GEORGIA INSTITUTE OF TECHNOLOGY
Engineering Experiment Station

PROJECT INITIATION

Date: January 31, 1973

Project Title: A Study of Comparative Costs for Far-Field Antenna Patterns Determined by Near-Field Measurements and by Far-Field Measurements

Project No.: A-1498*

Project Director: Mr. C. F. Burns

Sponsor: U. S. Army Missile Command; Redstone Arsenal, Alabama

Effective January 15, 1973 Estimated to run until: November 15, 1973

Type Agreement: Contract No. DAAH01-73-C-0430 Amount: $ 6,483 *

*Constitutes sub-project under E-21-624, School of EE, Dr. G. P. Rodrigue - Project Director. Total Contract estimate is $14,726.

REPORTS REQUIRED: See E-21-624

SPONSOR CONTACT PERSONS: See E-21-624

Defense Priority Rating: DO-A2 under DMS Reg. 1.

Assigned to Radar Division

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RA-62

GEORGIA INSTITUTE OF TECHNOLOGY
Engineering Experiment Station

PROJECT TERMINATION

Date March 15, 1974

PROJECT TITLE: "A Study of Comparative Costs for Far-Field Antenna Patterns Determined by Near-Field Measurements and by Far-Field Measurements"

PROJECT NO: A-1498*

PROJECT DIRECTOR: Mr. C. P. Burns

SPONSOR: U.S. Army Missile Command; Redstone Arsenal, Alabama

TERMINATION EFFECTIVE: January 31, 1974 (Contract Expiration)

CHARGES SHOULD CLEAR ACCOUNTING BY: January 31, 1974

*Sub-project under E-21-624/EE)

CONTRACT CLOSEOUT ITEMS REMAINING: (See E-21-624)

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RESEARCH PROJECT INITIATION

Date: January 31, 1973

Project Title: A Study of Comparative Costs for Far-Field Antenna Patterns Determined by Near-Field Measurements and by Far-Field Measurements

Project No: E-21-624* (S)

Principal Investigator Dr. G. P. Rodrigue

Sponsor: U. S. Army Missile Command

Agreement Period: From Jan. 15, 1973 Until Nov. 15, 1973

Type Agreement: Contract No. DAAH01-73-C-0430

Amount: $8,243*
*Project includes sub-project A-1498(EES); budgeted for $6,483. Total Contract estimate is $14,726.

Reports Required: Final Technical Report

Sponsor Contact Person (s):

Technical Matters
(Individual not named)
Radar Technology
Advanced Sensors Directorate
Directorate for Res, Engr., & Missile Sys. Laboratory
U. S. Army Missile Command
Attn: AMSMI-REG
Redstone Arsenal, Ala. 35809

Contractual Matters
(Thru ORA)
Mr. R. J. Whitcomb (ACO)
ONR Resident Representative
Hinman Research Building
Campus

Defense Priority Rating: DO-A2, DMS Reg. 1

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RA-3 (6-71)

GEORGIA INSTITUTE OF TECHNOLOGY

OFFICE OF RESEARCH ADMINISTRATION

RESEARCH PROJECT TERMINATION

Date: 14 March 1974

Project Title: A Study of Comparative Costs for Far-Field Antenna Patterns Determined by Near-Field Measurements and by Far-Field Measurements

Project No: E-21-624 (Includes sub-proj. A-1498/EES)

Principal Investigator: Dr. G. P. Rodrigue

Sponsor: U. S. Army Missile Command; Redstone Arsenal, Ala.

Effective Termination Date: ~~1-31-74 (Contract Expiration)~~

Clearance of Accounting Charges: by 1-31-74

Contract Closeout Items Remaining: Final Invoice & Closing Doc's.
Final Report of Inventions
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Classified Material Cert.

School of Electrical Engineering

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RA-4 (5/70)

A STUDY OF COMPARATIVE COSTS FOR FAR–FIELD ANTENNA PATTERNS DETERMINED BY NEAR–FIELD MEASUREMENTS AND BY FAR–FIELD MEASUREMENTS

BY

G. P. Rodrigue and C. P. Burns

GEORGIA INSTITUTE OF TECHNOLOGY
Atlanta, Georgia 30332

31 January 1974

Prepared for

ADVANCED SENSORS DIRECTORATE
RESEARCH, DEVELOPMENT, ENGINEERING AND MISSILE SYSTEMS LABORATORY
U. S. ARMY MISSILE COMMAND
REDSTONE ARSENAL, ALABAMA

A STUDY OF COMPARATIVE COSTS FOR FAR-FIELD ANTENNA PATTERNS DETERMINED BY NEAR-FIELD MEASUREMENTS AND BY FAR-FIELD MEASUREMENTS

by

G. P. Rodrigue and C. P. Burns

Georgia Institute of Technology
Atlanta, Georgia 30332

31 January 1974

Prepared for

Advanced Sensors Directorate
Research, Development, Engineering and Missile Systems Laboratory
U. S. Army Missile Command
Redstone Arsenal, Alabama

FOREWORD

This study of the relative cost of far-field antenna patterns of large phased arrays determined by near-field and far-field measurements was conducted under Contract No. DAAH01-73-C-0430 from the U.S. Army Missile Command. The work reported was performed at Georgia Tech in the School of Electrical Engineering and in the Radar Division of the Engineering Experiment Station during the period January 1973 to January 1974.

In addition to the authors, Georgia Tech personnel who contributed to the report include R. P. Zimmer and B. D. Wright. Acknowledgement is made to the industrial concerns who were extremely helpful in supplying cost estimates and time schedules for previous phased array measurements on far field ranges. In some instances specific data is referenced to a specific manufacturer, but in most cases, no specific manufacturer is identified because of the proprietary nature of cost information. The authors wish to express appreciation to the following industrial concerns:

Raytheon Company, Missile Systems Division
Radio Corporation of America, Military Products Division
General Electric Company, Heavy Military Electronic Systems Division
Scientific Atlanta

Special acknowledgement is made of the contributions of Mr. William G, Spaulding of the Advanced Sensors Directorate, RDE and Missile Systems Laboratory, who was Technical Representative for the Army Missile Command on this project.

ABSTRACT

Antenna pattern measurement costs for both acceptance testing and production testing of a large phased array were determined for both near-field and far-field measurement techniques. Operating costs depend on the thoroughness to which the antenna is tested. Extremely large amounts of data can be generated very efficiently using the near-field technique. However, most test programs are limited by budget and time considerations to a relatively small volume of data. Since requirements for more data would always favor the near-field techniques, a limited set of measurements comparable to previous far-field measurement experience was used.

In terms of total cost, the cost associated with the near-field measurement technique is approximately 75 percent of the cost of conventional far-field range techniques. Initial investment costs, including capital equipment, for the near-field technique are only 50 percent of those for a far-field range, while operational costs for the near-field average 84 percent of far-field costs. A large percentage of operational measurement costs is for initial check-out of the phased array, and these costs are independent of the type of range used. If a moveable near-field positioner is used in the near-field, the total cost of near-field measurements increases to an estimated 85 percent of far-field costs. This type of positioner may be desirable but not essential to the measurement process.

An estimate of the expected rate of return on capital investment showed that the near-field range with fixed positioner was a slightly better investment than either a far-field range or near-field range with moveable positioner.

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SECTION 1

INTRODUCTION

The cost of antenna pattern measurements for large phased arrays using conventional far-field ranges has been very high. The results of recent work at Georgia Tech under Contract No. DAAH01-72-C-0950 have conclusively demonstrated that measurements in the near-field can yield far-field antenna patterns with an accuracy equal to that of a high quality far-field range.[1] The objective of this work has been to compare the cost of pattern measurements of large phased arrays by the conventional far-field method to the cost of equivalent near-field measurements. Costs are derived and documented for each measurement approach using a common basis for the estimation.

Cost accounting procedures vary for different organizations. Depreciation rates, benefit-to-cost ratios, real estate taxes, etc. can be estimated in many ways. For comparison purposes, the cost for each measurement technique has been computed in three different ways. For each cost estimate, operational costs are considered fully chargeable to the measurements program for the duration of the program. The first cost estimate includes all initial investments, including land and capital equipment. A second cost estimate assumes the initial investment depreciates linearly with time, and a portion of this cost is included in the total cost estimate. The third estimate determines the internal rate of return of the initial investment and the benefit-to-cost ratio. Other procedures could be used with equal merit.

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[1] Rodrigue, G. P., Joy, E. B., and Burns, C. P., "An Investigation of the Accuracy of Far-Field Radiation Patterns Determined from Near-Field Measurements", Final Report, Contract No. DAAH01-72-C-0950, August 1973.

Section 2 contains a description of the model antenna and a list of the pattern measurements that would be required for acceptance testing of the model phased array. The initial investment required for far-field and near-field ranges capable of measuring the model antenna is estimated in Section 3. Recurring costs are itemized in Section 4. Section 5 compares the total cost of measurements on the two ranges using three different types of cost analysis. A hybrid approach combining the near-field and far-field methods is described in Section 6. The relative advantages and disadvantages of each range are discussed in Section 7. A description of the Technical Requirements for a measurement program is presented in the Appendix.

SECTION 2

BASIS OF COMPARISON

2.1 Introduction

In this analysis comparisons of costs were established for an antenna model having fixed parameter values and an assumed schedule of measurements. Inasmuch as the physical size and weight of the antenna significantly affect capital equipment costs for both near-field and far-field measurement techniques, the resulting cost estimates are dependent on the particular antenna model. Although a particular model is used for costing in this analysis, where appropriate, consideration is given to the sensitivity of cost to the model.

Operating or recurring costs depend to a large extent on the thoroughness to which the antenna is to be tested. The schedule of measurements specified in the Technical Requirements (See Appendix A) has been condensed based on the experience of two recent phased array antenna test programs. It appears that although more measurements of phased array antenna characteristics are always desirable, test programs, in practice, are invariably limited by budget, time, volume of data, and boredom. A set of data subject to the above restrictions was selected for the analysis and is typical of that collected on other phased array antenna programs. Requirements for more data would always favor the near-field measurement technique, and to assure unbiased results, efforts were made to avoid the specification of a very ellaborate set of data.

In the following sub-sections a description is given of the baseline antenna model and associated measurements that were used in arriving at detailed costs of each measurement technique.

2.2 Baseline Antenna Model

The physical model of the antenna selected for costing purposes can be described simply in terms of the overall physical characteristics. Table 2.1 lists the pertinent parameter values that were assumed for the baseline antenna model. The particular values approximate those of antennas that are of particular interest to the Army.

The cost of the near-field range equipment is most strongly influenced by the area of the antenna plane, since that determines the near-field plane to be scanned. Similarly the far-field capital costs are strongly influenced by weight of the antenna since that dictates the necessary load capacity of the antenna positioner. The depth of the antenna will affect the size of absorbing material used in the near-field measurement technique as well as the weight of the antenna. In Sections 3 and 4 these physical characteristics will be used in arriving at the initial investment costs and the operational costs, respectively.

2.3 Schedule of Measurements

Detailed descriptions of measurements that should be performed and schedules for such data acquisition are heavily dependent on the function of the particular radar system and its operational modes. The measurements outlined in Table 2.2 constitute a typical set that might be acquired on a monopulse phased array antenna incorporating sidelobe blanking features.

One of the most critical parameters of the antenna is pointing accuracy as derived from the monopulse difference pattern. The measurements prescribed in Table 2.2 indicate that pointing accuracy measurements would be conducted

Table 2.1

Baseline Antenna Model

Frequency	3 to 4 GHz
Active Radiating Plane	13 ft. x 14 ft.
Total Area of Antenna Plane	15 ft. x 16 ft.
Depth of Antenna	10 ft.
Weight	60,000 lbs.

Table 2.2

Schedule of Measurements

Parameter	Frequencies	Port	Scan Angles
Beam Pointing Accuracy (Null depth)	7 3	R(ΔAZ ΔEℓ)	10 50
Absolute Gain	10	Transmit, R Σ	1
Relative Gain & Polarization	3	T,R(Σ, ΔEℓ ΔAZ)	80
* D/S Amplitude D/S Phase	3	R(Σ, ΔEℓ, ΔAZ)	50
Antenna Pattern Cuts (Beamwidths)	10 6	T,R(Σ, ΔEℓ, ΔAZ)	1 30
Cross Polarization	3	R(Σ, ΔAZ ΔEℓ)	10
Near Sidelobe Contours	3	T,R(Σ, ΔEℓ ΔAZ)	8
Far Sidelobe Contours	3	T,R(Σ, ΔEℓ ΔAZ)	8
Sidelobe Blanking	3	R	6

* Monopulse difference-to-sum ratio

for ten different beam scan angles at each of seven different frequencies within the operating band. Further, the measurements would be made at three of these frequencies for forty additional scan angles of the beam.

Absolute gain would be determined on the sum beams only at boresight. The absolute gain of both transmit and receive sum patterns would be measured at each of ten different frequencies. All other gain measurements would be referenced to those absolute values.

Relative gain would be determined on transmit and on receive sum, azimuth and elevation difference patterns at three frequencies for eighty different scan angles. These data would include gain degradation with scan angle and beamwidths, and could be acquired in the form of pattern cuts.

Cross polarized components would be measured on all receive patterns at three frequencies for each of ten scan angles and referenced to the absolute gain measurements of the sum beam.

Near sidelobe contours are assumed to be determined from a raster scan procedure covering 40^{o} by 40^{o} scan sectors centered on the main beam and covered in 0.5^{o} steps. These measurements would be conducted at three frequencies and eight scan angles for the transmit patterns and all receive patterns.

Far out sidelobe levels would be also determined by a raster scan process (on the far field range) covering a 20^{o} by 20^{o} scan sector located at least 20^{o} off beam pointing direction. Again, scan sectors would be covered in 0.5^{o} steps.

The above schedule of measurements serves to define briefly a realistic test program for an antenna whether the near-field or far-field measurement technique is used. Because the schedule would be common to both techniques, it was used to arrive at the measurment costs associated with each technique. These costs are considered in Section 4.

SECTION 3

INITIAL INVESTMENT

3.1 Introduction

To arrive at a cost comparison between the near-field and far-field measurement techniques, it is necessary to consider first the investment required to establish the appropriate test facilities, that is, land, building, and equipment. A starting base of "zero" for both near- and far-field test facilities has been assumed such that land must be acquired, building constructed, and all equipment procured. This approach provides a valid cost basis for capital investment and avoids the analytical complexities associated with valuations of existing land and equipment.

In this section, initial investment costs are arrived at first for the far-field test facility and then for the near-field facility using the antenna model described in Section 2.2. Costing techniques or criteria were used that are applicable to both measurement techniques with emphasis on obtaining a consistent set of data suitable for valid comparisons.

3.2 Far-Field Range

In estimating the cost of far-field range equipment it is assumed that the range is one of high quality with spurious reflections greater than 35 dB below the direct beam. It is further assumed that the range equipment is computer controlled and has facilities for the simultaneous recording of the three receive patterns (sum, difference azimuth, and difference elevation). Table 3.1 summarizes the estimated ranges of cost for the far-field measurement facility in terms of capital or monetary investment.

Table 3.1

Cost Summary of Far-Field Range Capital Investment

Item	Cost (Thousands of Dollars)	Lifetime, Years	Salvage Value (Thousands of Dollars)
1. Range Acreage	200-600	∞	200-600
2. Building and Structures	200-330	20	10-16.5
3. Antenna Positioner (Includes Installation)	350-400	10	35-40
4. Transmitter Towers and Sources	100-200	10	10-20
5. Range Control Equipment and Instrumentation for Computer Control of Data Acquisition	60-200	10	6-20
TOTAL COST	910-1730		

3.2.1 Range Acreage

The cost of the far-field land area is a highly variable item that is a strong function of location. It is estimated to be on the order of $200,000 to $600,000. This estimate is obtained by assuming a range area of 20 acres valued at approximately $10,000 to $30,000 per acre for industrial zone property.

To achieve a 35 dB spurious reflection level on a nominal 1000 foot range, it is estimated that a minimum 400 foot width must be dedicated. For the S-band antenna used as a model in this study $2D^2/\lambda$ = 1350 ft., and a range of approximately 1500 ft. length would be required. With an assumed 600 ft. width of dedicated usage a range acreage requirement of 20 acres is obtained. The cost per acre is assumed to vary from a low of $10,000 per acre (30 miles outside of Atlanta) to a high of $30,000 per acre (vicinity of Boston, Los Angeles, New York, etc.). The "lifetime" of this property is infinite, but as will be seen in Section 5, the cost of the range can be considered in the light of possible other income that this investment could produce, i.e. opportunity costs. Thus if a 10% interest rate is assumed typical, then the range investment results in a loss of income or an opportunity cost to the organization of between $20,000 and $60,000 per year.

3.2.2 Buildings and Structures

The buildings and structures are estimated to cost between $200,000 and $330,000. Included in this category are those structures necessary to house the antenna positioner, the computer control facilities and the bulk of the electronic instrumentation. The building is assumed to be 40 to 50 feet in height with a base area of 500 square feet and to be structurally sufficient to support the antenna (about 62,000 pounds) and its positioner. Additionally, air conditioning equipment, etc., is included in this estimate.

3.2.3 Antenna Positioner

The cost of the antenna positioner is a strong function of the size and weight of the antenna to be tested. Figure 3-1 gives some indication of this dependence. These data points reflect the cost of the positioner only, without peripheral equipment, and are standard catalog prices. Recent industry experience provides a calibration point at approximately 40,000 pounds. Including installation, peripheral equipment, etc., the cost for this mount was approximately $350,000. Thus, to handle the 62,000 pound load specified in Table 2.1, a relatively conservative $350,000 to $400,000 is estimated for the positioner, peripheral console indicators, and installation.

3.2.4 Transmitter Towers and Sources

Included in this category are the costs of the structural transmitter tower, remote control equipment, rf sources, transmitter antenna, polarization positioners, cables, interface equipment, and installation costs. The figure of $100,000 to $200,000 reflects a spread experienced by three industries on similar ranges.

3.2.5 Range Control Equipment

Under this category is included the cost of the range control computer and peripheral equipment, interface equipment, rf signal sources, receivers and miscellaneous parts, pattern recorders, A/D converters, and the cost of integration of these subsystems.

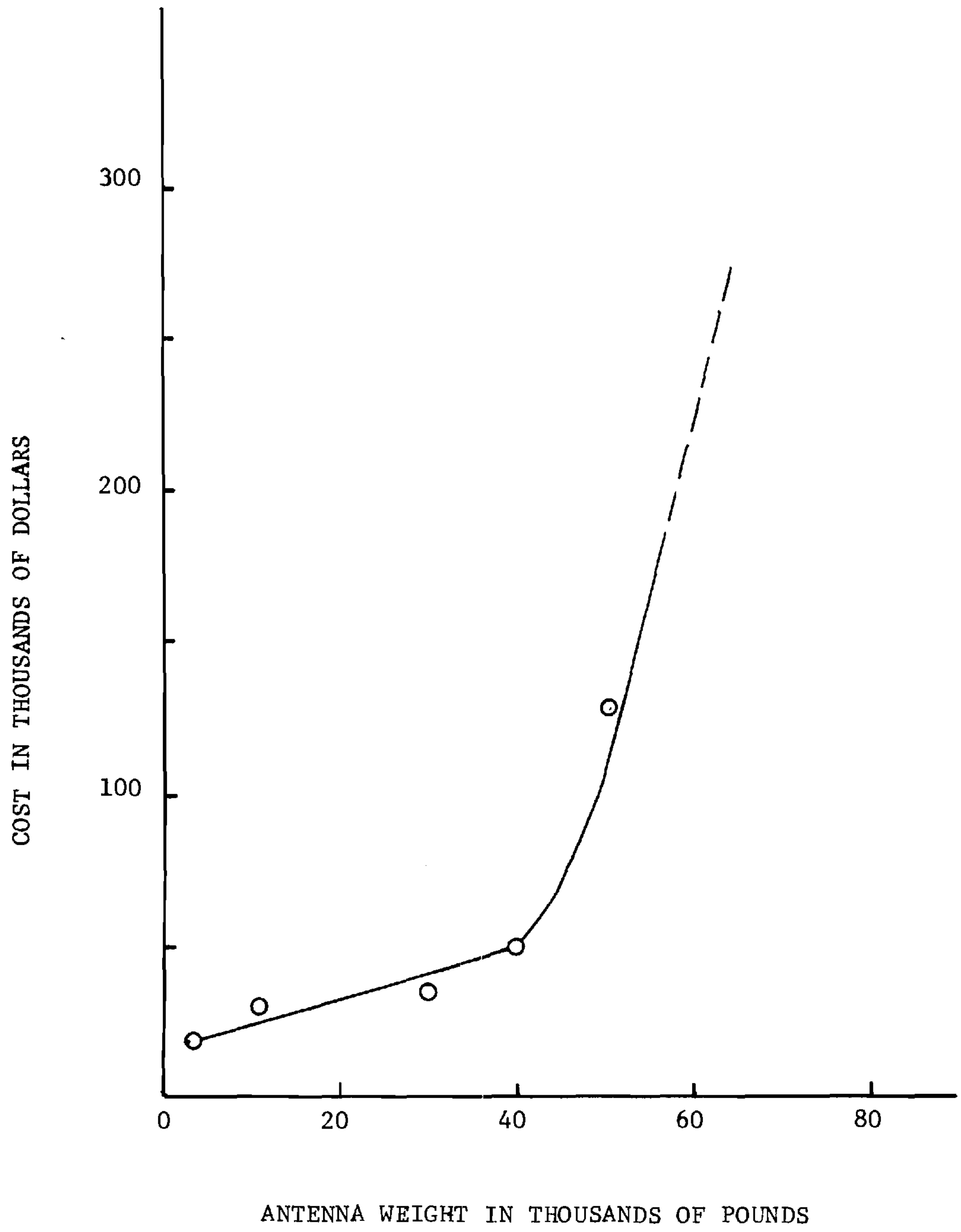

Figure 3-1. Estimated Cost of Far-Field Positioner as a Function of Antenna Weight

The total capital cost of approximately \$900,000 to \$1,700,000 is in general agreement with the cost experienced by several manufacturers.

3.3 Near-Field Range

The estimated cost for the equipment necessary to implement the near-field measurement technique is based on a measurement facility of high quality with all reflections from the positioner support structure and absorber walls at least 40 dB below the direct radiation.* Since the size of the positioner itself also determines the amount of microwave absorber needed as well as the size of the building which will house the range, it will be discussed first.

3.3.1 Near-Field Positioner

The useful measurement area of the near-field positioner must be at least as large as the antenna to be measured, and preferably much larger. However, economic considerations limit the size of the positioner, since the cost of the positioner varies directly with the area of the positioner.

From Table 2.1 the maximum size of the phased array is 15 feet by 16 feet. Since a planar phased array usually has no mechanical structure extending beyond the face of the array, the near-field measurement plane can be very close to the face of the phased array, and is limited only by the sample spacing criterion.[2] For a sample spacing less than half a wavelength, the distance between the near-field probe and the phased array surface can be only a few wavelengths. Therefore

---

* The parametric analysis of the earlier accuracy study showed that this level of reflections is adequate to achieve the specified accuracy of far-field pattern.

[2] Joy, E. B., and Paris, D. T., "Spatial Sampling and Filtering in Near-Field Measurements", IEEE Transactions on Antennas and Propagation Vol. AP-20, No. 3, May 1972, pp. 253-261.

at this distance most of the radiated energy from the phased array will be contained within an area only slightly larger than the physical size of the phased array. A near-field positioner with an active measurement area of 20 feet by 20 feet should be sufficient for testing the phased array described in Table 2.1.

Since no positioner of this size has been built, its cost must be based on the largest precision near-field positioner which has been built. The largest existing positioner, built by Scientific Atlanta, has an active area 8 feet by 8 feet and an estimated cost of \$40,000. If the cost is assumed to increase linearly with the area of the positioner, the cost of the large positioner is

$$\frac{\text{Area of Large Positioner}}{\text{Area of Existing Positioner}} = \left(\frac{400}{64}\right) \times (\$40{,}000) = \$250{,}000.$$

With inflation and manufacturing problems, the cost is assumed to range from \$250,000 to \$350,000 for the near-field positioner.

Also of interest is the estimated cost of a moveable near-field positioner. A moveable near-field positioner would allow the antenna measurements to be made on the phased array (or other large antenna) as it comes off the assembly line and would be of tremendous benefit in a production situation. A moveable positioner, in this sense, means a positioner that can be moved from one test site to another in about a week, rather than a completely portable unit that could be moved in a few minutes.

The cost of a moveable positioner of this type with a useful measurement area of 12 feet by 12 feet has been estimated by Scientific Atlanta to be \$250,000. If this estimate is extrapolated as before for a near-field positioner 20 feet by 20 feet in size, the cost is

$$\left(\frac{400 \text{ Sq. Ft.}}{144 \text{ Sq. Ft.}}\right) \times (\$250{,}000) \cong \$700{,}000.$$

The cost of a moveable positioner with a useful measurement area of 14 feet by 14 feet has been estimated independently by RCA to be $350,000. If this estimate is extrapolated for a postioner 20 feet by 20 feet in size, the estimated cost is also $700,000. Again with inflation and manufacturing problems, the cost is estimated to range between $700,000 and $800,000.

3.3.2 Microwave Absorber

The near-field measurement area must be surrounded by microwave absorber to ensure that extraneous radiation is kept below tolerable levels. A tolerable stray radiation level has been determined in previous work at Georgia Tech for many different situations[3]. The tolerable level depends on the type of far-field data desired; depth of the difference null is most sensitive to stray radiation. The difference null and monopulse error slope are very important parameters in most cases, and the cost estimate will assume stray radiation is held to a level suitable for accurate measurement of these parameters. A stray radiation level of -40 dB is satisfactory for null depths of about the same level.

The absorber-enclosed area is depicted in Figure 3-2. The enclosed area is large enough to contain the near-field positioner, phased array, and assorted beam steering computer, phased array power supplies, and cooling equipment. If the height of the enclosed area is assumed to be the same as the width, a total of approximately 4,000 square feet of absorber

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[3] Rodrigue, G. P., op. cit., pg. 57.

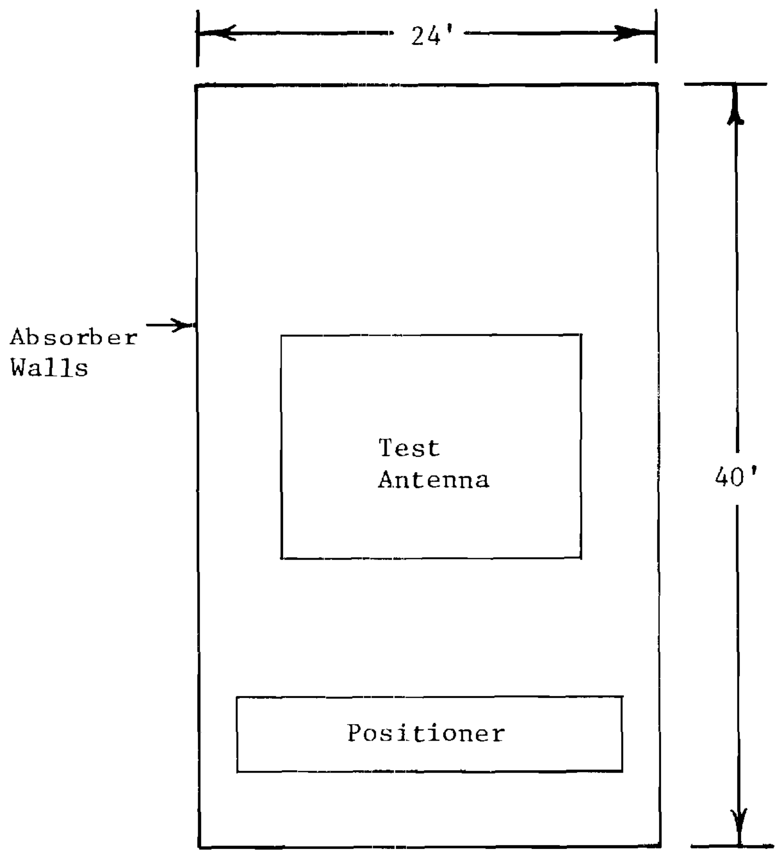

Figure 3.2. Top View of Near-Field Range Showing Absorber-enclosed area.

would be required. For a stray radiation level of -40 dB at 3 GHz, a suitable type of absorber is Emerson Type EHP-8, with a length of 8 inches. The estimated cost of one block with an area of 4 square feet is $25. Since the price of microwave absorber varies greatly, it is assumed that the cost ranges between $25 and $50 per block, with a total cost for the near-field range of $25,000 to $50,000.

3.3.3 Building Costs

A building with 2500 square feet of floor space, and interior height of 30 feet is required to house the near-field positioner. At $40 to $80 a square foot, the price of a suitable building should be between $100,000 and $200,000. Only one building is required.

3.3.4 Positioner Control Equipment

The near-field positioner can be controlled by an instrumentation computer, allowing fully automatic operation of the system. In addition, the data handling and recording can be controlled by the computer. The current near-field system at Georgia Tech uses a minicomputer and a graphics display to present both near-field amplitude and phase as the positioner moves and calculated far-field plots in different formats. The equipment in use at Georgia Tech is listed in Table 3.2 and costs $47,655. Since this equipment is very similar to the equipment used on fully automated far-field ranges, the cost is assumed to be the same as the estimate used for the far-field equipment. This cost varies between $60,000 for a system similar to the Georgia Tech near-field system, and $200,000 which is representative of a deluxe system similar to the far-field systems used for large phased array measurements.

Table 3.2

Near-Field Instrumentation Costs at Georgia Tech

ITEM		COST
Receiver, Phase and Amplitude		$17,750
Positioner Control (Manual)		600
Digital Phase Display/Converter		1,875
Digital Amplitude Display/Converter		1,300
Digital Interface (estimated cost)		5,000
Console		635
Minicomputer with 8K memory		8,000
Cassette Recorder		3,000
Graphics Display/Terminal		3,000
Microwave Source		2,000
Phase Lock Control		2,500
Position Synchros		845
Optical Encoders, Including Installation		1,000
Mixer		150
	Total	47,655
(Optional)		
3-D Graphics Display		15,000

3.3.5 Total Capital Investment

The near-field capital investments and estimated lifetime of each investment are listed in Table 3.3. The total cost of a near-field system with a fixed-in-place positoner is estimated to range between $465,000 and $860,000. The cost of a system with a moveable positioner is estimated to be between $915,000 and $1,310,000. It should be emphasized that the total cost of a system with a smaller positioner (less than 20 feet by 20 feet) would be significantly less. A graph showing the cost of both fixed and moveable positioner as a function of the useful measurement area is shown in Figure 3.3.

Table 3.3

Near-Field Range Capital Investment

Item	Cost (Thousands of Dollars)	Lifetime, Years	Salvage Value (Thousands of Dollars)
Range (land)	30-60	∞	30-60
Building and Structures	100-200	20	50-100
Near Field Positioner	250-350	10	25-35
Near Field Positioner, Moveable (Optional)	700-800	10	70-80
Microwave Absorber	25-50	10	2.5-5
Positioner Control Equipment and Instrumentation for Computer Control of Data Acquisition, and Microwave Sources	60-200	10	6-20
Total, Fixed Positioner:	465-860		
Total, Moveable Positioner:	915-1,310		

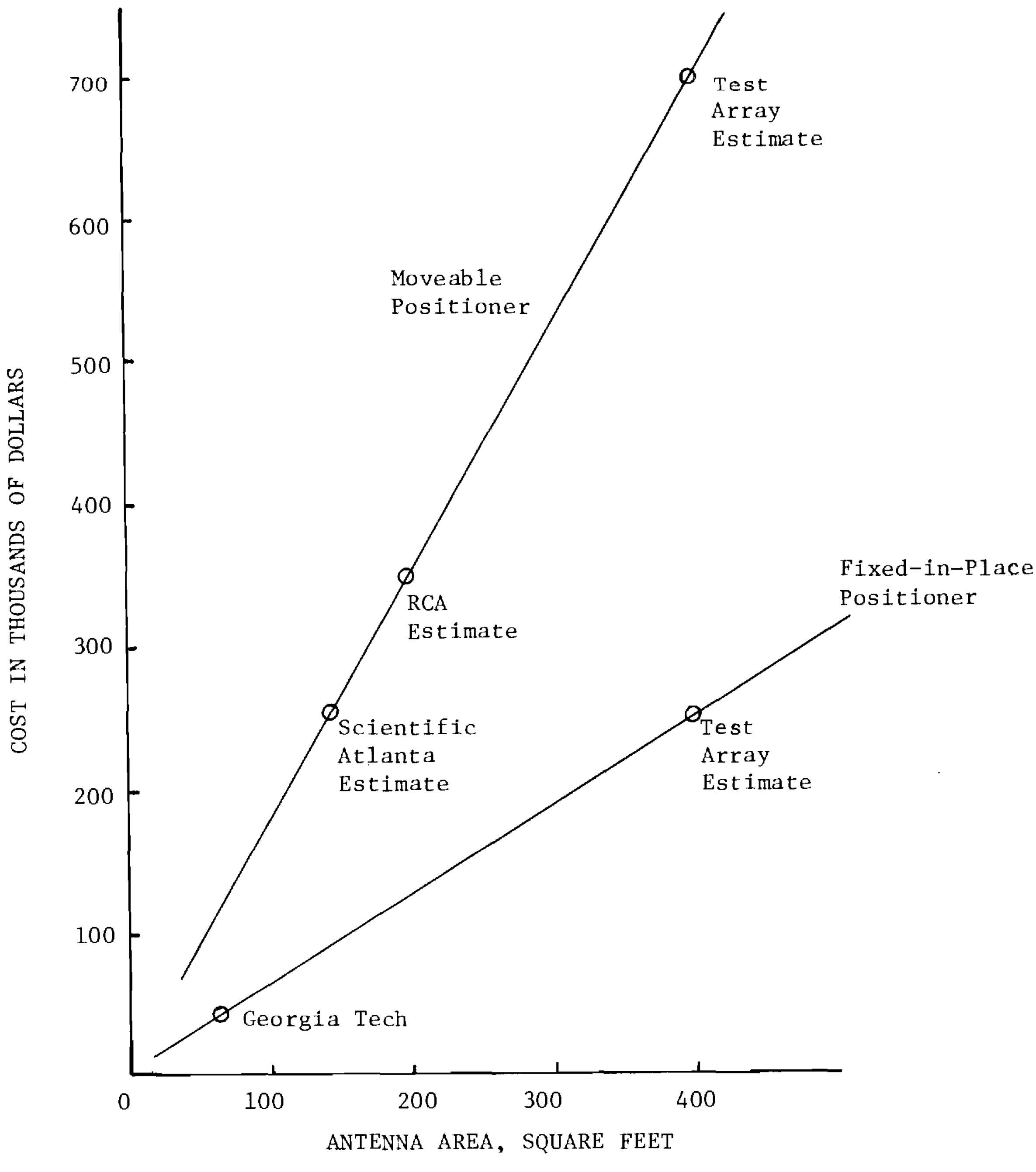

Figure 3-3. Estimated Cost of Near-Field Positioner as a Function of Useful Measurement Area

SECTION 4

OPERATIONAL COSTS

4.1 Introduction

For this analysis, operational type costs are considered to be expenses associated with the operation of the antenna ranges and those costs associated with an actual measurement program. These operational costs have been categorized as fixed costs and measurement costs. Fixed costs are those that are incurred whether or not a measurement program is actually underway, whereas, measurement costs are those that are highly dependent on the type of measurement program under consideration. The categories of fixed costs that are used in this analysis are real estate tax, electricity, heating, insurance, and maintenance. The categories of measurement costs are test facility preparation, antenna transfer, initial check-out, initial debugging, and pattern data collection and analysis. Cost estimates for these various categories were made for both the far-field and near-field measurement techniques and are discussed below.

4.2 Far-Field Range Operational Costs

4.2.1 Fixed Costs

Table 4.1 lists the various estimated operational costs associated with the far-field test facility with the total fixed costs being \$23,000 to \$46,000 per year. Real estate taxes are estimated to be \$16,000 to \$37,000 per year based on industry experience for similar ranges. The costs for <u>electricity</u>, <u>heating</u>, and <u>insurance</u> are rough estimates that depend on local conditions. <u>Maintenance</u> included here is of a custodian type with no electronic maintenance implied. This estimate is based on one day per week at a cost of \$80 per day.

Table 4.1

Operational Costs of Far-Field Test Facility

Item		Cost (Thousands of Dollars)
1. Fixed Costs		
Real Estate Tax		16-37
Electricity		1-1.5
Heating		1-1.5
Insurance		1.0
Maintenance		4.0-5.0
	Subtotal	23-46
2. Measurement Costs		
Test Facility Preparation		120-180
Antenna Transfer		6-12
Initial Check-out		80-120
Initial Debugging		30-50
Pattern Data Collection and Analysis		50-75
	Subtotal	286-437
	Total	309-483

4.2.4 Measurement Costs

In Table 4.1 the cost of test facility preparation includes the cost of a relatively large body of computer programming expressly for the measurement program at hand. Also included in this category would be the costs of special platforms, etc., as may be required. Peripheral supporting equipment required for the particular array under test is also included in this item.

The antenna transfer cost is the cost of transferring the antenna physically from assembly area to the far-field site and of locating it on the antenna positioner. This cost is estimated to be $6,000 to $12,000, depending on the antenna and remoteness of site.

Initial check-out of the antenna including wire checks, etc., on a large phased array antenna is estimated to cost from $80,000 to $120,000. This estimate is consistent with industry experience and involves a labor estimate of fifteen to twenty engineering man-months and an equal time of technician man-months.

Initial debugging under rf excitation includes some pattern inspection. This is estimated to cost $30,000 to $50,000 based on the expenditure of six to nine engineering man-months and the same number of technician man-months.

Pattern data collection and analysis involves actual measurement of the antenna pattern parameters after completion of all debugging operations and is estimated to cost $50,000 to $75,000. This cost is based on a measurement program like that described in Table 2.2 with an estimated personnel requirement of ten to fifteen engineering man-months and nine to thirteen technician-months.

Thus the total cost of the measurements is estimated to be from $286,000 to $437,000. The total of all operational costs for a one year program is estimated to be from $309,000, to $483,000. These figures will be used in comparing the costs of the far-field and near-field techniques.

4.3 Near-Field Range

As in the analysis for the far-field test facility, the operational costs for the near-field range consist of fixed costs and measurement costs. In general, unless there is an identifiable reason for a particular cost of the near-field range to be significantly different from that of the far-field range, the cost is assumed to be the same for both techniques. Aspects of the differences in costs are discussed below in view of the costs listed in Table 4.2.

4.3.1 Fixed Costs

Fixed costs for the near-field range should be the same or less than the costs associated with a far-field range, assuming the costs for heating, electricity, insurance, and maintenance are the same. However, real estate taxes are much lower due to the smaller land area required for the near-field range.

4.3.2 Measurement Costs

Measurement costs for the near-field range will vary considerably depending on the antenna to be measured. The following estimate is based on the array parameters and set of measurements described in Section 2.

The cost of test facility prepartion which includes site preparation and a programming effort is estimated to be approximately the same for the near-field and the far-field measurements. Site preparation could cost less for the near-field technique since the preparation required for moving the array

Table 4.2

Operational Costs of Near-Field Test Facility

Item		Cost (Thousands of Dollars)
1. Fixed Costs		
Real Estate Tax		5-10
Electricity		1-1.5
Heating		1-1.5
Insurance		1.0
Maintenance		4-5
	Subtotal	12-19
2. Measurement Costs		
Test Facility Preparation		120-180
Antenna Transfer		0-2
Initial Check-Out		80-120
Initial Debugging		30-50
Pattern Data Collection and Analysis		20-35
	Subtotal	250-387
	Total	262-406

is less, but this cost will be balanced out by additional computer programming required for the near-field measurements.

Antenna transfer cost is estimated to be less than $2,000. The near field range could be located in the same building as the production facility, and the array moved on rails to the test range. No difficult lifting of the antenna is required. Alternately, a moveable positioner could be transfered to the antenna for about the same cost.

The initial check-out cost reflects the fact that the antenna check-out can be performed on the near-field range, and this cost should be independent of the range. Certain types of check-out may be simpler using the near-field range because the probe can be used to sample the aperture phase distribution and the insertion phase of all the phase shifters can be checked very rapidly. The near-field system at Georgia Tech through the use of a computer program can provide a plot on a graphics terminal of the amplitude and phase of each row of near-field data as the data for each row is taken. Faulty array elements and/or phase shifters could be quickly identified by monitoring the near-field data. However, alignment of the feed horn of a space fed array may be more difficult. It would, in any case, involve accurate phasing of elements which can certainly be measured on the near-field facility. On the average the cost of initial check-out is estimated to be the same for both range types.

The estimated cost of pattern data collection and analysis is based on a required set of near-field measurements equivalent to that of the far-field measurements described in Section 2. As will be shown, for such a set, a total of 26 complete near-field scans are required. Each run would take approximately one day and 26 working days would be required. Thus, the complete set of data could be obtained in slightly more than one month since there are no delays due to weather on an indoor range. Personnel requirements for the automated system are estimated to be two men for the actual pattern measurements and two men for data handling and processing. Personnel requirements are slightly less than five man-months and the total estimated cost for pattern data collection and analysis is $20,000 to $35,000.

To determine the above time estimates, consideration was given to the detailed operation of the near-field positioner together with the data processing techniques as well as the nature of the antenna itself. These considerations are discussed below.

The estimated cost of near-field data collection on a phased array depends on the number of scanned beams which can be measured simultaneously during one complete scan of the near-field positioner. Because the positioner movement is relatively slow compared to the beam switching speed of the phased array, the phased array can be scanned between many beam positions and return to the original beam position before the next sample point is reached.

For the antenna model depicted in Table 2.1, the required positioner movement is twenty feet. The near-field positioner requires about two minutes to complete one scan of one line so that the positioner speed is

$$\frac{240 \text{ inches}}{120 \text{ seconds}} = 2 \text{ inches per second}$$

From the basic sampling theorem, the largest sample spacing without loss of information is $\lambda/2$ where λ is the operating wavelength. At a frequency of 3 GHz, this spacing is 1.97 inches. However, the number of samples, n, is also constrained to be 2^n if the Fast Fourier Transform is to be used. For the full length of the positioner (20 feet) and the minimum number of samples, the desired sampling interval is

$$\frac{240 \text{ inches}}{128 \text{ samples}} = 1.87 \text{ inches} = 0.47\lambda$$

which satisfies the sampling criterion and is within the physical limitations of the positioner. Then the time between samples of any one beam is

$$\frac{\text{Sample interval}}{\text{Probe speed}} = \frac{1.87 \text{ inches}}{2 \text{ inches per second}} = 0.935 \text{ second}$$

Therefore, a total of 935 milliseconds are available between the sample points required for any one beam. Although the phased array beam switching speed is typically 5-10 microseconds, the measurement speed is limited by the recovery time of the phase and amplitude receiver used in the near-field system. For example, the Scientific Atlanta Series 1740 receiver has a recovery time between samples of approximately 25 milliseconds (limited only be receiver design). Therefore, the maximum number of scan positions that can be measured during one near-field scan is

$$\left(\frac{\text{Time between samples}}{\text{Receiver recovery time}}\right) - 1 = \left(\frac{935 \text{ msec}}{25 \text{ msec}}\right) - 1 = 36$$

Thus, the time required to measure 36 beam positions is the same as the time required to measure one beam position. One complete near-field scan requires

$$128 \text{ rows} \left(\frac{2 \text{ minutes}}{\text{row}}\right) = 256 \text{ minutes}$$

Since a complete scan is required for <u>two</u> polarizations in the near-field, the total measurement time per frequency is 512 minutes, or approximately

8.5 hours, i.e. one working day. During one run it is possible to measure either 36 beam positions for one mode at one frequency, or 18 sum patterns and 18 difference patterns at the same scan angles and the same frequency, or any other combination of scan angles and modes at one frequency.

Based on the schedule of measurements shown in Table 2.2, and on a maximum of 36 beam positions and mode combinations at a single frequency, a schedule of equivalent near-field measurements can be determined. The required near-field measurements are listed in Table 4.3. Assuming all three receive mode patterns can be recorded simultaneously, the first set of measurements requires a total of 12 runs, and the second set of measurements requires 14 runs in the near-field, for a total of 26 runs requiring one day each.

Table 4.3

Near-Field Measurements Schedule

Set	Parameter	Frequencies	Port	Scan Angles
1	Any	3	T,R(Σ, $\Delta E\ell$, ΔAz)	72
2	Any	7	T,R(Σ, $\Delta E\ell$, ΔAz)	36

SECTION 5

COMPARATIVE COSTS

5.1 Introduction

The cost data presented in Sections 3 and 4 relevant [illegible] invest-ment and operational costs can be analyzed in various ways to [illegible] the relative cost-benefits between the far-field and near-field measurement techniques. Cost comparisons of the two techniques can be [illegible]ed on cost to the government, return on investment to corporation and other criteria. The paragraphs below present a summary of comparative results obtained using these criteria. Of importance to the government as well as to the manufacturer is the cost associated with testing more than one antenna for acceptance or production. Considerations have been given to costs associated with such testing and are discussed following the discussion on comparative costs for single unit testing.

5.2 Comparative Costs on Zero Base

The cost data presented in Sections 3 and 4 are summarized in Table 5.1 to illustrate a direct comparison of the various costs for the far field and near-field measurement techniques. Costs are also presented for the alternative near-field technique that utilizes a moveable probe positioner.

From Table 5.1 the total Initial Investment for the near-field measurement equipment employing a stationary probe positioner is approximately one-half the cost of the far-field range equipment, and the cost of the near-field technique employing a moveable positioner is about the same as the far-field technique. The Operational Cost for either near-field technique is about

Table 5.1

Comparative Cost Summary (In Thousands of Dollars)

	Far-Field	Near-Field Stationary	Near-Field Moveable
	Initial Investments		
Range, land	200-600	30-60	30-60
Buildings	200-330	100-200	100-200
Equipment	510-800	335-600	785-1050
	910-1730	465-860	915-1310
	Operational Costs (Per Year)		
Fixed Costs	23-46	12-19	12-19
Pattern measurements (includes alignment)	286-437	250-387	250-387
	309-483	262-406	262-406

84 percent of the cost for the far-field range. A large percentage of the total operational cost is associated with initial antenna alignment and debugging, and this cost is independent of the type of range used. As a result, the difference in operational cost between the two range types is relatively small. Once an antenna has been aligned and debugged, the pattern measurement time is twice as long for the far-field range as for the near-field range. It should be emphasized that the near-field measurement prescribed would yield much more complete information on antenna patterns than would be available from the recommended far-field measurements.

Thus, the required Initial Investment to start up from a zero base is considerably more for the far-field measurement technique than for the near-field measurement technique employing a stationary positioner. Also, the operational costs of the far-field technique are inherently more than either near-field technique.

5.3 Comparative Costs Using Linear Depreciation to Zero Salvage Value

Although the Initial Investment figures of Table 5.1 suggest the amount of money needed to establish a measurement facility, these figures do not represent the cost to the government for an antenna pattern measurement program of the type described in Section 4. The Initial Investments are considered here to be spread over a long period of time to gain some insight into the government's cost for such a program. In the following discussion, no attempt has been made to treat the effect of time on investment decision making from an accountant's or financial analyst's viewpoint, but rather efforts were made to arrive at a standard so that the relative merits of the measurement techniques could be established with reasonable credibility.

The data of Tables 3.1, 3.2, and 4.1, 4.2 were analyzed to determine the cost of a measurement program based on a very simple depreciation technique. The resulting data are shown in Table 5.2. In this table that portion of the cost of land attributable to the measurements program is treated as loss of possible investment income or an oppportunity cost. Assuming a possible interest return of ten percent per year, the cost to the program (of a one year duration) is 10 percent of the total. In both near-field and far-field approaches the total time of range utilization is approximately one year, including range programming, antenna alignment, debugging, etc.

The cost to the program of buildings is figured on the basis of a twenty year straight line depreciation with zero salvage value. Thus for a one year program the cost is five percent of the total building costs. A similar calculation is done for equipment with a ten year depreciation to zero salvage value. Operational Costs are, as before, fully chargeable to the measurements program.

On this basis the near-field method using a stationary positioner has a cost of approximately 76 percent the cost of the far-field approach. The near-field approach using a moveable probe positioner has a total cost that is approximately 85 percent of the far-field costs. As the number of antennas tested increases, the shorter measurement time for the near-field approach becomes a more significant factor, and the near-field approach is even more favorable from a cost standpoint. This cost dependence on the number of antennas tested is discussed in Section 5.5.

Table 5.2

Amortized Measurement Cost Per Year (In Thousands of Dollars)

	Far-Field	Near-Field Stationary	Near-Field Moveable
	Initial Investment		
Range, land (10% of value/yr)	20-60	3-6	3-6
Buildings (20 yr straight line depreciation)	10-17	5-10	5-10
Equipment (10 yr straight line depreciation)	51-80	34-60	79-105
	81-157	42-76	87-121
	Operational Costs		
Fixed Costs	23-46	12-19	12-19
Pattern Measurements (includes alignment)	286-437	250-387	250-387
	309-483	262-406	262-406
	390-640	304-482	349-527

5.4 Costs Based on a Benefit-to-Cost Ratio

A comparison of the relative investment potential from the viewpoint of the range owner is described below. The internal rate of return and benefit-to-cost ratio is shown based on the cost estimates of the preceeding sections, and standard business practice. Cash inflow is calculated based on a net profit of ten percent of pattern measurement costs, plus a tax savings per year equal to fifty percent of the depreciation of buildings and capital equipment. The depreciation rate is assumed to be zero for land, and equal to the cash value less salvage value divided by the lifetime of the investment for buildings and capital equipment. Buildings were assumed to have a lifetime of 20 years and salvage value of five percent of original cost. Capital equipment was assumed to have a lifetime of 10 years and a salvage value of 10 percent of original cost. The original value of range land and salvage value of capital equipment is included as cash inflow in year ten. Table 5.3 summarizes the cash inflows, tax savings, and salvage values assuming a ten year investment.

As shown in Table 5.4, the investment return over a ten year period for either far-field or near-field measurements is poor, but the near-field range with fixed positioner has a rate of return which produces an additional income of three percent over the income produced by a far-field range. As shown in the table, the rate of return for the far-field range (and near-field range with moveable positioner) is actually negative. The benefit-to-cost ratios shown in Table 5.4 assume the cost of capital for the initial investment to be either 10 percent or 16 percent. In either case, the near-field range with fixed positioner has a benefit-to-cost ratio approximately 30

Table 5.3

Estimated Cash Inflows, Tax Savings, and Salvage Values Over a Ten Year Period

(In Thousands of Dollars)

Range	Initial Investment	Net Profit Per Year	Depreciation Rate Per Year	Tax Savings Per Year
Far-Field	910	28.6	55.4	22.7
Near-Field Stationary	465	25	34.5	17.2
Near-Field Moveable	920	25	74.9	37.5

	Cash Inflow Per Year Years 1-9	Salvage Value (Includes Land)	Cash Inflow Year 10
Far-Field	51.3	261	312.3
Near-Field Stationary	42.2	68.5	110.7
Near-Field Moveable	62.5	113.5	176

Table 5.4

Investment Return Based on 10 Year Lifetime

Range	Capital Investment	Cash Inflow (per year)	Internal Rate of Return	Benefit/Cost Ratio 10% Capital	Benefit/Cost Ratio 16% Capital
Far Field	$910,000	$51,300	-2.2%	.46	.34
Near Field (Stationary)	$465,000	$48,200	0.88%	.61	.47
Near Field (Moveable)	$920,000	$62,500	-3.4%	.46	.36

percent higher than the ratio for a far-field range or near-field range with moveable positioner. All three ranges have a benefit-to-cost ratio which is less than one, which indicates that benefit (profit) is less than the cost of capital. These figures are consistent with the principle that an antenna range is usually run as a necessary expense by antenna manufacturers rather than as a profitable venture.

5.5 Acceptance Testing of Multiple Units

A comparison of the relative cost of near-field and far-field measurements on more than one antenna of the same type is of considerable interest since most antenna development programs include testing of several units.

For multiple unit acceptance testing the initial investments (Tables 3.1 and 3.2) remain unchanged for both the far-field range and the near-field range. Fixed Operational Costs (Table 4.1 and 4.2) can be prorated on the basis of the time spent on the respective range. Test facility preparation is a non-recurring cost for any given program. It involves programming range equipment for specific measurements and would be a constant for the measurement of one to four antennas. Antenna transfer, initial check-out, and initial debugging, are all essentially equipment set-up items that must be repeated for each unit tested. Some form of learning curve should be postulated for cost reduction based on experience, and that used in this estimation is shown in Figure 5-1.

With this learning curve used as a basis for estimation of the equipment set-up costs, the computed Far-Field Operational Costs for acceptance testing of one, two, three and four units is as shown in Table 5.5. To these costs must be added the Initial Investment Costs of Table

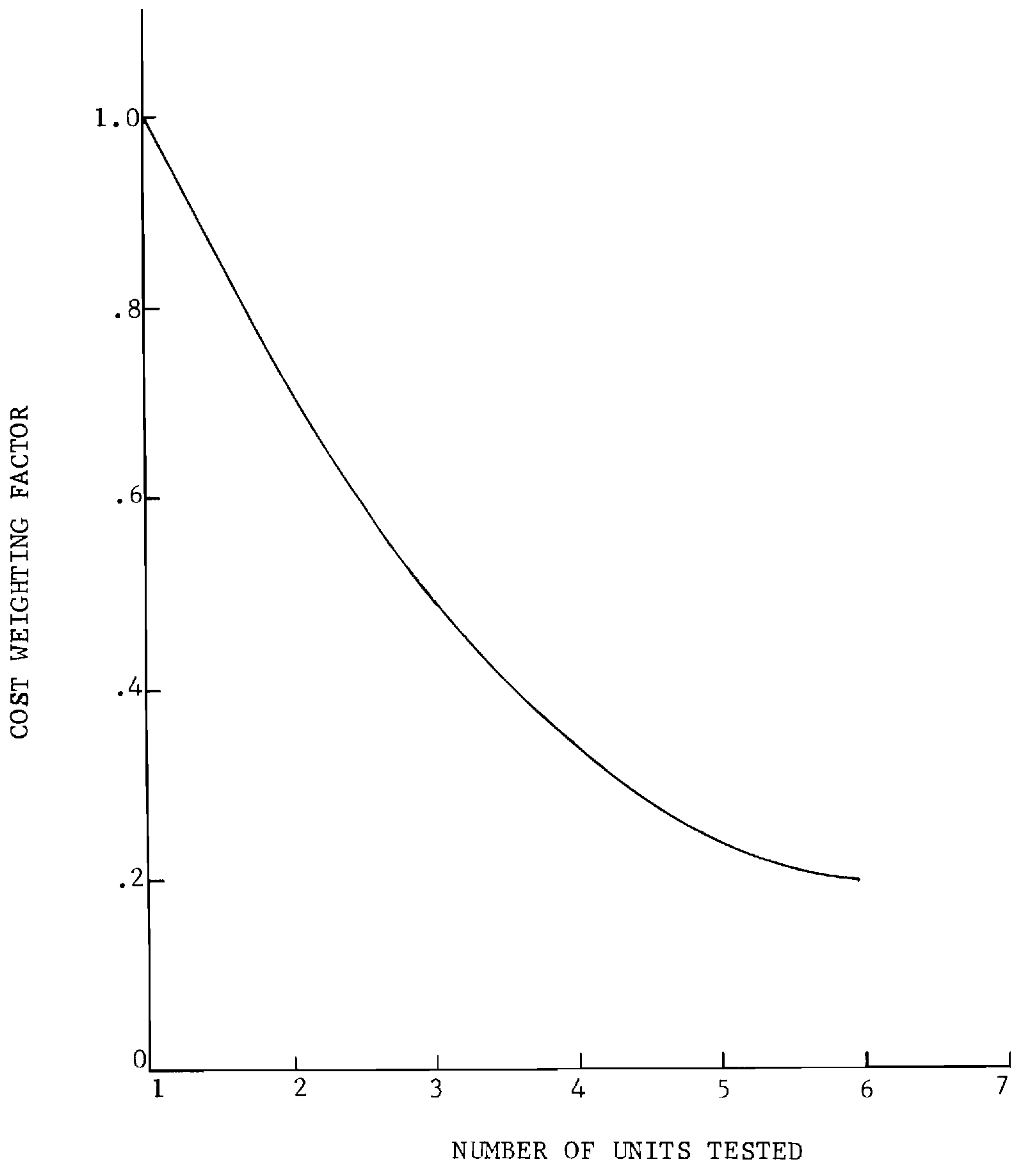

Figure 5-1. Learning curve used to estimate antenna preparation time as a function of number of units.

Table 5.5

Far-Field Range Operational Costs (In Thousands of Dollars)

	Number of units tested 1	2	3	4
1. Fixed costs (prorated for measurement time)	23–46	29–57	33–65	36–73
Time of measurement on range	1 year	15 months	17 months	19 months
2. Measurement Costs				
Test Facility Preparation	120–180	120–180	120–180	120–180
Antenna Transfer	6–12	10–20	14–27	16–31
Initial Check-out	80–120	137–206	183–275	208–312
Initial Debugging	30–50	51–86	69–115	78–130
Pattern Data Collection and Analysis	50–75	100–150	150–225	200–300
Subtotal	286–437	418–642	536–817	622–953
Grand Total	309–483	447–699	569–882	658–1026

3.1, \$910,000 to \$1,730,000. In compiling this table it has been assumed that identical acceptance testing is required on each of the first four units. It can be argued that some of this testing could be shared among the four units. Such a shared test program would reduce the cost of pattern data collection and analysis in proportion to the amount of sharing permitted. Such contingencies, however, are beyond the scope of this program and would hinge on the requirements of the specific system involved.

Table 5.6 displays the estimated cost of acceptance testing one, two three, or four units on a near-field range. The learning curve of Figure 5-1 has been applied to the cost of antenna transfer, initial check-out, and initial debugging, and identical acceptance testing is assumed to be required on all units. If acceptance testing is permitted to be shared, some reduction of pattern data collection and analysis costs would result.

Tables 5-5 and 5-6 indicate that the Operational Costs of Testing on the near-field range vary from 85 percent of the far-field range costs for one unit to 76 percent of the far-field range costs for four units.

5.6 Production Testing

To date there has been no production of large phased-array antennas, and thus experience in the area of production testing of such units is non-existant. In Technical Requirement No. 1696, included in the Appendix, a Suggested Schedule of Antenna Measurements for Acceptance Testing and for Production Testing is outlined. As described in Section 2, it was the feeling of both industry and government representatives that these test schedules were unreasonably detailed and required more extensive testing than is the industry practice. The modified Acceptance Test of Table 2.1

Table 5.6

Near-Field Range Operational Costs (In Thousands of Dollars)

	Number of units tested			
	1	2	3	4
1. Fixed Costs				
(Prorated for measurement time)	12-19	13-21	14-22	15-24
Time of Measurement on Range	12 months	13 months	14 months	15 months
2. Measurement Cost				
Test Facility Preparation	120-180	120-180	120-180	120-180
Antenna Transfer	0-2	0-3	0-4	0-5
Initial Check-out	80-120	137-206	183-274	207-312
Initial Debugging	30-50	51-86	69-114	78-130
Pattern Data Collection and Analysis	20-35	40-70	60-105	80-140
	250-387	348-545	432-677	485-767
	262-406	361-566	446-699	500-791

was therefore used as a base of estimation for Acceptance Testing. Insofar as Production Testing is concerned, it is reasonable to use a scaled, reduced schedule of measurements. In the original Technical Requirement the scale factor between Acceptance and Production Testing was 10:1. The same scale factor can be applied for purposes of the present estimate, and it is assumed that production testing requires 0.1 the number of pattern measurements specified for acceptance testing.

On the above basis the production test time per unit on the far-field range and on the near-field range is estimated to be as given in Table 5-7. Using these estimates it is seen that in terms of actual measurement time, the near-field approach would have about a two to one advantage over the far-field range measurement. When it is considered that the near-field measurement could be conducted in the production facility without relocation of the unit to a far-field range, this estimate of an approximate two to one advantage seems conservative. Of course, the cost involved in debugging 100, 200, and 300 production units may completely override production test costs. Experience in debugging large numbers of phased arrays is wholly inadequate to postulate a learning curve.

Table 5.7

Production Test Time Requirements

Test Time For	Far-Field Range	Near-Field Range
100 units	24 months*	14 months**
200 units	48 months*	29 months**
300 units	72 months*	43 months**

* Based on 2days/unit of Measurement Time and 3/days unit to set-up and tear down.

** Based on 1 day/unit of Measurement Time and 2 days/unit to set-up and tear down.

SECTION 6

HYBRID COSTS

6.1 Introduction

A hybrid approach is considered to be one wherein both a near-field and a far-field capability are combined into a single facility. Since a large portion of the total Capital Investment is common to both measurement methods, the initial investment for the combined facility would clearly be considerably less than that required for two separate facilities. Similarly, a major portion of the Operational Costs are attributable to the initial check-out of the phased array antenna and thus a combined facility would have an operational cost greater than that for either individual facility but less than the combined cost for two separate facilities. In the following, consideration is given to the costs of a hybrid type of facility compared to those of a facility dedicated to an individual measurement technique.

6.2 Capital Investment Costs

As a base for considering the cost of a hybrid facility it is assumed that the far-field range and equipment exists. The incremental cost of adding the near-field capability is then determined. This scenario is felt to fairly closely approximate a real world situation. Note that this increment is not equivalent to assuming a complete switch to a near-field measurement, since the hybrid approach still necessitates maintaining the far-field facility, removal of the antenna from the production assembly area to the remote far field range, and purchase of an expensive far-field range antenna positioner.

For the hybrid facility all the items of Table 3.1 are still required. Incremental costs of providing the near-field facility are best discussed with reference to Table 3.3 and Table 6.1. Range Land is not necessary as adequate space is clearly available on the far-field facility. A modification or addition to the far-field building is necessary to house the near-field probe, but no additional structure is required for the phased array antenna or its supporting equipment. An approximate cost of the building addition is 40% of the estimated cost of a new building (Table 3.3), or $40,000 to $80,000. The near-field positioner cost is valid in its entirety and may be increased somewhat because of the remote location of the far-field tower. A ten percent increase allowance puts the positioner cost at $275,000 to $385,000 for a 20 ft. by 20 ft. fixed-in-place positioner. Since the antenna is assumed to be situated on a far-field range, a minimum of microwave absorber material is required. Approximately $10,000 for absorber material should be adequate. The equipment listed in Table 3.2 is common to both near- and far-field ranges, and only a small allowance need be made for dual use. Twenty percent of the total equipment cost is adequate to modify it for dual use, or $12,000 to $24,000. Thus the total of incremental capital equipment costs would be from $337,000 to $499,000 to add a near-field capability to an existing far-field range. It is worth noting that almost 80% of the incremental cost is for the near-field probe positioner. Furthermore, it should be pointed out that this incremental cost is very nearly equal to the cost of the antenna positioner for the far-field range.

6.3 Operational Costs

A reasonable estimate of the incremental increase in Fixed Operational Costs can be made based on the added building facilities. This would mean an annual property tax increase of $1,600 to $3,200 and a $2,800 to $3,600 increase in maintenance, utilities, and insurance. In the Measurement Cost

Table 6.1

Incremental Cost of Hybrid Facility
(in Thousands of Dollars)

1. Fixed Costs	
Land	0
Buildings and Structures	40-80
Near-Field Positioner	275-385
Microwave Absorber	10
Other Capital Equipment	12-24
	337-499
2. Operational Costs	
Real Estate Tax	1.6 - 3.2
Maintenance, Utilities and Insurance	2.8 - 3.6
Test Facility Preparation	30-45
Antenna Transfer, Initial Check-out, and Initial Debugging	0
Pattern Data Collection and Analysis	-27 - (-40.5)
	7.4 - 11.3
	345-510

category, antenna transfer, initial check-out, and initial debugging would involve no incremental cost, as they are associated with getting the antenna on the air and are already required for the far-field measurement. Some additional programming effort is required for hybrid operation, and the increase in test facility preparation cost is estimated to be $30,000 to $45,000. Finally, the incremental cost of the hybrid approach for pattern data collection and analysis is strongly dependent on the division of measurements effort. A rough approximation is made by assuming the bulk of the pattern measurements (90 percent) would be made on the near-field range, and a minimum number of checks (10 percent) conducted on the far-field range, as shown in Table 6.2.

Thus the actual pattern measurements cost would have a negative increment, with respect to a pure far-field measurement, of from $27,000 to $40,500. The total increment in Operational Costs to convert form a pure far-field system to a hybrid measurement is estimated to be from $7,400 to $11,300.

6.4 Hybrid Approach Possibilities

As outlined in the two sections above, and shown in Table 6.1, the total incremental costs of upgrading a far-field range (including antenna positioner) to a hybrid facility with both near-field and far-field capabilities would be from approximately $345,000 to $510,000. A vital question arises as to what additional capability such an expenditure would provide.

The additional near-field capability would make it possible to obtain a greater volume of pattern data in a shorter time. This is reflected in the decreased cost with a hybrid system of pattern data collection and analysis. More information can be extracted from the near-field data bank than is feasible to obtain on conventional far field-ranges.

Table 6.2

Hybrid Operational Costs for Pattern Data Collection and Analysis
(in Thousands of Dollars)

Near-Field Cost	90% of Near-Field Cost	Far-Field Cost	10% of Far-Field Cost	Total Cost
20-30	18-27	50-75	5-7.5	23-34.5

If the near-field range portion of the hybrid facility provides more data, what does the far-field portion provide? It seems that the answer to this question must be confidence. With proper data reduction the near-field method is fully capable of providing all necessary pattern data, including absolute gain measurements. One area where the hybrid approach might at first appear promising is in initial alignment of the phased array antenna, more commonly accomplished on a far-field range under r.f. excitation. However, when it is considered that all such alignments involve phase adjustments (in the near-field!), it is obvious that all such alignment adjustments can be equally well carried out by near-field measurements. With state-of-the-art computing facilities and real-time oscilloscope presentation the results of alignment procedures can be readily seen in the same "real time" base that is currently available on a far-field range. Thus, it seems that realistically the chief reason for a hybrid facility would be to establish confidence in the near-field results by making available an independent accuracy check. Actual data acquisition would be handled on the near-field equipment with subsequent computer-aided data reduction to pattern parameters.

SECTION 7

CONCLUSIONS

The relative cost of the two principal methods of measuring the characteristics of large phased arrays has been determined. The cost of near-field measurements and far-field measurements were derived using a common basis for the estimation. The costs comparison assumed (1) antenna physical dimensions, (2) specific sets of required far-field plots for initial acceptance testing and production testing, and (3) specific numbers of units to be tested from an acceptance and a production viewpoint.

The accuracy of measurements using either technique was assumed to be equal to that associated with a conventional far-field range having extraneous field levels less than 35 dB below the direct path field of a far-field source.

The cost estimates in the preceding sections have shown that near-field measurements with a fixed positioner require a smaller initial investment and are less expensive than far-field measurements for the model phased array. The relative costs for near-field and far-field measurements are summarized in Tables 7.1 through 7.3.

The actual cost savings using near-field measurement depends greatly on the method used to determine investment costs, since operational costs for the near-field range average 84 percent of far-field costs. If the total investment cost is included in the cost estimate, as a lump sum expense, near-field investment costs are 47 percent of the far-field costs, resulting in the overall cost of near-field being 75 percent of far-field costs.

If the depreciable assets associated with the initial investment are considered to have salvage value and tax savings are included as income in the cost estimate, then the benefit-to-cost ratio for the near-field range is 33 percent higher than those for the far-field range.

Estimated costs for a near-field range with moveable positioner are 85 percent of the far-field costs. This type of positioner is desirable but not essential to the measurement process.

Most phased array manufacturers already own a far-field range with an existing positioner capable of supporting a large antenna. However, in many cases, the positioner will not support the phased array described in Section 2. Therefore, the relative cost of a larger far-field positioner and a near-field positioner, without common receiving and control equipment, is important. As shown in Section 3, the cost of a fixed near-field positioner alone is $250,000, while the cost of a far-field positioner is $350,000.

This estimate of far-field positioner cost is felt to be quite conservative. It is based on the cost of a positioner to support a 40,000 pound load, and was not scaled for inflation factors, etc. Other estimates of the cost of a far-field positioner to be used with a 60,000 pound antenna are far above this value. For example, the government furnished facility at Bedford, Massachusetts, built earlier for phased array testing, cost in the vicinity of $2,000,000.

All other equipment is assumed to be compatible with the exception of microwave absorber for the near-field range. The additional cost for absorber would be $25,000 to $50,000. Thus, in realistic terms the cost of converting to the near-field approach is substantially less than that of acquiring a far-field positioner for the antenna model described in Section 2.

The added capabilities of the near-field range measurements are an additional dividend. The near-field method is enormously efficient in terms of data acquisition. Information about every feature of the antenna pattern can be obtained by processing the vast amount of raw data stored on magnetic tape. Central processor time is only a matter of one or two minutes for a single beam position. Near-field measurements can yield data on cross-polarized components and very wide beam patterns that are impractical to obtain on a far-field range. Determination of contour plots, RMS sidelobe levels, and other standard pattern parameters are much simplified. The near-field measurement time is one-half that required on a far-field range and in this time more complete data is acquired.

It is therefore seen that the use of the near-field technique results not only in a cost savings to the government but also in a more complete characterization of the antenna patterns. The industry as a whole should be encouraged to overcome the binds of precedent and adopt this more advanced technique.

Table 7.1

Relative Costs of Near-Field and Far-Field Measurements

	Far Field	Near Field (Fixed)	Near Field (Moveable)
Initial Investment	1.0	0.47	0.84
Amortized Investment	1.0	0.50	0.87
Operational Costs	1.0	0.84	0.84

Table 7.2

Relative Operational Costs of Acceptance Testing of Multiple Units

Number of Units	Far-Field	Near-Field
1	1.0	0.84
2	1.0	0.81
3	1.0	0.79
4	1.0	0.77

Table 7.3

Relative Measurement Time for Production Testing of Multiple Units

Number of Units	Far-Field	Near-Field
100	1.0	0.6
200	1.0	0.6
300	1.0	0.6

APPENDIX

NEAR FIELD MEASUREMENT COST ANALYSIS

TECHNICAL REQUIREMENT NO. 1696

5 June 1972

1.0 OBJECTIVE

There are two principal methods for measuring the characteristics of large phased array antennas. The first and more conventional of these is the far-field method and the second is the near-field method. The objective of this work is to compare the costs of these two methods. Costs shall be derived and documented for each of the measurement approaches using a common basis for the estimation as described herein.

2.0 ASSUMPTIONS TO BE MADE FOR THE COST COMPARISON.

The cost comparison study shall be made assuming

1) antenna physical dimensions,

2) specific sets of required far-field pattern plots for (a) initial unit acceptance testing, and (b) production testing,

3) specific numbers of units to be tested from an acceptance and from a production standpoint.

2.1 Test Antenna

The antenna to be tested shall be an S-band antenna with an aperture of approximately 11.5 square meters, measured with its plane in a vertical plane for the near-field data collection, and on a mount rotatable about two orthogonal axes on the far-field range.

2.2 Required Pattern Plots

2.2.1 Initial Unit Testing

For the acceptance testing of initial units detailed antenna plots are required as summarized in Table I. This table lists three dimensional contour plots, each of which requires a number of pattern cuts for its definition. Listed in Table II are the far-field pattern cuts that shall be assumed in the construction of this three dimensional pattern data. This data shall characterize the following essential features of the antenna.

Gain of the main beam

Pointing accuracy

Polarization of the main beam

Polarization of the first sidelobe

Magnitude of sidelobe levels

Monopulse error slope

Main beam 3 db width

Main beam 10 db width

The acceptance tests of Table I are divided into two groups of measurements; e.g., those along principal planes and those of slew planes with respect to the antenna broadside (or the normal to the face of the antenna).

2.2.2 Production Unit Testing

After the initial units testing, the production units involve a less stringent testing procedure. Table III lists a typical schedule of required far-field three dimensional antenna plots for the production units.

2.3 Number of Units Tested

In determining the cost of an antenna test program, the cost involved in acceptance testing of one, two, three, and four antennas shall be independently determined. Also, production test costs for 100, 200, and 300 production units shall be separately detailed.

2.4 Cost Categories

The costs derived for the two measurement techniques shall be listed in two categories:

a. Nonrecurring capital investments costs.

b. Recurring operational costs.

Capital investment costs for the far-field technique shall include, but not be limited to, such items as:

Far-field range acquisition
Rotatable mount for array antenna
Microwave and recording equipment
Buildings for equipment enclosures and personnel working areas.

Capital investments for the near-field technique shall include, but not be limited to, costs such as:

- Test site building acquisition
- Microwave absorber materials
- X-Y-Z probe positioner
- Microwave and recording equipment.

Operational costs for both techniques shall include all costs associated with data acquisition and reduction including:

- Equipment maintenance
- Personnel and support services
- Computer and plotting time.

Allowance will be made and specified in both cases for equipment "down" time and maintenance.

2.5 Accuracy Basis

The accuracy of both techniques will be referred to that associated with a conventional far-field range having extraneous field levels less than 35 db below the direct path field of a far-field source.

3.0 HYBRID COSTS

In addition to the cost determination of the separate far-field and near-field approaches, a hybrid approach shall be considered. The hybrid approach shall study the cost effectiveness of establishing a single combined facility and developing the capability for both measurements. This study shall determine how much of the capital equipment is common to the two types of measurements, what portions of the software control and computer interface is common, etc. The study shall indicate what portions of the required pattern plots of Section 2.3, the number of units tested, and the types of tests should be allocated to each of the measurement methods, thus establishing a basis for an efficient estimate of recurring operational costs for the hybrid approach.

4.0 SCHEDULE

This effort will extend through a calendar year. One interim report and one final report are required per DD Form 1423.

TABLE I

SUGGESTED SCHEDULE OF ANTENNA MEASUREMENTS
FOR ACCEPTANCE TESTING OF INITIAL UNITS.

TEST CONDITIONS

a. Principal Planes --Sum Patterns

Frequency	5 equally spaced across band
Beam Scan Angles	5° intervals in the principal, azimuth and elevation, planes
Polarization	Vertical and Horizontal

Principal Planes --Difference Patterns

Frequency	5 equally spaced across band
Beam Scan Angles	10° intervals in the principal, azimuth and elevation, planes
Polarization	Vertical and Horizontal

b. Slew Planes--Sum Patterns

Frequency	3 at equal intervals across band
Beam Scan Angle	10° intervals in 8 planes rotated at 10° angular increments with respect to principal planes over scan volume
Polarization	Vertical and Horizontal

Slew Planes --Difference Patterns

Frequency	3 at equal intervals across band
Beam Scan Angle	10° intervals in planes rotated 10°, 30°, 50°, 70°, 80° with respect to principal plane
Polarization	Vertical and Horizontal

TABLE II

SUGGESTED FAR-FIELD PATTERN CUTS FOR
DETERMINATION OF FAR-FIELD PLOTS

El	AZ
0°	0° to $\pm 70^\circ$
$+\frac{1}{2}$ Beam Width	0° to $\pm 70^\circ$
+1 BW	0° to $\pm 70^\circ$
+2 BW	0° to $\pm 70^\circ$
$-\frac{1}{2}$ BW	0° to $\pm 70^\circ$
-1 BW	0° to $\pm 70^\circ$
-2BW	0° to $\pm 70^\circ$
0° to + 70°	0°
0° to + 70°	$+\frac{1}{2}$ BW
0° to + 70°	+1 BW
0° to + 70°	+2 BW
0° to + 70°	$-\frac{1}{2}$ BW
0° to + 70°	-1 BW
0° to + 70°	-2 BW

Total 7 AZ cuts, 7 El cuts = 14 cuts

<u>RMS sidelobe measurements</u>

20° X 20° sector located 30° off boresight
incremented in 0.5° steps (40 cuts 20° wide)
1600 data points

TABLE III

SUGGESTED SCHEDULE OF ANTENNA MEASUREMENTS
FOR PRODUCTION TESTING OF UNITS

TEST CONDITIONS

a. Principal Planes--Sum Patterns

Frequency	3 at equally spaced intervals across band
Beam Scan Angle	15° intervals in the azimuth and elevation planes
Polarization	Vertical and Horizontal

Principal Planes--Difference Patterns

Frequency	3 at equally spaced intervals across band
Beam Scan Angle	30° intervals in the azimuth and elevation planes
Polarization	Vertical and Horizontal

b. Slew Planes--Sum Patterns

Frequency	1 at band center
Beam Scan Angle	15° intervals in 5 slew planes rotated in 15° increments from principal planes
Polarization	Horizontal and Vertical

Slew Planes--Difference Patterns

Frequency	1 at band center
Beam Scan Angle	15° intervals in 5 slew planes rotated in 15° increments from principal planes
Polarization	Horizontal and Vertical

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UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Georgia Institute of Technology Atlanta, Georgia 30332	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE

A STUDY OF COMPARATIVE COSTS FOR FAR-FIELD ANTENNA PATTERNS DETERMINED BY NEAR-FIELD MEASUREMENTS AND BY FAR-FIELD MEASUREMENTS

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final Report, 15 January 1973 to 31 January 1974

5. AUTHOR(S) (First name, middle initial, last name)

Rodrigue, G. P. and Burns, Charles P.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
January 1974	77	3

8a. CONTRACT OR GRANT NO. DAAH01-73-C-0430 b. PROJECT NO. c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) A-1498 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

Reproduction in whole or in part is permitted for any purpose of the United States Government.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Advanced Sensors Directorate Research Development, Engineering and Missile Systems Laboratory, U.S. Army Missile Command, Redstone Arsenal, Alabama

13. ABSTRACT

Antenna pattern measurement costs for both acceptance testing and production testing of a large phased array were determined for both near-field and far-field measurement techniques. Operating costs depend on the thoroughness to which the antenna is tested. Extremely large amounts of data can be generated very efficiently using the near-field technique. However, most test programs are limited by budget and time considerations to a relatively small volume of data. Since requirements for more data would always favor the near-field techniques, a limited set of measurements comparable to previous far-field measurement experience was used.

In terms of total cost, the cost associated with the near-field measurement technique is approximately 75 percent of the cost of conventional far-field range techniques. Initial investment costs, including capital equipment, for the near-field technique are only 50 percent of those for a far-field range, while operational costs for the near-field average 84 percent of far-field costs. A large percentage of operational measurement costs is for initial check-out of the phased array, and these costs are independent of the type of range used. If a moveable near-field positioner is used in the near-field, the total cost of near-field measurements increases to an estimated 85 percent of far-field costs. This type of positioner may be desirable but not essential to the measurement process.

An estimate of the expected rate of return on capital investment showed that the near-field range with fixed positioner was a slightly better investment than either a far-field range or near-field range with moveable positioner.

DD FORM 1 NOV 65 1473 (PAGE 1)

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Near-Field						
Far-Field						
Antenna Patterns						
Phased Array						
Cost						