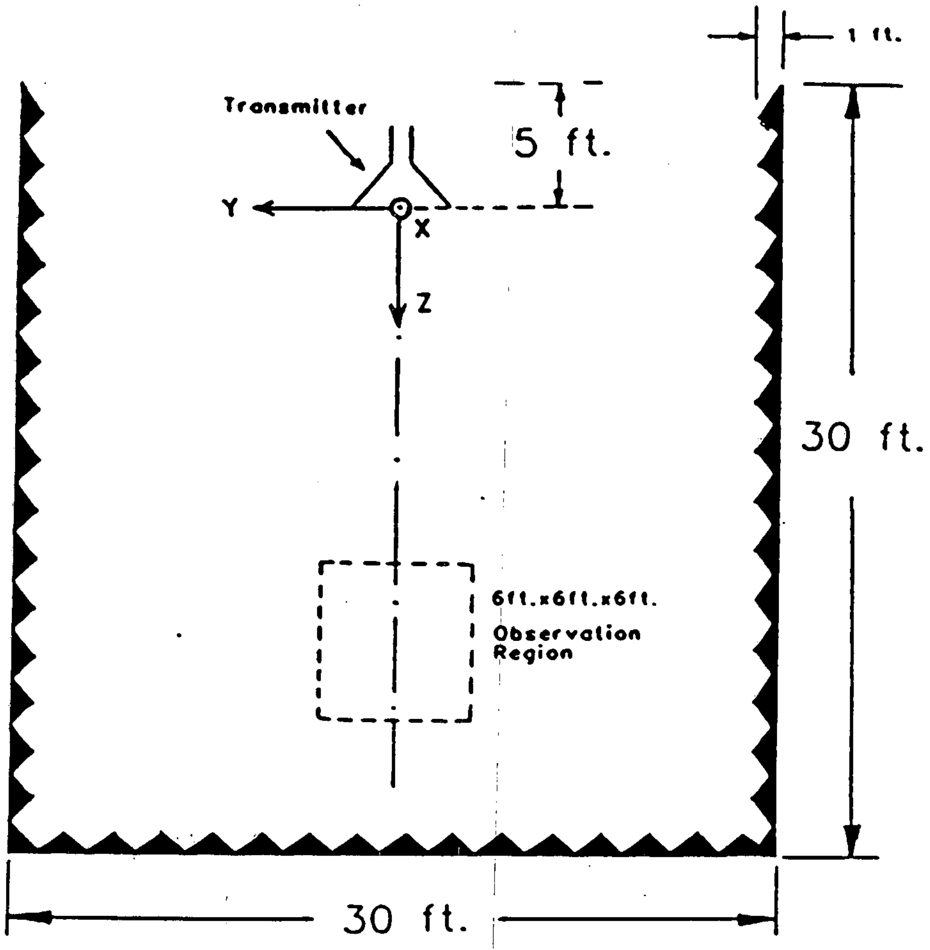


Fig. 6

Table - 7

Location of the centre of the 6ftx6ftx6ft observation region on the z-axis	Reflectivity Level - (DB)						
	f = 1GHz.	f = 2GHz.	f = 3GHz.	f = 4GHz.	f = 5GHz.	f = 6GHz.	f = 10GHz.
10 ft.	-26.97	-36.46	-44.85	-46.46	-46.85	-47.61	-52.37
13 ft.	-23.80	-34.80	-41.98	-44.28	-44.37	-45.74	-49.37
16 ft.	-21.76	-30.94	-39.59	-44.28	-41.76	-42.45	-46.21
19 ft.	-19.25	-28.39	-38.01	-39.08	-39.58	-38.56	-44.07

Frequency = 1 G.Hz

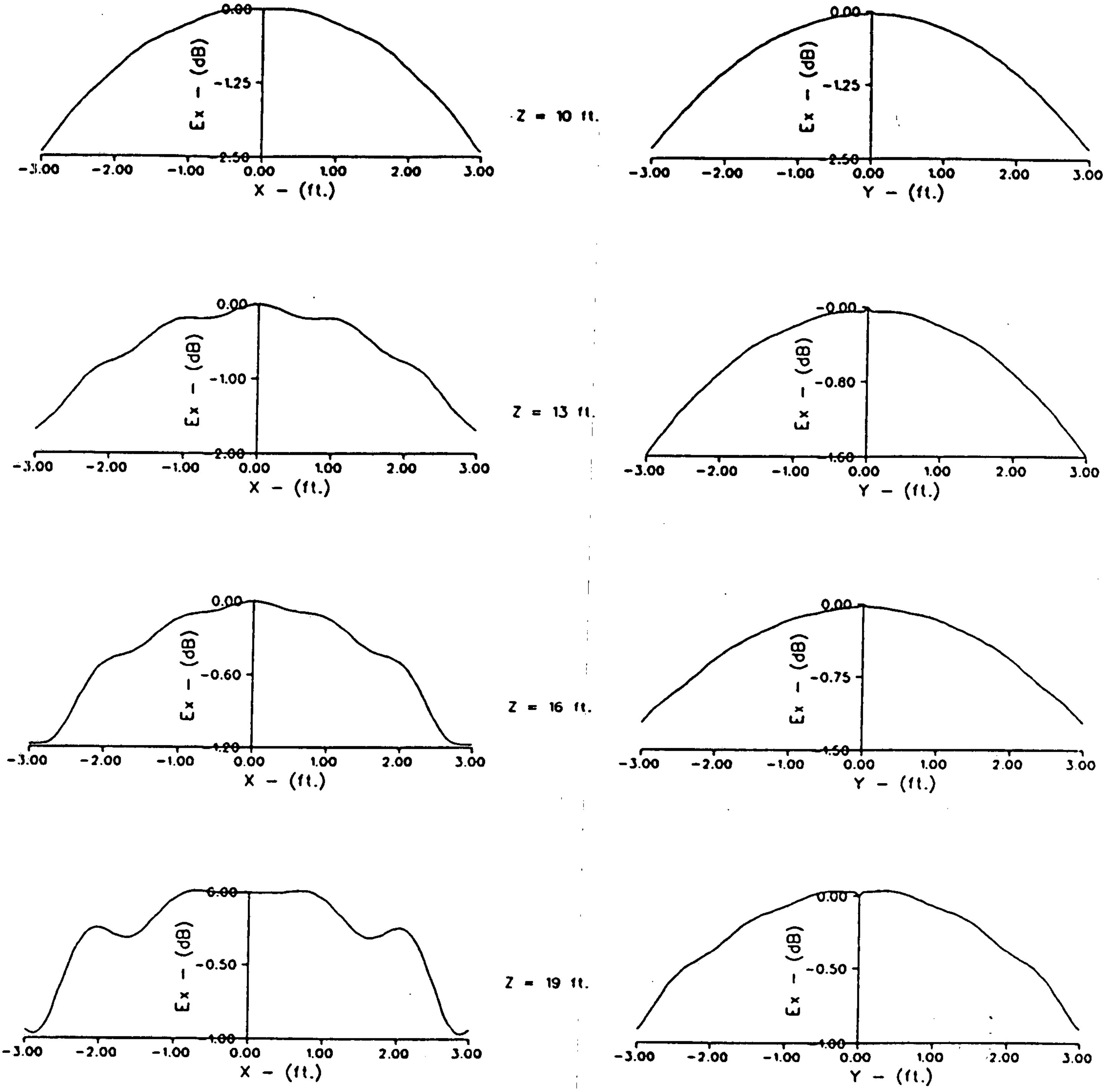


Fig. 7a. Amplitude variation, f = 1GHz

Frequency = 2 G.Hz

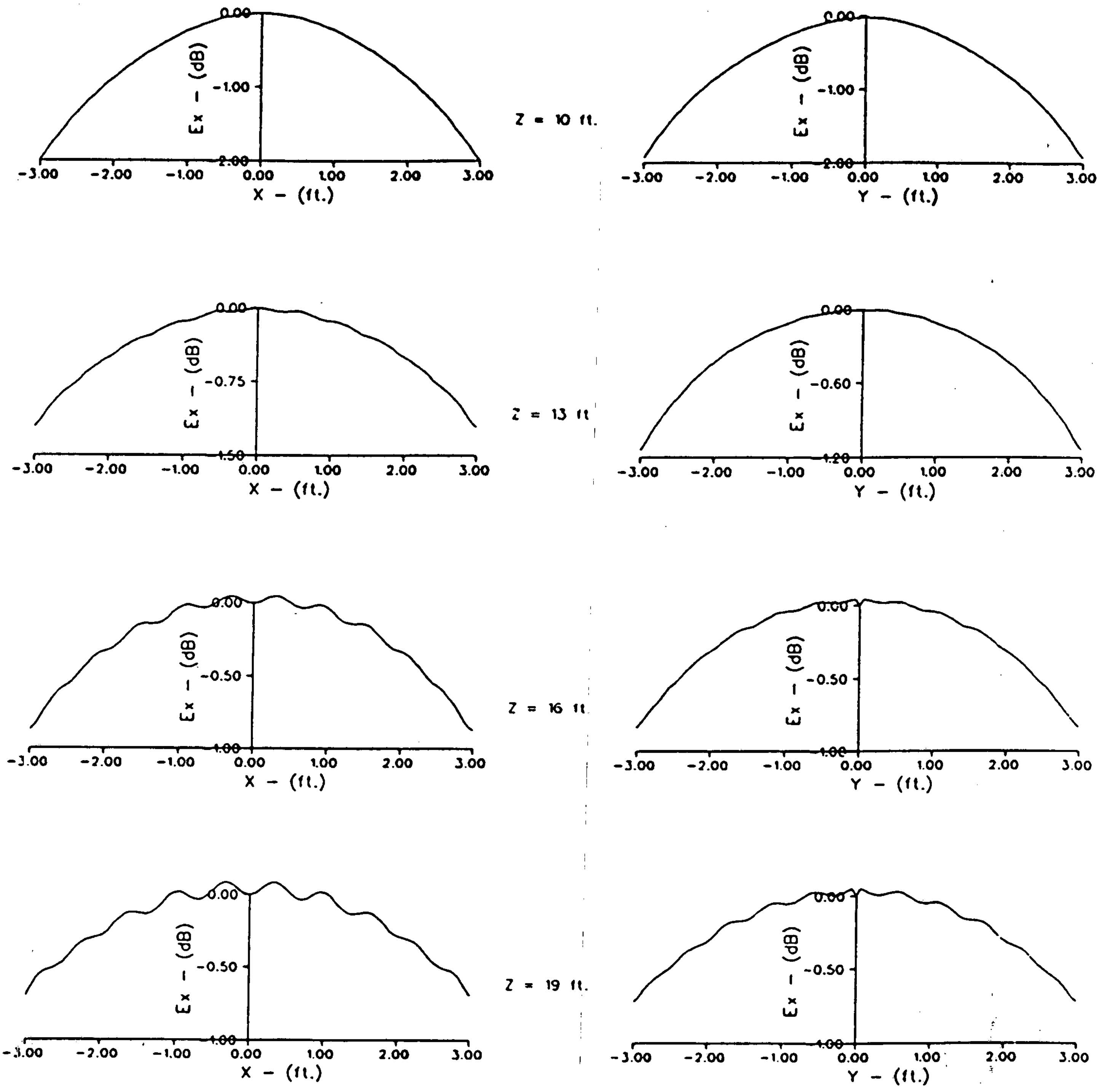


Fig. 7b. Amplitude variation, f = 2GHz

Frequency = 3 GHz

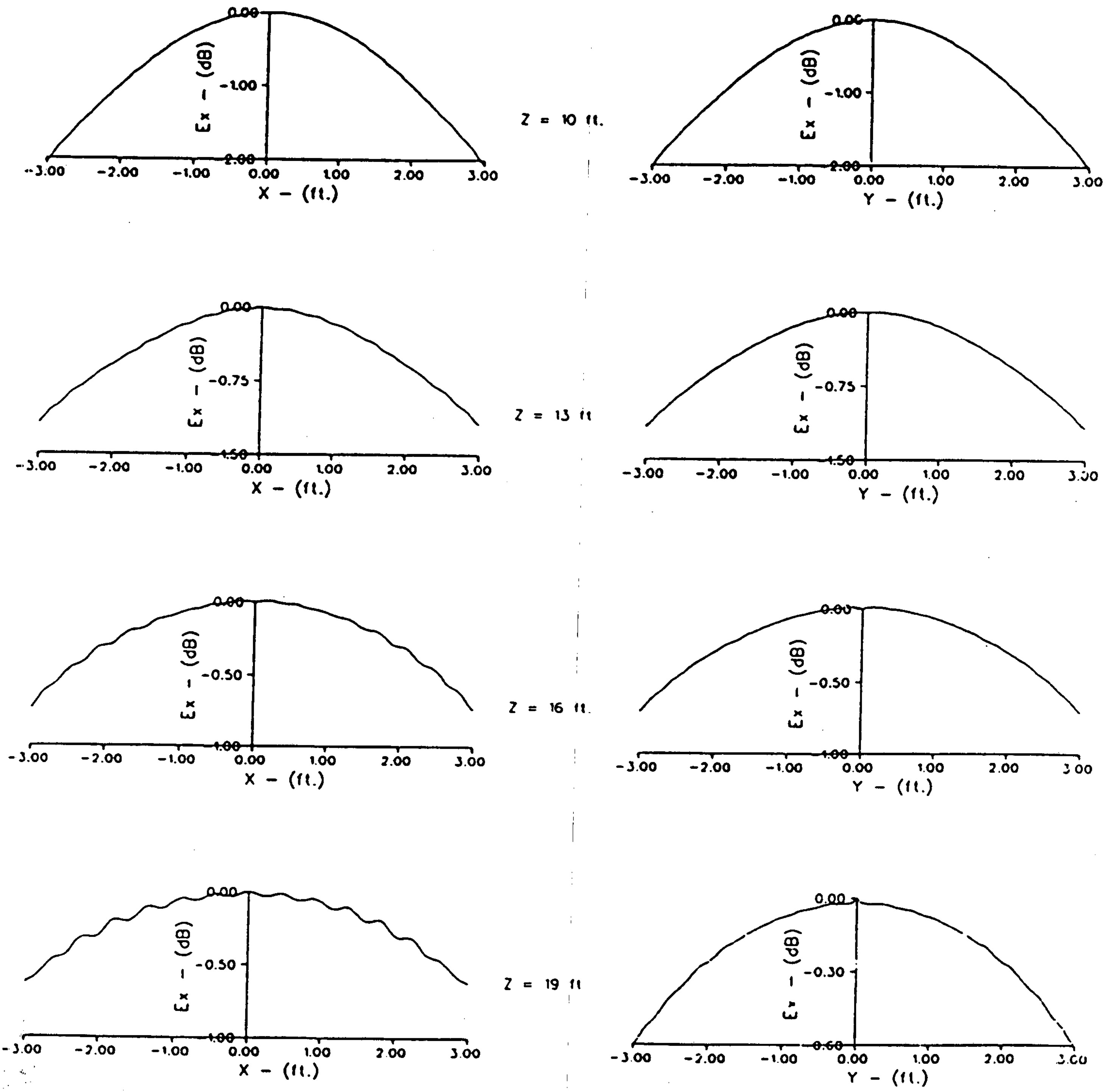


Fig. 7c. Amplitude variation, f = 3GHz

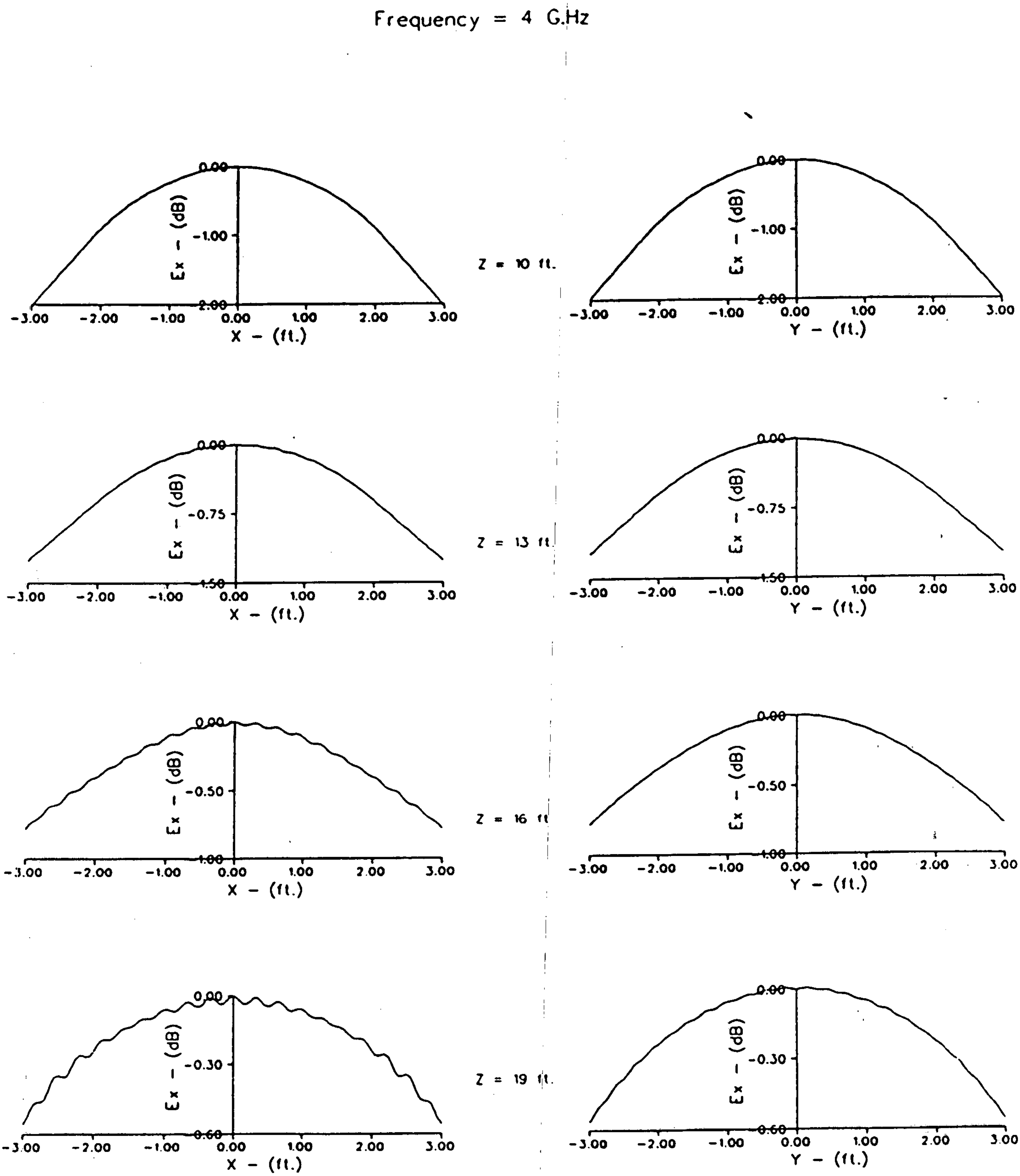


Fig. 7d. Amplitude variation, f = 4GHz

Frequency = 5 G.Hz

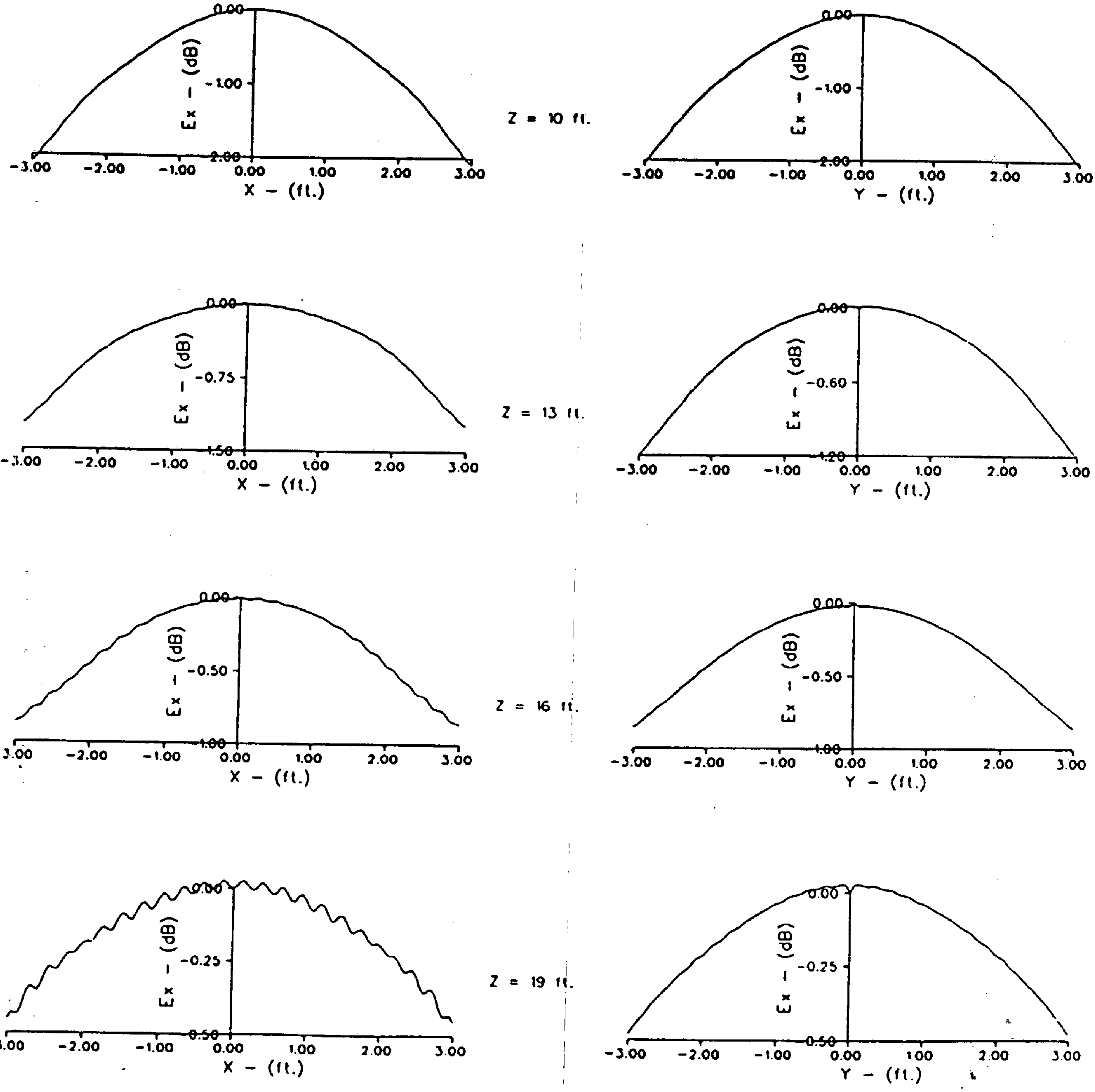


Fig. 7e. Amplitude variation, f = 5GHz

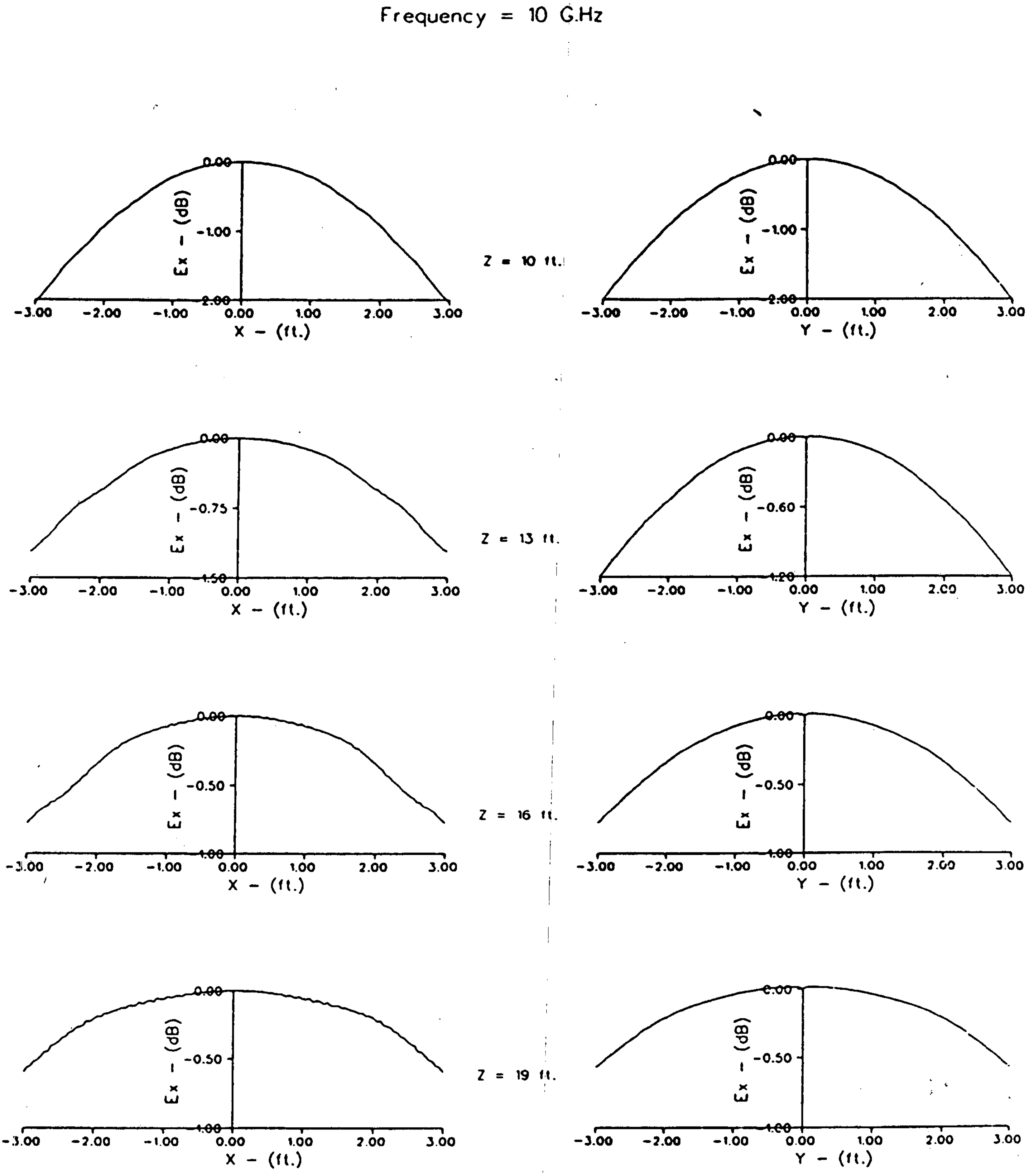


Fig. 7f. Amplitude variation, f = 10GHz

Frequency = 1 G.Hz

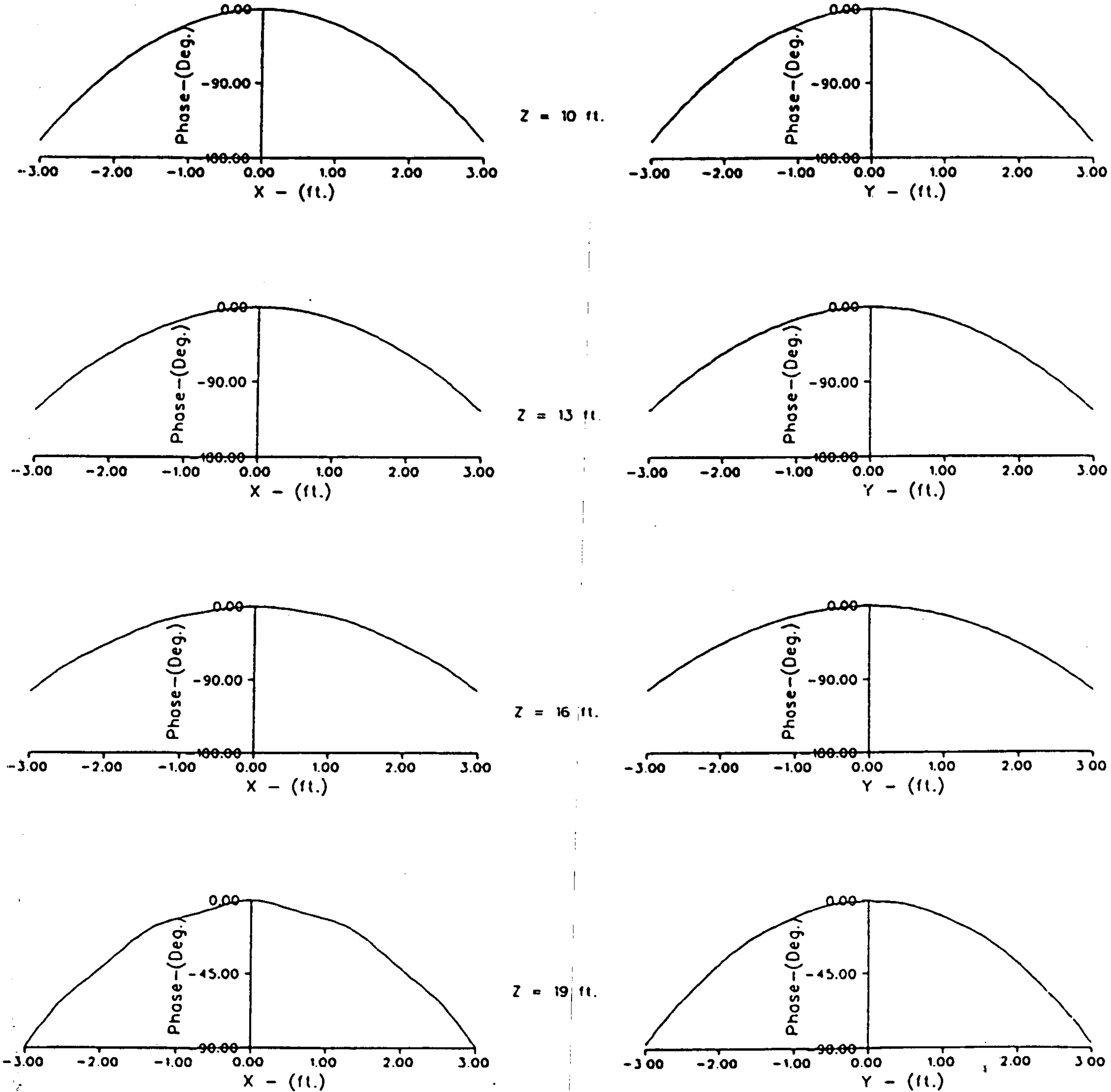


Fig. 8a. Phase variation, f = 1GHz

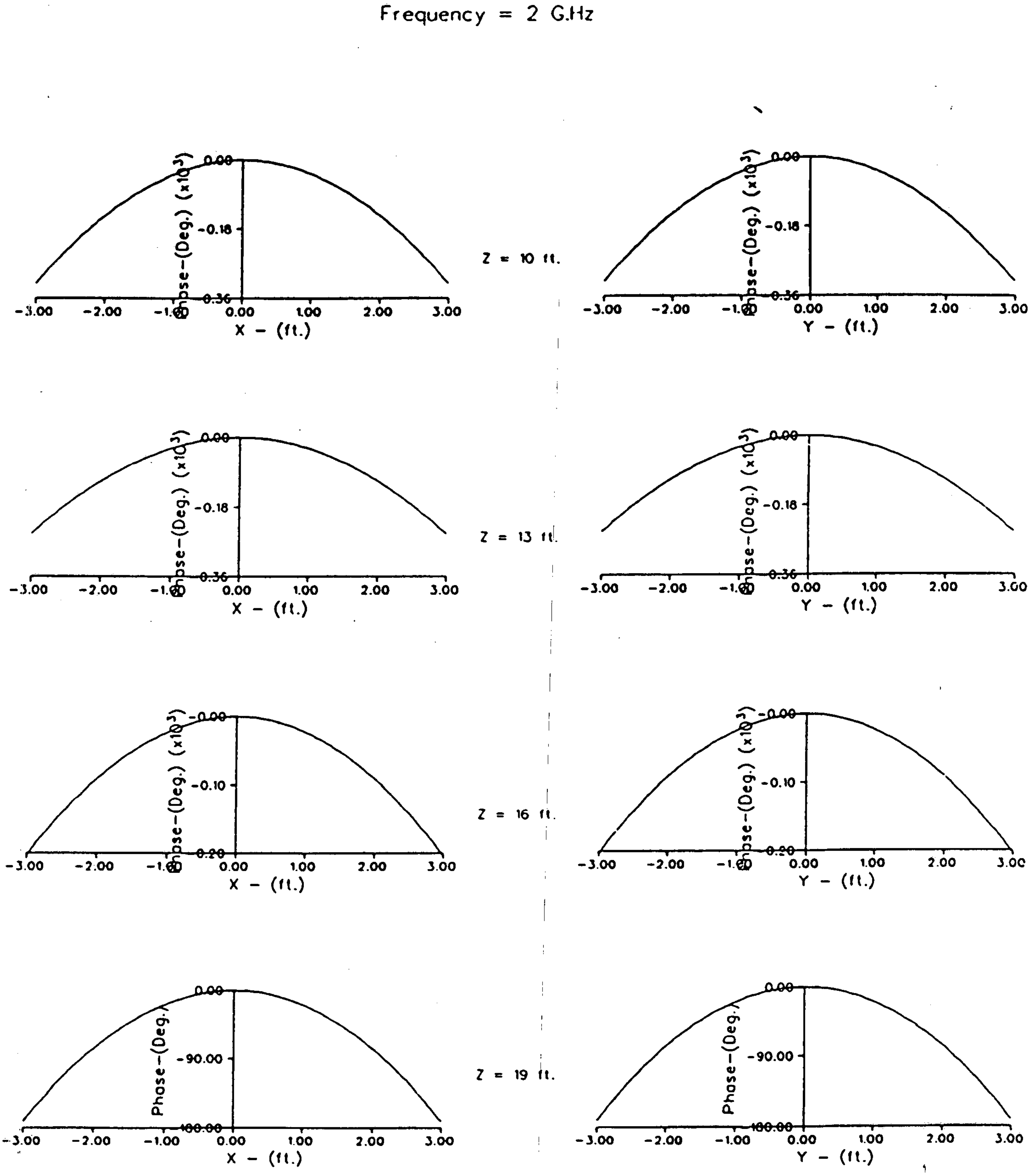


Fig. 8b. Phase variation, f = 2GHz

Frequency = 3 G.Hz

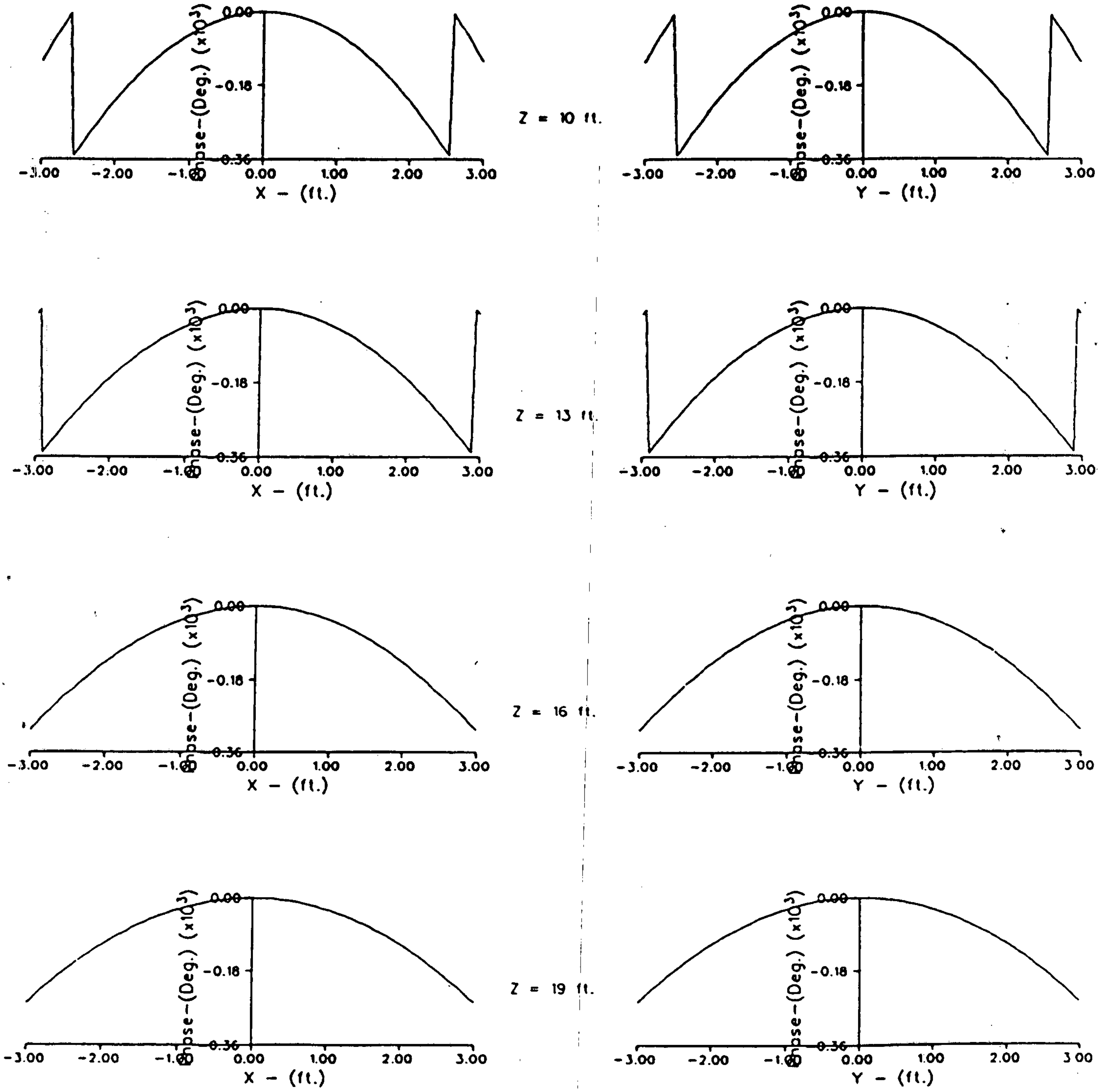


Fig. 8c. Phase variation, f = 3GHz

Frequency = 4 GHz

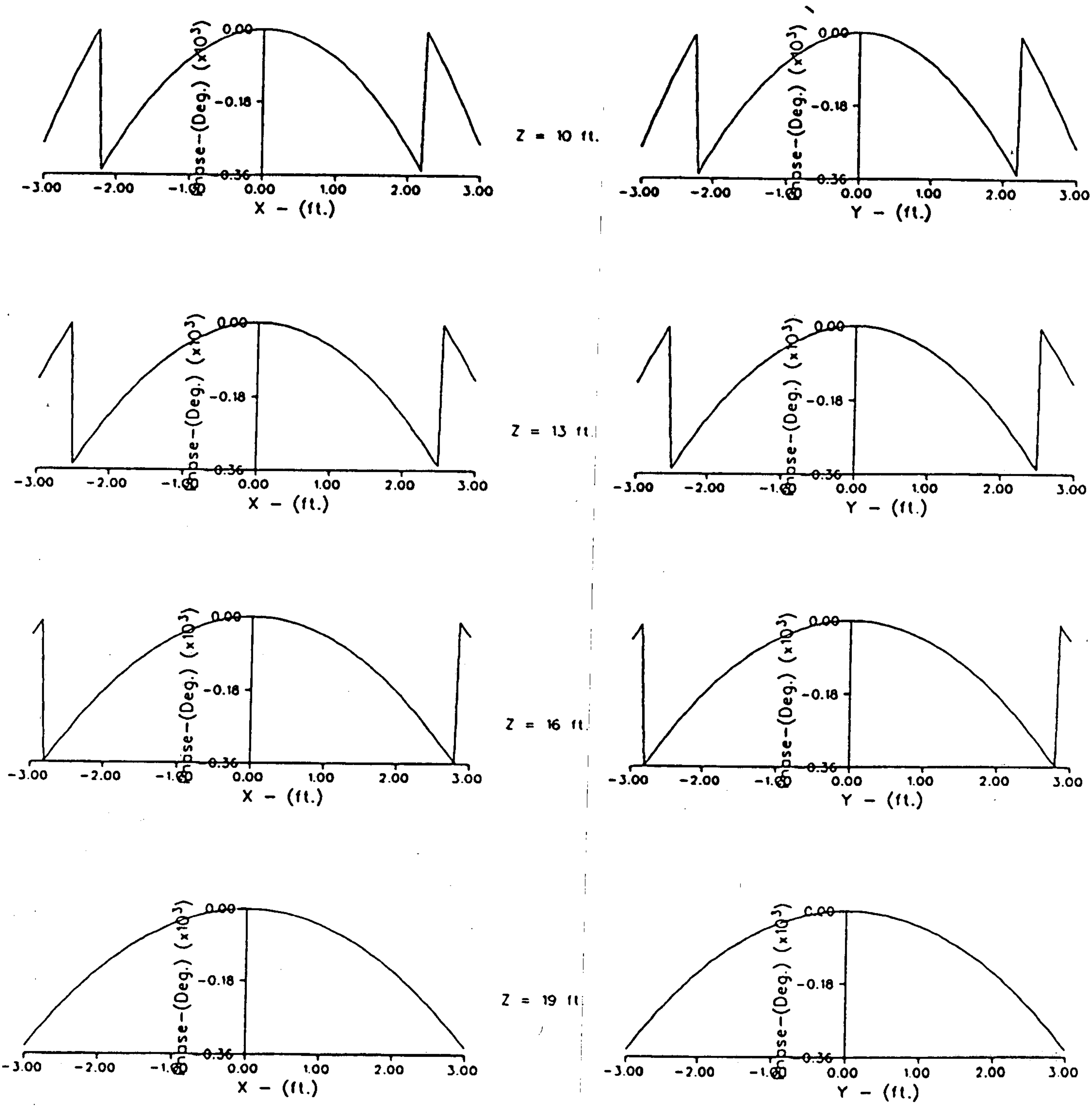


Fig. 8d. Phase variation, f = 4GHz

Frequency = 5 G.Hz

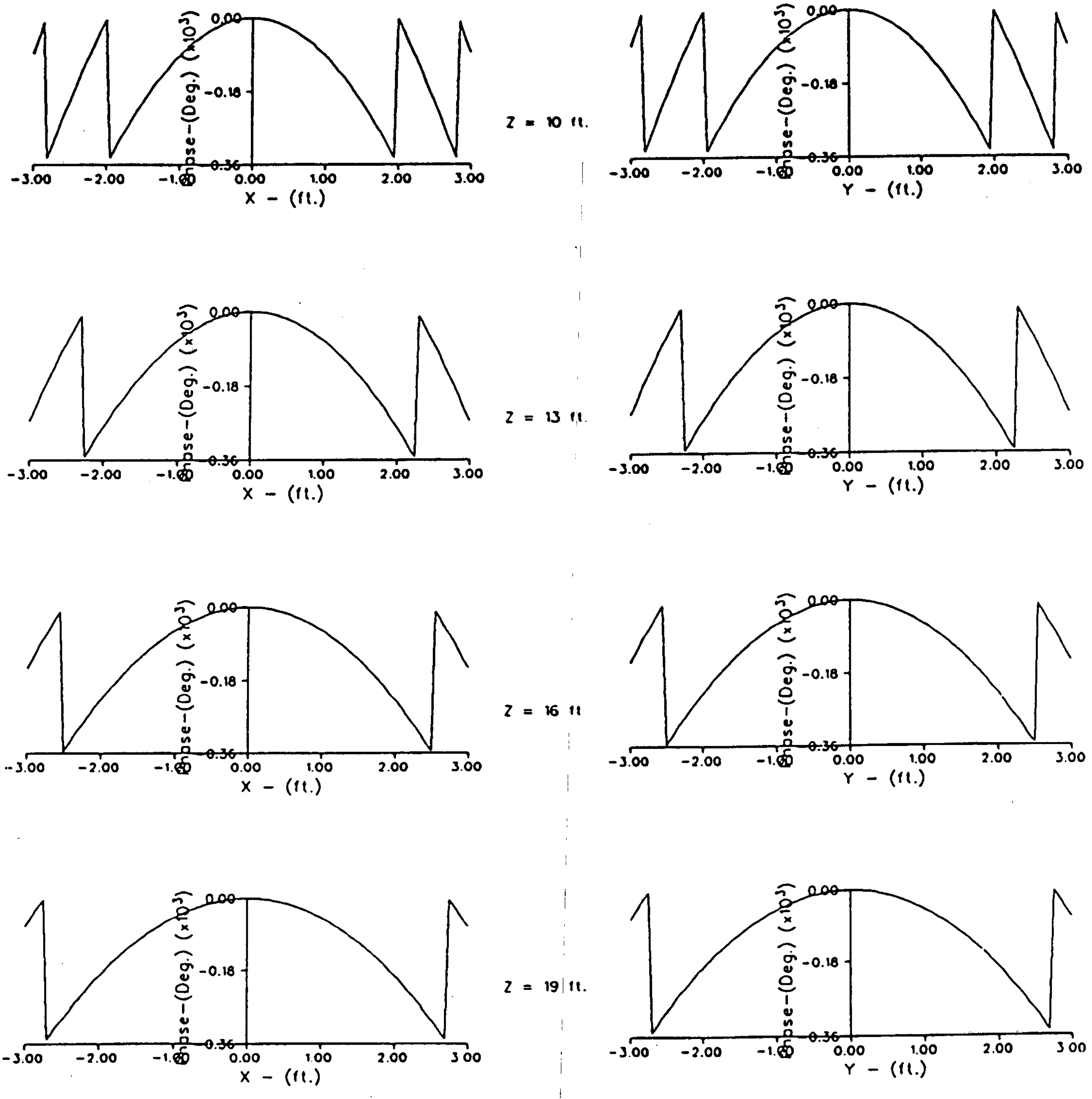


Fig. 8e. Phase variation, f = 5GHz

Frequency = 10 G.Hz

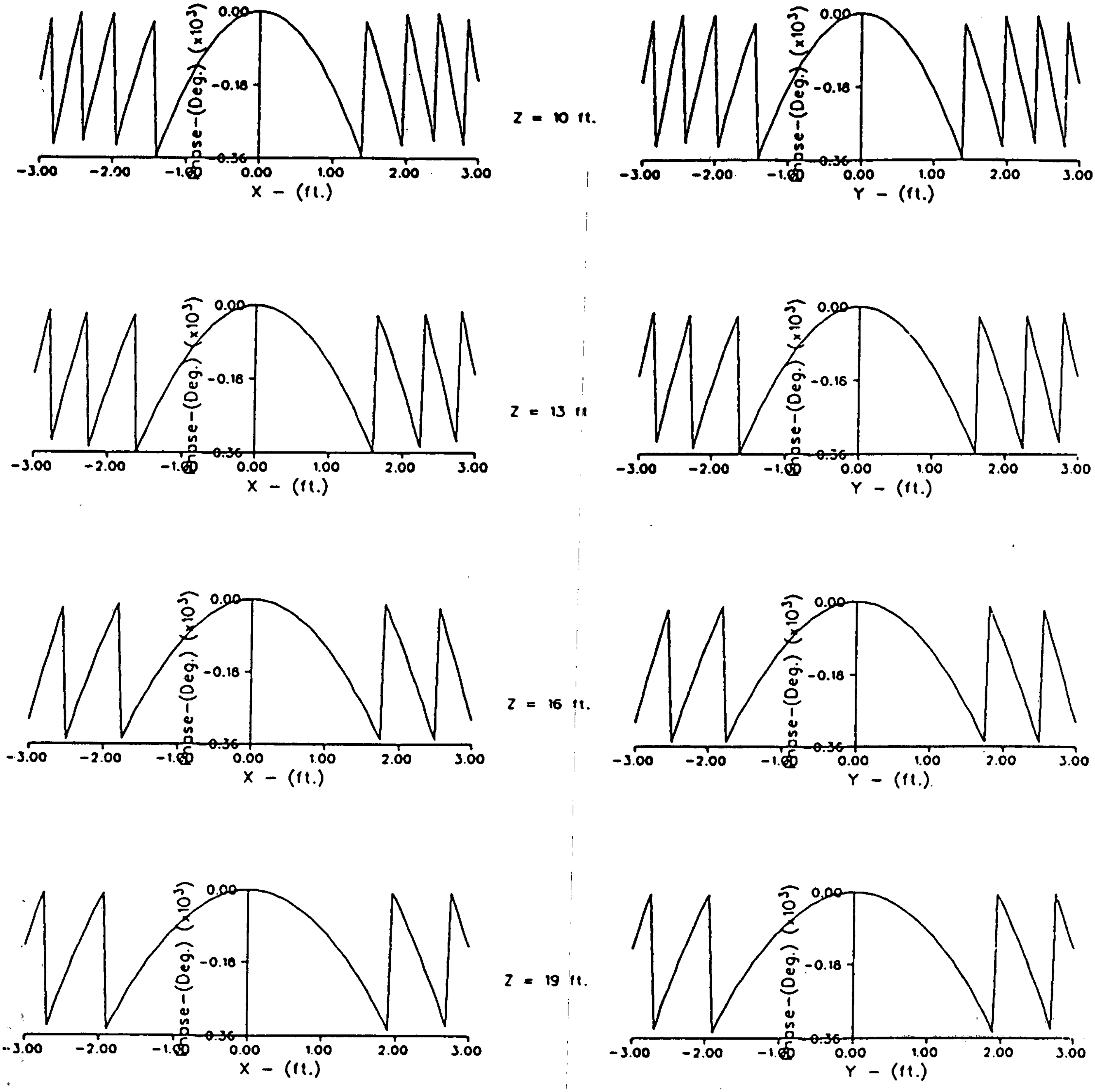


Fig. 8f. Phase variation, f = 10GHz

Anechoic Chamber dimensions =20.0ft.X 30.0ft.X 30.0ft.

Transmitter location from the open-end of the Chamber = 5.0ft.

Frequency = 1.0GHz.

Z = 6.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-37.19	-38.53	-36.76	-34.10	-30.87	-27.34	-23.67	-19.93
1	-36.54	-36.86	-35.74	-33.36	-30.30	-26.88	-23.28	-19.60
2	-34.70	-34.50	-33.46	-31.44	-28.71	-25.57	-22.17	-18.63
3	-31.92	-31.60	-30.55	-28.77	-26.39	-23.60	-20.47	-17.13
4	-28.51	-28.18	-27.20	-25.62	-23.59	-21.17	-18.35	-15.22
5	-24.77	-24.45	-23.56	-22.18	-20.47	-18.46	-15.96	-13.02
6	-20.93	-20.64	-19.80	-18.57	-17.16	-15.58	-13.41	-10.63
7	-17.24	-16.94	-16.09	-14.90	-13.71	-12.60	-10.80	-8.12

Z = 7.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-35.91	-37.51	-36.24	-34.26	-31.71	-28.69	-25.37	-21.97
1	-35.44	-35.97	-35.36	-33.63	-31.21	-28.27	-25.02	-21.71
2	-34.09	-34.05	-33.47	-32.02	-29.83	-27.09	-24.03	-20.94
3	-32.00	-31.82	-31.16	-29.84	-27.85	-25.30	-22.49	-19.72
4	-29.38	-29.18	-28.52	-27.32	-25.48	-23.09	-20.50	-18.11
5	-26.40	-26.22	-25.66	-24.61	-22.91	-20.61	-18.71	-16.21
6	-23.14	-23.01	-22.62	-21.82	-20.28	-17.99	-15.72	-14.14
7	-19.62	-19.57	-19.41	-18.98	-17.69	-15.32	-13.11	-12.01

Z = 8.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-34.46	-36.09	-34.98	-33.25	-31.07	-28.66	-26.23	-23.88
1	-34.09	-34.66	-34.20	-32.71	-30.66	-28.35	-26.00	-23.68
2	-33.00	-33.01	-32.55	-31.32	-29.53	-27.48	-25.34	-23.09
3	-31.29	-31.13	-30.53	-29.40	-27.85	-26.11	-24.29	-22.14
4	-29.08	-28.86	-28.19	-27.09	-25.73	-24.33	-22.87	-20.83
5	-26.56	-26.31	-25.58	-24.49	-23.29	-22.23	-21.15	-19.13
6	-23.92	-23.64	-22.84	-21.72	-20.64	-19.94	-19.23	-17.07
7	-21.34	-21.01	-20.08	-18.86	-17.87	-17.60	-17.31	-14.75

Z = 9.0ft. PLANE

X ---- (ft.)	Y ---- (ft.) 0	1	2	3	4	5	6	7
0	-32.71	-34.35	-33.65	-32.58	-31.23	-29.61	-27.62	-25.15
1	-32.48	-33.14	-33.03	-32.18	-30.90	-29.28	-27.24	-24.78
2	-31.81	-31.94	-31.84	-31.20	-30.03	-28.36	-26.19	-23.75
3	-30.74	-30.72	-30.52	-29.94	-28.83	-27.04	-24.71	-22.32
4	-29.28	-29.24	-29.04	-28.52	-27.41	-25.46	-22.93	-20.76
5	-27.45	-27.43	-27.32	-26.93	-25.80	-23.65	-21.14	-19.22
6	-25.27	-25.30	-25.36	-25.17	-23.97	-21.54	-19.09	-17.74
7	-22.85	-22.97	-23.30	-23.39	-21.94	-19.07	-16.79	-16.26

Z = 10.0ft. PLANE

X ---- (ft.)	Y ---- (ft.) 0	1	2	3	4	5	6	7
0	-32.92	-34.90	-34.11	-32.80	-31.00	-28.89	-26.68	-24.59
1	-32.57	-33.34	-33.25	-32.20	-30.58	-28.64	-26.62	-24.68
2	-31.55	-31.67	-31.52	-30.72	-29.42	-27.93	-26.36	-24.82
3	-30.02	-29.94	-29.59	-28.82	-27.77	-26.69	-25.76	-24.72
4	-28.18	-28.02	-27.54	-26.77	-25.90	-25.22	-24.84	-24.04
5	-26.17	-25.97	-25.44	-24.71	-24.07	-23.82	-23.85	-22.67
6	-23.98	-23.78	-23.25	-22.64	-22.35	-22.69	-22.96	-20.70
7	-21.48	-21.28	-20.80	-20.40	-20.60	-21.81	-21.91	-18.24

Z = 11.0ft. PLANE

X ---- (ft.)	Y ---- (ft.) 0	1	2	3	4	5	6	7
0	-29.96	-31.56	-31.16	-30.57	-29.88	-29.18	-28.43	-27.30
1	-29.99	-30.71	-30.87	-30.48	-29.84	-29.03	-28.00	-26.58
2	-30.05	-30.28	-30.53	-30.31	-29.68	-28.54	-26.87	-24.94
3	-29.96	-30.07	-30.20	-30.03	-29.25	-27.61	-25.39	-23.29
4	-29.50	-29.56	-29.62	-29.33	-28.20	-26.12	-23.80	-22.04
5	-28.60	-28.62	-28.54	-27.88	-26.25	-23.99	-21.99	-21.04
6	-27.58	-27.51	-27.06	-25.75	-23.60	-21.39	-19.98	-20.06
7	-26.72	-26.43	-25.32	-23.23	-20.80	-18.91	-18.33	-19.64

Z - 12.0ft. PLANE

X ---- (ft.)	Y ---- (ft.)							
	0	1	2	3	4	5	6	7
0	-31.25	-33.37	-32.70	-31.56	-30.04	-28.19	-26.17	-24.23
1	-30.63	-31.46	-31.53	-30.76	-29.53	-28.01	-26.33	-24.67
2	-29.11	-29.28	-29.31	-28.89	-28.16	-27.33	-26.48	-25.59
3	-27.39	-27.39	-27.27	-26.97	-26.61	-26.36	-26.27	-25.98
4	-25.96	-25.92	-25.80	-25.66	-25.66	-25.90	-26.12	-25.13
5	-24.86	-24.85	-24.87	-25.07	-25.62	-26.39	-25.98	-23.13
6	-23.71	-23.78	-24.08	-24.84	-26.23	-27.12	-24.54	-20.74
7	-22.41	-22.60	-23.28	-24.80	-26.91	-25.61	-21.28	-18.32

Z - 13.0ft. PLANE

X ---- (ft.)	Y ---- (ft.)							
	0	1	2	3	4	5	6	7
0	-28.15	-29.84	-29.64	-29.38	-29.18	-29.17	-29.30	-28.94
1	-28.61	-29.43	-29.79	-29.65	-29.31	-28.89	-28.31	-27.33
2	-29.70	-30.00	-30.29	-30.01	-29.12	-27.74	-26.16	-24.68
3	-30.37	-30.41	-30.24	-29.46	-27.97	-26.15	-24.49	-23.30
4	-29.15	-29.00	-28.46	-27.39	-25.93	-24.49	-23.52	-23.36
5	-26.23	-26.01	-25.36	-24.36	-23.27	-22.51	-22.57	-23.81
6	-23.23	-23.02	-22.47	-21.73	-21.14	-21.18	-22.39	-24.50
7	-20.85	-20.72	-20.39	-20.10	-23.28	-21.57	-24.37	-23.65

Z - 14.0ft. PLANE

X ---- (ft.)	Y ---- (ft.)							
	0	1	2	3	4	5	6	7
0	-28.01	-29.73	-29.24	-28.45	-27.37	-26.00	-24.52	-23.28
1	-27.63	-28.40	-28.64	-28.30	-27.61	-26.62	-25.48	-24.47
2	-26.49	-26.77	-27.18	-27.42	-27.49	-27.44	-27.30	-26.88
3	-25.62	-25.79	-26.19	-26.70	-27.24	-27.72	-27.77	-26.60
4	-26.23	-26.41	-26.91	-27.59	-28.11	-27.66	-25.76	-23.18
5	-28.36	-28.57	-29.05	-29.22	-28.09	-25.62	-22.86	-20.72
6	-29.39	-29.31	-28.75	-27.22	-24.95	-22.58	-20.73	-19.97
7	-25.51	-25.10	-23.93	-22.33	-20.68	-19.38	-18.91	-20.04

Z = 15.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-28.88	-31.13	-31.05	-31.04	-31.14	-31.11	-30.31	-28.41
1	-28.57	-29.53	-29.85	-29.52	-28.95	-28.29	-27.44	-26.29
2	-27.12	-27.25	-27.12	-26.47	-25.58	-24.74	-24.04	-23.48
3	-25.78	-25.72	-25.44	-24.91	-24.31	-23.91	-23.79	-23.94
4	-24.61	-24.56	-24.43	-24.30	-24.42	-25.04	-26.21	-27.48
5	-23.28	-23.29	-23.39	-23.74	-24.64	-26.33	-28.10	-26.96
6	-24.11	-24.24	-24.70	-25.69	-27.16	-27.36	-24.53	-21.09
7	-28.72	-29.10	-30.15	-30.34	-27.10	-23.02	-19.85	-17.77

Z = 16.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-23.80	-25.21	-25.21	-25.09	-24.71	-24.16	-23.79	-23.70
1	-25.23	-26.08	-26.71	-26.92	-26.73	-26.25	-25.80	-25.35
2	-28.03	-28.61	-29.71	-30.60	-30.79	-29.98	-28.31	-26.19
3	-28.12	-28.41	-28.99	-29.25	-28.62	-27.11	-25.37	-23.82
4	-24.66	-24.67	-24.61	-24.27	-23.50	-22.44	-21.57	-21.10
5	-22.13	-22.13	-22.11	-21.98	-21.66	-21.37	-21.59	-22.54
6	-20.73	-20.81	-21.04	-21.34	-21.76	-22.69	-24.93	-28.95
7	-19.82	-20.01	-20.60	-21.57	-23.22	-26.50	-30.74	-25.57

Z = 17.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-28.21	-30.26	-29.15	-27.77	-26.52	-25.44	-24.17	-22.68
1	-26.25	-26.99	-26.95	-26.37	-25.87	-25.50	-24.91	-24.18
2	-23.61	-23.75	-23.84	-23.84	-24.00	-24.33	-24.60	-25.39
3	-24.98	-25.03	-25.14	-25.37	-25.86	-26.40	-26.32	-25.35
4	-30.34	-30.26	-30.01	-29.47	-28.51	-26.97	-24.78	-22.38
5	-28.35	-27.91	-26.74	-25.26	-23.87	-22.59	-21.19	-19.93
6	-21.78	-21.49	-20.76	-19.93	-19.29	-18.87	-18.57	-18.87
7	-19.22	-19.06	-18.72	-18.55	-18.83	-19.62	-21.11	-24.70

Z - 18.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-25.23	-27.36	-28.02	-28.60	-28.83	-29.30	-30.59	-31.74
1	-24.79	-25.88	-26.94	-27.43	-27.14	-26.46	-26.05	-25.66
2	-22.90	-23.24	-23.82	-24.09	-23.73	-22.99	-22.50	-22.18
3	-22.49	-22.77	-23.39	-23.90	-23.97	-23.98	-24.56	-25.30
4	-21.90	-22.17	-22.81	-23.46	-23.99	-24.94	-26.78	-28.74
5	-25.43	-25.87	-27.02	-28.29	-28.93	-28.35	-26.66	-24.47
6	-27.64	-27.73	-27.70	-26.85	-24.88	-22.67	-21.17	-20.14
7	-19.86	-19.88	-19.80	-19.35	-18.47	-17.76	-17.65	-17.88

Z - 19.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-21.76	-22.96	-22.33	-21.76	-21.56	-21.44	-20.90	-20.39
1	-25.34	-26.07	-25.89	-25.36	-25.27	-25.33	-24.68	-23.86
2	-30.26	-30.39	-29.96	-29.14	-28.73	-28.43	-27.01	-25.12
3	-23.61	-23.43	-22.91	-22.31	-21.97	-21.65	-20.77	-19.88
4	-20.82	-20.65	-20.24	-19.93	-19.97	-20.06	-19.81	-19.81
5	-22.64	-22.47	-22.22	-22.41	-23.22	-24.07	-24.84	-26.73
6	-26.51	-26.44	-26.56	-27.41	-28.83	-28.85	-26.13	-22.91
7	-26.84	-26.05	-24.12	-22.15	-20.71	-19.38	-17.70	-16.49

Z - 20.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-22.44	-24.13	-24.34	-24.52	-24.07	-22.99	-22.36	-22.09
1	-22.41	-23.49	-24.74	-25.52	-25.28	-24.66	-24.77	-24.94
2	-21.83	-22.42	-23.67	-24.62	-24.70	-24.72	-25.48	-25.93
3	-24.93	-25.41	-26.52	-27.37	-26.87	-25.40	-24.42	-23.70
4	-22.51	-22.76	-23.34	-23.72	-23.16	-22.15	-21.74	-21.35
5	-18.10	-18.34	-18.89	-19.23	-19.05	-18.99	-19.43	-19.65
6	-19.77	-20.20	-21.20	-22.09	-22.95	-24.96	-25.64	-33.16
7	-27.75	-28.67	-30.65	-33.38	-46.29	-33.37	-26.99	-22.95

Z - 21.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-28.12	-32.17	-31.22	-30.07	-30.83	-32.73	-31.99	-32.09
1	-21.59	-22.33	-22.47	-22.12	-22.30	-22.85	-22.52	-22.15
2	-19.83	-20.01	-20.06	-19.95	-20.30	-20.90	-20.77	-20.75
3	-26.09	-25.88	-25.24	-25.04	-26.07	-26.97	-26.65	-27.57
4	-25.90	-25.77	-25.15	-24.63	-25.10	-25.78	-24.96	-24.18
5	-19.26	-19.18	-18.85	-18.54	-18.77	-19.15	-18.86	-18.85
6	-18.34	-18.02	-17.41	-17.21	-17.57	-17.66	-17.58	-18.16
7	-20.58	-20.25	-19.89	-20.41	-21.65	-22.66	-25.03	-30.59

Z - 22.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-21.54	-23.05	-23.18	-23.18	-22.23	-20.95	-20.57	-19.92
1	-23.16	-23.76	-23.62	-23.67	-23.60	-22.66	-22.55	-22.35
2	-21.90	-21.86	-21.72	-21.92	-21.98	-21.25	-21.18	-21.34
3	-19.25	-19.40	-19.81	-20.08	-19.52	-18.70	-18.57	-18.03
4	-24.59	-25.00	-26.00	-26.99	-26.46	-25.54	-26.39	-26.58
5	-25.73	-25.34	-24.69	-24.57	-23.93	-22.48	-22.15	-21.48
6	-16.41	-16.50	-16.74	-16.77	-16.15	-15.57	-15.57	-15.16
7	-16.47	-16.91	-17.81	-18.09	-17.76	-17.97	-18.12	-17.73

Z - 23.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-17.23	-18.89	-19.67	-19.66	-19.37	-19.56	-19.20	-15.43
1	-22.60	-24.65	-27.33	-27.74	-27.67	-28.82	-27.37	-26.38
2	-22.52	-23.84	-26.36	-27.06	-26.80	-27.57	-25.87	-25.29
3	-16.67	-17.18	-18.07	-18.32	-18.38	-18.32	-18.58	-18.10
4	-20.68	-21.02	-21.24	-21.22	-22.12	-22.85	-21.91	-21.74
5	-25.93	-26.63	-26.98	-27.24	-29.83	-32.85	-30.93	-29.61
6	-17.94	-18.45	-19.17	-19.27	-19.54	-20.11	-19.48	-19.07
7	-14.92	-14.77	-14.39	-14.36	-14.95	-15.09	-14.83	-15.13

Anechoic Chamber dimensions -20.0ft.X 30.0ft.X 30.0ft.

Transmitter location from the open-end of the Chamber - 5.0ft.

Frequency - 4.0GHz.

Z - 6.0ft. PLANE

	Y ---- (ft.)							
X ---- (ft.)	0	1	2	3	4	5	6	7
0	-57.45	-59.87	-57.94	-55.02	-51.98	-48.32	-44.58	-40.77
1	-56.78	-57.56	-56.67	-54.22	-51.30	-47.78	-44.16	-40.57
2	-54.92	-54.87	-54.01	-52.12	-49.58	-46.23	-43.02	-39.62
3	-52.21	-51.95	-50.92	-49.17	-47.17	-44.06	-41.10	-38.09
4	-48.83	-48.62	-47.69	-45.86	-44.22	-41.44	-38.76	-36.02
5	-44.78	-44.64	-44.16	-42.42	-41.09	-38.47	-36.07	-33.73
6	-40.84	-40.53	-40.17	-39.22	-37.50	-35.32	-33.35	-31.05
7	-37.81	-37.33	-35.96	-36.01	-33.76	-32.20	-30.48	-28.42

Z - 7.0ft. PLANE

	Y ---- (ft.)							
X ---- (ft.)	0	1	2	3	4	5	6	7
0	-55.67	-58.09	-56.68	-54.95	-52.61	-49.21	-46.62	-43.05
1	-55.23	-56.11	-55.74	-54.24	-51.80	-49.08	-45.88	-43.12
2	-53.81	-53.94	-53.76	-52.60	-49.98	-48.05	-44.74	-42.07
3	-51.55	-51.44	-51.16	-50.28	-47.93	-46.11	-43.35	-40.34
4	-48.93	-48.71	-48.32	-47.60	-45.28	-43.94	-41.54	-38.66
5	-45.97	-45.60	-45.00	-44.87	-42.52	-41.44	-39.40	-37.10
6	-43.48	-42.98	-41.67	-41.76	-39.44	-38.93	-37.31	-35.11
7	-40.61	-40.58	-38.89	-38.06	-36.08	-36.41	-34.93	-33.10

Z - 8.0ft. PLANE

	Y ---- (ft.)							
X ---- (ft.)	0	1	2	3	4	5	6	7
0	-54.62	-57.49	-56.62	-54.49	-51.90	-50.50	-47.13	-45.14
1	-54.20	-55.24	-55.09	-53.67	-52.02	-49.47	-47.44	-44.05
2	-53.26	-53.33	-52.79	-51.82	-51.06	-48.19	-46.55	-43.63
3	-51.56	-51.38	-50.72	-50.21	-49.00	-46.56	-44.91	-42.79
4	-49.35	-48.99	-48.10	-47.94	-46.77	-45.17	-42.41	-41.16
5	-47.18	-46.73	-45.58	-45.65	-44.09	-43.34	-40.54	-38.56
6	-45.12	-44.60	-42.85	-42.84	-41.34	-41.40	-39.00	-36.59
7	-42.85	-42.69	-40.38	-39.80	-38.85	-39.38	-37.36	-35.70

Z - 9.0ft. PLANE

				Y ---- (ft.)				
X ---- (ft.)	0	1	2	3	4	5	6	7
0	-52.65	-55.18	-54.66	-54.41	-52.69	-49.43	-48.85	-45.22
1	-53.04	-54.23	-54.49	-53.21	-51.44	-50.37	-47.20	-46.39
2	-52.53	-52.92	-52.95	-51.57	-50.58	-48.93	-47.03	-44.56
3	-51.26	-51.12	-50.26	-49.29	-49.82	-47.08	-46.12	-43.73
4	-49.42	-49.09	-48.10	-47.91	-47.74	-45.24	-44.06	-43.18
5	-47.34	-46.81	-45.66	-46.15	-44.82	-44.29	-41.69	-40.31
6	-45.03	-44.29	-43.06	-44.58	-42.12	-43.24	-40.12	-38.00
7	-43.06	-41.98	-40.36	-43.11	-39.28	-41.17	-39.80	-37.61

Z - 10.0ft. PLANE

				Y ---- (ft.)				
X ---- (ft.)	0	1	2	3	4	5	6	7
0	-51.71	-54.15	-53.12	-52.34	-52.78	-50.12	-47.99	-46.66
1	-51.60	-52.93	-53.85	-53.22	-50.66	-49.82	-48.79	-45.45
2	-51.33	-51.78	-52.05	-50.81	-50.11	-49.79	-46.62	-46.15
3	-50.84	-50.75	-49.93	-49.04	-49.54	-46.84	-47.67	-43.59
4	-48.36	-48.00	-47.40	-48.10	-47.68	-45.69	-44.82	-44.33
5	-45.83	-45.61	-45.94	-47.98	-44.69	-45.87	-41.87	-41.69
6	-43.64	-43.67	-45.14	-45.97	-42.27	-43.70	-42.33	-39.19
7	-41.45	-41.87	-44.73	-42.65	-41.31	-39.19	-41.47	-41.16

Z - 11.0ft. PLANE

				Y ---- (ft.)				
X ---- (ft.)	0	1	2	3	4	5	6	7
0	-51.05	-53.45	-52.22	-51.38	-52.05	-50.76	-47.01	-48.61
1	-50.52	-51.88	-53.34	-53.72	-50.58	-48.64	-49.37	-45.81
2	-51.32	-51.52	-51.03	-49.71	-49.65	-50.47	-46.29	-46.88
3	-48.98	-48.75	-48.48	-49.50	-50.45	-46.70	-47.34	-44.29
4	-47.38	-47.46	-48.42	-49.62	-46.03	-47.10	-44.56	-45.37
5	-47.21	-47.70	-48.45	-45.49	-44.54	-45.72	-44.39	-41.27
6	-47.76	-47.63	-44.91	-42.46	-46.21	-41.36	-43.94	-42.76
7	-44.75	-43.47	-40.85	-42.46	-42.69	-42.11	-38.48	-38.74

Z - 12.0ft. PLANE

	Y ---- (ft.)							
X ---- (ft.)	0	1	2	3	4	5	6	7
0	-49.10	-51.47	-50.60	-50.34	-51.73	-50.27	-46.84	-48.84
1	-50.17	-51.89	-53.35	-52.49	-49.23	-48.28	-49.61	-46.26
2	-49.31	-49.47	-49.04	-48.68	-49.89	-48.87	-47.13	-46.81
3	-47.30	-47.77	-49.00	-50.45	-48.05	-47.40	-46.52	-44.97
4	-49.33	-49.72	-48.99	-46.57	-47.22	-47.33	-43.80	-44.59
5	-46.11	-45.68	-44.91	-46.33	-47.77	-43.26	-45.87	-42.51
6	-43.13	-43.53	-45.84	-47.49	-41.97	-46.72	-40.78	-42.56
7	-45.47	-47.16	-46.93	-40.61	-43.59	-39.88	-45.12	-39.80

Z - 13.0ft. PLANE

	Y ---- (ft.)							
X ---- (ft.)	0	1	2	3	4	5	6	7
0	-47.79	-59.02	-50.29	-51.67	-52.56	-48.20	-46.92	-49.74
1	-50.81	-51.79	-51.28	-49.48	-48.36	-49.35	-48.80	-46.76
2	-47.97	-48.20	-49.12	-50.12	-48.73	-47.07	-49.85	-45.35
3	-49.07	-48.61	-47.55	-46.46	-47.57	-49.44	-44.89	-47.53
4	-45.38	-45.28	-46.10	-49.11	-47.57	-44.53	-47.05	-42.79
5	-48.63	-48.95	-48.40	-44.92	-44.55	-47.64	-41.84	-44.38
6	-44.01	-43.35	-42.31	-44.54	-47.69	-41.56	-46.01	-40.61
7	-41.31	-42.11	-46.28	-45.51	-40.24	-48.22	-39.60	-40.43

Z - 14.0ft. PLANE

	Y ---- (ft.)							
X ---- (ft.)	0	1	2	3	4	5	6	7
0	-49.78	-54.17	-54.73	-51.67	-48.10	-46.69	-49.69	-43.85
1	-47.19	-48.37	-49.09	-49.25	-49.84	-48.83	-47.92	-48.29
2	-48.14	-48.25	-47.89	-46.69	-47.20	-51.05	-47.14	-45.11
3	-45.83	-46.38	-48.03	-49.99	-47.87	-45.69	-48.59	-44.20
4	-47.52	-46.84	-45.58	-44.61	-47.17	-47.61	-43.07	-47.14
5	-44.07	-44.50	-46.73	-49.15	-44.04	-44.10	-45.31	-41.65
6	-47.61	-45.81	-43.09	-41.52	-46.13	-43.70	-42.80	-40.85
7	-40.34	-40.40	-42.88	-49.05	-40.45	-43.68	-40.65	-47.04

Z = 15.0ft. PLANE

X ---- (ft.)	Y ---- (ft.)							
	0	1	2	3	4	5	6	7
0	-45.65	-48.27	-47.40	-47.02	-47.76	-51.19	-48.88	-44.79
1	-47.33	-49.30	-49.50	-48.73	-47.70	-48.42	-48.98	-45.63
2	-46.06	-47.45	-49.33	-51.96	-49.18	-45.61	-45.94	-47.83
3	-45.32	-45.80	-45.59	-46.45	-49.22	-47.49	-43.22	-46.22
4	-48.69	-50.17	-49.49	-46.22	-43.86	-46.18	-45.23	-41.77
5	-42.51	-43.03	-43.59	-47.16	-48.07	-42.18	-45.31	-41.50
6	-48.51	-48.12	-44.19	-41.28	-42.45	-48.94	-40.44	-47.56
7	-39.69	-40.43	-42.32	-49.35	-40.91	-40.44	-44.86	-39.93

Z = 16.0ft. PLANE

X ---- (ft.)	Y ---- (ft.)							
	0	1	2	3	4	5	6	7
0	-48.33	-54.00	-54.35	-52.42	-48.06	-44.76	-43.93	-47.57
1	-46.54	-49.07	-50.29	-50.84	-48.89	-45.54	-43.50	-46.50
2	-44.70	-45.73	-45.74	-46.22	-47.49	-47.51	-44.40	-44.25
3	-47.00	-47.66	-45.83	-44.28	-43.80	-45.74	-46.46	-42.62
4	-46.44	-48.15	-49.66	-48.34	-44.05	-42.30	-45.60	-43.23
5	-42.14	-42.75	-42.69	-44.59	-50.27	-43.69	-41.55	-46.89
6	-48.02	-48.32	-43.94	-40.97	-41.42	-50.75	-41.75	-43.26
7	-40.17	-41.47	-44.70	-48.64	-40.31	-39.70	-49.95	-38.56

Z = 17.0ft. PLANE

X ---- (ft.)	Y ---- (ft.)							
	0	1	2	3	4	5	6	7
0	-42.84	-45.88	-45.46	-45.73	-47.70	-51.72	-50.37	-44.11
1	-43.05	-44.89	-44.91	-45.10	-46.67	-50.34	-51.18	-44.49
2	-44.20	-45.39	-44.70	-44.22	-44.70	-46.95	-51.76	-45.01
3	-46.36	-47.83	-46.59	-44.98	-43.74	-43.76	-47.28	-49.41
4	-43.62	-45.00	-46.24	-47.27	-45.60	-42.50	-42.69	-48.90
5	-40.97	-41.71	-41.73	-43.09	-48.25	-45.15	-40.80	-44.09
6	-44.85	-45.10	-42.04	-40.23	-41.53	-51.86	-42.50	-41.13
7	-44.50	-46.28	-51.11	-43.44	-38.74	-40.03	-49.96	-37.98

Z = 18.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-43.42	-46.04	-44.38	-44.19	-44.06	-44.13	-45.44	-49.54
1	-43.87	-45.31	-44.27	-44.15	-43.90	-43.82	-45.01	-48.74
2	-45.66	-46.57	-45.05	-44.67	-43.87	-43.26	-44.13	-47.33
3	-48.51	-50.70	-48.38	-47.40	-45.15	-43.23	-43.53	-47.14
4	-44.30	-46.23	-47.30	-50.09	-49.19	-44.09	-42.63	-47.02
5	-39.89	-40.85	-41.15	-43.11	-48.73	-45.05	-40.24	-41.63
6	-39.95	-40.51	-39.47	-39.81	-43.42	-51.08	-40.27	-38.91
7	-46.99	-47.11	-42.15	-39.11	-38.44	-43.14	-45.31	-37.14

Z = 19.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-47.42	-48.92	-48.90	-47.47	-44.86	-43.05	-41.61	-49.65
1	-47.84	-47.94	-48.76	-47.82	-45.25	-43.52	-42.30	-41.70
2	-47.97	-47.79	-48.16	-47.99	-45.48	-43.82	-43.12	-43.83
3	-46.36	-46.79	-46.49	-46.42	-43.79	-41.83	-41.05	-42.12
4	-45.52	-46.85	-46.78	-47.07	-43.42	-40.67	-39.55	-40.76
5	-42.69	-44.53	-45.43	-51.08	-49.46	-43.17	-40.35	-40.85
6	-38.12	-39.06	-39.30	-42.03	-47.54	-44.72	-39.03	-37.96
7	-38.07	-38.63	-37.95	-38.99	-42.34	-56.31	-41.70	-37.49

Z = 20.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-49.32	-53.02	-54.04	-51.73	-52.81	-50.16	-46.33	-44.05
1	-47.65	-47.86	-50.10	-48.65	-49.51	-48.63	-46.21	-44.99
2	-44.53	-43.65	-44.73	-43.69	-43.81	-43.21	-42.02	-41.76
3	-44.39	-43.15	-43.58	-42.34	-42.28	-41.70	-41.09	-41.87
4	-49.92	-47.26	-47.53	-44.68	-43.69	-42.57	-41.78	-42.49
5	-47.50	-46.74	-47.26	-43.76	-41.67	-40.03	-39.26	-40.60
6	-45.12	-47.73	-51.14	-52.93	-46.27	-41.97	-39.31	-39.27
7	-39.02	-40.47	-42.20	-50.13	-53.19	-41.79	-37.92	-38.55

Z - 21.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-46.78	-56.94	-54.31	-59.91	-53.75	-51.94	-52.60	-56.18
1	-43.36	-46.48	-46.53	-48.40	-45.94	-44.66	-44.42	-44.79
2	-40.07	-41.36	-41.32	-42.38	-41.08	-40.49	-40.63	-41.35
3	-41.16	-42.25	-41.91	-43.34	-42.20	-41.25	-41.38	-41.70
4	-39.91	-40.05	-39.34	-39.83	-39.02	-38.10	-38.77	-40.31
5	-41.09	-40.75	-39.96	-40.27	-39.88	-38.93	-39.11	-39.74
6	-41.34	-40.11	-39.09	-38.17	-37.88	-37.29	-38.13	-41.09
7	-47.05	-44.56	-42.72	-39.42	-38.08	-36.13	-35.87	-33.83

Z - 22.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-49.06	-52.95	-53.93	-52.80	-59.39	-53.83	-46.81	-44.25
1	-42.35	-42.67	-44.02	-43.02	-44.72	-43.34	-41.64	-42.00
2	-39.25	-39.08	-40.22	-39.93	-41.81	-41.53	-40.82	-41.69
3	-39.92	-40.19	-41.32	-40.21	-40.71	-40.19	-38.65	-38.21
4	-37.90	-38.56	-39.54	-39.49	-40.53	-42.22	-42.52	-41.33
5	-37.60	-38.23	-38.03	-38.48	-38.16	-40.43	-42.72	-44.13
6	-38.14	-38.32	-37.80	-39.11	-38.63	-40.35	-43.10	-46.90
7	-36.76	-36.43	-36.40	-37.95	-38.69	-39.60	-43.69	-63.20

Z - 23.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-42.17	-46.53	-48.98	-49.31	-51.83	-54.16	-46.92	-41.31
1	-38.96	-40.58	-40.57	-40.74	-40.20	-42.30	-41.84	-42.30
2	-39.00	-39.85	-39.81	-41.05	-40.83	-43.45	-42.47	-40.80
3	-42.81	-42.31	-40.99	-42.11	-40.30	-40.70	-41.34	-41.63
4	-49.56	-48.52	-47.73	-52.80	-48.88	-44.19	-45.05	-44.18
5	-47.27	-46.17	-46.77	-49.95	-49.45	-51.59	-60.89	-59.97
6	-47.58	-48.24	-51.14	-47.43	-47.27	-44.60	-49.43	-47.50
7	-55.38	-59.46	-58.57	-49.52	-48.75	-42.31	-40.87	-41.16

Anechoic Chamber dimensions =20.0ft.X 30.0ft.X 30.0ft.

Transmitter location from the open-end of the Chamber = 5.0ft.

Frequency = 10.0GHz.

Z = 6.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)

	0	1	2	3	4	5	6	7
0	-62.43	-71.90	-69.52	-67.38	-64.28	-60.51	-56.20	-53.19
1	-61.66	-64.64	-66.29	-64.76	-62.12	-58.94	-55.96	-52.20
2	-59.89	-60.48	-61.29	-60.65	-58.92	-56.76	-53.47	-50.46
3	-57.20	-57.22	-57.09	-56.37	-55.05	-53.40	-50.71	-48.04
4	-53.55	-53.69	-53.14	-52.52	-51.05	-49.83	-47.72	-45.45
5	-50.15	-49.68	-49.65	-48.93	-47.41	-46.30	-44.54	-42.06
6	-45.77	-45.88	-45.32	-44.41	-44.12	-42.41	-41.24	-38.65
7	-42.15	-42.72	-41.46	-41.40	-39.59	-38.43	-38.00	-35.66

Z = 7.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)

	0	1	2	3	4	5	6	7
0	-60.63	-69.59	-69.28	-66.35	-64.32	-61.17	-57.78	-55.92
1	-60.25	-63.65	-65.51	-65.17	-62.73	-60.48	-57.49	-55.09
2	-59.04	-60.00	-60.62	-61.42	-60.21	-57.68	-55.71	-52.68
3	-56.88	-57.29	-57.09	-57.44	-56.36	-54.47	-52.87	-51.03
4	-53.92	-54.23	-54.00	-54.13	-52.67	-51.72	-49.52	-47.58
5	-51.17	-50.72	-51.44	-50.88	-49.65	-48.77	-46.95	-45.81
6	-48.30	-48.57	-47.21	-46.78	-46.92	-45.62	-44.63	-42.15
7	-44.52	-43.80	-44.70	-43.48	-43.52	-42.09	-41.90	-33.99

Z = 8.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)

	0	1	2	3	4	5	6	7
0	-59.77	-69.51	-66.95	-67.46	-65.26	-62.73	-60.38	-55.85
1	-58.69	-61.94	-65.29	-63.92	-62.81	-60.90	-59.57	-55.41
2	-58.07	-59.25	-60.13	-61.14	-61.03	-53.24	-56.58	-54.84
3	-56.68	-56.85	-56.90	-57.01	-56.71	-55.45	-54.57	-53.31
4	-54.81	-54.50	-54.12	-53.80	-53.16	-53.73	-51.27	-49.44
5	-52.52	-52.55	-51.16	-50.58	-50.71	-50.11	-49.70	-48.01
6	-48.76	-49.88	-47.94	-47.72	-47.83	-46.39	-45.31	-44.08
7	-45.34	-45.23	-46.10	-45.37	-44.80	-43.17	-42.71	-43.27

Z = 9.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-58.33	-67.07	-65.94	-66.67	-65.55	-63.03	-61.88	-57.72
1	-57.95	-61.45	-63.46	-64.67	-63.07	-61.30	-60.73	-57.41
2	-56.66	-57.37	-60.06	-59.72	-59.63	-57.97	-57.56	-55.09
3	-55.55	-56.41	-56.64	-58.34	-57.75	-57.30	-54.45	-54.11
4	-54.79	-55.15	-53.72	-54.28	-54.05	-52.87	-52.98	-52.80
5	-53.22	-52.47	-51.44	-50.99	-50.83	-52.56	-50.17	-48.72
6	-51.24	-50.10	-49.61	-48.69	-50.16	-47.30	-47.20	-45.36
7	-49.58	-48.13	-47.25	-46.80	-48.33	-46.25	-45.30	-46.32

Z = 10.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-56.87	-67.70	-67.83	-63.32	-62.86	-62.82	-60.48	-56.56
1	-56.28	-60.01	-64.70	-61.32	-62.50	-62.14	-59.59	-58.19
2	-55.91	-56.63	-59.02	-59.17	-61.38	-59.49	-56.54	-56.72
3	-55.26	-56.28	-55.77	-58.56	-57.41	-58.92	-55.46	-55.63
4	-53.96	-53.25	-54.52	-53.23	-53.36	-53.19	-54.82	-53.65
5	-50.92	-51.58	-53.12	-53.53	-54.23	-50.97	-52.81	-49.85
6	-50.42	-52.36	-48.52	-49.37	-48.31	-50.88	-47.47	-46.22
7	-51.26	-49.25	-47.38	-46.12	-49.29	-45.03	-45.61	-43.62

Z = 11.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-55.22	-64.49	-69.34	-61.67	-67.01	-63.72	-61.57	-62.51
1	-55.03	-58.46	-63.57	-61.30	-62.63	-61.11	-59.95	-56.55
2	-54.80	-55.82	-58.93	-57.91	-59.01	-60.36	-57.44	-55.81
3	-54.12	-53.84	-55.73	-55.83	-57.52	-57.11	-54.81	-56.78
4	-54.48	-55.30	-52.88	-55.81	-56.94	-55.62	-52.43	-56.46
5	-50.50	-50.72	-54.41	-51.53	-51.65	-54.43	-50.10	-52.99
6	-52.73	-52.76	-48.47	-49.15	-48.49	-49.30	-48.47	-50.18
7	-46.45	-45.98	-52.10	-51.06	-51.93	-45.33	-47.83	-47.77

Z = 12.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-55.68	-69.91	-65.17	-60.54	-63.88	-65.11	-60.39	-58.76
1	-55.08	-53.38	-59.83	-64.51	-59.05	-59.02	-59.45	-57.60
2	-55.71	-56.21	-56.07	-59.89	-59.41	-56.71	-55.96	-59.12
3	-54.97	-54.33	-53.27	-58.47	-57.44	-56.81	-57.79	-55.43
4	-54.23	-54.34	-51.77	-57.13	-55.53	-55.87	-55.65	-51.54
5	-50.70	-52.40	-51.72	-53.83	-52.72	-54.57	-51.76	-52.36
6	-48.20	-48.18	-53.84	-48.94	-48.75	-53.28	-47.89	-53.98
7	-51.49	-47.84	-47.66	-45.89	-45.73	-50.89	-45.44	-46.21

Z = 13.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-52.79	-59.80	-60.91	-69.35	-58.35	-59.76	-68.14	-64.71
1	-54.50	-59.63	-63.02	-57.76	-66.04	-59.31	-59.43	-59.07
2	-55.35	-55.59	-54.64	-59.19	-57.30	-56.46	-56.73	-56.04
3	-53.10	-52.37	-52.85	-57.44	-58.07	-54.19	-55.54	-59.15
4	-51.71	-50.85	-52.36	-52.73	-58.41	-57.44	-58.11	-50.72
5	-50.82	-49.74	-51.71	-50.04	-53.27	-53.32	-49.14	-53.95
6	-49.75	-47.97	-49.14	-48.38	-49.89	-47.78	-49.05	-48.74
7	-51.15	-47.56	-47.38	-45.99	-45.95	-45.28	-55.73	-45.91

Z = 14.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-53.18	-59.98	-58.08	-63.11	-58.54	-64.41	-55.95	-54.51
1	-53.00	-56.99	-61.40	-59.26	-61.39	-59.77	-55.75	-54.94
2	-51.65	-52.25	-54.72	-62.07	-54.76	-57.60	-57.47	-59.42
3	-50.90	-52.25	-56.23	-53.31	-58.14	-57.04	-57.46	-57.74
4	-54.05	-54.25	-50.50	-53.58	-51.78	-51.78	-51.69	-50.71
5	-52.52	-50.76	-49.21	-54.70	-53.21	-51.79	-56.57	-53.20
6	-48.20	-47.04	-49.80	-47.61	-52.68	-53.05	-47.37	-49.27
7	-45.08	-45.08	-53.91	-45.22	-45.68	-45.63	-50.56	-46.14

Z - 15.0ft. PLANE

	Y ---- (ft.)							
X ---- (ft.)	0	1	2	3	4	5	6	7
0	-50.69	-56.81	-57.15	-65.22	-57.63	-59.01	-54.83	-65.13
1	-51.28	-54.22	-55.38	-59.75	-58.93	-56.72	-55.48	-62.27
2	-52.47	-54.11	-55.71	-53.83	-65.68	-53.47	-56.52	-55.89
3	-50.53	-50.53	-52.86	-55.55	-52.59	-54.62	-55.37	-60.72
4	-51.97	-53.49	-52.20	-51.18	-53.16	-58.26	-57.57	-58.44
5	-50.05	-48.77	-49.15	-53.66	-51.30	-48.97	-49.73	-50.34
6	-47.25	-48.75	-54.21	-46.59	-48.47	-52.17	-49.54	-46.13
7	-56.39	-53.11	-44.99	-55.89	-47.55	-47.14	-54.54	-47.76

Z - 16.0ft. PLANE

	Y ---- (ft.)							
X ---- (ft.)	0	1	2	3	4	5	6	7
0	-51.04	-69.30	-72.45	-59.59	-54.61	-69.96	-53.63	-65.56
1	-50.21	-54.06	-62.68	-60.72	-56.04	-62.24	-58.83	-53.71
2	-49.37	-50.71	-55.08	-56.63	-55.28	-58.66	-54.75	-53.98
3	-49.67	-49.83	-51.88	-59.50	-51.03	-60.12	-56.75	-50.99
4	-53.44	-52.44	-49.14	-50.29	-52.42	-58.03	-52.10	-49.65
5	-47.07	-48.26	-53.91	-48.03	-56.76	-49.80	-48.09	-47.38
6	-49.09	-47.22	-45.56	-55.89	-46.57	-47.04	-47.64	-45.95
7	-46.57	-49.66	-51.11	-44.98	-45.91	-50.53	-49.76	-45.46

Z - 17.0ft. PLANE

	Y ---- (ft.)							
X ---- (ft.)	0	1	2	3	4	5	6	7
0	-48.41	-54.23	-53.94	-56.90	-76.58	-53.65	-55.60	-54.17
1	-50.10	-53.73	-58.09	-61.85	-54.93	-56.25	-56.76	-53.08
2	-47.99	-49.42	-53.48	-62.68	-54.43	-60.01	-51.41	-69.30
3	-48.54	-49.56	-53.54	-53.03	-50.23	-57.92	-50.96	-53.65
4	-47.78	-47.94	-49.54	-57.23	-48.24	-57.77	-50.34	-50.67
5	-49.96	-48.76	-46.92	-53.17	-47.93	-57.47	-48.79	-48.19
6	-53.86	-55.99	-48.32	-46.81	-51.21	-54.93	-47.64	-46.02
7	-44.41	-45.89	-56.81	-43.60	-60.36	-46.80	-44.54	-45.07

Z = 18.0ft. PLANE

X ---- (ft.)	Y ---- (ft.) 0	1	2	3	4	5	6	7
0	-49.77	-55.43	-54.13	-52.58	-54.86	-77.12	-53.17	-51.75
1	-48.12	-51.20	-55.25	-64.28	-58.64	-51.89	-54.79	-57.92
2	-52.67	-55.45	-60.23	-53.90	-51.00	-55.32	-54.15	-56.98
3	-53.40	-54.01	-52.11	-48.97	-51.25	-55.06	-49.96	-57.54
4	-53.83	-53.85	-50.13	-47.58	-54.24	-48.88	-53.36	-48.20
5	-54.21	-56.11	-50.78	-46.90	-58.16	-47.45	-60.60	-50.93
6	-49.93	-52.57	-50.73	-44.34	-54.05	-44.63	-51.16	-62.87
7	-46.09	-47.95	-60.95	-43.94	-53.98	-43.93	-45.78	-48.83

Z = 19.0ft. PLANE

X ---- (ft.)	Y ---- (ft.) 0	1	2	3	4	5	6	7
0	-47.42	-53.41	-52.52	-51.46	-52.34	-55.45	-70.85	-53.41
1	-48.88	-52.34	-57.27	-61.94	-59.76	-55.61	-59.01	-58.74
2	-48.25	-48.90	-50.04	-50.89	-55.24	-75.26	-53.54	-54.36
3	-46.21	-46.42	-48.50	-53.86	-57.20	-50.25	-55.25	-55.09
4	-48.11	-48.79	-52.12	-50.51	-47.08	-50.40	-50.73	-49.29
5	-52.81	-55.71	-54.32	-47.57	-48.11	-59.30	-47.52	-55.16
6	-53.50	-55.60	-48.27	-44.01	-49.57	-46.02	-52.20	-45.12
7	-56.90	-56.44	-45.91	-42.27	-56.84	-42.22	-52.64	-49.71

Z = 20.0ft. PLANE

X ---- (ft.)	Y ---- (ft.) 0	1	2	3	4	5	6	7
0	-45.73	-50.78	-50.84	-51.39	-52.94	-54.57	-60.75	-60.48
1	-47.38	-49.55	-51.26	-51.53	-51.94	-52.52	-56.75	-64.78
2	-49.08	-50.34	-53.40	-55.97	-53.56	-50.61	-50.17	-53.48
3	-45.69	-45.83	-46.22	-47.53	-51.51	-60.23	-51.21	-48.94
4	-46.89	-48.22	-51.03	-58.47	-53.45	-47.32	-50.03	-55.21
5	-53.23	-53.94	-50.51	-46.29	-46.27	-54.32	-50.73	-47.77
6	-47.24	-45.67	-43.73	-43.60	-50.90	-47.65	-46.03	-51.58
7	-42.34	-41.87	-41.64	-45.90	-51.63	-42.75	-58.36	-42.67

Z = 21.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-53.92	-64.99	-63.62	-63.05	-64.62	-63.03	-64.77	-61.23
1	-51.98	-57.18	-59.48	-59.10	-60.69	-66.80	-63.22	-62.56
2	-45.33	-46.34	-47.75	-49.08	-51.09	-56.08	-58.46	-56.63
3	-45.99	-46.55	-47.02	-47.87	-48.94	-50.93	-50.43	-54.95
4	-46.28	-47.06	-49.31	-53.74	-52.02	-48.64	-47.29	-48.35
5	-48.19	-47.19	-45.78	-43.86	-44.36	-49.60	-57.11	-47.63
6	-41.95	-42.13	-42.76	-46.70	-61.60	-45.64	-44.70	-52.13
7	-46.37	-48.10	-60.01	-48.50	-42.74	-43.41	-60.42	-41.17

Z = 22.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-44.38	-49.43	-49.55	-48.69	-48.85	-53.05	-53.55	-58.40
1	-45.52	-48.06	-51.04	-52.04	-53.88	-54.75	-52.52	-49.58
2	-46.01	-46.66	-43.00	-43.42	-47.70	-47.25	-48.46	-50.52
3	-44.07	-44.57	-46.02	-48.40	-49.77	-47.83	-46.47	-46.45
4	-49.94	-50.95	-51.84	-53.47	-54.94	-52.99	-48.68	-45.53
5	-42.41	-42.48	-43.48	-45.35	-47.26	-49.74	-60.65	-50.36
6	-59.06	-59.37	-57.16	-50.77	-45.33	-42.56	-43.90	-47.13
7	-41.25	-40.80	-40.14	-40.91	-44.64	-51.92	-46.56	-42.13

Z = 23.0ft. PLANE

Y ---- (ft.)

X ---- (ft.)	0	1	2	3	4	5	6	7
0	-43.47	-49.27	-50.58	-53.53	-59.31	-52.61	-43.33	-43.07
1	-46.06	-49.29	-49.42	-49.50	-49.33	-51.64	-59.49	-49.38
2	-44.78	-45.84	-47.22	-49.75	-50.02	-48.14	-49.64	-63.54
3	-42.54	-42.68	-43.94	-45.45	-47.83	-47.45	-48.36	-52.85
4	-42.27	-42.67	-44.19	-45.72	-48.30	-48.60	-49.20	-56.14
5	-56.73	-58.20	-59.95	-60.14	-58.61	-63.77	-62.23	-82.96
6	-40.67	-40.83	-41.04	-41.74	-43.43	-43.04	-45.19	-45.95
7	-63.72	-61.50	-55.31	-50.18	-44.55	-43.78	-41.40	-41.17

APPENDIX A

ANECHOIC CHAMBERS - DESIGN AND EVALUATION

INTRODUCTION

A.1 General Description

This appendix concentrates on the discussion of anechoic chambers for antenna measurements. In Secs. A.2 and A.3 the microwave absorbing material and its testing and specification are described. In Secs. A.3 and A.6 the two most often used test ranges, the rectangular and the tapered chambers, are outlined and compared. In Secs. A.7 - A.11 a detailed discussion of chamber evaluation is given.

MICROWAVE ABSORBERS

A.2 Absorbing material

For the use in versatile chambers, broad band absorbers having a good impedance match to free space over a wide spectrum of frequencies for a large range of angles of incidence around normal are available. A continuous transition from the free space impedance to the impedance of the metal walls on which absorbers are usually mounted in shielded chambers is obtained either geometrically (e.g., pyramidal absorbers) or electrically (e.g., absorbers made of alternating layers). The most commonly used material for absorbers is light-weight expanded foam (often polyurethane) impregnated with carbon. The thickness of the absorbers depends on the required lowest operating frequency.

Absorbers in the form of solid as well as hollow pyramids with a height up to 4.57 m have been developed for operation down to 26 MHz.

When the pyramidal tapering is combined with a resistive tapering, the result is a high performance absorber having a reflection coefficient of -60 dB at frequencies for which absorber thickness is more than about ten wavelengths. Typically, the reflection coefficient may vary from -50 dB at normal incidenct to -25 dB at a 70° incidence angle, see Fig. A.1. It should be mentioned that absorbers have been developed for special purposes, such as weatherproof, high power absortion, working floor and reduction of surface currents [Emerson, 1978].

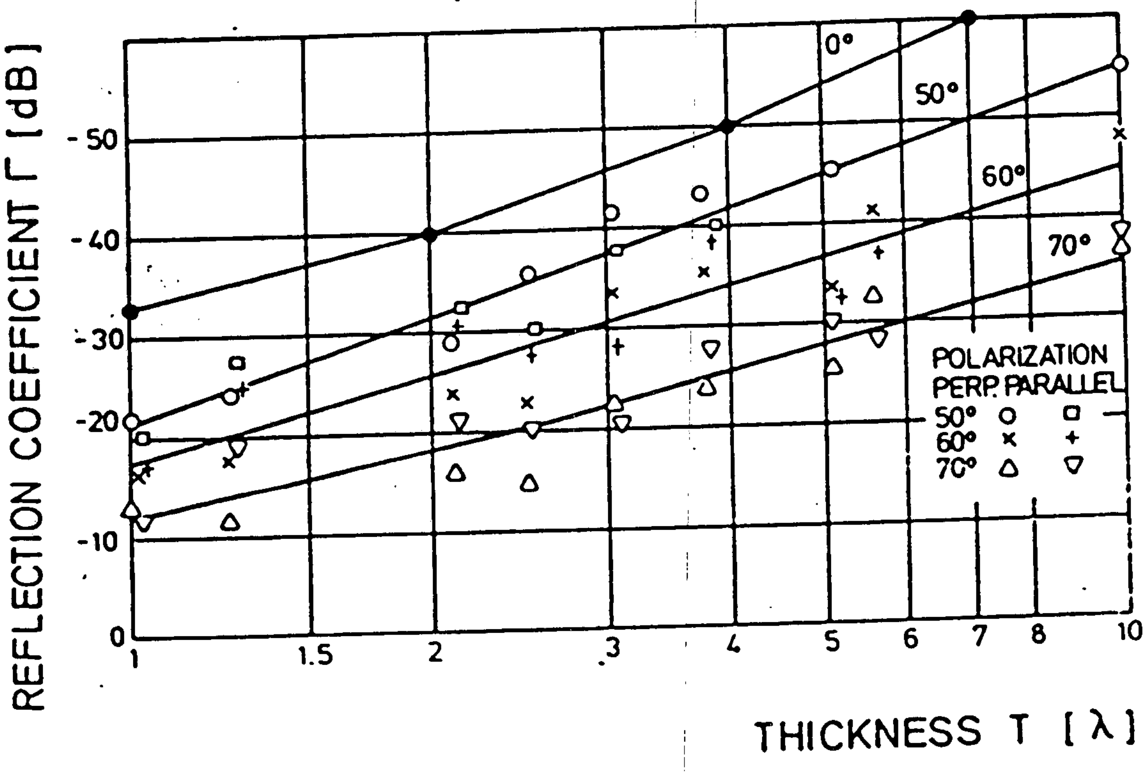


Fig. A.1. Reflection coefficient as a function of absorbers thickness in wavelength λ with incidence angle as a parameter [Emerson, 1973].

A.3 Testing and Specification

Absorbers may be tested in free space or in closed systems. In Fig. A.2, free space measurements are illustrated. An illuminating antenna and a receiving antenna is mounted so that they can be moved along a semicircule while point towards the center of the circle where a sample of absorber backed by a metal plate is placed. In that manner the angle of incidence θ can be varied from 0° towards 90°. The illuminating antenna causes an incident wave E_D on the absorber. Let that part of the incident wave reflected by the absorber towards the receiving antenna cause a received signal E_A when the receiving antenna is positioned for detection of the specular reflection. Then, the reflection coefficient Γ of the absorbers is defined by

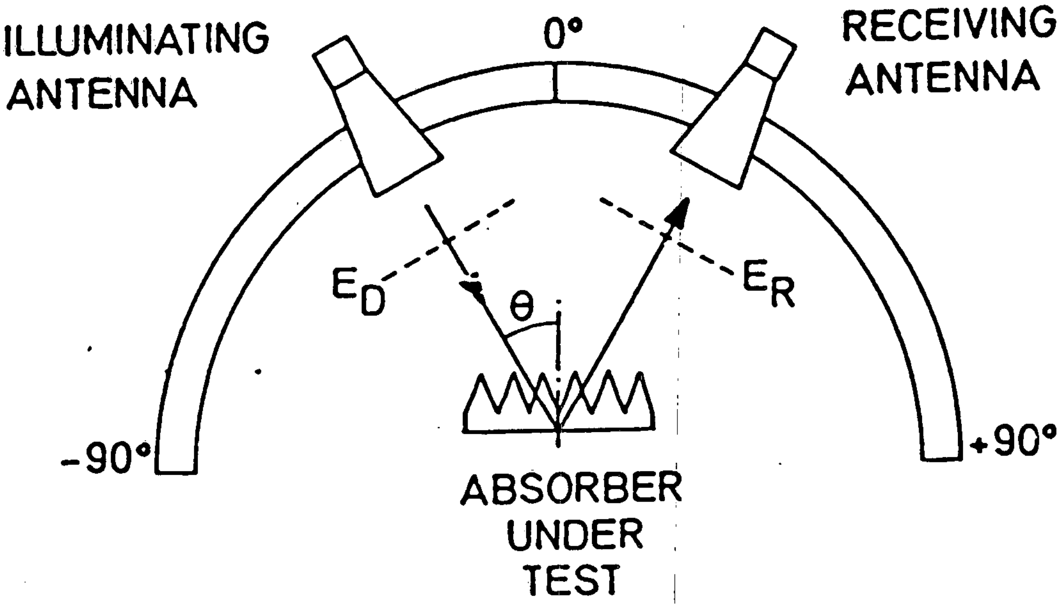


Fig. A.2 The arch technique for testing absorbers

$$\Gamma = 20 \log \frac{E_A}{E_M} \qquad (1)$$

where E_M is the signal detected when the absorber is substituted by a metal plate. The measurements may be performed accurately by adjusting an attenuator inserted between the signal source and illuminating antenna Γ (dB) to obtain the same magnitude of detected signal for the two measurement situations. Instead of using this so-called arch technique, absorbers may also be mounted on a complete wall and special tests carried out on the wall placed, e.g., in a large anechoic chamber. Measurements should be carried out for both normal and parallel polarization. Also, the properties of absorbers may be determined by comparing the back scattering cross section of a metal plate with that of the metal plate covered with absorbers. The plate with and without absorbers may be rotated as in conventional radar cross section measurements.

Although absorbers are made to consume the impinging electromagnetic signals, diffraction from edges of the absorbers are considerable. This means that for free space measurements the side length of the absorbers should be at least about 10 wavelengths so that surface reflections are dominant. However, this also means that at low frequencies a large set up has to be established. Instead of doing this, the VSWR may be measured in a large waveguide system which is flared to a large aperture filled with the absorber [Hiatt, Knott and Senior, 1963]. It should be noted that the reflection coefficient at higher frequencies may also be determined by mesuring the VSWR caused by an absorber backed by a metal plate and placed directly up to a horn aperture.

Besides specifying the reflection coefficient of the absorber in the recommended frequency range for various angles of incidence, information may be required for such properties as shape, dimensions of basic blocks, and their weight, hardness, strength, and flexibility, weatherproof, working temperature range, colour of surface, power handling capability, fire retardancy, fuel oil resistancy, basic material, recommended adhesive or fasteners, and uses.

TYPES OF CHAMBERS

A.4 Rectangular Chambers

In the first attempts to increase the accuracy of indoor antrenna measurements by use of absorbing material, it was natural to place the material as wall liners in laboratores. Thus, the first chambers were rectangular in shape. In order to continue the improvement of measurement accuracy special rooms were installed with the walls folded and baffles and wedges of absorbers were introduced in the lining. Very exotic shapes were patented and several built. However, with the advent of high performance absorbers, the rectangular chamber has become the predominant type of chamber for versatile use.

In general, design of this type of chamber for conventional far-field measurements is based on considerations which are illustrated in Fig. A.3. A transmitting antenna T is placed near one end wall and a receiving antenna R is placed at a distance $2D^2/\lambda$ in the direction of the other end wall referred to as the back wall. Here, D is the diameter of the receiving antenna and λ is the wavelength, i.e., the far-field criterion is satisfied. The width of the chamber is chosen so large that the angle of incidence θ for the ray resulting in a specular reflection E_{R1} from the side wall is less than 70°. A larger angle will result in large side wall reflections, see Fig. A.1.

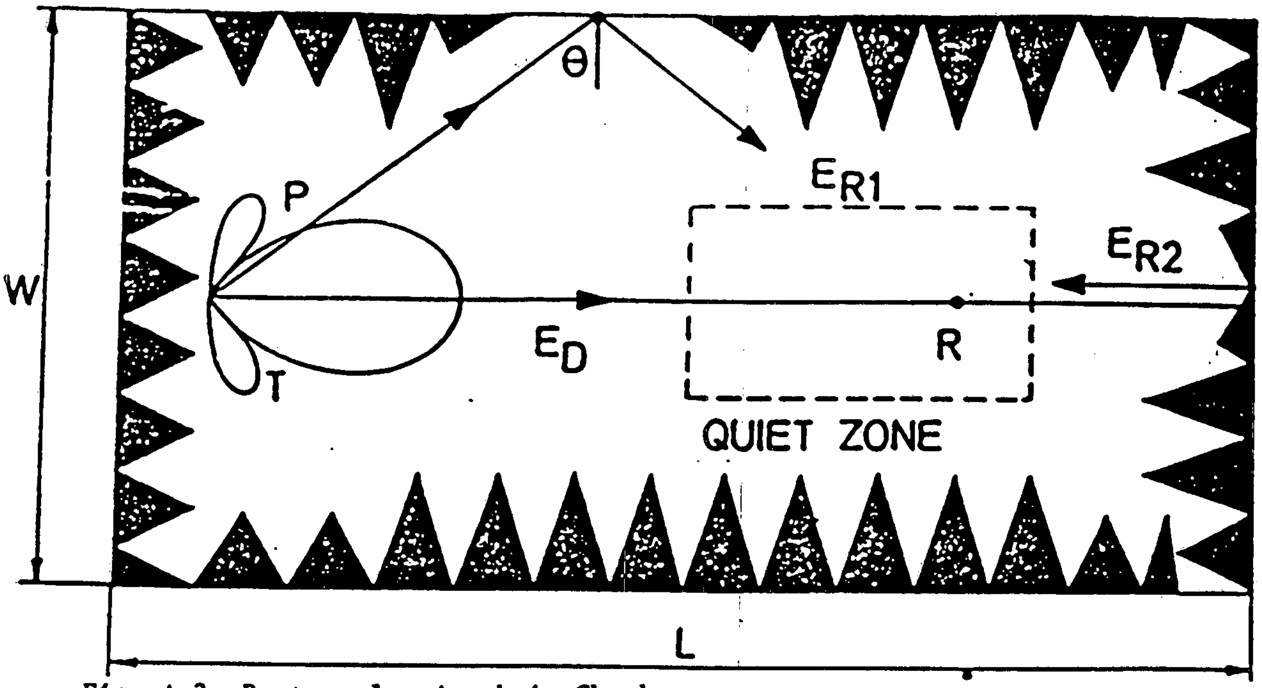


Fig. A.3 Rectangular Anechoic Chamber

Furthermore, the receiving antenna is placed a distance from the back wall which is about half the width of the chamber. This should secure that the receiving antenna does not couple too strongly with the back wall absorbers whose reflections are E_{R2}. The choices result in a chamber total length L and width (equal to height) W given approximately by

$$L = \frac{7}{3}\frac{D^2}{\lambda} \tag{2}$$

and

$$W = \frac{3}{4}\frac{D^2}{\lambda} \tag{3}$$

i.e., a length-to-width ratio of about 3:1. In order to reduce side wall reflections a ratio of, e.g., 2:1 may be chosen. The final choice depends on required measurement accuracy and available absorbing material. Often funds and an existing building limit and determine the final dimensions.

The chamber may be lined with the same type of absorbers all over. However, often thick absorbers may be placed in Fresnel zones around the specular reflection points. In particular, back wall absorbers, which are illuminated with the main lobe, may be chosen to be long. In general, the properties of absorbing material are chosen so that reflections within a volume, a so-called quiet zone, around the test antenna are sufficiently small to satisfy specified measurement accuracy. For example, the back wall absorbers and side wall absorbers may be chosen so that E_{R1} and E_{R2} are of the same magnitude.

This means that

$$\Gamma_b = \Gamma_s + P \tag{4}$$

where Γ_b and Γ_s are the reflection coefficients of the absorbers on the back wall and side walls (longitudinal surfaces), respectively, and P is the pattern level of the illuminating antenna in the direction of the specular reflection point.

It is understood that side wall and front wall reflections can be reduced by proper choice of the illuminating antenna pattern. However, this cannot be made arbitrarily directive because then the direct signal E_D may not be sufficiently plain with respect to amplitude and phase variation in the quiet zone. A careful investigation of the significance of choosing an illuminating antenna with pattern nulls in the direction of specular reflection points does not seem to exist.

Since the reflections from all walls, floor and ceiling add up, the reflectivity level of the quiet zone will depend on the directive properties of the receiving antenna. In case all six specular reflections add up in a constructive manner, the reflectivity level may be up to 15.6 dB larger than Γ_b, but typically when measured with directive antennas it may be only 5 dB larger.

A.5 Tapered Chambers

Out of the chambers with shapes other than the rectangular, the tapered chamber illustrated in Fig. A.4 is often constructed for antenna pattern measurements at low frequencies. It consists of a tapered section and a rectangular or cubical section. The illuminating antenna is placed at the apex. The tapered section may be considered as a large horn antenna terminated into a large waveguide in which a single mode in the form of a plane wave is to be generated. In order not to generate higher order modes, three major problems exist (a) the positioning of the illuminating antenna, (b) the coupling of the field to the lossy side walls, and (c) the transition from the tapered section to the rectangular section.

The positioning of the illuminating antenna may depend on experience obtained from probing the field in the quiet zone for various locations of the illuminating antenna in the apex region.

In order to have a proper transition between the two sections and adequate coupling in the tapered section, its absorbers may have varying properties from the transition to the apex. Experience has even shown that metal foil at the apex end may be helpful [Hollmann, 1972]. It turns out that at low frequencies, where the chamber is illuminated with low gain antennas, the chamber operates similarly to the description given above. At higher frequencies, e.g., above 2 GHz depending

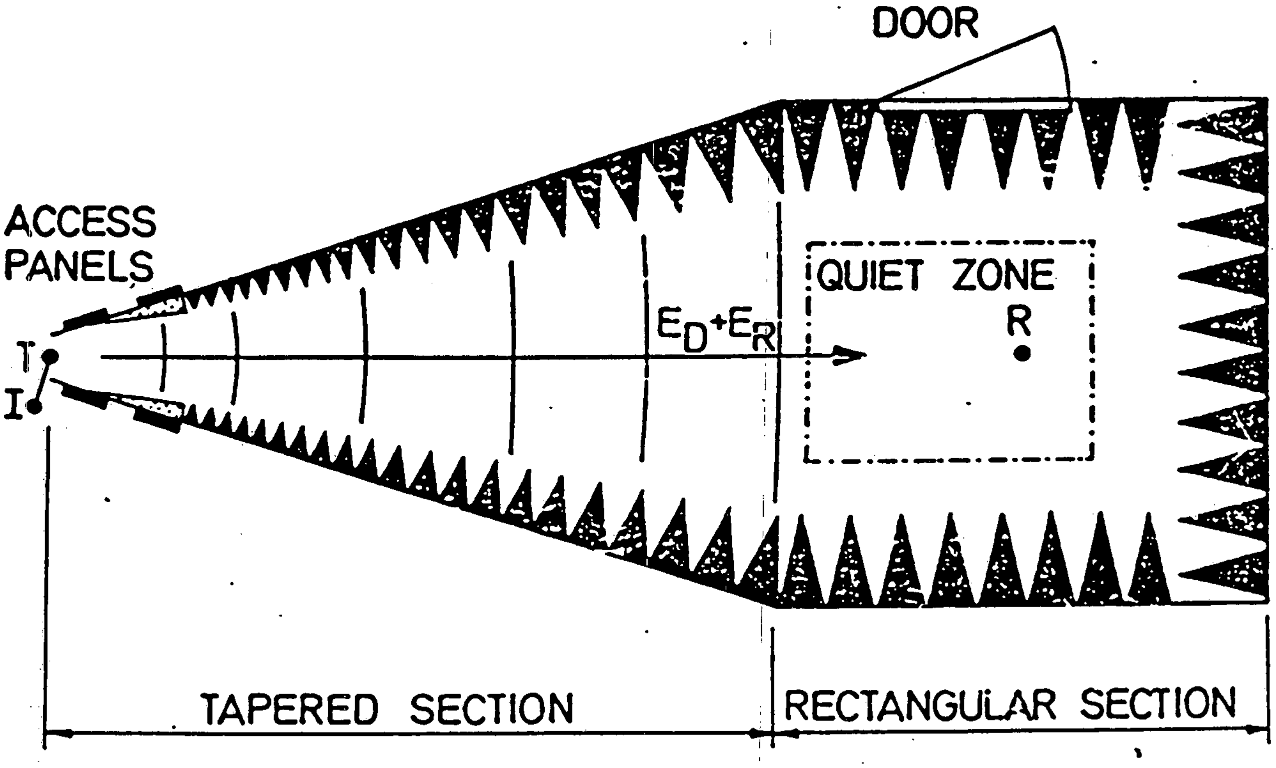
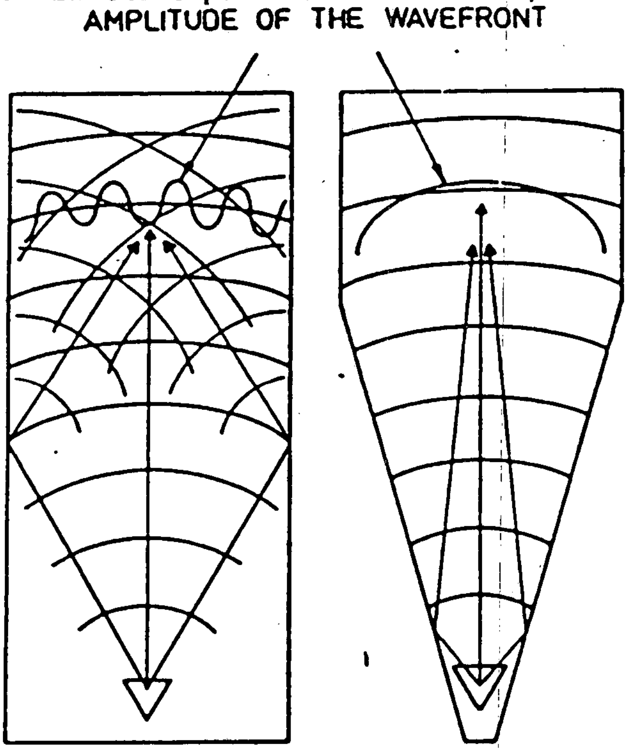


Fig. A.4 Tapered Anechoic Chamber

upon the size of chamber and absorbing material, the field may not couple adequately to the walls in the tapered section. Here, the use of directive antennas placed down the tapered section may be advantageous to use. Thus, at the high frequency end of operation, the tapered chamber becomes similar to the rectangular chamber.

A.6 Comparison of Chambers

Experience has shown that tapered chambers are superior to rectangular chambers at lower frequencies. This is due to the fact that in rectangular chambers at low frequencies, side walls give large reflections which cannot be controlled by using directive antennas as at high frequencies. The superiority of the tapered chamber at lower frequencies may also be understood by considering the image I of the illuminating antenna in the walls of the tapered section as illustrated in Fig. A.4. Since the path length difference between the signals arriving from T and I in the quiet zone is small in wavelengths at low frequencies, the result is that a relatively large quiet zone can be established in the tapered chamber in comparison with the rectangular



(a)
RECTANGULAR
CHAMBER

(b)
TAPERED
CHAMBER

Fig. A.5 Side wall specular reflection comparison between rectangular and tapered chambers [Kummer and Gillespie, 1978] chamber. This is also illustrated in Fig. A.5 [Kummer and Gillespie, 1978].

Besides the advantage of improved operation at low frequencies, the tapered chamber uses less absorbing material. However, the resulting reduction of cost is to some extent offset by the cost of setting up the special tapered section. In addition to this the tapered chamber has some disadvantages in comparison with the rectangular chamber. A path loss occurs in the tapered section so that conventional measurements based on Friis's transmission formula cannot be carried out [King, Shimabukuro, and Wong, 1967]. Further more, small asymmetries may influence the polarization state in the quiet zone. Use of conical tapered sections may improve the polarization performance in the case of circular polarization. In order to obtain propert coupling to the tapered section, the positioning of the illuminating antenna requires more time for the tapered chamber. For critical measurements careful probing of the quiet zone may be required. But, it should be noted that the tapered chamber is not critical with respect to the directive properties of the illuminating antenna, and special supports and exchangeable tips for the apex may facilitate the setting up. However, the tapered section can only be used to feed the rectangular section. This means that, e.g., bistatic measurements cannot make use of the total length of the chamber which may typically be three times that of the rectangular section. In conclusion, the rectangular chamber is a more general purpose test range than the tapered chamber.

EVALUATION OF CHAMBERS

A.7 General Test Problem

The most accepted evaluation procedure for anechoic chambers may be described with reference to a conventional set up for antenna pattern measurements as shown in Fig. A.6. An illuminating antenna is placed close to an end wall and pointing in the direction of the longitudinal axis of the chamber. A receiving antenna is mounted on a model tower. The model tower is arranged on some traversing mechanism. This means that the receiving antenna may be rotated to certain aspect angles and moved about. Before discussing the evaluation let the receiving antenna be placed at a reference position on the longitudinal axis at a distance from the illuminating antenna so that the conventional far field criterion is satisfied.

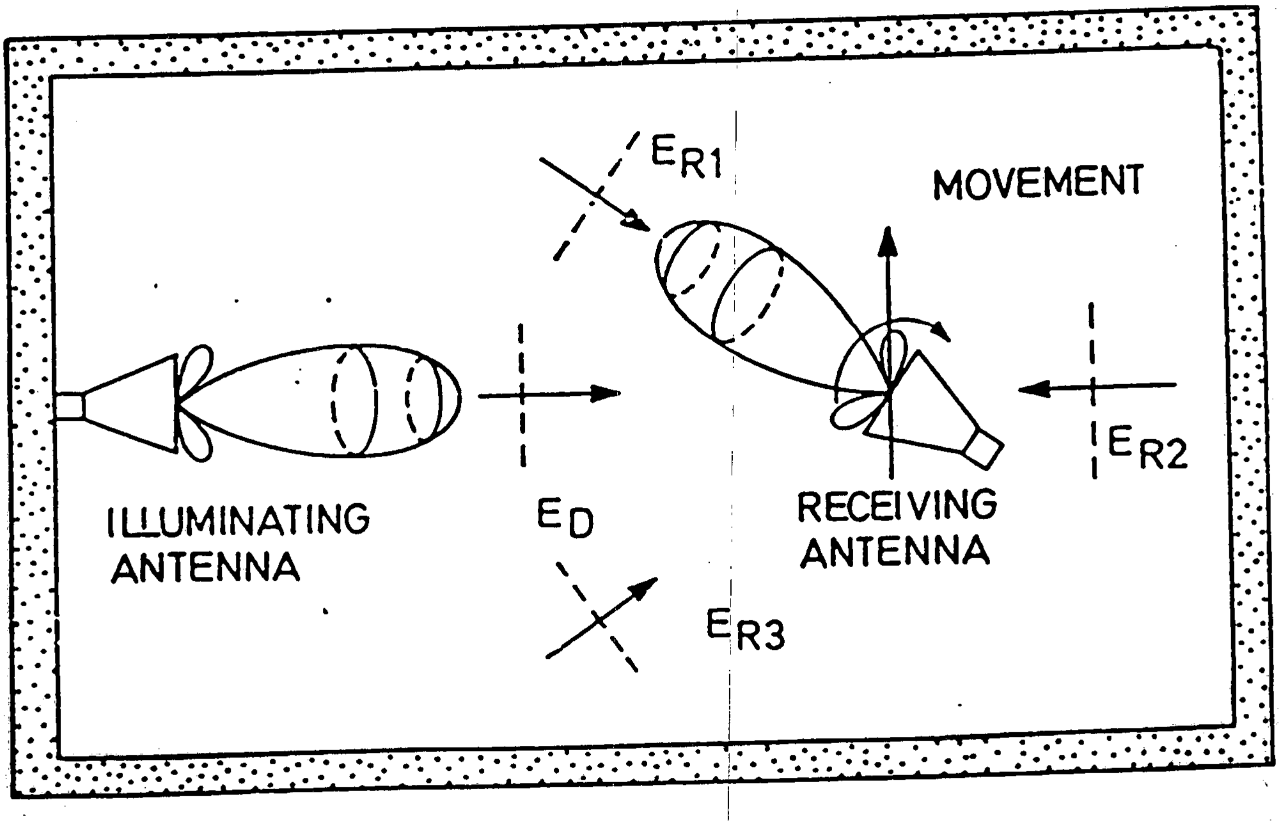


Fig. A.6 General Test Problem

Thus, by rotating the antenna a pattern measurement may be carried out. However, the measurement is disturbed by error signals. These may be classified as follows [Appel-Hansen, 1983].

1. Multiple reflections caused by the illuminating antenna and the receiving antenna.
2. Interactions from model tower, traversing mechanism, and other instruments placed in the test range.
3. Interactions from cabling to antennas.
4. Leakage signals from the source to the detector.
5. Extraneous reflections from the absorber lining of the chamber.
6. Electromagnetic perturbations due to coupling with external sources.
7. Mismatch reflections due to mismatch in the applied components.

In the evaluation of the anechoic chamber it is the influence of the extraneous reflections from the absorber lining which has to be determined. Therefore, the chamber evaluation and the interpretation of the results should be made so that the influence of the remaining error signals is negligible. Unless the opposite appears from the context, let us assume this in the following and make some general considerations.

The illuminating antenna creates a field distribution in the chamber. At every point the field may be considered as the sum of two signals, viz., a direct path signal E_D from the illuminating antenna and an indirect path signal E_R from the absorber lining. The signal E_R is referred to as the reflected signal because it is due to absorber reflections of the field incident on the absorber lining from the illuminating antenna. The direct signal depends on the radiation characteristics of the illuminating antenna. The same is true for the reflected signal. But in addition to this E_R depends on the characteristics of the absorber lining and its position relative to the illuminating antenna. Thus, while the direct signal under conventional far-field conditions vary in a relatively simple manner with position, the variation of the reflected signal is complex. However, in analysis of measured data, the reflected signal may be decomposed into major contributions, e.g., E_{R1} and E_{R3} from the side walls as illustrated in the figure. As discussed in Sec. A.4, this is also done in the design of chambers.

The goal of chamber evaluation is to be able to predict the error caused by E_R. In case the error is small, the chamber performance is said to be high. A theoretical prediction is prevented due to the complicated problem of finding the response of the receiving antenna to E_D and to E_D+E_R. An experimental prediction usually takes its starting point in a consideration of the complicated interference between E_R to E_D. However, this ratio cannot be determined with a conventional set up. This is because the reflections arriving from different directions are detected at the same time and in different manners depending upon the characteristics of the reeiving antenna. In particular, in case a reflection is cross polarized to the antenna or is arriving at a pattern null, it is not detected by the antenna and does not cause any error. Such deficiencies may be avoided by the use of three mutually orthogonal dipoles [Crawford, 1974]. However, even when a complete picture of the intereference phenomenon is obtained in this manner, an exact prediction of measurement error for a set up would probably be impossible.

Therefore, evaluation procedures do not usually study the interference phenomenon itself, but the influence of E_R on patterns measured by using standard antennas. When patterns are recorded at different positions, i.e., for various distances between the illuminating antenna, variations in the recordings are observed. These are mainly due to three effects. The first effect is an in-and-out-of phase interference between the reflected signal and the direct signal. The second effect is variations in the amplitudes of the direct and reflected signals. These measured variations are influenced by the fact that as the receiving antenna is moved, its pattern scans with respect to the directions of propagation of the detected signals. The third effect is variations in the recorded patterns due to the fact that far-field conditions with respect to E_D can only be met to some extend depending upon the length of the test range. Now, suppose that the correct pattern of the antenna is known, then a so-called reflectivity level is found from the observed variations. As described in the next sections the reflectivity level can be considered as a figure of merit for the performance of the absorber lining. In fact, because the reflectivity level should characterize E_R, the measurements and the analysis of results should be carried out so that variations due to imperfect far-field illumination, changes in the detected amplitude of E_D, and error signals other than E_R are kept at an insignificant level. If this is not the case, it is still possible to analyse the data, but the measured figure of mereit would then represent an equivalent error signal level characterizing the sum of error signals and imperfections causing the observed variations [Appel-Hansen, 1983].

A.8 Reflectivity Level

In Fig. A.7 the test situation is simplified in order to describe the magnitudes involved in the determination of the reflectivity level. The radiation patterns of the illuminating and recieving antennas are shown. The main beam of the receiving antenna is rotated to an angle ϕ with respect to the direction to the illuminating antenna. At this angle, let the output voltage caused by a plane-wave direct-path signal E_D be denoted E_{DP}. Furthermore, let E_{DO} be the output voltage for $\phi=0$. Then, the pattern level P at ϕ is defined as the ratio in dB between E_{DP} and E_{DO}. However, due to the influence of reflections, the pattern level at ϕ is detected with a possible error. A reflectivity level characterizing the possible error is found in the following manner. The influence of all reflections incident from avrious directions

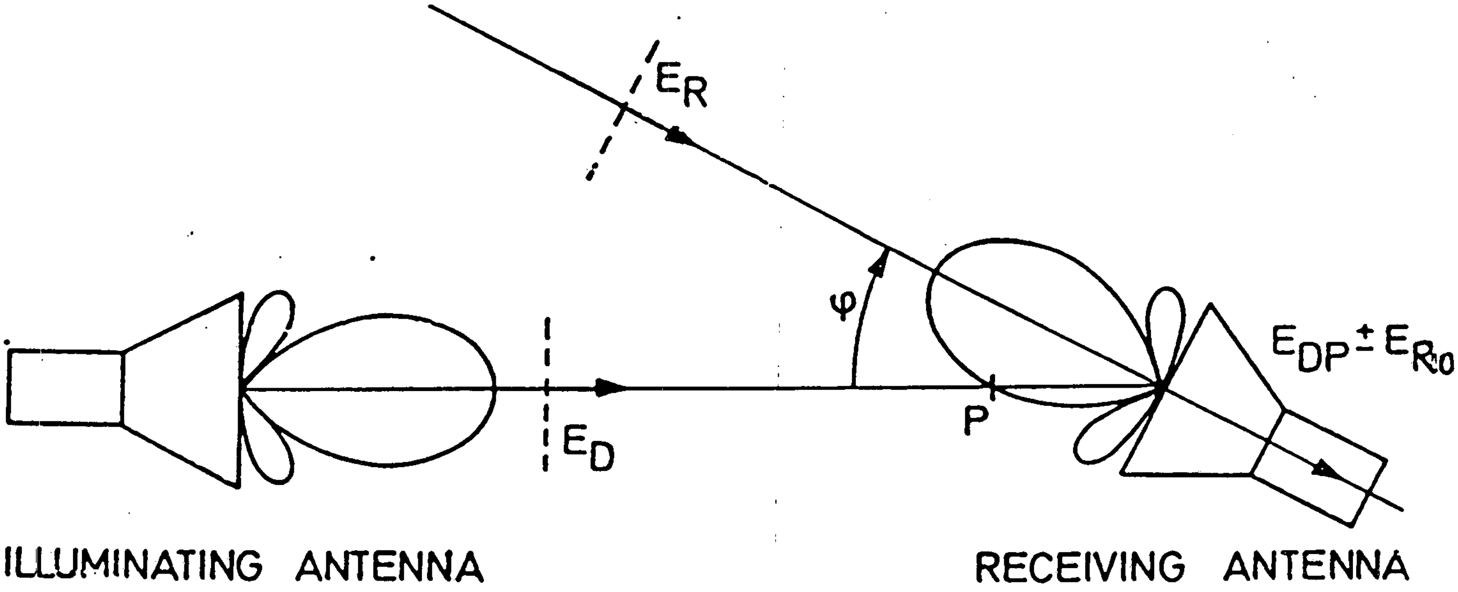


Fig. A.7 Equivalent reflected signal E_R.

and detected at corresponding pattern levels with particular polarization states is substituted with an equivalent plane-wave reflected signal E_R incident along the main beam direction for the angle considered and polarization match to this direction. Let E_R cause an output voltage E_{RO}. By moving the receiving antenna, the intereference between E_{RO} and E_{DP} may be detected in the form of a VSW curve. From this, the reflectivity level

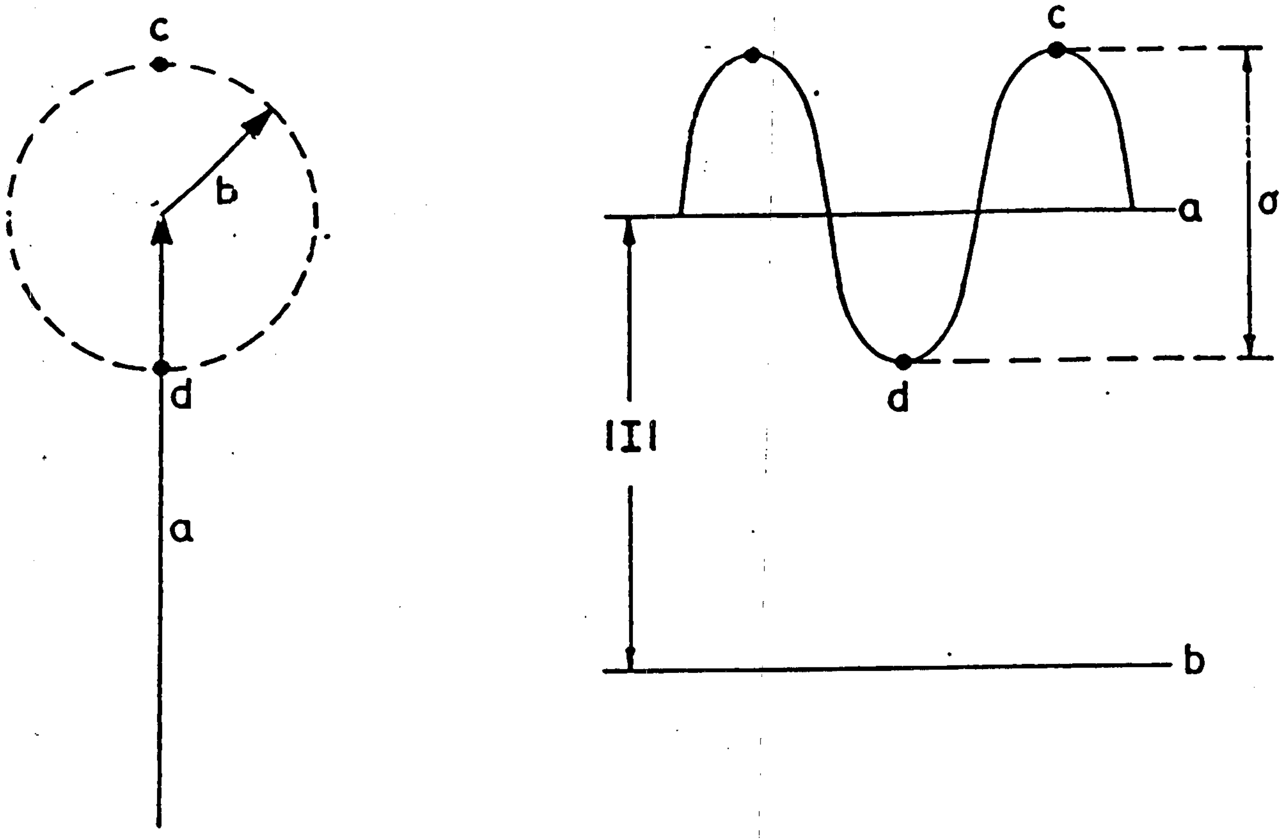
$$R = 20 \log \frac{E_R}{E_D} \tag{5}$$

may be found as described below. Here, and in the following for simplicity, E_R and E_D denote E_{RO} and E_{DO}, respectively. Because it is $E_R = E_D 10^{\frac{R}{20}}$ and $E_{DP} = E_D 10^{\frac{P}{20}}$ which interfere, it is convenient to define an interference level I as

$$I = 20 \log \frac{E_R}{E_{DP}} = R-P \tag{6}$$

Thus $I < 0$ implies $E_R < E_{DP}$ and $I > 0$ implies $E_R > E_{DP}$, i.e., for $I < 0$, E_R is the minor of the interfering signals and for $I > 0$, E_R is the major signal.

Suppose that the amplitudes of the two intefering signals do not change during the movement of the antenna. Furthermore, suppose that the movement is carried out along a line not parallel to the bisector of the angle between the directions of propagation of the two signals. Then, the two signals interfere in-and-out-of phase and the situation may be illustrated by the simple phasor diagram and the regular VSW



(b) PHASOR DIAGRAM (a) INTERFERENCE CURVE

Fig. A.8 In-and-out-of phase interference.

curve in Fig. A.8. Beforehand, it is not known which one of the two signals is the larger, i.e., the sign of I is not known. Therfore, let a be a major interfering signal and b the minor signal. Furthermore, let c and d be the levels detected when a and b are in-phase and out-of-phase, respectively, and let all signals be given in dB over some reference level, e.g., the maximum level detected when the receiving antenna is rotated. This means that

$$c = 20 \log (10^{\frac{a}{20}} + 10^{\frac{b}{20}}) \tag{7}$$

$$d = 20 \log (10^{\frac{a}{20}} - 10^{\frac{b}{20}}) \qquad (8)$$

and from observed values of c and d, the levels of a and b may be found directly from

$$a = c + 20 \log \frac{1 + 10^{\frac{d-c}{20}}}{2} \qquad (9)$$

$$b = c + 20 \log \frac{1 - 10^{\frac{d-c}{20}}}{2} \qquad (10)$$

In practice c and d may be read from the recorded curves and a and b found from handheld computers. Alternatively, a and b may be obtained from the graphs in Fig. A.9 showing c-a and c-b as functions of the peak-to-peak variation $\sigma = c-d$. It is seen that as σ tends to infinity both interfering signals become equal and 6 dB below the maximum level c of the interference curve. From knowledge of P it may be decided whether a or b represents R.

In actual measurement the receiving antenna is rotated 360° at a fixed position. At the angle ϕ, a signal in the range between c and d is detected. This is seldom equal to P. Therefore, we define c-P as the possible in-phase error ε_+ and d-P as the possible out-of-ohase error ε_-. In Fig. A.10, the errors are shown as functions of the interference level I. It can be shown that

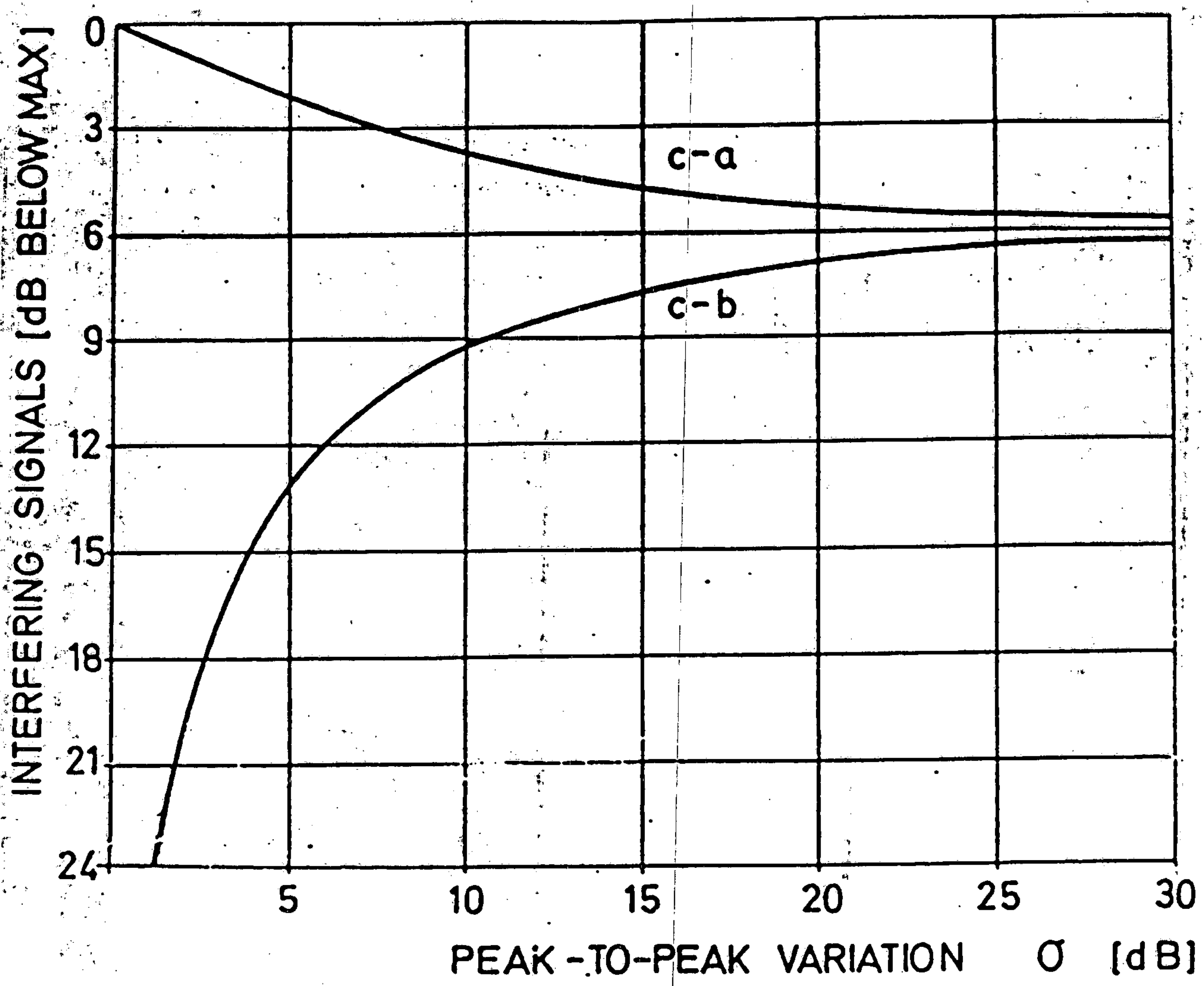


Fig. A.9 Level of major (a) and minor (b) interfering signals below the maximum (c) of the interference curve as a function of the peak-to-peak variation σ = c-d

$$\varepsilon_{+} = 20 \log (1 + 10^{\frac{R-P}{20}} \qquad (11)$$

and

$$\varepsilon_{-} = 20 \log (\pm 1 \mp 10^{\frac{R-P}{20}} \qquad (12)$$

where the upper signs are used for R < P and the lower signs for R > P. Furthermore, $\sigma = \varepsilon_+ - \varepsilon_- = c - d$. It is noted that c - a and c - b as functions of σ in Fig. A.9 have the same variations as ε_+ and ε_-, respectively, as functions of I for I < 0 in Fig. A.10. In Fig. A.11 the peak-to-peak variation is shown as function of P with R as a parameter. Only curves for I < 0 are shown.

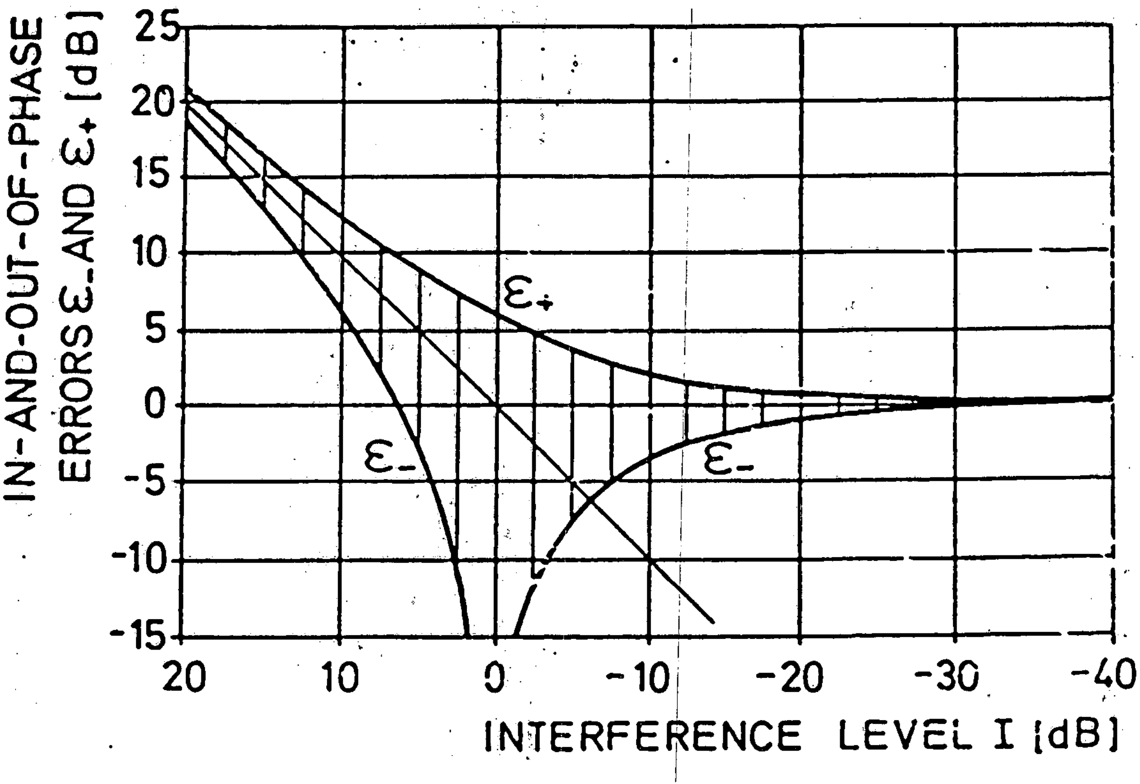


Fig. A.10 In- and out-of-phase errors as functions of interference level I = R - P

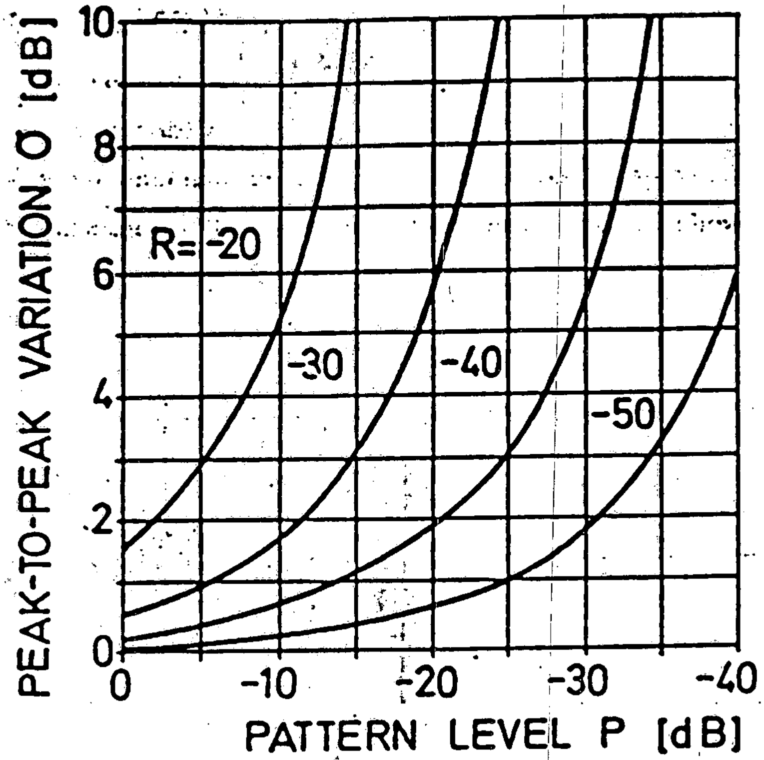


Fig. A.11 Peak-to-peak variation as a function of pattern level with reflectivity level as a parameter for I < 0

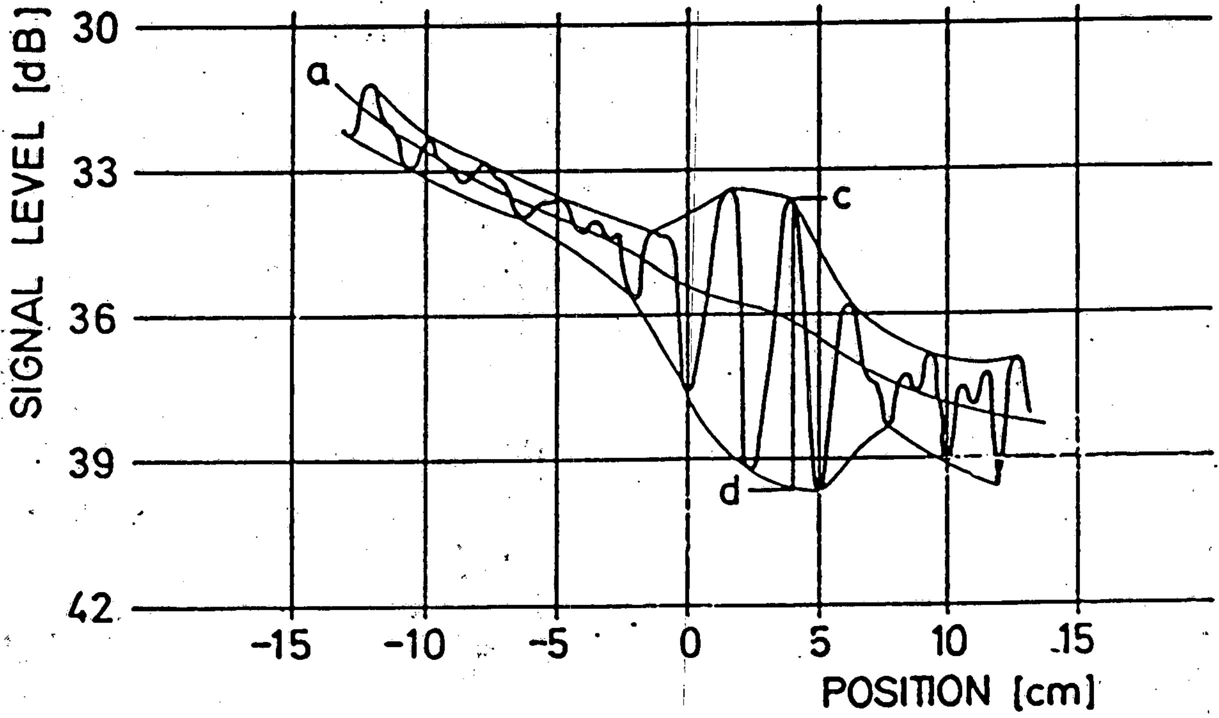


Fig. A.12 A free space VSW curve

A.9 Interpretation of Results

In practice, when the receiving antenna is moved, the recorded interference curve may deviate considerably from the regular VSW curve in Fig. A.8. Suppose that the receiving antenna in Fig. A.6 is moved transverse to the longitudinal axis of the chamber. Then an interference curve as shown in Fig. A.12 may be recorded. The sloping character of the curve is due to the scanning of the pattern of the receiving antenna relative to the pattern of the illuminating antenna, i.e., both the direct path signal level and the pattern level P change. The oscillations are due to the interference between E_{DP} and E_R. Since E_R is composed of several signals which interfere during movement, the amplitudes of the oscillations vary.

In the anlysis of the interference curve, it is enveloped by curves drawn through maxima and minima. If a pattern was recorded by rotating the antenna at an arbitrary position along the traverse line, the pattern level at ϕ would be recorded in the range between the two enveloping curves. It is understood that the worst case error may occur where the maximum peak-to-peak variation is recorded. Therefore, at this position the values of c and d are read and values of a and b may be found from eqns. (9 and 10). Since the sloping character is supposed to be due to the scanning of the pattern, P is interpreted to be equal to a and R to be equal to b. Thus, P and R are about -36 dB and -46 dB, respectively, corresponding to σ about 6 dB and I about -10 dB.

From the above given discussion, it is seen that in the evaluation of a chamber, it is not the reflected signal which is found but an equivalent signal which, when propagating along the axis of the receiving antenna and polarization match to this direction would cause a variation equal to that observed.

The equivalent signal expressed as the reflectivity level may be used to find the possible errors ε_+ and ε_- in a direct manner related to an evaluation situation and in an indirect manner related to a different measurement situation as described below.

First, it is convenient to define what is meant by an evaluation situation. This is a measurement situation in which the set up used during evaluation is arranged exactly in position chosen among the continuum of positions passed during the recording of a VSW curve. Then in the direct manner, the reflectivity level is used to predict the possible error for the set up in an evaluation situation. The error is denoted possible because it may be less or worse depending upon the manner in which the interference data are analysed. When the reflectivity level is found as above, which has become common practice, from that evaluation situation which has the worst case error, the error will in general be less. The direct manner may be claimed to be rather hypothetical since for an evaluation situation the error is known from data measured during evaluation. But the description of the direct manner will hopefully facilitate understanding.

In the indirect manner, the equivalent error signal is used to predict the possible error in a measurement situation which is not equal to one of the evaluation situaitons. The set up may be that used in the evaluation but arranged in a manner not equal to an evaluation situation, e.g., with other aspect angles, as well as other set ups. For such a case, the reflected signals cannot be expected to be detected in the same manner as in one of the evaluation situations. Therefore, the error may be less than the predicted error, but it may also be worse than this. If precise information on the error is required, it may be needed to evaluate the test range with the actual set up.

It should be noted that when evaluation is carried out, data are also available for making a reduction of the influence of E_R. This is due to the fact that from the recorded VSW curve, two signals a and b may be found as described above. One of these signals is the pattern level P and the other is the reflectivity level R. Usually, P is the larger when E_{DP} corresponds to levels not more than about 20 dB below the main lobe level and P is the minor when E_{DP} is close to pattern nulls. In general, the ambiguity problem can be solved, for example, by one or more of the following methods:

1. Obtain knowledge of the pattern level from independent measurements or theory.
2. Analyse the VSW curve at various positions and identify P as a or b depending on whether, a or b respectively, has a regular variation with position corresponding to that which could be expected for E_{DP} [Appel-Hansen, 1967].
3. Analyse several VSW curves at closely spaced angles and identify P at the various aspect angles as a combination of levels and b which has a variation with aspect angle similar to that which could be expected for E_{DP}.
4. Use expected symmetries in P and R.
5. Changing R by changing the test range, e.g., introducing a metallic plate or removing some absorbers.
6. Using Fourier analysis or other mathematical methods to identify P.

When the ambiguity problem is solved, the influence of E_R on the so determined pattern level, is usually less than in the case the pattern is recorded at an arbitrary position. Therefore, it is said that reduction of the influence of E_R is made. However, it should be mentioned that by using such a procedure, the influence of E_R may not be eliminated. For example, if a component of E_R causes a constant systematic error during the movement. This may be the case, if the movement is too short.

A.10 Experimental Techniques

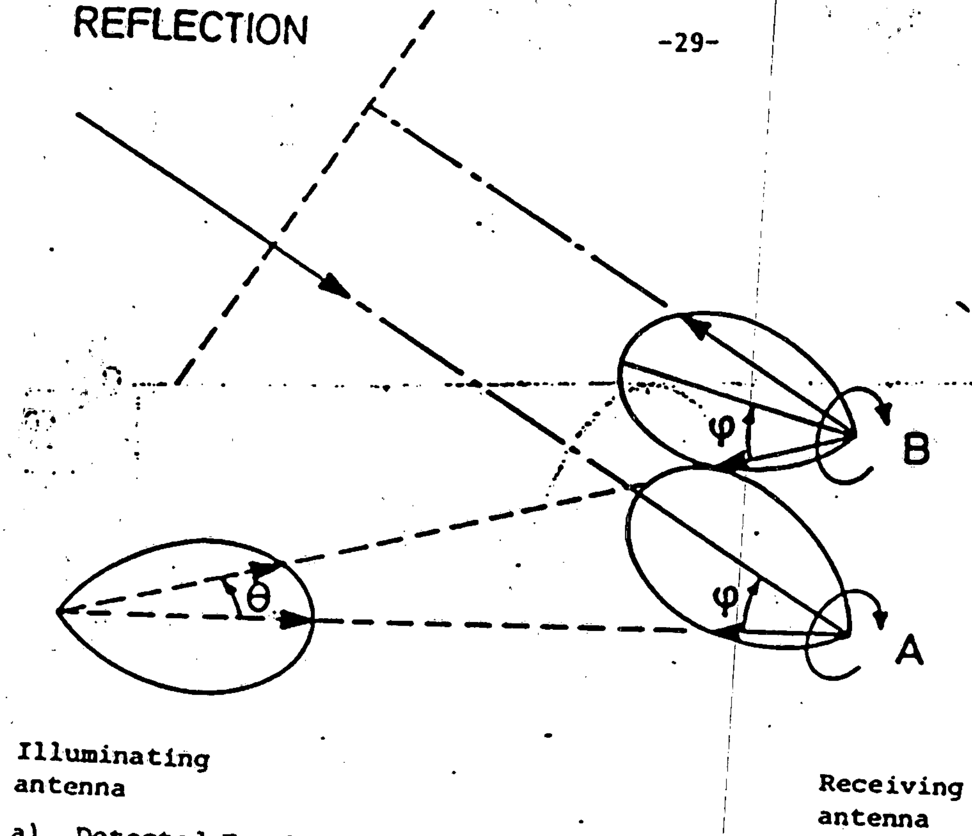
From the previous seciton, it is understood that the influence of E_R may be evaluated by moving the receiving antenna. The movement may be carried out in various manners. The two most often used techniques, i.e., the antenna pattern comparison (APC) technique and the voltage standing wave ratio (VSWR) technique are described with reference to Fig. A.13 a and b, respectively. In order to compare the technqiues, suppose that there is only one plane wave refleciton.

In the APC technique anenna patterns are recorded at discrete positions, e.g., at several positions interspaced a quarter wavelength along a transverse line. The recorded patterns are superimposed so that the peak levels of their main beams coincide as illustrated in Fig. A.14. The influence of reflections is found at the aspect angle ϕ by reading c and d. From a consideratin of Fig. A.13a, it is evident that the level of the detected reflected signal at the aspect angle ϕ is not the same in the positions A and B.

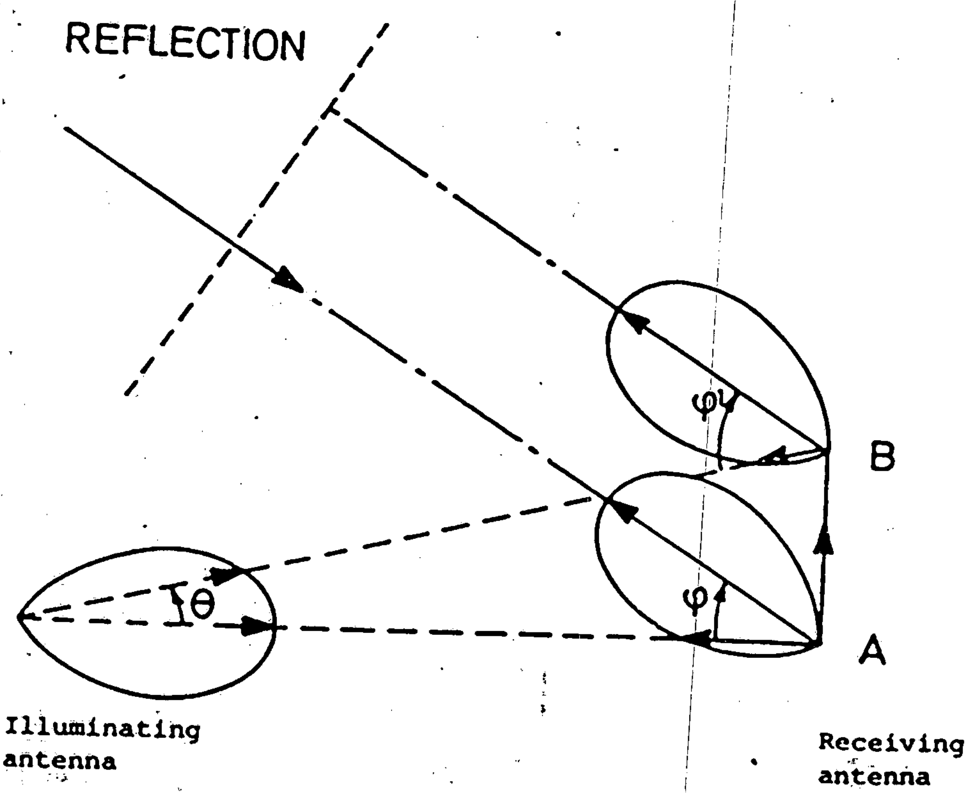
In attempts to secure that levels c and d depend on and only on E_R the following precautions may be taken

1) Usually, the set up is arranged such that 0° on the chart paper corresponds to the receiving antenna pointing in a direction parallel to the main axis of the chamber. This means that when the antenna is moved off the main axis of the chamber, the main beam is not recorded at 0°. This is usually due to the scanning of the antenna patterns. However, in case reflections are strong, they may also influence the direction of the recorded main beam. Then, if the patterns are superimposed, such an influence would not be observed. In order to avoid this, the recorded patterns may be adjusted so that 0° on the chart paper corresponds to the receiving antenna axis point in the direction of a reference point on the transmitting antenna.

2) During the measurements the main lobes of the different patterns may be adjusted to the same level on the chart paper by changing the gain of the receiver. The purpose of the adjustment is to take into account variations in E_{DP} due to scanning of the antenna patterns and change of distance between the antennas. It should be noted that in case the reflections are so large that they influence the main beam level, the adjustment does not answer its purpose. Large reflections can be observed by moving the receiving antenna continuously along the main axis of the chamber while detecting the main beam level. If oscillations larger than a few tenths of a dB are observed, the VSWR technique is recommended as a better technique for determining R.



a) Detected E_{DP} kept constant in APC technique



b) Detected E_{RO} kept constant in VSWR technique

Fig. A.13 APC and VSWR techniques

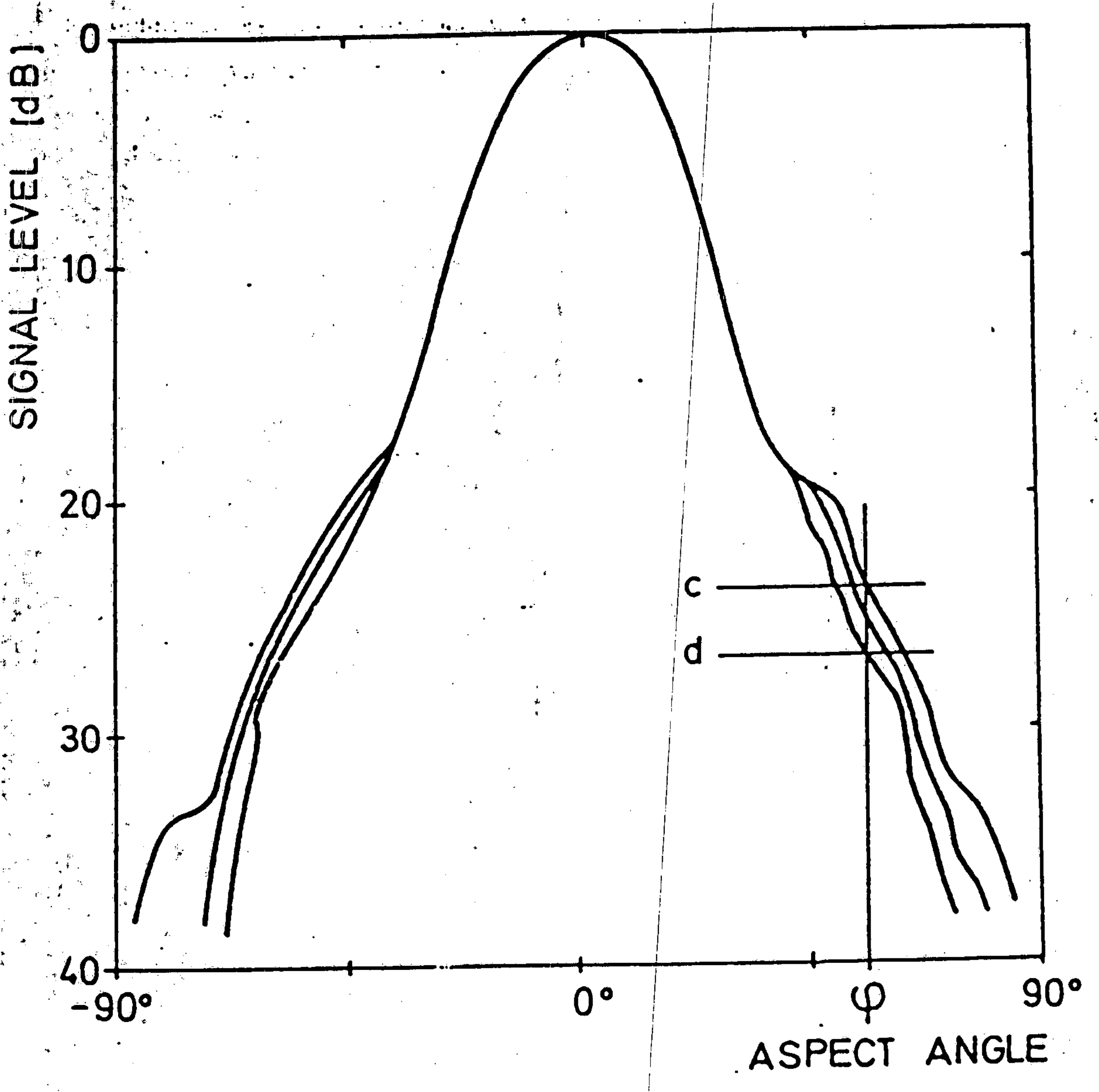


Fig. A.14 The antenna pattern comparison technique

The VSWR technique may be described with reference to Fig. A.13b. Here, the receiving antenna is turned to an angle ϕ with respect to the longitudinal axis of the chamber. Then, during a continuous movement of the receiving antenna, a VSW curve may be recorded. While E_{DP} was kept constant in the APC technique, E_R is kept constant in the VSWR technique. It is also noted that in the APC technique, pattern recording is made during continuous rotation, while in the VSWR technique, VSW recording is made during continuous linear movement. This means that discrete data from one technique should agree with discrete data from the other technique. If sufficient data are recorded both techniques may be implemented to give the same results. However, as illustrated in Figs. A.12 to A.14, the analysis of the superimposed patterns in the APC technique does not correspond to the analysis of the VSW curves in the VSWR technique. Therefore, the results obtained by the two techniques often disagree. Usually, the APC technique indicates better performance than the VSWR technique. However, especially when E_R influence the main beam level, the opposite may be the case. While the APC technique may be used to give an ilustrative and a preliminary indication of measurement error, the VSWR technique is considered to be the most accurate for chamber evaluation.

From the previous discussion it is apparent that two types of movements are carried out, i.e., rotation and translation. In order to describe actual measurements, it is convenient to have a reference system of traverse lines and test planes as shown in Fig. A.15. Traverse lines (TL) are lines along which a reference point of the antenna is moved during a translation. Test planes (TP) are planes in which the main beam axis of the receiving antenna is scanned during a rotation. As it

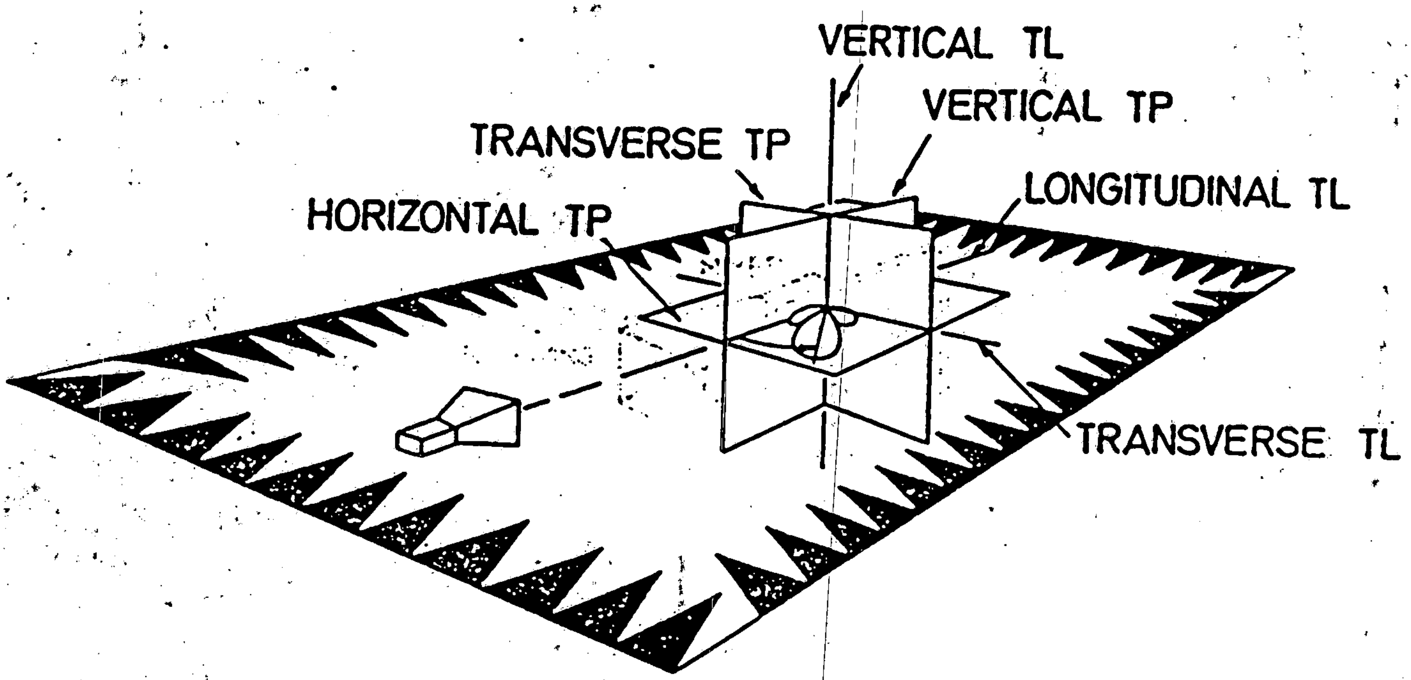


Fig. A.15 Test planes (TP) and traverse lines (TL) for test range evaluation.

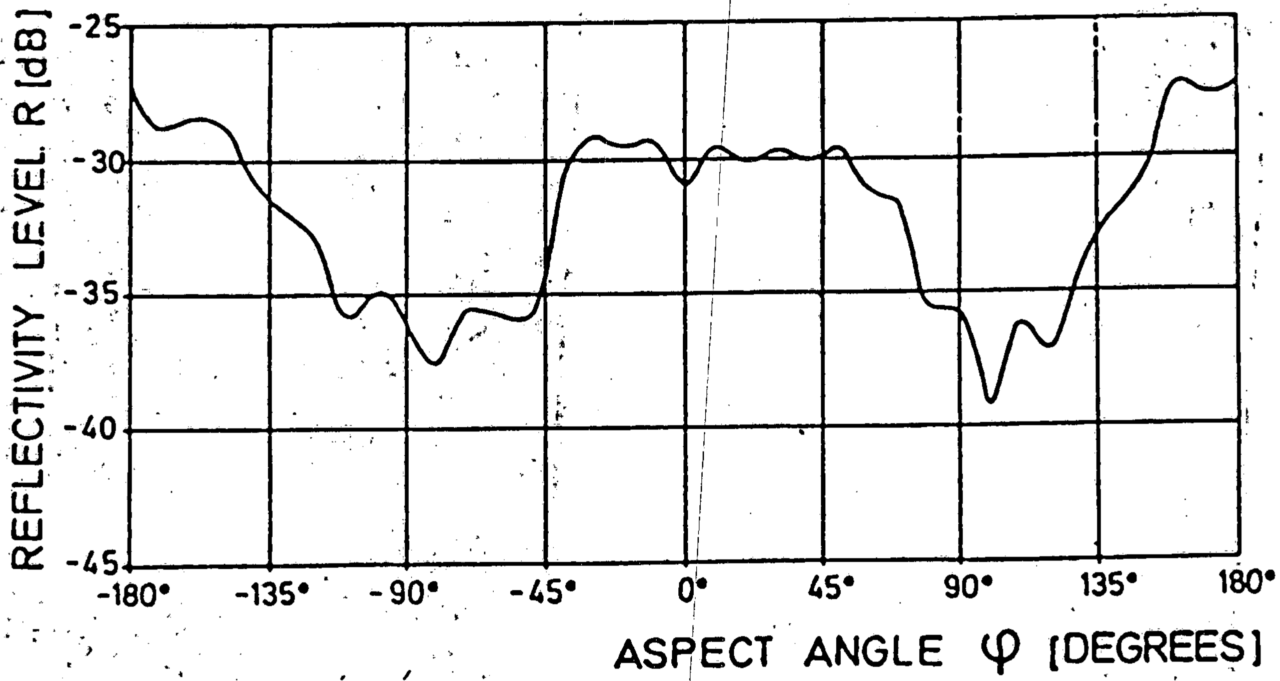


Fig. A.16 Reflectivity level as a function of aspect angle.

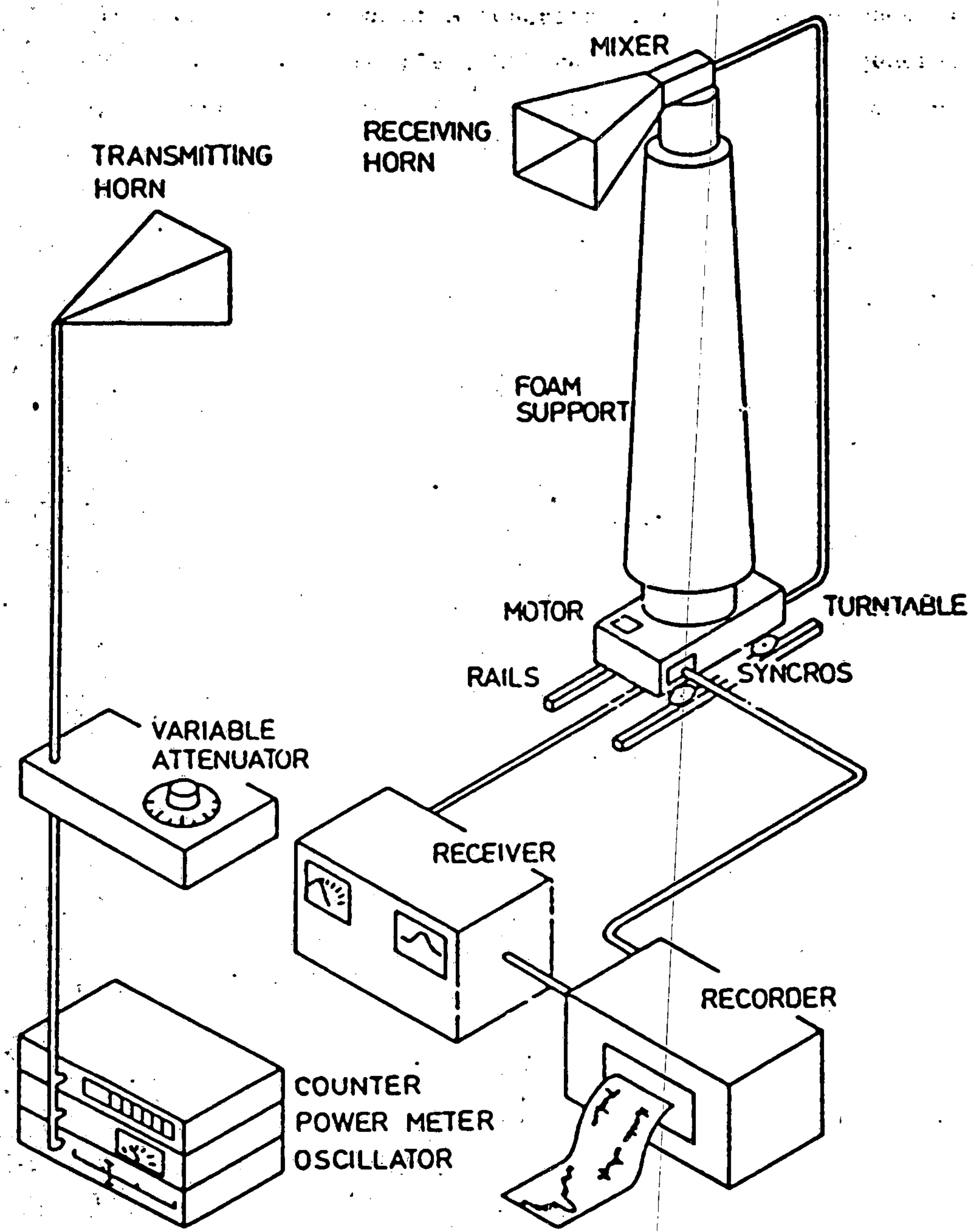


Fig. A.17 Experimental set up for chamber evaluation.

appears there are three major test planes and three major traverse lines. Thus, there are nine major combinations of test planes and traverse lines. The chosen combinations are most easily described with reference to the VSWR technique. For each traverse line VSW curves are recorded as the angle ϕ is varied in steps. For each angle a reflectivity level may be found. As an example, in Fig. A.16 the reflectivity level is shown as a function of ϕ for measurements with half wve dipoles at 10 GHz. The experimental set up in Fig. A.17 was used. A horizontal TP and a longitudinal TL were employed.

A.11 Choice of Test Parameters

The evaluation situations passed during the recording of a VSW curve may be described by using some test parameters. As it could be expected, the obtained value of R depends on the test parameters. This has already been observed in Fig. A.16 where R was shown as a function of ϕ. The dependence of R on test parameters is in general, complex. However, there are some general tendencies, which may be used in choices of test parameters for a test of an implemented test range. Because absorber performance improves with increase in frequency, the reflectivity level usually decreases with increase in frequency. Therefore, it is often chosen to evaluate the test range at a low, an intermediate, and a high frequency. This should secure that different problems in the frequency range are detected. Carefull tests at the low frequency end may require measurements at closely spaced frequencies in order to detect worse case errors. Fig. A.18 shows R as a function of frequency f. It is observed that at 215 MHz a strong maximum of R is observed. This is probably due to a constructive interference between several major components of E_R or a poor performance of the back wall [Appel-Hansen and Kalhor, 1982a]. Half-wave dipoles were used in the tests.

Usually, R decreases with increase in directivity. This is due to the fact that directive antennas mainly detect reflections arriving along their main beam axis. This means that several components of E_R will usually not interfere in a constructive manner as may be the case for low gain antennas. This also means that experiments using directive antennas especially at high frequencies may disclose sources of for example specular reflections. Such experiments may also be used to diagnose impovements introduced in the absorber lining [Appel-Hansen, 1973]. However, it should be noted that in case there is only one reflection as in Fig. A.7, the worse case reflectivity level obtained when the antenna is pointing in the direction from where E_R is received will be independent of the receiving directivity. Thus, when there is only a major source of reflection, the reflectivity level is nearly independent of the directivity. It is customary to choose standard antennas for evaluation of anechoic chambers, e.g., Yagi antennas at low frequencies and horn antenna at high frequencies. In case detailed information is required, a low gain, an intermediate gain, and a high gain antenna may be used at each test frequency, and tests may be carried out with the antennas vertically as well as horizontally polarized.

The chosen combination of traverse lines and test planes depends on the dimensions of the anechoic chamber and the characteristics of the absorber lining. In order to detect specular reflections from side walls, a horizontal TP and a transverse TL may be chosen for ϕ varying from 0° to ± 90°. Reflections from the back wall may be detected by choosing a horizontal TP and a longitudinal TL for ϕ varying from ± 90° to 180°. In case the height of the chamber is less than its width or the chamber has special floor absorbers, it may be necessary to arrange a traversing mechanism which can move the antenna along a vertical TL.

In the diagnose of sources of major reflections use may be made of the fact that a single reflection arriving at an angle ϕ with respect to

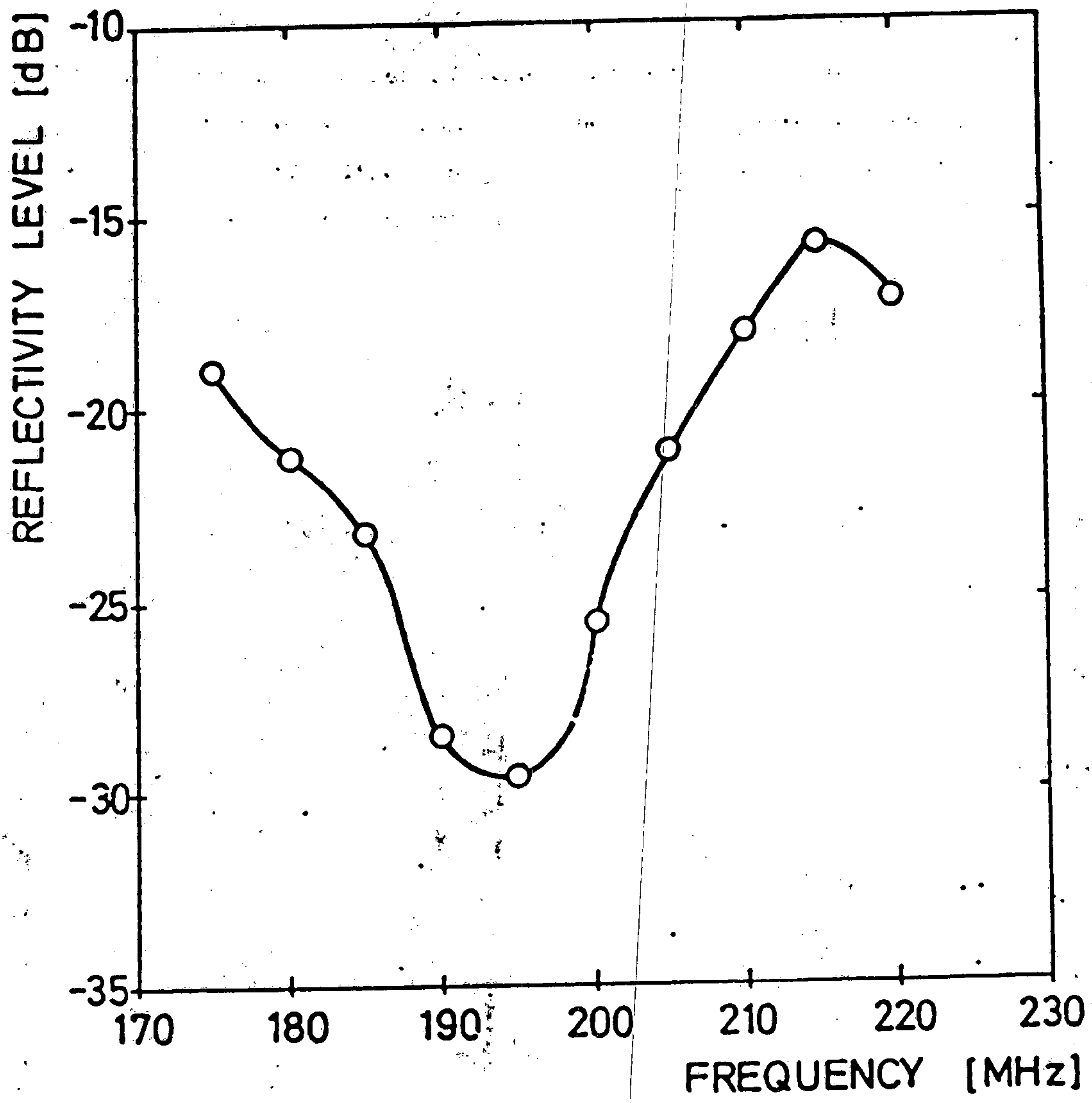


Fig. A.18 Reflectivity level as a function of frequency.

the direction of the direct signal causes an interference period along a longitudinal traverse line given by

$$P_{\ell} = \frac{\lambda}{2\sin^2\frac{\phi}{2}} \tag{13}$$

and an interference period along a tranverse traverse line given by

$$P_t = \frac{\lambda}{\sin\phi\cos\alpha} \qquad (14)$$

where λ is the free space wavelength and α is the angle between the tranverse traverse line and the plane containing the directions of propagation of the direct signal and the single reflection.

These formulas are valid for the case of two plane waves interfering as shown in Fig. A.7. However, in general, when the difference in path length between E_R and E_D is many wavelengths the expressions for P_ℓ and P_t can be considered as good approximations. If this condition is satisfied, we obtain for a side wall specular reflection case with λ = 1 m; ϕ = 25°, and α = 0°, P_ℓ = 10.7 m and P_t = 2.4 m. Thus, for examination of such a reflection, a transverse TL requires less movement. In the case of end wall reflections, P_ℓ is the familiar $\lambda/2$ period from slotted line experiments, while P_t becomes infinite indicating that end wall reflections cannot be detected using transverse movements.

The position of the traverse line segments along which the antenna are moved depends on the specified quiet zone of the anechoic chamber. The quiet zone is a volume within which certain specifications with respect to the uniformity of the field distribution are met. Usually, the quiet zone is specified as the volume within which the reflectivity level is below a specified maximum value. A reasonable upper limit for the cross section of the quiet zone may be found by using the far-field criterion at the lowest operating frequency of the chamber and for the largest test distance. This results in a quiet zone having a cylindrical volume with its axis coincident with the longitudinal axis of the chamber. However, the zone may have any shape and size depending upon the measurements to be carried out. Typically, the final ratio of the width of the quiet zone to the total width of the test range is about 1:5 in the case of rectangular chambers and about 1:3 in the case of tapered chambers. Since R can be expected to increase as the distance of the traverse lines to the internal surfaces of the test range is decreased, the traverse lines should mainly be chosen at the maximum test distance and evenly distributed along the boundary of the quiet zone.

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