RGIA INSTITUTE OF TECHNOLOGY | OFFICE OF CONTRACT ADMINISTRATION

PROJECT ADMINISTRATION DATA SHEET

[x] ORIGINAL [ ] REVISION NO. ______

ect No. A-3226 | DATE 6/4/82

ect Director: ~~J. S. Ussailis~~ H. BASSETT | School/Lab RAIL/MAD

nsor: Air Force Systems Command, Electronic Sys. Div., Hanscom AFB, MA

e Agreement: SFRC F19628-82-K-0038 and Mod P00001* 7-31-84

rd Period: From 4/13/82 To ~~4/12/83~~ 10/31/83 (Performance) 10/12/83 (Reports)

sor Amount: $186,000 ($49,000 partial funding est. thru 9/30/82) | Contracted through:

Sharing: None | GTRI/~~GIT~~

e: Polarization Diversity Addition to 10 Centimeter Doppler Weather Radar

MINISTRATIVE DATA

OCA Contact William F. Brown x4820

ponsor Technical Contact:

ham Armstrong, AFGL/LYR

scom AFB, MA 01731

7) 861-4405

2) Sponsor Admin/Contractual Matters:

Thomas A. Bryant

ONRRR

Ga. Tech

Atlanta, GA 30332

ense Priority Rating: None

Security Classification: None

TRICTIONS

Attached Gov't Supplemental Information Sheet for Additional Requirements.

el: Foreign travel must have prior approval – Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of $500 or 125% of approved proposal budget category.

ipment: Title vests with none proposed or anticipated

MMENTS:

od P00001 incorporates Advance Payment Pool Agreement and changes payment office o DCASR-Atlanta (see revised Financial Data Sheet)

JUN 1982 RECEIVED Research Reports Office

PIES TO:

ministrative Coordinator
earch Property Management
ounting
curement/EES Supply Services
Research Security Services
~~Reports Coordinator~~ (OCA)
Legal Services (OCA)
Library
EES Public Relations (2)
Computer Input
Project File
Other ______

RGIA INSTITUTE OF TECHNOLOGY OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION/CLOSEOUT SHEET

Date February 1, 1985

t No. A-3226 ~~School~~/Lab RAIL/MSD

es Subproject No.(s)

t Director(s) J. S. Ussailis GTRI / ~~GIT~~

or Air Force Systems Command, Electronic Sys. Div., Hanscom AFB, MA.

Polarization Diversity Addition to 10 Centimeter Doppler Weather Radar

ive Completion Date: 7/31/84 (Performance) 7/31/84 (Reports)

/Contract Closeout Actions Remaining:

- [ ] None
- [X] Final Invoice or Final Fiscal Report
- [X] Closing Documents
- [ ] Final Report of Inventions Already Sent Out
- [X] Govt. Property Inventory & Related Certificate
- [ ] Classified Material Certificate
- [ ] Other

nues Project No. Continued by Project No.

ES TO:

t Director
rch Administrative Network
rch Property Management
nting
rement/EES Supply Services
rch Security Services
ts Coordinator (CCA)
Services

Library
GTRI
Research Communications (2)
Project File
Other A. Jones; M. Heyser

OCA 60:1028

A-3226

Georgia Institute of Technology

ENGINEERING EXPERIMENT STATION

ATLANTA, GEORGIA 30332

2 August 1982

Electronics Systems Command, PKR
Air Force Systems Command, USAF
Hanscom AFB, Massachusetts 07131

Attention: Mr. Graham M. Armstrong, AFGL/LYR

Reference: Contract No. F19268-82-K-0038
Georgia Tech/EES Project A-3226
"Engineering Study of Radar Modification for Dual Polarization Meteorological Measurements"

Subject: Progress Report No. 1 covering the period 13 April 1982 to 30 June 1982

Gentlemen:

An attachment to this letter summarizes the activities, results, status and costs of work being performed under the referenced contracted during this reporting period.

Respectfully submitted,

James S. Ussailis
Project Director

JSU/jm

Approved:

Harold L. Bassett, Chief
Modeling and Simulation Division

Contact No. F19628-82-K-0038
Quarterly Report No. 1 (13 April 1982 - 30 June 1982)

POLARIZATION DIVERSITY ADDITION TO 10 CENTIMETER DOPPLER WEATHER RADAR

Contract with
Air Force Geophysics Laboratory
Air Force Systems Command
Hanscom AFB, Massachusetts 01731

Graham M. Armstrong, AFGL/LYR, Contract Monitor

Prepared by

GEORGIA INSTITUTE OF TECHNOLOGY
Engineering Experiment Station
Atlanta, Georgia 30332

Contracting through

GEORGIA TECH RESEARCH INSTITUTE
Atlanta, Georgia 30332

James S. Ussailis, Project Director

Summary of Objectives

This program has, as its goal, the modification of the present 10 cm Air Force Geophysics Laboratory (AFGL) coherent weather radar antenna into a polarization diversity antenna capable of operation in either circular or linear polarization modes of operation. This modification, together with a high power radio frequency switch to be procured by AFGL will allow non-coherent linear polarization diversity research to be performed, however, circular polarization diversity operation will require the future additions of receiver channels, local oscillator circuitry, phase and amplitude matching sections and a microwave package, located within an environmentally controlled enclosure. Three additions to the present facility are required for the present program objective: (1) modification of the antenna from a prime focus to a Cassegrain configuration to achieve the required f/D for linear polarization discrimination, (2) alteration of the feed horn to a corrugated or multitaper horn which will provide high circular polarization discrimination, and (3) addition of a polarizer assembly located between the feed horn and high speed radio frequency switch. This assembly will be selectable between linear and circular transmission operation as well as allow reception of both the orthogonal channel and channel of transmission.

Accomplishments This Quarter

During this period, a project management plan has been established with the compilation of the expenditure and construction schedules. It should be noted that, due to incremental funding, this plan (attached) extends beyond the official termination of funding as does some of the contract deliverables. Additonal delays could result if the final incremental commitment extends beyond 15 October 1982.

The subcontractors required for the reflector modifications (H&W Ind., Cohasst, MA) and polarizer construction (Atlantic Microwave, Boston, MA) have been contacted, furthermore evaluation of the remaining undetermined specifications of these items has begun. Atlantic Microwave requested and Georgia Tech agreed to perform a high power "break-down" test on a representative polarizer during the next quarter to determine the necesity of pressurization and subsequent location of a pressure window.

Travel

In mid-July 1982, Mr. Joseph Newton, Senior Research Engineer and Mr. James S. Ussailis, Project Director, visited AFGL, Atlantic Microwave, and H&W Industries. Specific details of the reflector modifications and polarizer construction were discussed, as well as the requirements for issuance of appropriate subcontracts. Additionally, Mr. Newton visited Mr. E. Wilkerson of GTE International Systems, Waltham, Massachusetts, to discuss the appropriate feed antenna as well as the possibility of employing GTE as subcontractor of this antenna.

Next Quarter

Several unresolved issues resulted from aforementioned meetings. Specifically they are: (1) the tolerable level of reflector surfce roughness must be determined, following this, a check of the surface of an reflector as presently configured must be performed so that the allowable amount of surface degradation can be ascertained; (2) prior to static and dynamic structural analysis, the specific antenna parameters such as the size and mass of the individual elements as well as the tolerable displacement of these elements with regard to increased cross-polarized radiation must be determined; (3) a resolution of the difference of opinion between Altantic Microwave and Georgia Tech on the VSWR requirements of polarizer and surrounding microwave components must be accomplished. Each of these items will be considered with a conclusion midway through the next quarter. Following this, appropriate subcontacts will be issued so that each of the vendors can begin the design phase of their efforts.

The choice of feed antenna will also be determined during the next quarter. The present plan is to design, construct and range test a silver painted wooden model of a multitaper horn. Should this effort be succesful, final drawings for such an antena will be begun, and an appropriate manufacturer located.

Fiscal Information

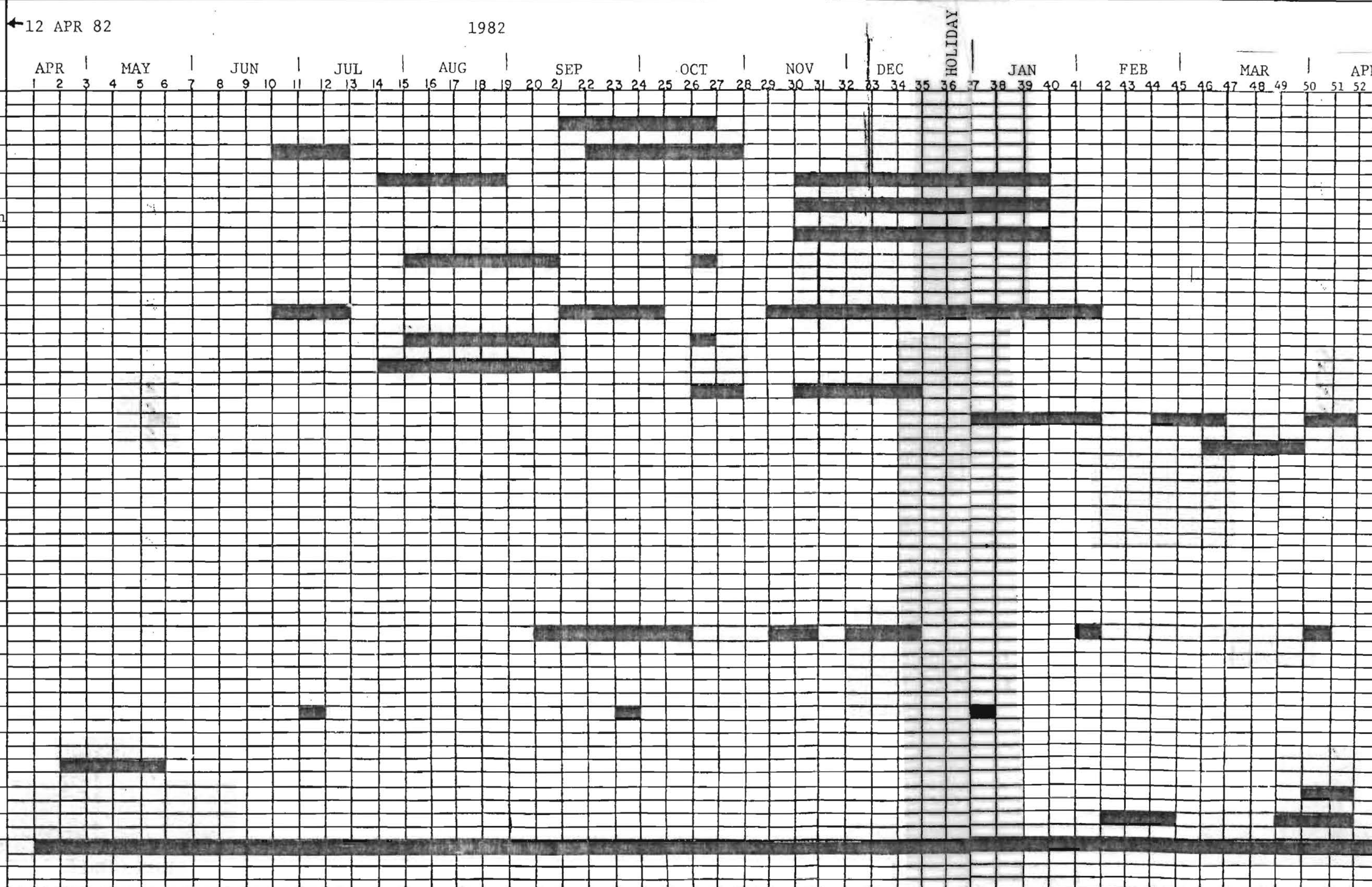
Of the total funds of $186,000 authorized for twelve months of work, approximately 7% has been expended after three months; 7% of the work has been completed.

PLANNING ESTIMATE AS OF 15 MAY 1982

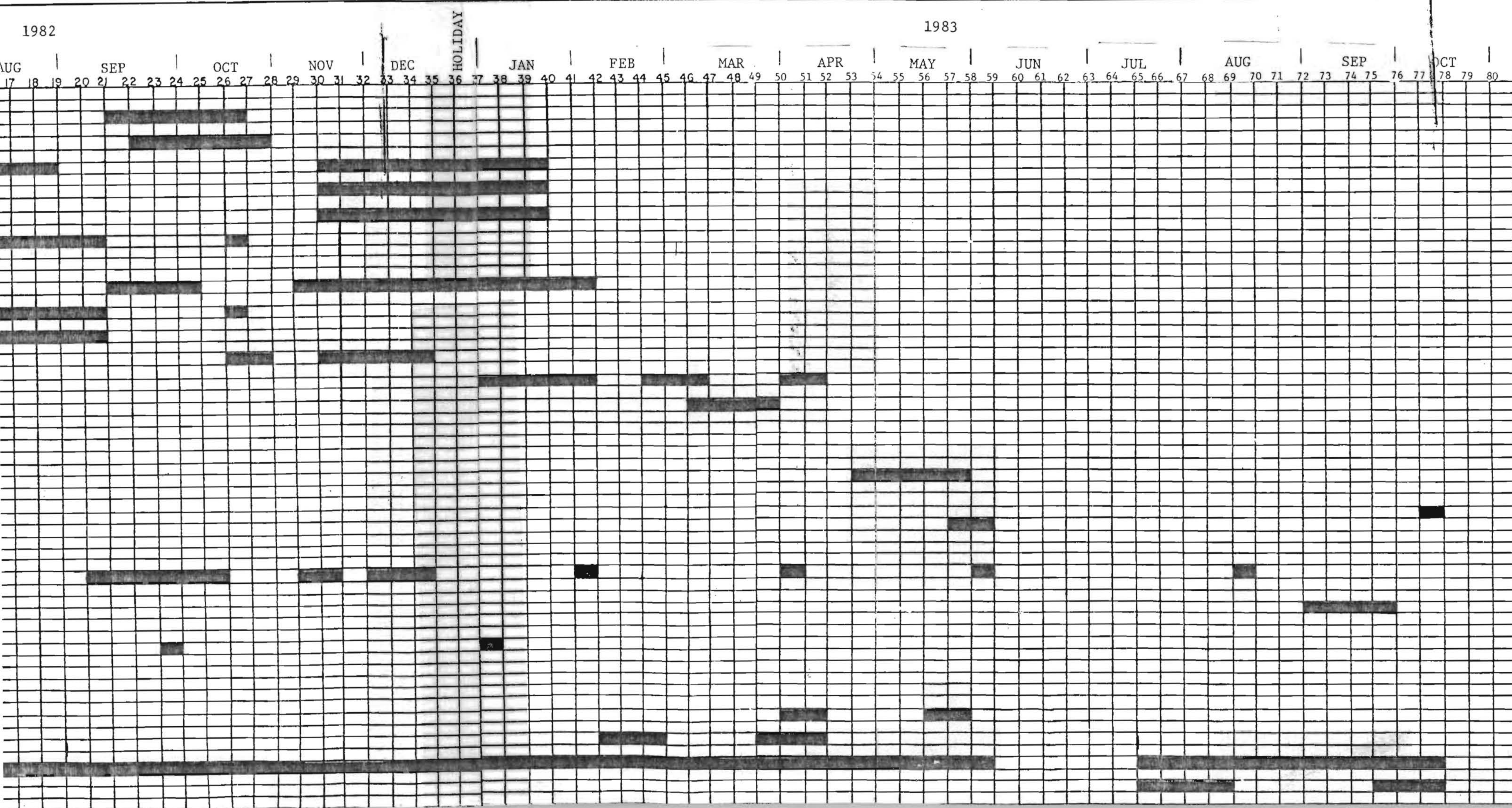
	REPORTING PERIOD							
	First		Second		Third		Fourth	
Planned Percentage of Technical Completion	7		26		72		100	
Labor Elements	Hours	Amount	Hours	Amount	Hours	Amount	Hours	Amount
Project Director	385	$7,030	601	$11,078	857	$16,198	1241	$24,520
Principal Research Engineer	18	503	38	1,062	51	1,425	165	4,612
Senior Research Engineer/Scientist	4	91	129	2,926	153	3,470	189	4,287
Research Engineer II	---	---	---	---	33	596	83	1,500
Research Engineer I	---	---	---	---	96	1,412	239	3,516
Drafting	---	---	---	---	341	3,226	853	8,069
Secretary	5	40	17	136	68	543	145	1,157
Programmer	20	137	40	274	84	575	149	1,019
TOTAL LABOR	397	$7,801	810	$15,476	1,668	$27,445	3,049	$48,680
Other Expenses								
Material and Supplies		100		400		8,700		12,775
Travel		---		2,600		4,100		9,031
Computer		---		400		1,400		1,400
Subcontracts (committed)		---		12,350		60,140		60,140
TOTAL OTHER EXPENSES		$100		$15,750		$74,340		$83,346
Retirement/Fringe Benefits		867		3,250		5,763		10,222
Overhead		4,822		14,547		27,269		43,751
GRAND TOTAL		$ 13,590		$49,023		$134,817		$186,000

TASK AND SCHEDULE

TASK NO.	PROJECT A-3226 WORK DESCRIPTION Polarization Diversity Addition
000	Antenna Modifications
100	Monitor H&W Identification of Mechanical Mods. & Analysis
101	Ant. & Sup. Structure Analysis
102	Construct Sub-reflector
103	Sup. Struct. Design/Fabrication
104	Feed Sup. Struct. Design/Fab.
105	Issue Sub-contract to H&W
200	Design & Procure Feed Assembly
201	Subcontract Specify Proc. of Feed Assembly
202	Design Horn
203	Construct Horn
204	Range Test Horn /Feed Assembly
205	Modifications & Final Design
300	Installation
301	Inst. of Sub-reflector & Feed
302	Install RF Switch
303	Minimal On-site Testing
400	Procure High Speed RF Switch
401	Acceptance Testing of Switch
500	Documentation
501	Quarterly Reports
502	Switch Specifications
503	Monitor Antenna Modifications
504	Antenna Performance Test Plan
505	General Project Direction
506	Yearly/Final Report



TASK AND SCHEDULE



ENGINEERING EXPERIMENT STATION
Georgia Institute of Technology
A Unit of the University System of Georgia
Atlanta, Georgia 30332

19 October 1982

Electronics Systems Command, PKR
Air Force Systems Command, USAF
Hanscom AFB, Massachusetts 07131

Attention: Mr. Graham M. Armstrong, AFGL/LYR

Reference: Contract No. F19268-82-K-0038
Georgia Tech/EES Project A-3226
"Engineering Study of Radar Modification for
Dual Polarization Meteorological Measurements"

Subject: Progress Report No. 2 covering the period
1 July 1982 to 30 September 1982

Gentlemen:

An attachment to this letter summarizes the activities, results, status and costs of work being performed under the referenced contracted during this reporting period.

Respectfully submitted,

James S. Ussailis
Project Director

Approved:

Harold L. Bassett, Chief
Modeling and Simulation Division

JSU/ms

Contact No. F19628-82-K-0038
Quarterly Report No. 2 (1 July 1982 - 30 September 1982)

POLARIZATION DIVERSITY ADDITION TO 10 CENTIMETER DOPPLER WEATHER RADAR

Contract with
Air Force Geophysics Laboratory
Air Force Systems Command
Hanscom AFB, Massachusetts 01731

Graham M. Armstrong, AFGL/LYR, Contract Monitor

Prepared by

GEORGIA INSTITUTE OF TECHNOLOGY
Engineering Experiment Station
Atlanta, Georgia 30332

Contracting through

GEORGIA TECH RESEARCH INSTITUTE
Atlanta, Georgia 30332

James S. Ussailis, Project Director

Summary of Objectives

This program has, as its goal, the modification of the present 10 cm Air Force Geophysics Laboratory (AFGL) coherent weather radar antenna into a polarization diversity antenna capable of operation in either circular or linear polarizaton modes of operation. This modification, together with a high power radio frequency switch to be procured by AFGL will allow non-coherent linear polarization diversity research to be performed, however, circular polarization diversity operation will require the future additions of receiver channels, local osillator circuitry, phase and amplitude matching sections and a microwave package, located within an environmentally controlled enclosure. Three additions to the present facility are required for the present program objective; (1) modification of the antenna from a prime focus to a Cassegrain configuration to achieve the required f/D for linear polarization discrimination, (2) alteration of the feed horn to a corrugated or multipaper horn which will provide high circular polarization discrimination, and (3) addition of a polarizer assembly located between the feed horn and high speed radio frequency switch. This assembly will be selectable between linear and circular transmission operation as well as allow reception of both the orthogonal channel and channel of transmission.

Accomplishments this Quarter

Antenna Modification

The tolerable amount of surface error has been determined for the reflector in the case of linear polarization. It appears that a 0.050" RMS error over the equivalent correlated area of each panel yields a boresight cross-polarization of -45 dB with respect to the peak of the main beam, as well as no significant degradation to be cross-polarized sidelobe intensity or structure. While the present reflector was specified to this surface error level, it was tested prior to shipment and found to have an error of 0.033" RMS. No circular cross-polarization tolerable surface calculation has been performed, nor has any information, relating to the same, been located in an extensive literature search.

The foregoing has been reported, together with a synopsis of the mid-July meeting, to the proposed manufacturer of the antenna modifications. This synopsis carefully addresses the requirements for and the expected results of the static and dynamic analysis that is to be performed. Furthermore, a statement of work which requests a confirmation of this surface error and reflects the agreed upon level of effort has been prepared to be forwarded to this manufacturer.

Antenna Feed Antenna Replacement

An electroformed X-Band scale model of the mulitaper horn antenna has been designed, constructed, and tested. Its performance was less than expected due to an error in the calculation of the length of the phasing sections. A computer model of the feed horn has confirmed this error by accurately predicting the measured patterns. From the results of this program the correct length of the phasing sections have been calculated and improved, acceptable but not faultless, patterns have been predicted.

Polarizer Construction

The required VSWR disagreement between Georgia Tech and the prospective polarizer manufacturer has been resolved; we have determind that his calculations were correct, and ours excessively stringent. A high power performance test of a similar X-Band polarizer has been performed at the manufacturer's request. Breakdown occurred at 125 KW peak power, which scaled for the frequency and waveguide difference implies breakdown in the S-Band polarizer will exist at slightly greater than 1.0 MW peak power. Since this level is not significantly greater than the anticipated operational power level, polarizer pressurization will be required. A statement of work reflecting these and the previous agreed upon applicable results has been prepared to be forwarded to the polarizer manufacturer.

Travel

In mid-September 1982, Mr. James S. Ussailis, Project Director, visited AFGL for the purpose of assisting AFGL in preparation of the statement of work for the High Power Radio Frequency Switch. Additionally, the specific operational schedule of the radar was discussed so that the appropriate time might be determined for installation and testing of the modified and newly developed equipment.

Next Quarter

The bulk of the effort over the next quarter will be the interface with the prospective antenna modification and polarizer vendors to not only initiate their efforts but also to ensure that no unresolved issues exist. Other effort on the part of Georgia Tech will be to (1) retest the X-Band model feed antenna after it is modified and determine if a new front section is required, (2) install the operational X-Band feed into a small reflector so as to determine an applicable method to measure integrated cancellation ratio on an antenna range, (3) prepared a print package for a full size multitaper horn, and (4) review anticipated correspondence on the effect of circular cross-polarization with respect to surface errors.

Fiscal Information

On 13 April 1982 this project was incremently funded to the extent of \$49,000, as of the date of this report the remaining \$137,000 funding has not arrived. Should this funding be further delayed the effort discussed above as well as timely installation will receive significant schedule alteration.

Of the total funds of \$186,000 authorized for twelve months of work, approximately 20.5% has been expended after three months; 20.5% of the work has been completed.

CUMULATIVE COST DATA AS OF 30 SEPTEMBER 1982

LABOR ELEMENTS	PLANNED		ACTUAL	
	Labor Hours	Amount	Labor Hours	Amount
Project Director	601	$11,078	755	$13,911
Principal Research Engineer	38	2,062	18	495
Senior Research Engineer/Scientist	129	2,926	12	284
Research Engineer/Scientist II	-	-	-	-
Research Engineer/Scientist I	-	-	58	861
Secretary	17	136	35	277
Cooperative Student	40	274	575	3,936
TOTAL LABOR	810	$15,476	1453	$19,764
OTHER EXPENSES				
Materials and Supplies		400		2800
Travel		2400		1512
Computer		400		216
Subcontracts		12,350		---
TOTAL OTHER EXPENSES		$15,750		$4,528
FRINGE BENEFITS		3,250		2,645
OVERHEAD		14,547		13,368
GRAND TOTAL		$49,027		$40,305

ENGINEERING EXPERIMENT STATION
Georgia Institute of Technology
A Unit of the University System of Georgia
Atlanta, Georgia 30332

15 April 1983

Electronics Systems Command, PKR
Air Force Systems Command, USAF
Hanscom AFB, Massachusetts 01731

Attention: Mr. Graham M. Armstrong, AFGL/LYR

Reference: Contract No. F19268-82-K-0038
Georgia Tech/EES Project A-3226
"Polarization Diversity Addition to 10 Centimeter Doppler Weather Radar"

Subject: Progress Report No. 3 covering the period 1 October 1982 - 31 December 1982

Gentlemen:

An attachment to this letter summarizes the activities, results, status and costs of work being performed under the referenced contracted during this reporting period.

Respectfully submitted,

James S. Ussailis
Project Director

Approved:

Harold L. Bassett, Chief
Modeling and Simulation Division

JSU/ms

Contact No. F19628-82-K-0038
Quarterly Report No. 3 (1 October 1982 - 31 December 1982)

POLARIZATION DIVERSITY ADDITION TO 10 CENTIMETER DOPPLER WEATHER RADAR

Georgia Tech Project A-3226

Contract with
Air Force Geophysics Laboratory
Air Force Systems Command
Hanscom AFB, Massachusetts 01731

Graham M. Armstrong, AFGL/LYR, Contract Monitor

Prepared by

GEORGIA INSTITUTE OF TECHNOLOGY
A Unit of the University System of Georgia
Engineering Experiment Station
Atlanta, Georgia 30332

Contracting through

GEORGIA TECH RESEARCH INSTITUTE
Atlanta, Georgia 30332

James S. Ussailis, Project Director

THIS REPORT IS INTENDED ONLY FOR THE
INTERNAL MANAGEMENT USE OF THE CONTRACTOR
AND THE AIR FORCE

Summary of Objectives

This program has, as its goal, the modification of the present 10 cm Air Force Geophysics Laboratory (AFGL) coherent weather radar antenna into a polarization diversity antenna capable of operation in either circular or linear polarizaton modes of operation. This modification, together with a high power radio frequency switch to be procured by AFGL will allow non-coherent linear polarization diversity research to be performed, however, circular polarization diversity operation will require the future additions of receiver channels, local osillator circuitry, phase and amplitude matching sections and a microwave package, located within an environmentally controlled enclosure. Three additions to the present facility are required for the present program objective; (1) modification of the antenna from a prime focus to a Cassegrain configuration to achieve the required f/D for linear polarization discrimination, (2) alteration of the feed horn to a corrugated or multipaper horn which will provide high circular polarization discrimination, and (3) addition of a polarizer assembly located between the feed horn and high speed radio frequency switch. This assembly will be selectable between linear and circular transmission operation as well as allow reception of both the orthogonal channel and channel of transmission.

Accomplishments this Quarter

Subcontract

The subcontracts for the polarizer, reflector modifications, and structural analysis of the antenna were resolved, negotiated, and signed during this quarter. Although this occurred about six weeks later than originally anticipated, Georgia Tech has been verbally assured that delivery of the polarizer and modification components will occur during June 1983. This is in accordance with our projected installation period of July 1983.

Antenna Feed Replacement

The X-band model feed horn was modified and range tested on two occasions, wherein it was determined that the appropriate level of power transfer within the taper sections between the circular waveguide TE_{11} mode and TM_{11} mode was not occurring. The cause of this failure is that the information gathered from the literature was apparently incorrect. Following, three "breadboard" taper sections of various flare angles were constructed and range tested to further understand and predict energy transfer between these modes. Finally, it was decided from this data that the design could most likely be optimized by employing a step transition in conjunction with the taper sections.

Antenna Cross-Polarization Due to Surface Errors

A cursory review of antenna cross polarization due to surface errors hs been accomplished. Very little literature exists in this area, but it was determined that a perceptive increase in linear cross polarization will occur for surface errors $\geq$ 0.050" RMS (0.125" peak). Since the RMS error was determined at the time of the manufacture to be approximately 0.033", no degradation is expected for linear polarization. The extent of the surface error induced circular cross polarization contribution is unknown, but expected to be less than for linear cross polarization.

Travel

In November 1982, Mr. James Ussailis, Project Director, visited Atlantic Microwave Corporation of Boston, MA for the purpose of finalizing the polarizer specifications. Additionally, he visited AFGL to collaborate with Dr. J. I. Metcalf on conference papers addressing polarimetric radar for the next radar meteorology conference.

Next Quarter

Our effort over the next quarter will concentrate on the feed antenna design. A rapid resolution is required so that the size and weight of the feed as well as the size and shape of the subreflector may be given to the H&W Engineering, the manufacturer of the antenna modification components. In juxtaposition with this effort, we will setup a small X-band radar to determine, in conjunction with the feed, an applicable method to measure integrated cancellation ratio. Finally, in this quarter, we will be submitting the aforementioned conference papers for approval.

Fiscal Information

On 13 April 1982 this project was incremently funded to the extent of $49,000, the remaining $137,000 arrived this quarter. Because of this incremental funding a no-cost contract extension was requested and granted. the new expiration date is 30 September 1983. Of the total funds of $186,000 authorized for eighteen months of work, approximately 69.2% has been expended after nine months; 69% of the work has been completed or subcontracted.

CUMULATIVE COST DATA AS OF 31 DECEMBER 1982

LABOR ELEMENTS	PLANNED		ACTUAL	
	Labor Hours	Amount	Labor Hours	Amount
Project Director	857	$16,198	941	$18,833
Principal Research Engineer	51	1,425	32	891
Senior Research Engineer/Scientist	153	3,470	12	284
Research Engineer/Scientist II	23	596	-	-
Research Engineer/Scientist I/GRA	96	1,412	136	2,573
Drafting	341	3,226	-	-
Secretary	68	543	107	857
Cooperative Student	84	575	1,330	9,098
TOTAL LABOR	1,668	$27,445	1453	$32,536
OTHER EXPENSES				
Materials and Supplies		8,700		4,694
Travel		4,100		2,304
Computer		1,400		594
Subcontracts		60,140		55,350
TOTAL OTHER EXPENSES		$74,340		$62,942
FRINGE BENEFITS		5,763		5,028
OVERHEAD		27,269		28,119
GRAND TOTAL		$134,817		$128,695

ENGINEERING EXPERIMENT STATION
Georgia Institute of Technology
A Unit of the University System of Georgia
Atlanta, Georgia 30332

27 April 1983

Electronics Systems Command, PKR
Air Force Systems Command, USAF
Hanscom AFB, Massachusetts 01731

Attention: Mr. Graham M. Armstrong, AFGL/LYR

Reference: Contract No. F19268-82-K-0038
Georgia Tech/EES Project A-3226

Subject: Progress Report No. 4 covering the period
1 January 1983 - 31 March 1983

Gentlemen:

An attachment to this letter summarizes the activities, results, status and costs of work being performed under the referenced contracted during this reporting period.

Respectfully submitted,

James S. Ussailis
Project Director

Approved:

Harold L. Bassett, Chief
Modeling and Simulation Division

JSU/jm

Contact No. F19628-82-K-0038
Quarterly Report No. 4 (1 January 1983 - 31 March 1983)

POLARIZATION DIVERSITY ADDITION TO 10 CENTIMETER DOPPLER WEATHER RADAR

Georgia Tech Project A-3226

Contract with
Air Force Geophysics Laboratory
Air Force Systems Command
Hanscom AFB, Massachusetts 01731

Graham M. Armstrong, AFGL/LYR, Contract Monitor

Prepared by

GEORGIA INSTITUTE OF TECHNOLOGY
A Unit of the University System of Georgia
Engineering Experiment Station
Atlanta, Georgia 30332

Contracting through

GEORGIA TECH RESEARCH INSTITUTE
Atlanta, Georgia 30332

James S. Ussailis, Project Director

Summary of Objectives

This program has, as its goal, the modification of the present 10 cm Air Force Geophysics Laboratory (AFGL) coherent weather radar antenna into a polarization diversity antenna capable of operation in either circular or linear polarizaton modes of operation. This modification, together with a high power radio frequency switch to be procured by AFGL will allow non-coherent linear polarization diversity research to be performed, however, circular polarization diversity operation will require the future additions of receiver channels, local osillator circuitry, phase and amplitude matching sections and a microwave package, located within an environmentally controlled enclosure. Three additions to the present facility are required for the present program objective; (1) modification of the antenna from a prime focus to a Cassegrain configuration to achieve the required f/D for linear polarization discrimination, (2) alteration of the feed horn to a corrugated or multipaper horn which will provide high circular polarization discrimination, and (3) addition of a polarizer assembly located between the feed horn and high speed radio frequency switch. This assembly will be selectable between linear and circular transmission operation as well as allow reception of both the orthogonal channel and channel of transmission.

Accomplishments this Quarter

Antenna Modification

A model two taper stepped transition feed horn (Potter Horn) has been constructed and successfully range tested at 9.4 GHz. The E and H plan patterns are virtually identical at the -18 dB level, and almost within a few percent of being identical at the -24 dB level. A print package of the full-size feed horn and secondary reflector has been completed. Copies have been sent to the polarization vendor, the reflector modification vendor, and to one machine shop for a construction quote. Shortly, additional copies of the print package will be forwarded to other potential machine shops.

A theoretical calculation of the antenna pattern has been computed which shows co-polarized sidelobe levels of -24 dB, and no cross-polarization to the threshold level set within the computer.

Since direct measurement of the polarization isolation of this antenna on an antenna range is virtually impossible, an X-band radar has been constructed from existing assemblies at Georgia Tech to test the feasibility of an in situ measurement scheme. This radar employs the model feed horn and appropriately scaled Cassegrainian reflector. Our theoretical analysis has shown that vertical observation of light rain should yield a measurement which contains the cross-polarization error component and in the limit of smaller drop sizes this measurement becomes the antenna integrated cross-polarization ratio. The radar will employ both linear and circular polarizers to confirm this theory in both sets of basis vectors.

Polarizer

According to the vendor, the polarizer castings are expected from the foundry shortly. Most of the specialized microwave testing hardware has been assembled, a rough layout of the top wall coupler has been finished, and delivery of the mechanical switches are expected in May. The delivery date of the completed polarizer assembly is anticipated, but not promised, to be late June 1983. The possibility of delivering those components required to test the feed horn at an earlier date has been expolored. Should the components be successfully tested, this method will be utilized to reduce the foreseen schedule pressure expected to occur in late June.

Reflector Modifications

A structural analysis of the reflector together with the feed, spars, and subreflector is being performed and expected to be finished within two weeks. Following this analysis, the preliminary design of the feed support will be finalized. H & W Engineering is still projecting an early June delivery for all the components of the reflector modification.

Polarization Errors

A complete review of the allowable system errors of a polarimetric weather radar, with particular attention given to the differential reflectivity (Z_{DR}) system, was undertaken. This effort confirmed our previous work which demonstrated a requirement of a -26 dB two-way (or -32 dB) one-way polarization isolation. This effort as well as a description of the considerations and analysis of this radar modification have been drafted and submitted for Air Force approval as conference papers for the 21st Radar Meteorology Conference.

Travel

Mr. James S. Ussailis, Project Director, visited AFGL, ESSCO (Concord, MA), and Omni-Wave Corp. (Beverly, MA) for the purposes of discussing the cross-polarization that might result from the existing radome, and discussing options to the high speed RF switch. Since this travel was in conjunction with another program, only subsistence and auto rental was charged to this project.

Next Quarter

We anticipate that in the next quarter the hardware will be sufficiently completed to begin the actual antenna modification. This modification is scheduled to start on 1 July and be completed by 1 August. Determination of the precise antenna cross-polarization is not anticipated during this time frame.

Fiscal Information

Of the total funds of $186,000 authorized for eighteen months of work, approximately 82.9% has been expended after nine months; 83% of the work has been completed or subcontracted.

CUMULATIVE COST DATA AS OF 31 DECEMBER 1982

LABOR ELEMENTS	PLANNED		ACTUAL	
	Labor Hours	Amount	Labor Hours	Amount
Project Director	1241	$24,520	1136	$22,738
Principal Research Engineer	165	4,612	32	891
Senior Research Engineer/Scientist	189	4,287	43	976
Research Engineer/Scientist II	83	1,500	-	-
Research Engineer/Scientist I/GRA	239	3,516	320	5,775
Drafting	853	8,069	-	-
Secretary	145	1,157	139	1,188
Cooperative Student	149	1,019	2,102	14,379
Machinist	-	-	49	560
TOTAL LABOR	3,064	$48,680	3,821	$46,507
OTHER EXPENSES				
Materials and Supplies		12,775		6,707
Travel		9,031		2,843
Computer		1,400		883
Subcontracts		60,140		55,350
TOTAL OTHER EXPENSES		$83,346		$65,783
FRINGE BENEFITS		10,222		6,602
OVERHEAD		43,751		35,304
GRAND TOTAL		$186,000		$154,196

ENGINEERING EXPERIMENT STATION
Georgia Institute of Technology
A Unit of the University System of Georgia
Atlanta, Georgia 30332

10 October 1983

Electronics Systems Command, PKR
Air Force Systems Command, USAF
Hanscom AFB, Massachusetts 01731

Attention: Mr. Graham M. Armstrong, AFGL/LYR

Reference: Contract No. F19268-82-K-0038
Georgia Tech/EES Project A-3226

Subject: Progress Report No. 5 covering the period
1 April 1983 - 30 June 1983

Gentlemen:

An attachment to this letter summarizes the activities, results, status and costs of work being performed under the referenced contracted during this reporting period.

Respectfully submitted,

Harold L. Bassett
Modeling and Simulation Division

HLB/jm

Contact No. F19628-82-K-00384

Quarterly Report No. 5 (1 April 1983 - 30 June 1983)

POLARIZATION DIVERSITY ADDITION TO 10 CENTIMETER DOPPLER WEATHER RADAR

Georgia Tech Project A-3226

Contract with
Air Force Geophysics Laboratory
Air Force Systems Command
Hanscom AFB, Massachusetts 01731

Graham M. Armstrong, AFGL/LYR, Contract Monitor

Prepared by

GEORGIA INSTITUTE OF TECHNOLOGY
A Unit of the University System of Georgia
Engineering Experiment Station
Atlanta, Georgia 30332

Contracting through

GEORGIA TECH RESEARCH INSTITUTE
Atlanta, Georgia 30332

Harold L. Bassett, Project Director

SUMMARY OF OBJECTIVES

This program has, as its goal, the modification of the present 10 cm Air Force Geophysics Laboratory (AFGL) coherent weather radar antenna into a polarization diversity antenna capable of operation in either circular or linear polarizaton modes of operation. This modification, together with a high power radio frequency switch to be procured by AFGL will allow non-coherent linear polarization diversity research to be performed, however, circular polarization diversity operation will require the future additions of receiver channels, local osillator circuitry, phase and amplitude matching sections and a microwave package, located within an environmentally controlled enclosure. Three additions to the present facility are required for the present program objective; (1) modification of the antenna from a prime focus to a Cassegrain configuration to achieve the required f/D for linear polarization discrimination, (2) alteration of the feed horn to a corrugated or multipaper horn which will provide high circular polarization discrimination, and (3) addition of a polarizer assembly located between the feed horn and high speed radio frequency switch. This assembly will be selectable between linear and circular transmission operation as well as allow reception of both the orthogonal channel and channel of transmission.

ACCOMPLISHMENTS THIS QUARTER

The S-Band feed horn was fabricated during this test period and preliminary tests were performed. The appropriate results were communicated to the polarizer vendor and the reflector modificaton vendor.

The reflector modification print package was approved.

The S-Band rectangular to circular waveguide section was fabricated.

TRAVEL

Mr. James S. Ussailis, Georgia Tech, and AFGL personnel visited H & W, Inc., and Atlantic Microwave on 5-6 June 1983. Discussions centered around the antenna structural analysis performed in May by H & W, Inc.

PAPER PRESENTATIONS

A conference paper was submitted in April 1983 for publication in the Proceedings of the 2nd Polarimetric Workshop held in Huntsville, Alabama.

During June 1983, two papers coauthored by Mr. James S. Ussailis, Georgia Tech, and Dr. James I. Metcalf, AFGL Remote Sensor Branch, were sent for publication in the 21st Weather Radar Conference Proceedings.

NEXT QUARTER

The S-Band feed horn will be fully tested at Georgia Tech prior to shipping to AFGL. It is planned to begin the modification of the AFGL reflector on 1 July 1983. It is anticipated that the modifications and tests can be completed during the month of July. The tests will not include antenna cross-polarization measurements.

FISCAL INFORMATION

Of the total funds of $186,000 authorized for eighteen months of work, approximately 93% have been expended; approximately 85% of the work has been completed or subcontracted.

Contract No. F19628-82-K-0038
GIT Project A-3226

CUMULATIVE COST DATA AS OF 30 JUNE 1983

LABOR ELEMENTS	PLANNED		ACTUAL	
	Labor Hours	Amount	Labor Hours	Amount
Project Director	1,241	$24,520	1,315	$26,183
Principal Research Engineer	165	4,612	40	1,114
Senior Research Engineer	189	4,287	58	1,271
Research Engineer II	83	1,500	0	0
Research Engineer I/GRA	259	3,516	335	6,000
Drafting	853	8,069	0	0
Secretary	145	1,157	216	1,832
Cooperative Student	149	1,019	2,391	16,456
Machinist	-	-	234	2,231
TOTAL LABOR	**3,064**	**$48,680**	**4,589**	**$55,087**
OTHER EXPENSES				
Materials and Supplies		$12,775		$7,074
Travel		9,031		3,837
Computer		1,400		1,128
Subcontracts		60,140		55,350
TOTAL OTHER EXPENSES		**$83,346**		**$67,389**
FRINGE BENEFITS		$10,222		$9,151
OVERHEAD		43,751		42,084
GRAND TOTAL		**$186,000**		**$173,711**

ENGINEERING EXPERIMENT STATION
Georgia Institute of Technology
A Unit of the University System of Georgia
Atlanta, Georgia 30332

18 October 1983

Electronics Systems Command, PKR
Air Force Systems Command, USAF
Hanscom AFB, Massachusetts 01731

Attention: Mr. Graham M. Armstrong, AFGL/LYR

Reference: Contract No. F19268-82-K-0038
Georgia Tech/EES Project A-3226

Subject: Progress Report No. 6 covering the period
1 July 1983 - 30 September 1983

Gentlemen:

An attachment to this letter summarizes the activities, results, status and costs of work being performed under the referenced contracted during this reporting period.

Respectfully submitted,

Harold L. Bassett
Modeling and Simulation Division

HLB/jm

Contact No. F19628-82-K-00384

Quarterly Report No. 6 (1 July 1983 - 30 September 1983)

POLARIZATION DIVERSITY ADDITION TO 10 CENTIMETER DOPPLER WEATHER RADAR

Georgia Tech Project A-3226

Contract with
Air Force Geophysics Laboratory
Air Force Systems Command
Hanscom AFB, Massachusetts 01731

Graham M. Armstrong, AFGL/LYR, Contract Monitor

Prepared by

GEORGIA INSTITUTE OF TECHNOLOGY
A Unit of the University System of Georgia
Engineering Experiment Station
Atlanta, Georgia 30332

Contracting through

GEORGIA TECH RESEARCH INSTITUTE
Atlanta, Georgia 30332

Harold L. Bassett, Project Director

THIS REPORT IS INTENDED ONLY FOR THE
INTERNAL MANAGEMENT USE OF THE CONTRACTOR
AND THE AIR FORCE

SUMMARY OF OBJECTIVES

This program has, as its goal, the modification of the present 10 cm Air Force Geophysics Laboratory (AFGL) coherent weather radar antenna into a polarization diversity antenna capable of operation in either circular or linear polarizaton modes of operation. This modification, together with a high power radio frequency switch to be procured by AFGL will allow non-coherent linear polarization diversity research to be performed, however, circular polarization diversity operation will require the future additions of receiver channels, local osillator circuitry, phase and amplitude matching sections and a microwave package, located within an environmentally controlled enclosure. Three additions to the present facility are required for the present program objective; (1) modification of the antenna from a prime focus to a Cassegrain configuration to achieve the required f/D for linear polarization discrimination, (2) alteration of the feed horn to a corrugated or multipaper horn which will provide high circular polarization discrimination, and (3) addition of a polarizer assembly located between the feed horn and high speed radio frequency switch. This assembly will be selectable between linear and circular transmission operation as well as allow reception of both the orthogonal channel and channel of transmission.

ACCOMPLISHMENTS THIS QUARTER

The S-band feed horn was completed, installed, and tested. It required more modification than was anticipated which resulted in additional costs to the program.

The VSWR of the polarizer was tested and the polarizer was then matched to the feed horn. The subreflector was installed and VSWR tests were then run on the antenna.

It was determined that the antenna sidelobes were higher than anticipated as was the antenna VSWR. A major problem developed upon initial installation of the feed horn. The feed horn support was sufficient and allowed the horn to sag slightly. This problem has since been corrected. Testing to-date indicates an alignment problem still exists between the feed horn assembly and reflector.

TRAVEL

Messrs. Ussailis and Vaughn of Georgia Tech traveled to the AFGL antenna site to install the feed horn assembly.

ADDITIONAL PERSONNEL

Mr. Wayne Higgins of H&W, Inc. was hired as a consultant for four days to direct the installation of the new subreflector and feed support assembly.

FISCAL INFORMATION

Of the total funds of $186,000 for eighteen months of work, approximately 110% have been either expended or encumbered. The Georgia Tech effort has been completed with the exception of the writing of the test report and the final report.

Contract No. F19628-82-K-0038

GIT Project A-3226

CUMULATIVE COST DATA AS OF 30 SEPTEMBER 1983

LABOR ELEMENTS	PLANNED		ACTUAL	
	Labor Hours	Amount	Labor Hours	Amount
Project Director	1,241	$24,520	1,397	$27,823
Principal Research Engineer	165	4,612	40	1,114
Senior Research Engineer	189	4,287	137	3,242
Research Engineer II	83	1,500	58	1,165
Research Engineer I/GRA	259	3,516	335	6,000
Drafting	853	8,069	0	0
Secretary	145	1,157	246	2,081
Cooperative Student	149	1,019	2,724	18,815
Machinist	-	-	498	5,122
TOTAL LABOR	**3,064**	**$48,680**	**5,435**	**$65,362**
OTHER EXPENSES				
Materials and Supplies		$12,775		$15,114
Travel		9,031		7,165
Computer		1,400		1,345
Subcontracts		60,140		55,350
TOTAL OTHER EXPENSES		**$83,346**		**$78,974**
FRINGE BENEFITS		$10,222		$11,138
OVERHEAD		43,751		60,815
GRAND TOTAL		**$186,000**		**$205,151**

A-3226

FINAL TECHNICAL REPORT
GIT/EES PROJECT A-3226

POLARIZATION DIVERSITY ADDITION TO THE 10 CENTIMETER DOPPLER WEATHER RADAR

BY
JAMES S. USSAILIS AND HAROLD L. BASSETT

PREPARED FOR:

U.S. AIR FORCE SYSTEMS COMMAND
AIR FORCE GEOPHYSICS LABORATORY
AFGL/LYR
HANSCOM AFB, MASSACHUSSETTS

UNDER
CONTRACT NO. F19628-82-K-0038

Georgia Institute of Technology
A Unit of the University System of Georgia
Engineering Experiment Station
Atlanta, Georgia 30332

August 1984

FINAL TECHNICAL REPORT
GIT/EES PROJECT A-3226

POLARIZATION DIVERSITY ADDITION TO THE 10 CENTIMETER DOPPLER WEATHER RADAR

BY
JAMES S. USSAILIS AND HAROLD L. BASSETT

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Atlanta, Georgia 30332

August 1984

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HANSCOM AFB, MA

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16. SUPPLEMENTARY NOTATION: MR. J. S. USSAILIS IS NOW ASSOCIATED WITH THE MITRE CORPORATION.

17. COSATI CODES

FIELD	GROUP	SUB. GR.

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number): POLARIZATION, WEATHER RADAR, ANTENNA TESTING, POTTER HORN, POLARIZER UNIT

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The research performed was that of providing antenna modifications for a polarization iversity addition to the AFGL 10 centimeter DOPPLER WEATHER RADAR. Described within are the ANTENNA FEED DESIGN (POTTER HORN), the conversion of the antenna from a prime focus to a Cassegrain Configuration, the results of the feed horn RF measurements, the construction of the POLARIZER ASSEMBLY, and the installation and testing of the antenna system.

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21. ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED

a. NAME OF RESPONSIBLE INDIVIDUAL: RAHAM M. ARMSTRONG, AFGL/LYR

22b. TELEPHONE NUMBER (Include Area Code): (617) 861-4405

22c. OFFICE SYMBOL: LYR

) FORM 1473, 83 APR EDITION OF 1 JAN 73 IS OBSOLETE.

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (continued)

LIST OF TABLES

SECTION 1
INTRODUCTION

The objective of this research program was to provide antenna modifications for a polarization diversifying addition to the AFGL 10 cm Doppler Weather radar.

This addition, together with a subsequent receiver addition, will allow measurement of one coherent linear or circular monostatic scattering matrix of meteorological phenomena. The observations provided by the modified radar will allow for more direct (rather than inferred) measurement of these phenomena than has been heretofore possible. Examples of these additional observations include measurement of hydrometer mean particle size, mean particle shape, phase state, and axial component of wind shear. The purpose of this report is to discuss the actual antenna modifications; the interested reader should review Reference [1], included as Appendix A, to gain insight into the radar measureables as well as the specifications required to attain a reasonable measurement accurately.

In Section 2 the radar modifications and the installation of the feed horn and associated microwave circuitry are discussed. A conclusion is drawn in Section 3.

SECTION 2

RADAR MODIFICATIONS

This modification required five steps and they are discussed in the following paragraphs.

2.1 STRUCTURAL ANALYSIS

T. Walsh of H & W Industries Inc. performed a structural analysis of the existing reflector together with the proposed subreflector, support span assembly, feed support assembly, and feed horn. This effort, consisting of both static and dynamic analyses, determined the distortional effects of dead weight, seasonal thermal changes, wind distortion, and inertial loading. The results of thee analyses are included as Appendix B.

2.2 CONVERSION TO CASSEGRAIN CONFIGURATION

The antenna was converted from a prime focus configuration to a Cassegrain configuration. This conversion extended the antenna's focal length to diameter ratio (f/D) and thus reduced the anticipated linear cross-polarization to acceptable levels. The conversion was accomplished by adding a subreflector and feed support assembly. The existing tripod feed support also had to be replaced with a relocated quadrapod support, not only to provide sufficient latitude to adjust the subreflector, but also to ensure a reduction of both circular and linear cross-polarized levels. The design and fabrication of these items, including the subreflector, was provided by H & W Industries under a Georgia Tech subcontract.

2.3 FABRICATION OF A HUYGEN'S SOURCE FEED

A Huygens source feed which radiates equal amplitude, TE_{11} and TM_{11} circular waveguide modes (also known as the hybrid or HE_{11} mode) will theoretically induce no cross-polarization when properly illuminating a reflector antenna. All non-Huygens source feeds, including dipoles, magnetic dipoles (slots), and crossed dipoles, will produce off-axis cross-polarization from the reflector. This is true for both linearly and circularly polarized systems. A few antennas will generate the HE_{11} mode.

On this project both a corrugated horn and a multitaper or Potter horn were considered. The Potter horn was chosen on the basis of cost. Because of a lack of design data in the literature, it was decided to construct a scaled feed operating at 10.4 GHz before proceeding with a full sized S-band feed. Five feeds of various tapers and phasing sections were constructed before the final configuration was fabricated. This feed achieved equal E and H phase patterns (Figures 1 and 2) over a 60 degree angular extent. By symmetry of its circular aperture it can be proclaimed a Huygens over this angular area. Figures 3 to 8 show that it is also a functional design from 9.3 to 9.7 GHz inclusive.

The dimensions of the successful 9.4 GHz feed were then scaled to 2.735 GH_z, the mid-band operating frequency of the radar. Fabrication of the full size feed proceeded with a different mechanical technology; rather than turn a full size horn from a large cylinder of aluminium, the various sections were rolled and machined. This provided a lighter weight, lower cost structure, as well as allowing for modification. This latter benefit was fortunate since the initial full size model did not provide equal E & H place patterns over a reasonable extent, nor did it have a sufficiently low VSWR ($\leq$ 1.02:1) for circular polarimetric operation.

An attempt was made to understand equalization of the patterns by extending the horn's phasing section in three incremental steps of 1/2 inch. This also had little effect on performance. Finally, after an analysis of the unit's characteristics, a front phasing section was added which succeeded in providing equal E & H phase patterns at 2.710 GHz (Figures 9 and 10). E phase pattern measurements were also recorded from 2.67 GHz to 2.80 GHz for future reference (Figures 11 through 20).

While initial VSWR measurements were undertaken at this time, final VSWR measurements were accomplished during installation. Initially the VSWR of the final feed horn was unacceptably high. While it was decided to reduce the reflections by use of an iris, it was also decided to limit our effort in this area since the significant VSWR specification was applicable only between the polarized-horn junction and not between our test set-up-horn junction. VSWR measurements were performed with various sized irises placed between the feed horn and the rectangular waveguide to circular waveguide transition. Minimum VSWR was attained with a 2.60 inch iris.

During component installation on the reflector in Sudbury, Massachusetts, the feed VSWR measurements were repeated. This was done to re-establish horn baseline data to: (1) show that no damage occurred in transit from Atlanta and (2) to complete the data package. The measurements are summarized below:

A. The loss of the rectangular to circular transition was measured so that the actual VSWR at the horn could be determined. The loss was determined by placing a short circuit at the input and then at the output of the transition and by measuring the return loss. The transition was found to have 1.0 dB two-way loss which implies a 0.5 dB one-way loss.

B. Transition VSWR was measured. These measurements depended on the Atlantic Microwave circular load reflection which was attached to the transition; one cannot separate these VSWR (or isolate) from the data. The data may not be useful, but are presented in Figure 21.

C. Peak and null measurements were made by using a short circuit on a slotted line and a short circuit on a slotted line plus the rectangular to circular transition. These data may be utilized with following measurements to determine the complex value of reflection coefficient. The data are presented as Table 1.

D. Horn and transition VSWR measurements were made to not only to ensure that no electrical damage occurred to the feed horn during shipment to Sudbury, Massachusetts but also acquire complex reflection coefficient data so a scientific approach to VSWR reduction could be performed. The data are presented in Table 2.

E. Polarization plus transition VSWR measurements were made. Only a few data points were taken with this combination to ensure a reasonable conversion match between the polarizer and horn. The remainder of the data requires completion of the polarizer. These data are required before installation so that the best possible match can be

TABLE 1. SLOTTED LINE PEAK AND NULL POSITION DATA

FREQUENCY MHz	SLOTTED SECTION PEAK POSITION cm	SLOTTED SECTION NULL POSITION cm	SLOTTED SECTION & TRANSITION PEAK POSITION cm	SLOTTED SECTION & TRANSITION NULL POSITION cm
2670	13.39	8.97	14.66	10.20
2675	13.30	8.90	14.34	9.90
2680	13.37	8.88	13.96	9.55
2685	13.23	8.77	13.69	9.23
2690	13.14	8.75	13.14	8.95
2695	13.04	8.71	12.87	8.62
2700	13.06	8.75	12.63	8.33
2705	13.04	8.66	12.23	8.05
2710	12.97	8.64	12.15	7.69
2715	12.78	8.60	11.90	7.40
2720	12.67	8.58	11.44	7.14
2725	12.77	8.50	11.02	6.83
2730	12.73	8.44	10.90	6.50
2735	12.46	8.44	10.54	6.20
2740	12.53	8.42	10.19	5.88
2745	12.43	8.36	9.96	5.64
2750	12.41	8.35	9.50	5.35
2755	12.32	8.33	9.05	13.30
2760	12.38	8.22	8.89	12.97
2765	12.48	8.30	8.74	12.72
2770	12.14	8.18	8.42	12.43
2775	12.20	8.21	7.90	12.05
2780	12.20	8.19	7.69	11.81
2785	12.20	8.10	7.45	11.45
2790	11.95	8.09	7.10	11.20
2795	11.87	8.00	6.94	10.98
2800	11.83	7.95	6.53	10.49

ensured. The available data are presented in Table 3 while the match with the tuning screws in the optimum position is shown in Figure 22. The Smith chart shows the reasonabless of the match between the polarizer and horn. The final match can be improved, but requires the final polarizer configuration.

F. VSWR measurements of the Horn plus the polarizer were made with the opposite polarizer port terminated (Figure 23). These measurements established that the horn reasonably matched the incomplete polarizer. The addition of the tuning screws improves the junction match sufficiently to be better than the requirement at 2710 MHz.

2.4 POLARIZER ASSEMBLY DEVICE

Construction of a polarizer assembly device, known as a polarizer, was required to generate the various linear and circular polarizations of operation.

The unit of choice is a sloped septum polarizer because this device can directly generate each step of circular polarization from a single waveguide input, thus minimizing the number of waveguide junctions. Circular polarization scattering matrix measurements require the most polarization isolation [2]. Since high polarization isolation implies a minimum VSWR ($<$ 1.02:1) on all polarizer ports, the minimization of the number of waveguide junctions is necessary to reduce VSWR sources.

In the less critical linear polarization diversity mode of operation, a topwall hybrid coupler is added into the circuit (Figures 24 and 25). Here the VSWR requirements are $<$ 1.1:1. Furthermore, reconsideration of the differential reflectivity polarization isolation requirements has indicated that a further reduction in the VSWR requirement may be applicable.[3]

The polarizer assembly including polarizer, switches, topwall coupler, square waveguide section, square waveguide to circular waveguide section, and assorted waveguide pieces was supplied by Atlantic Microwave Corporation of Boston, Massachusetts under a subcontract issued by Georgia Tech.

TABLE 2. VSWR OF HORN AND TRANSITION

FREQUENCY MHz	PEAK POSITION cm	NULL POSITION cm	VSWR
2670.05	12.44	8.23	1.055
2675.00	12.10	7.13	1.070
2680.03	12.04	7.50	1.030
2685.01	10.27	15.43	1.020
2690.08	9.00	12.88	1.012
2695.09	8.03	11.66	1.025
2700.09	6.70	11.53	1.050
2705.07	6.60	11.06	1.080
2710.06	6.24	10.30	1.095
2715.00	5.70	10.00	1.122
2719.98	5.40	9.80	1.138
2725.00	13.60	9.28	1.155
2730.03	13.25	9.02	1.162
2735.06	12.84	8.60	1.173
2740.02	12.65	8.33	1.157
2745.03	12.05	8.00	1.160
2750.02	11.87	7.69	1.148
2755.04	11.40	7.35	1.135
2759.98	11.27	7.38	1.120
2765.02	10.66	6.68	1.100
2770.02	10.30	6.57	1.095
2775.05	10.20	6.10	1.080
2780.02	10.03	5.80	1.077
2785.01	9.65	13.70	1.073
2790.04	8.98	12.80	1.069
2795.08	8.56	12.74	1.082
2800.00	8.10	11.96	1.090

TABLE 3. VSWR OF POLARIZER AND TRANSITION
(PORTS TERMINATED WITH MATCHED LOADS).

FREQUENCY MHz	PEAK POSITION cm	NULL POSITION cm	VSWR
Tuning Screws Out 1 Turn.			
2705.00	13.25	8.69	1.096
2710.02	13.27	8.60	1.095
2715.02	12.80	8.22	1.095
Tuning Screws Out 2 Turns.			
2700.04	13.03	8.36	1.10
2705.01	13.36	8.36	1.095
2710.00	13.04	8.34	1.10
2715.02	12.80	8.24	1.09
Tuning Screws Out 3 Turns.			
2705.00	12.90	8.57	1.10
2710.03	12.90	8.52	1.09
2715.00	12.66	8.25	1.085

2.5 INSTALLATION

The final step to the antenna modification was the installation and testing of the antenna system. While the installation proceeded in an orderly fashion, the system tests were halted soon after they started due to prior commitments of the system.

Georgia Tech began installing the antena hardware on 9 August 1983. The existing feed and tripod support assembly were removed and four reflector panels were removed after drilling and pinning. The quadrapod subreflector mount and feed mount were installed, and the modifed reflector was assembled. From 9 August to 18 August, we were assisted by a mechanical technician from H & W Industries of Cohassett, Massachusetts and by AFGL personnel.

Hardware installation was completed during the period from 22 August to 26 August 1983. The feed horn was installed, the subreflector and feed horn were mechanically aligned, and initial pattern measurements were performed. Azimuth sidelobes (below the main lobe peak) measured 18 dB adn 20 dB at 2.710 GHz and 16 dB and 17 dB at 2.600 GHz.

During the initial pattern measurements, moderate swings in boresight amplitude were noticed. AFGL believed that the amplitude change was due to shifting of the transmitting antenna. This antenna was a 10 foot prime focus reflector mounted approximately at the 40 foot level of a tower located at an approximate range of 6 miles. Since the owner of the tower (Raytheon Co.) donated the space with the provision that any attachment would employ no welding or drilled holes, a clamping arrangement was devised. Before these tests, the prevailing wind had sufficiently distorted the mount such that the antenna was no longer rigidly held.

Pattern measurements taken by AFGL personnel during the period from 29 August to 12 September idicated that all azimuthal patterns had asymetrical first null. Upon investigation, a drooping of the feed was discovered when the antenna was rotated from the vertical to the horizontal observation angle. This droop was obviously due to insufficient feed support. H & W Industries was then advised of the problem. They fabricated and assisted in the installation of four feed support spans during the period from 12 September to 17 September 1983.

On 17 September 1983, VSWR measurements of the antenna were performed. Two methods were attempted to reduce subreflector VSWR: the addition of a conically shaped reflector surface located at the center of the subreflector and the addition of a post at the same location. The theory of operation of these devices is straightforward. The former attempts to reflect those rays which may reflect from the second reflection into the feed horn towards the side of the antenna, while the latter introduces an out-of-phase component to the electric field to cancel the undesired reflected ray.

Both devices were inefficient at reducing antenna VSWR (Figure 26). However, since the post had a noticeable effect, it was left on the subreflector. During the next two weeks, antenna patterns were cut by AFGL personnel. Very high sidelobe levels were noted which were eventually determined to be a result of the VSWR reduction post.

Since no further testing could be permitted because of prior commitments of the radar system, the post was removed and the antenna placed in operation. Subsequent to this time, it was also discovered that the feed support assembly extends the feed one inch closer to the antenna than required. This overextension will have to be corrected so that the antenna assembly can be properly focused.

SECTION 3.
CONCLUSION

The antenna has been modified and its proper operation has been partially confirmed. Final focusing and overall VSWR reduction are required before cross-polarization levels can be determined. A reduction of the first sidelobe levels to tolerable levels is required, however before polarimetric measurements are made. Some suggested methods for accomplishing this have been discussed with AFGL personnel.

SECTION 4.

PERSONNEL

The following scientists and engineers contributed to the research reported in this document.

Person	Contribution and Affiliation
James S. Ussailis	Project Director; Georgia Tech
Joseph M. Newton	Electrical Design of Feed Horn; Georgia Tech
Donal Gallentine	Mechanical Design of Feed Horn; Georgia Tech
Keith D. Vaughn	Testing of Feed Horn, Installation; Georgia Tech
Edward Saltzberg	Polarizer Design and Manufacture; Atlantic Microwave Rt. 117, Boston, Massachussetts, 01740
Robert Dalton	Polarizer Mechanical Design; Atlantic Microwave
Thomas P. Walsh, PE	Mechanical Analysis of Antenna Design; H & W Industries Incorporated Cohassett, Massachusetts
James Hayes	Mechanical Design of Antenna; H & W Industries
Graham Armstrong	Contract Manager; Air Force Geophysics Lab, Remote Sensing Branch Hanscome AFB, Massachusetts, 01730
Al Bishop	Testing Assistance; AFGL
James I. Metcalf	Technical Assistance, AFGL

SECTION 5.

PUBLICATIONS

Previous Related Contract: F19628-81-K-0027

Final Report: "Analysis of a polarization diversifying weather Radar Design"; Ussaiis, J. S., Leiker, L. A., Goodman, R. M. IV, Metcalf, J. I., Georgia Institute of Technology EES Project A2807, Atlanta, GA, 2 July 1982. Report No. AFGL-TR-82-0234

Publications Partially Sponsored by this Contract:

1. "System Errors in Polarimetric Radar Backscatter Measurements", Ussailis, J. S. and Metcalf, J. I. Published in the proceedings of the second workshop of polarimetric radar technology. Redstone Arsenal, AL, 3-5 May 1983.
2. "Radar System Errors in Polarization Diversifying Measurements", Metcalf, J. I. and Ussailis, J. S., Preprints, 21st conference on Radar Meteorology, Edmonton, Alberta, Canada, 19-23 September 1983.
3. "Analysis of a Polarization Diversity Meteorological Radar Design", Ussailis, J. S., Metcalf, J. I., Preprints 21st conference on Radar Meteorology, Edmonton, Alberta, Canada, 19-23 September 1983.
4. "Radar System Errors in Polarization in Diversifying Measurements:, Metcalf, J. I. and Ussailis, J. S., Journal of Atmospheric and Oceanic Technology, in press.

SECTION 6.
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2. Metcalf, J. I. — "Coherent Polarization - Diversity Radar Techniques in Meteorology," J. Atmos Sci. 35, No. 10 (October 1978), with J. D. Echard.

3. Metcalf, J. I. and J. S. Ussailis — "Radar System Errors in Polarization Diversifying Measurements", Journal of Atmospheric and Oceanic Technology, in press (1984).

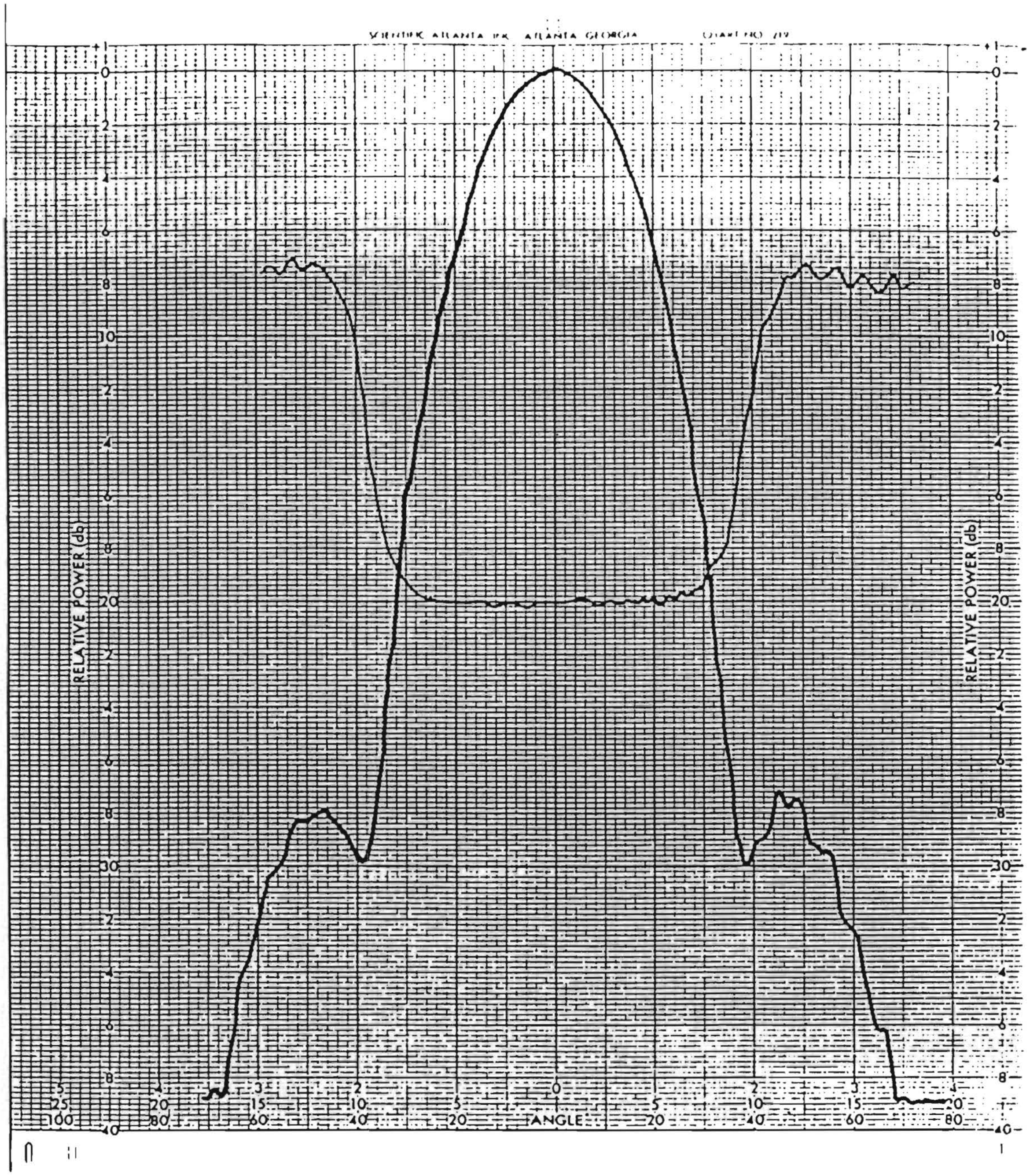

Figure 1. Scaled feed horn pattern, E-plane, f=9.4 GHz.

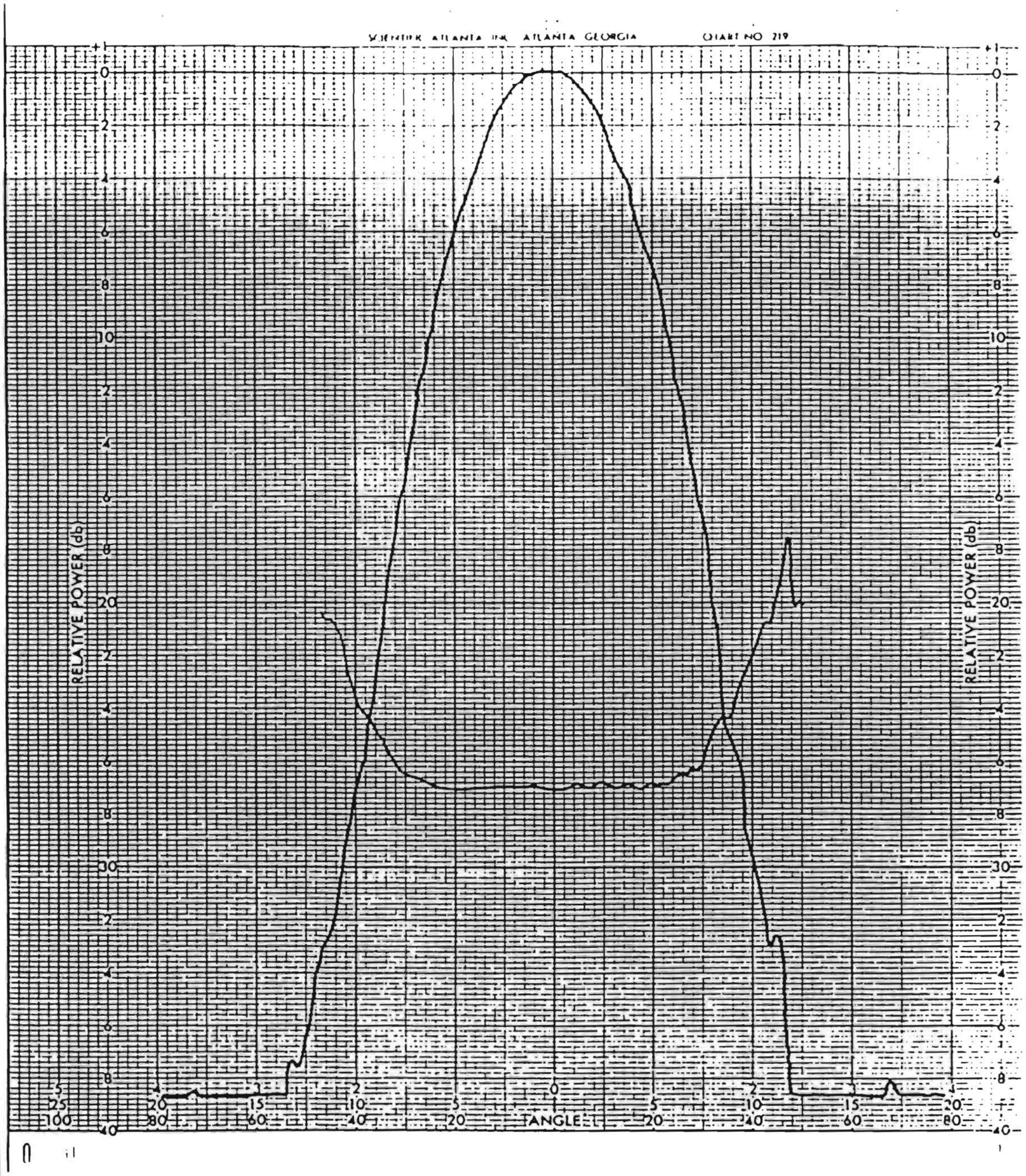

Figure 2. Scaled feed horn pattern, H-plane, f=9.4 GHz.

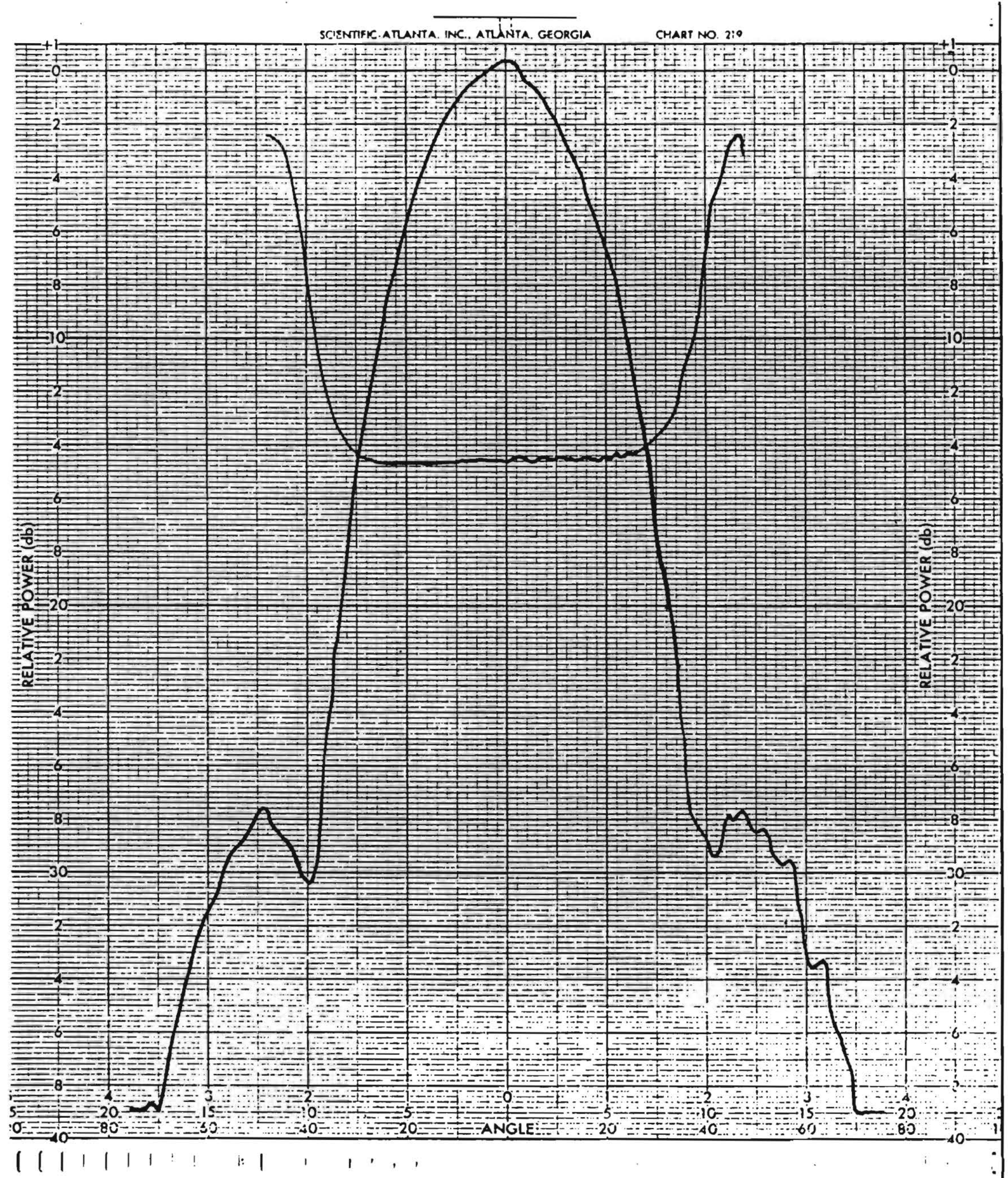

Figure 3. Scaled feed horn pattern, E-plane, F=9.3 GHz.

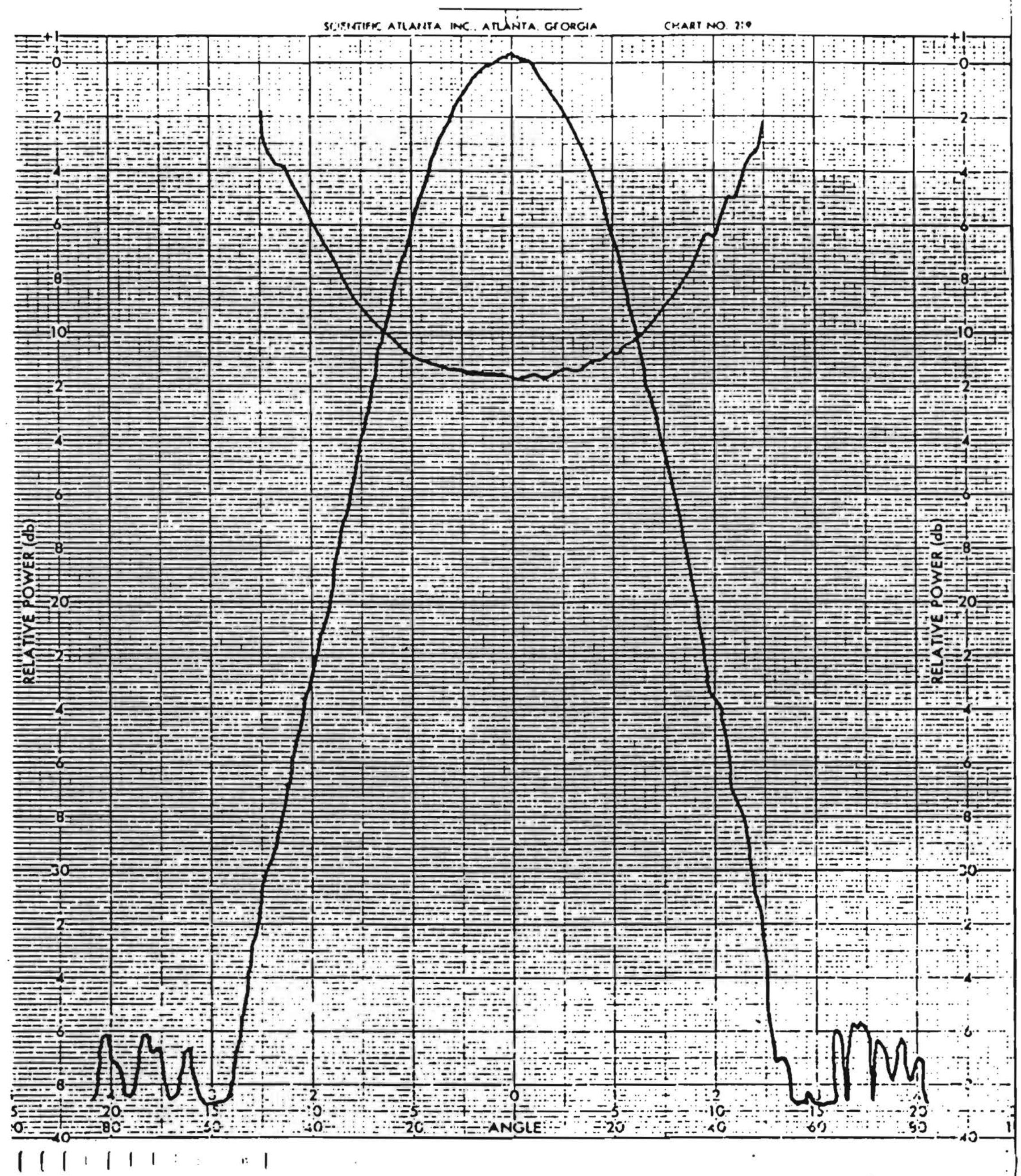

FIGURE 4. Scaled feed horn pattern, H-plane, f=9.3 GHz.

Figure 5. Scaled feed horn pattern, H-plane, f=9.5 GHz.

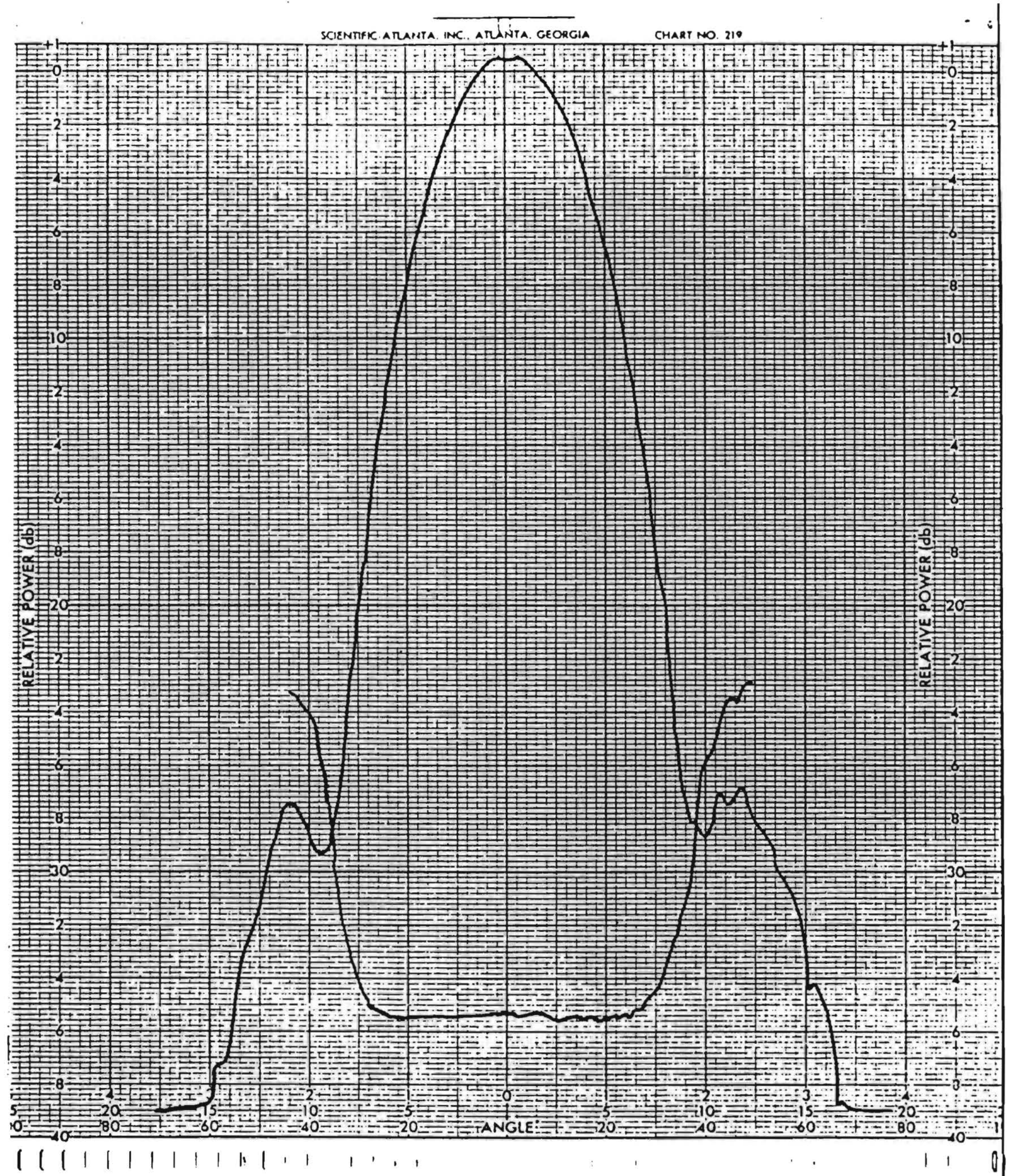

Figure 6. Scaled feed horn pattern, E-plane, f=9.5 GHz.

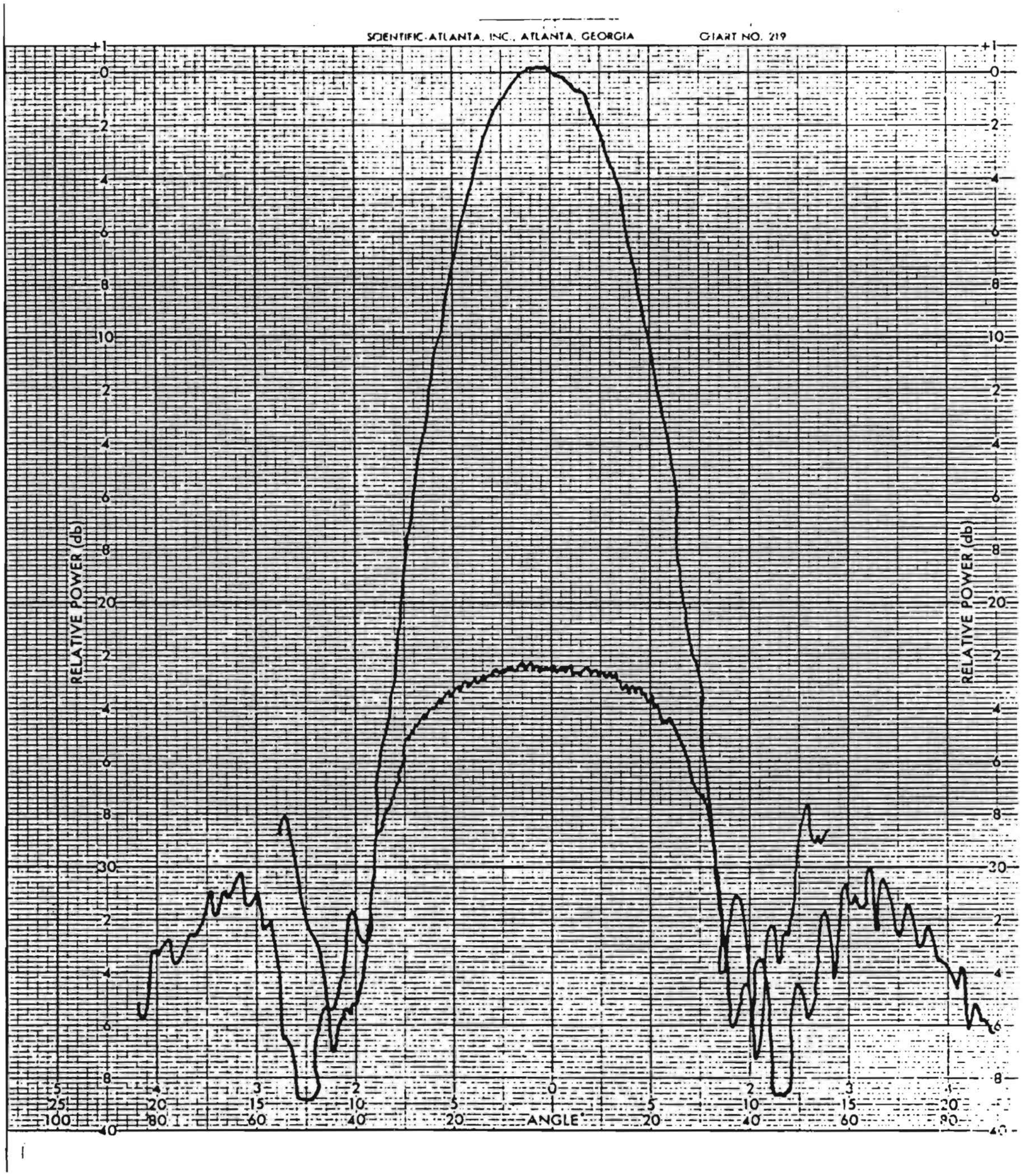

Figure 7. Scaled feed horn pattern, H-plane, F=9.6 GHz.

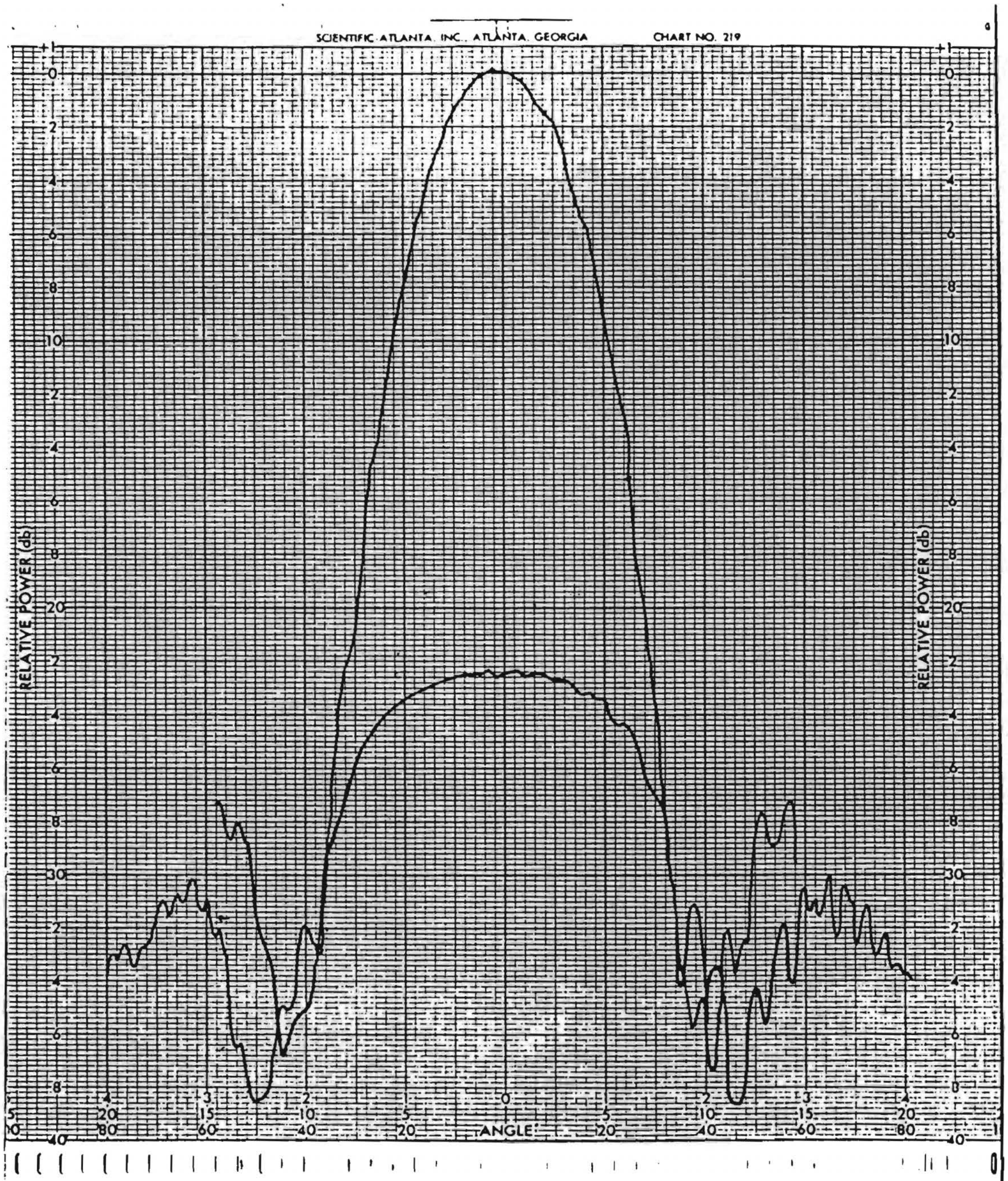

Figure 8. Scaled feed horn pattern, H-plane, f=9.7 GHz.

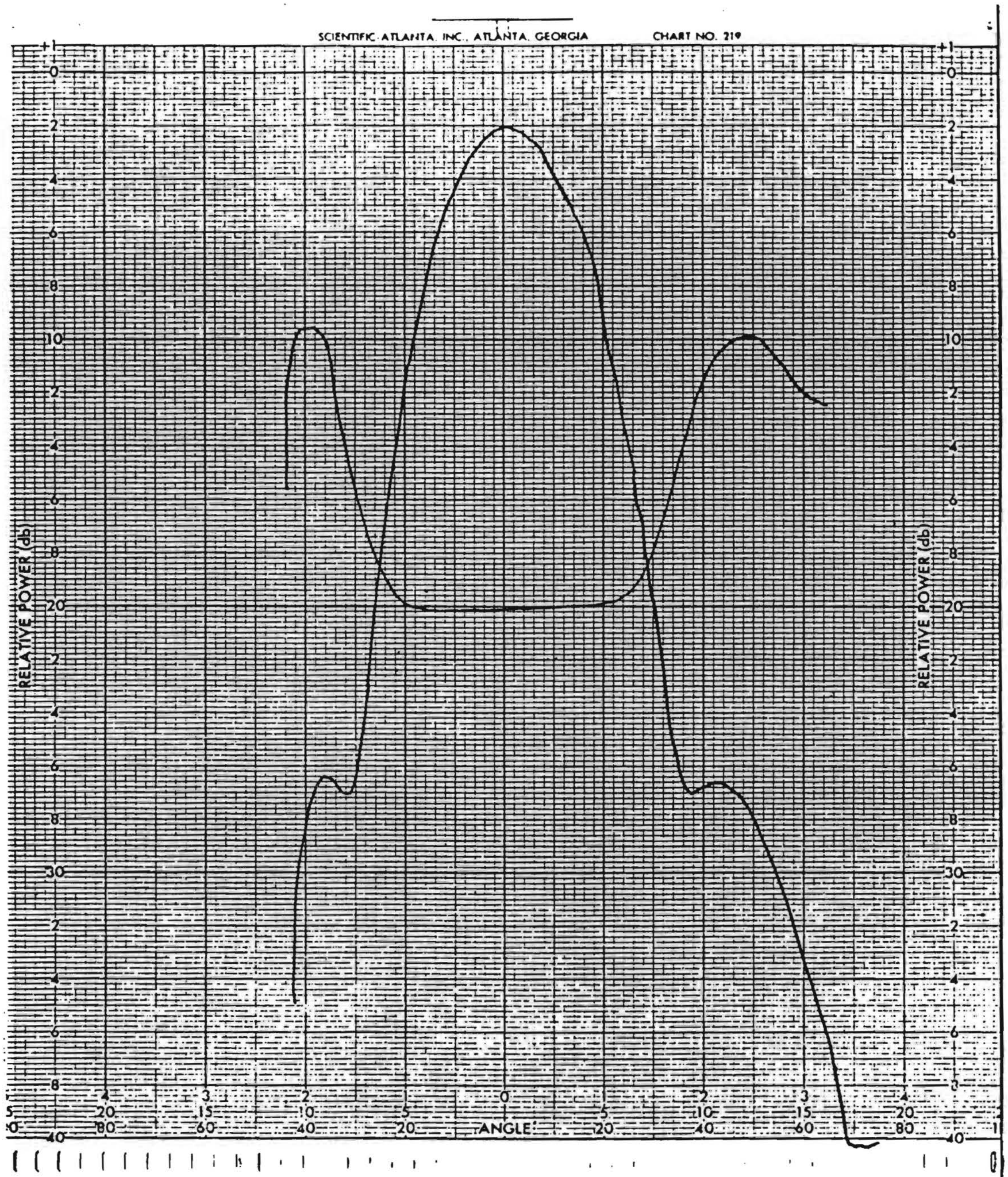

Figure 9. Feed H-plane pattern, f=2.71 GHz, no phase section spacer, 4-inch front piece, 32.8-inch rotation distance, phase center is 2-5/8 inches behind aperture.

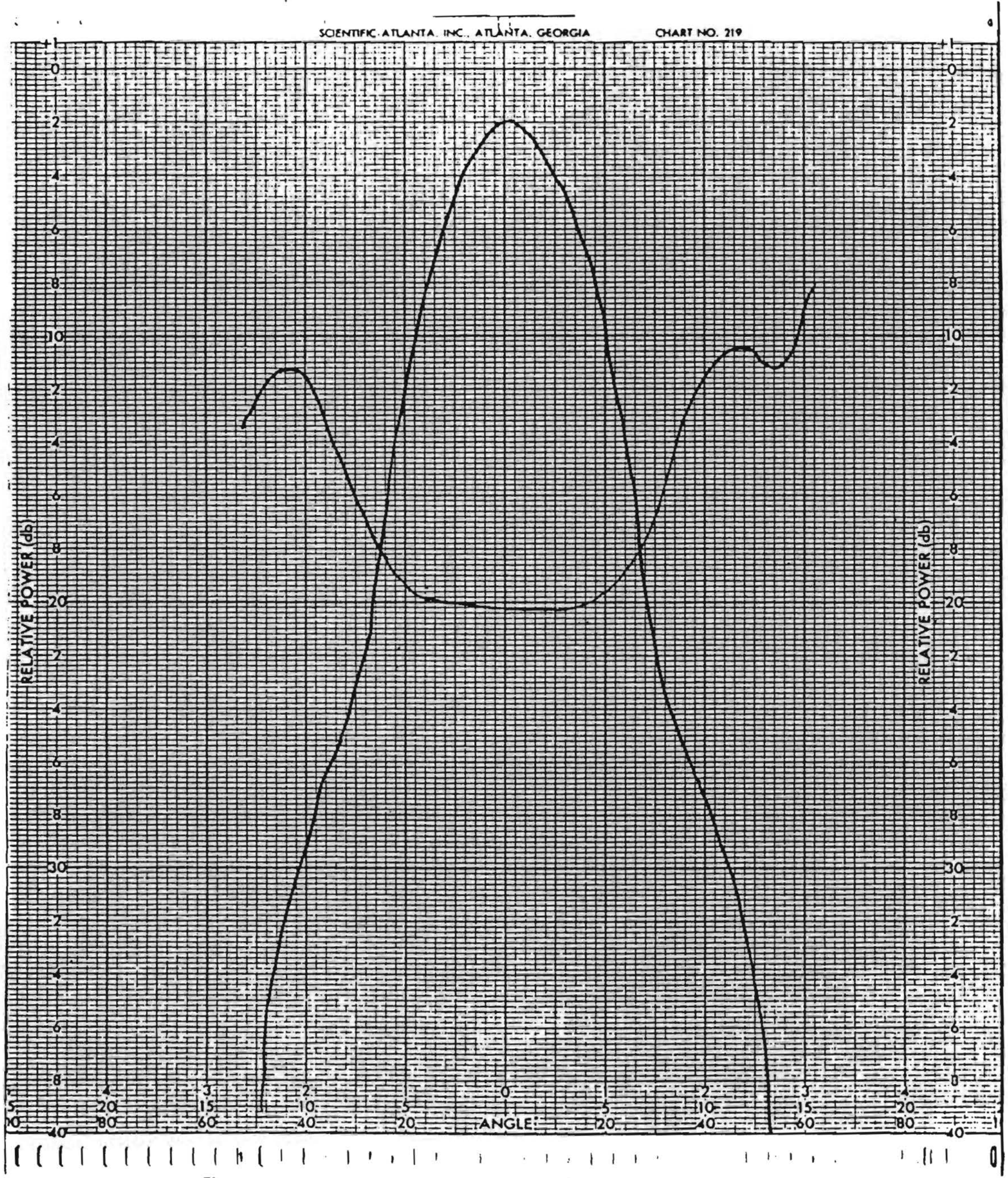

Figure 10. Feed E-plane pattern; same conditions as Figure 9.

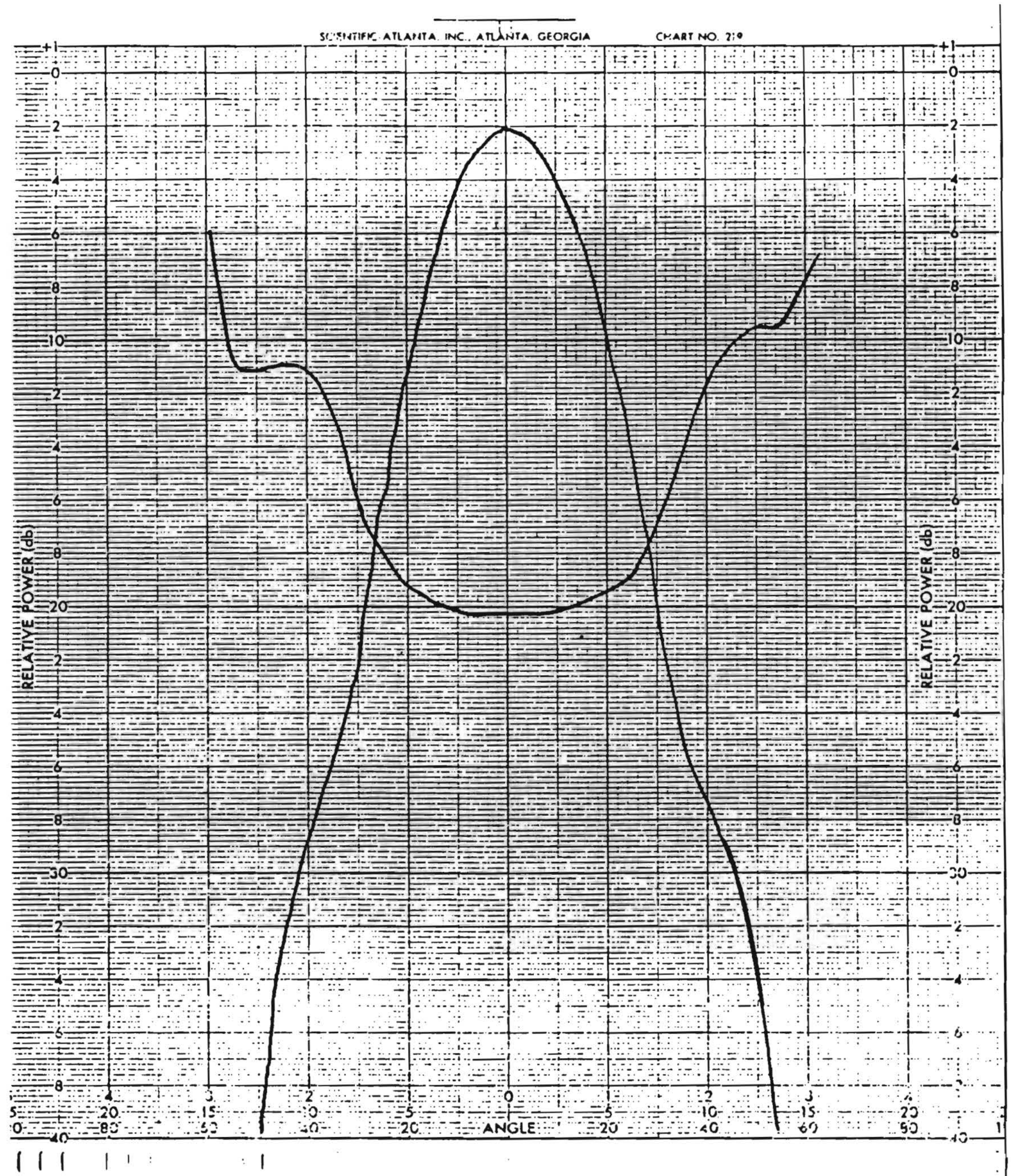

Figure 11. Feed E-plane pattern, f=2.7 GHz, no phase section spacer, 4-inch front piece, 32.8-inch rotation distance, phase center is 2-13/16 inches inside.

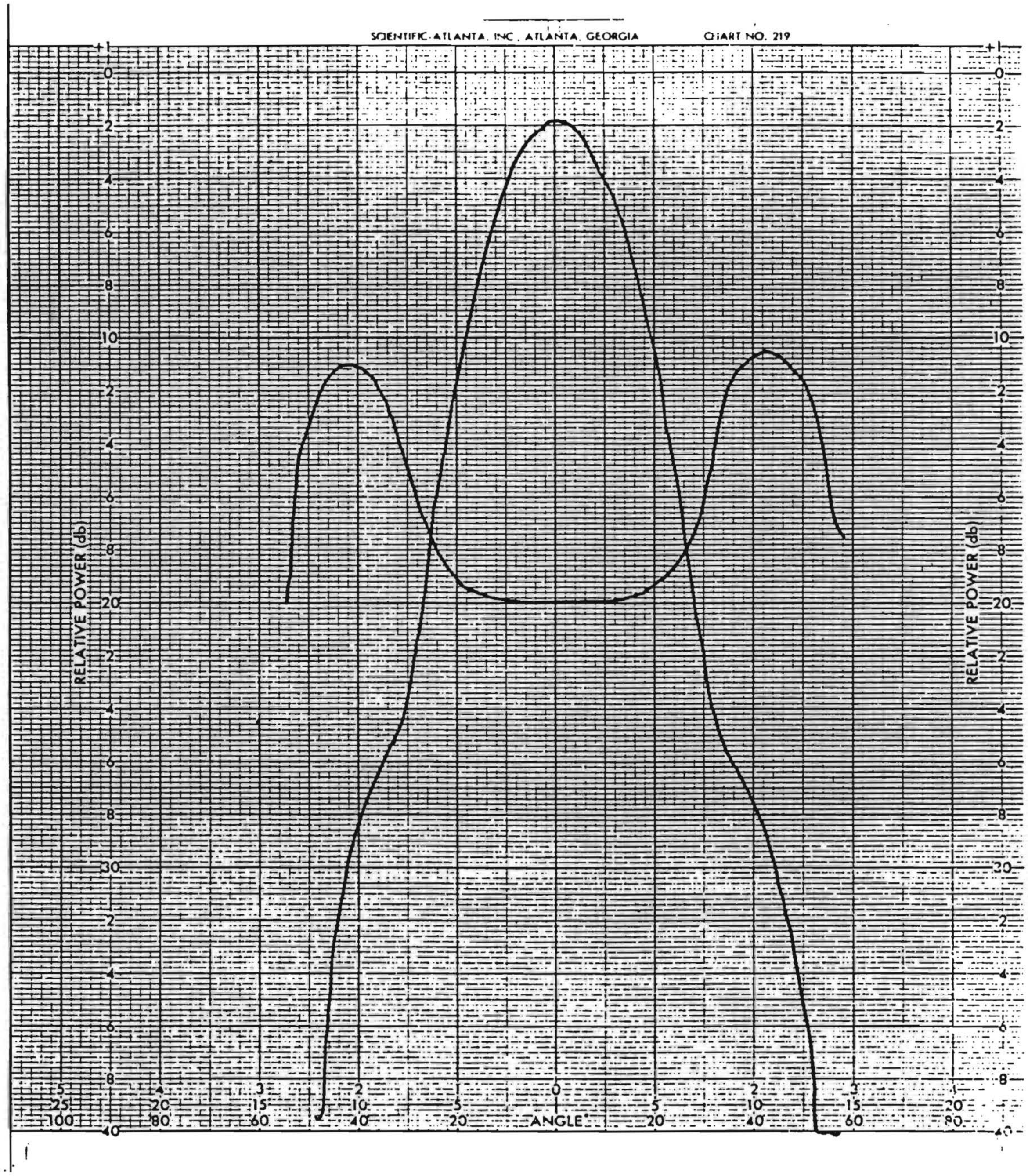

Figure 12. Feed E-plane pattern f=2.72 GHz (see caption on Figure 11).

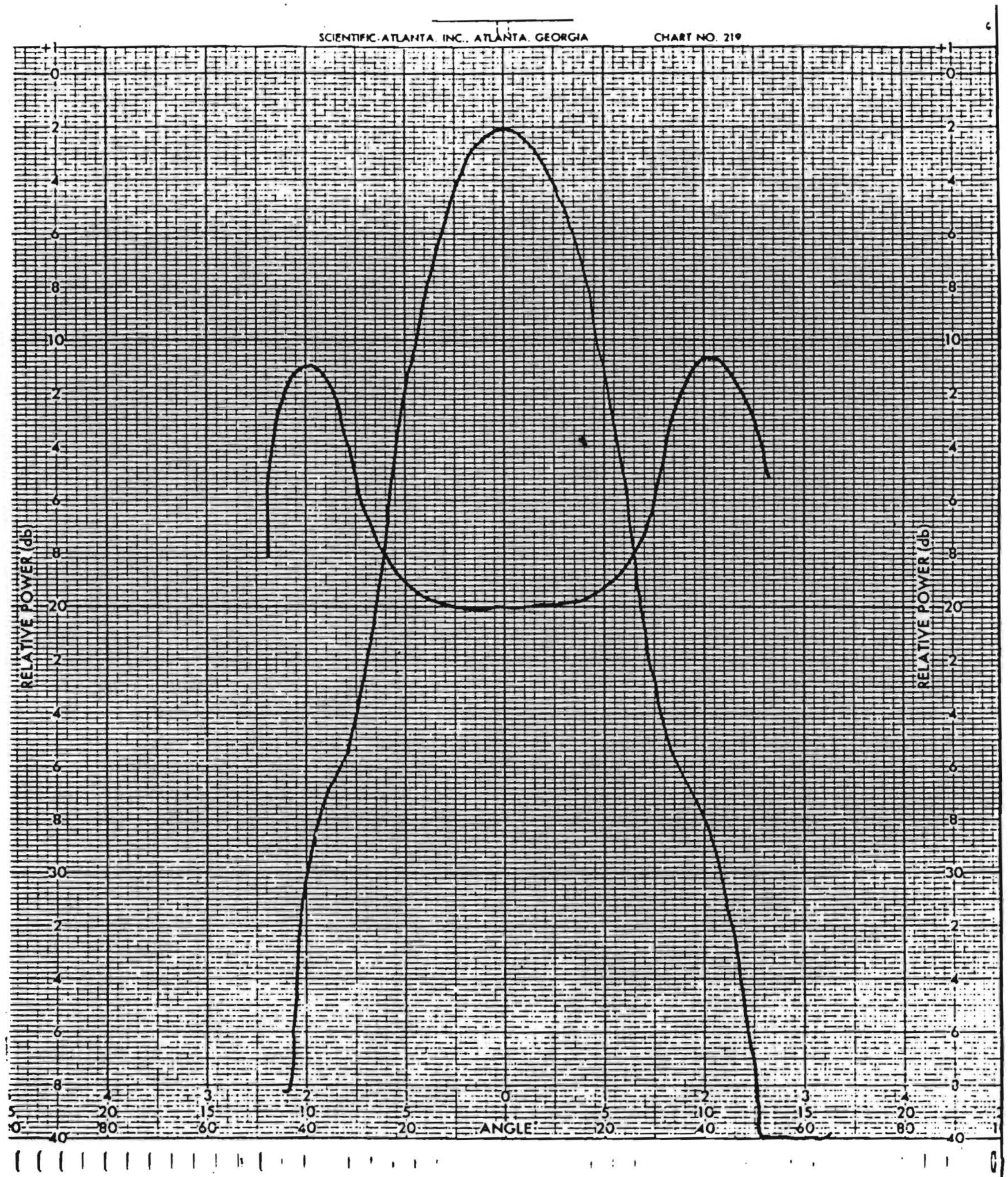

Figure 13. Feed E-plane pattern, f=2.73 GHz (see caption on Figure 11).

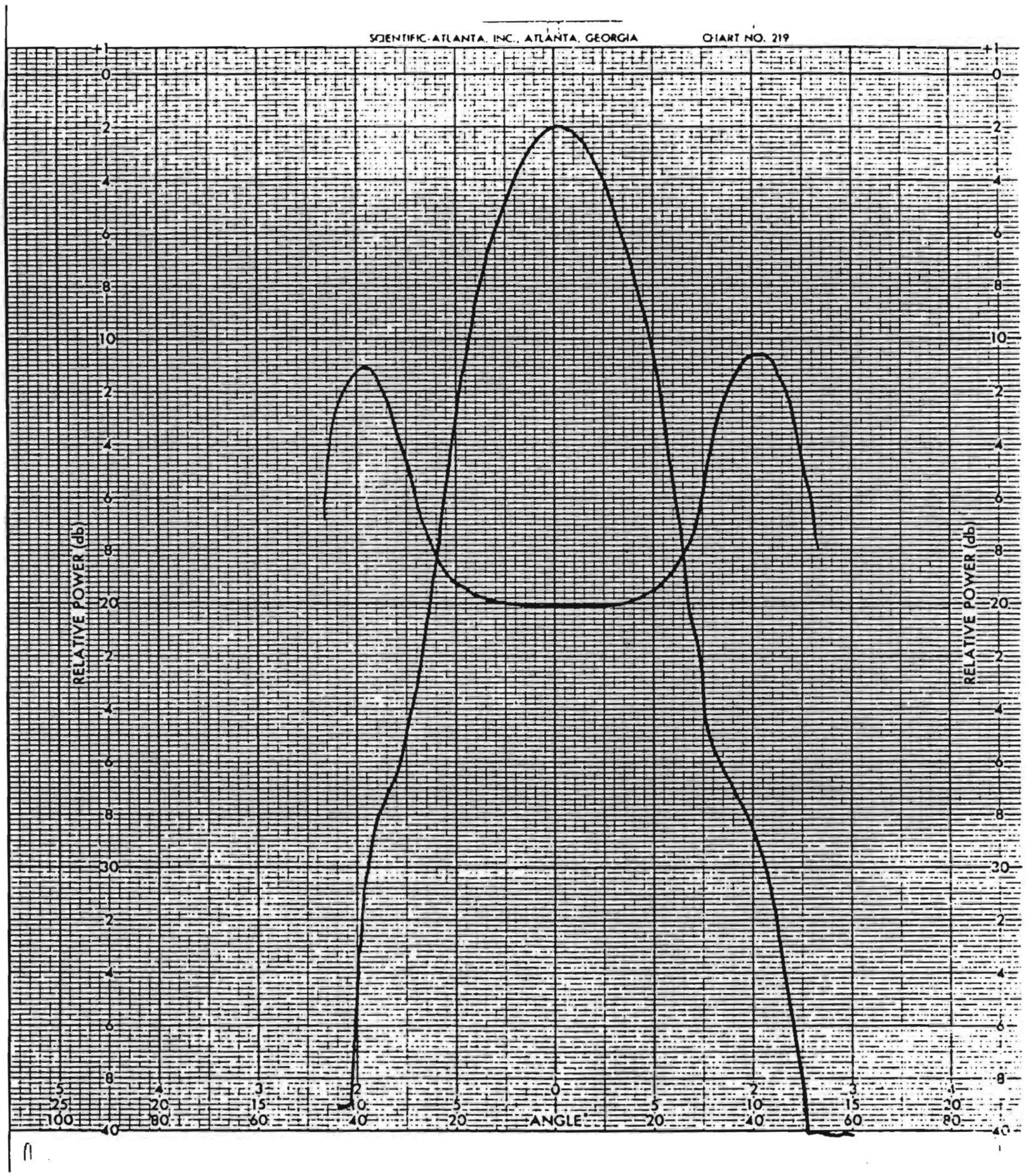

Figure 14. Feed E-plane pattern, f=2.74 GHz, (see caption in Figure 11).

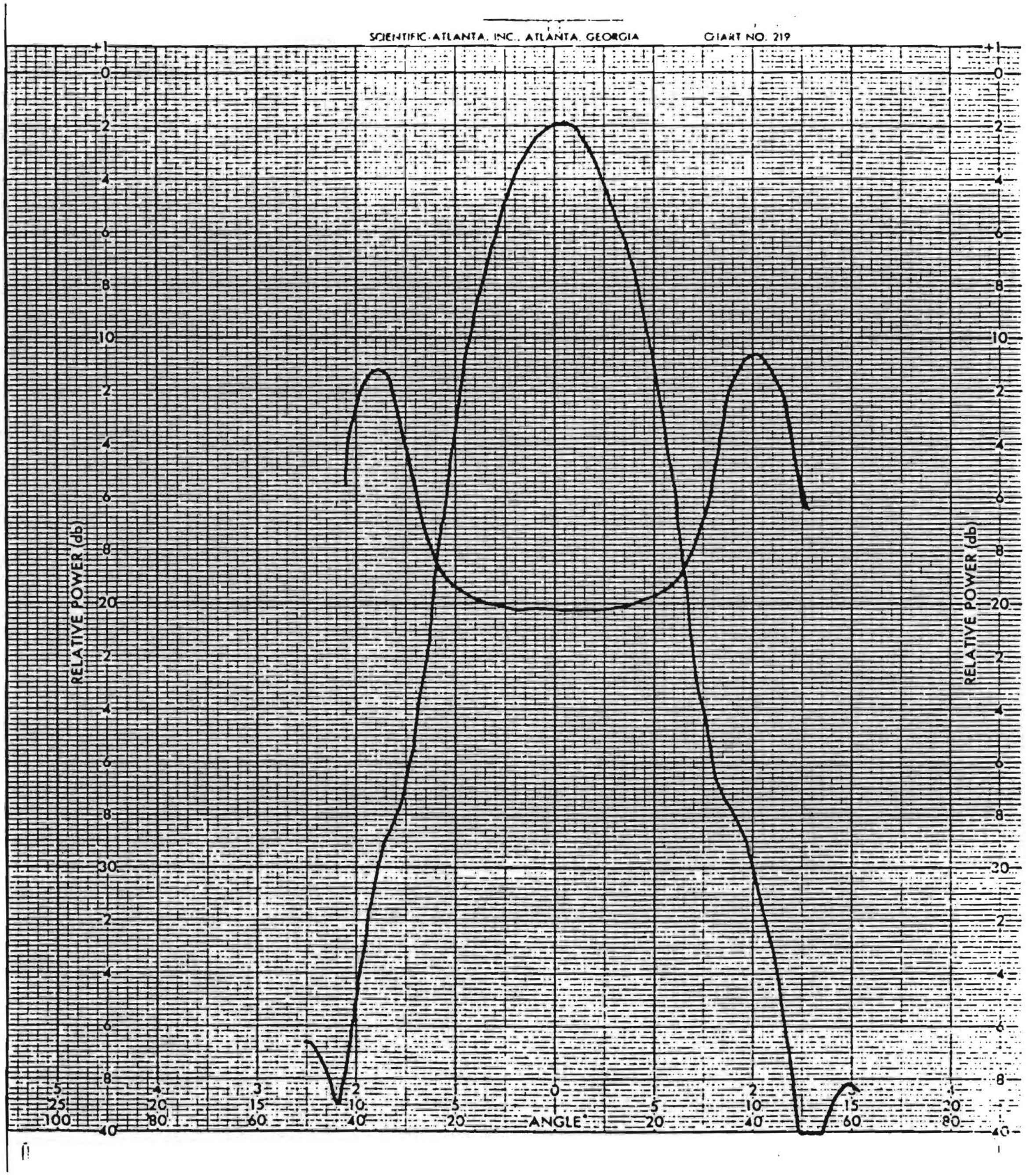

Figure 15. Feed E-plane pattern, f=2.75 GHz, (see caption on Figure 11).

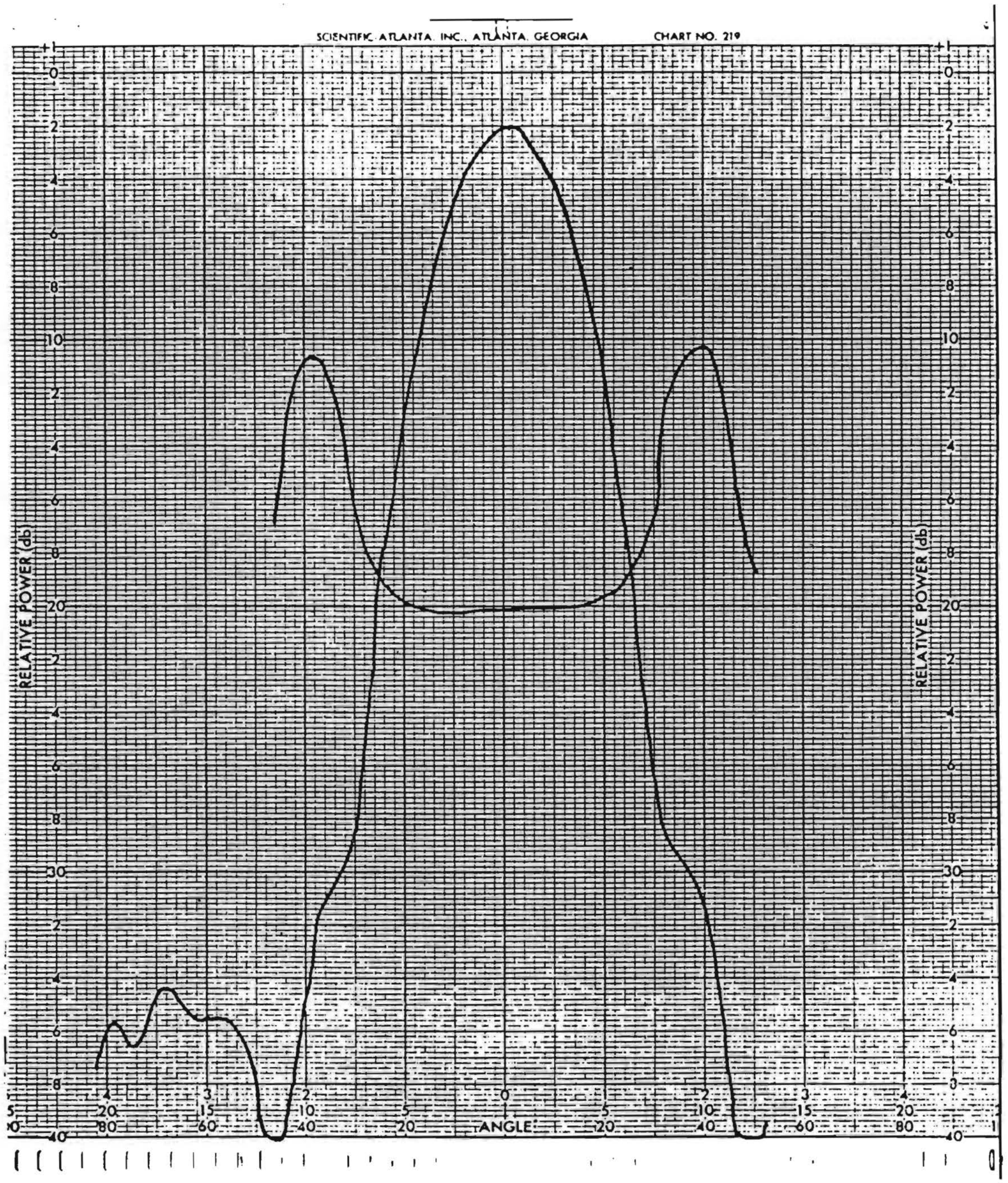

Figure 16. Feed E-plane pattern, f=2.76 GHz, (see caption on Figure 11).

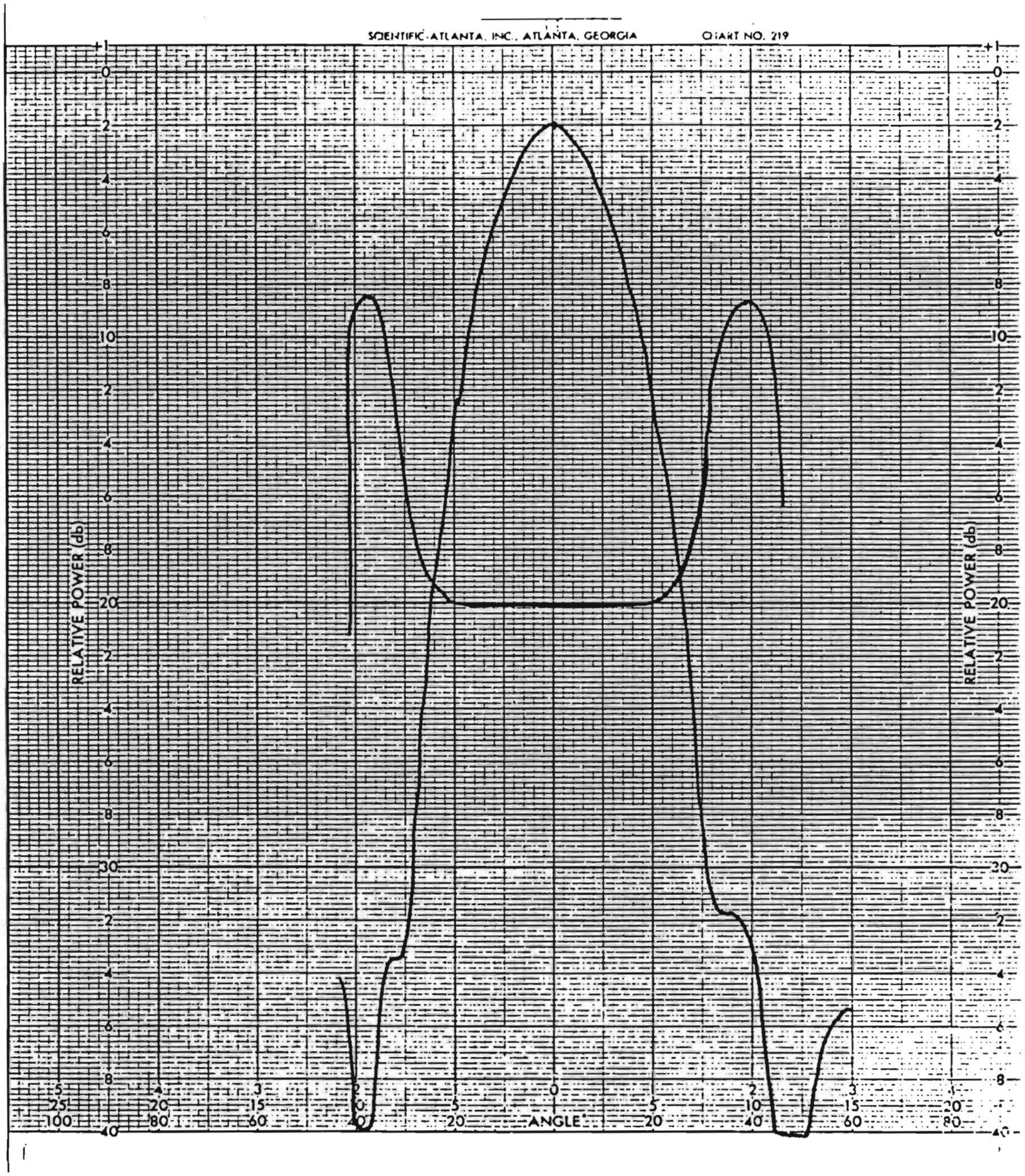

Figure 17. Feed E-plane pattern, f=2.77 GHz, (see caption on Figure 11).

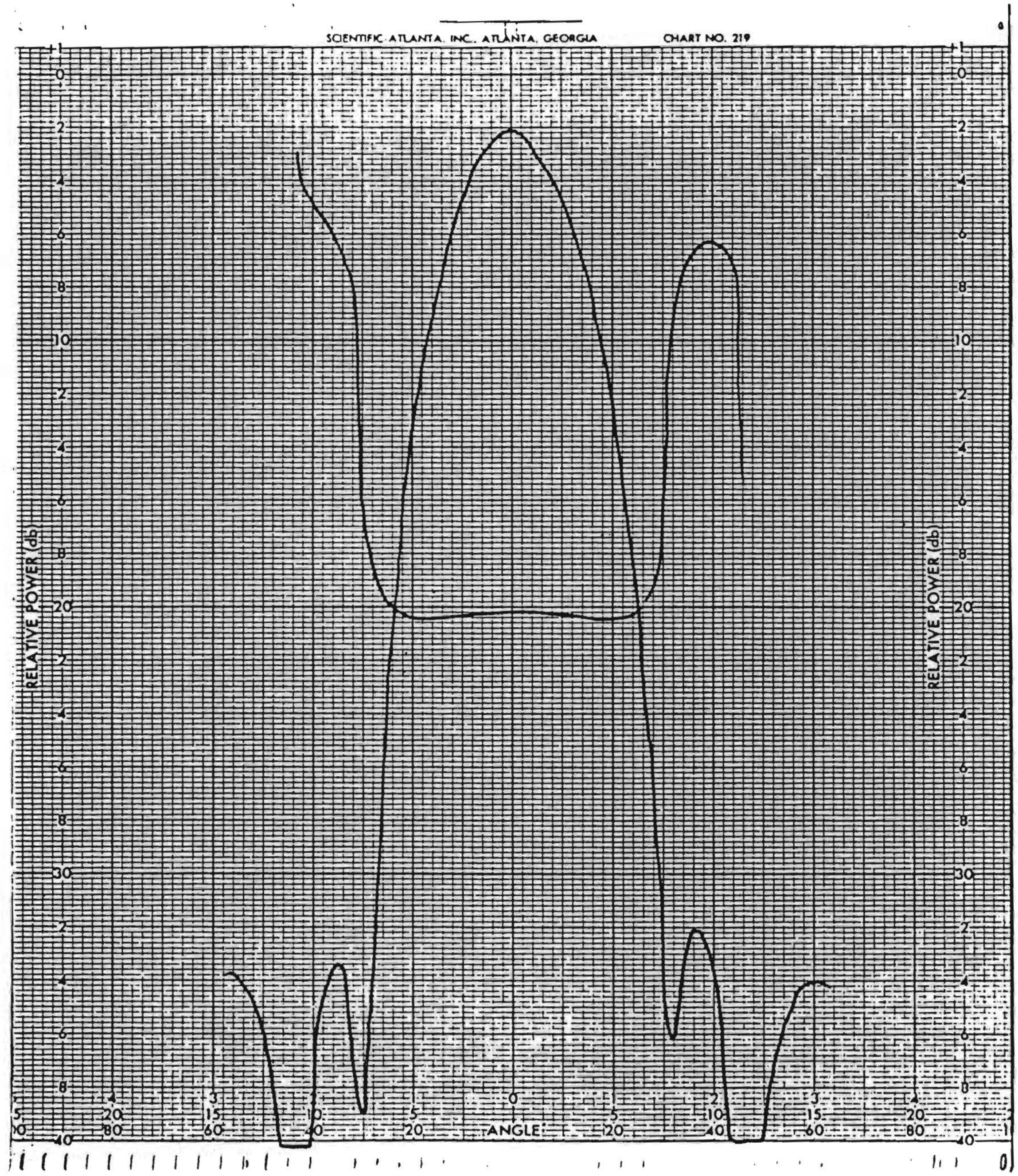

Figure 18. Feed E-plane pattern, f=2.78 GHz, (see caption on Figure 11).

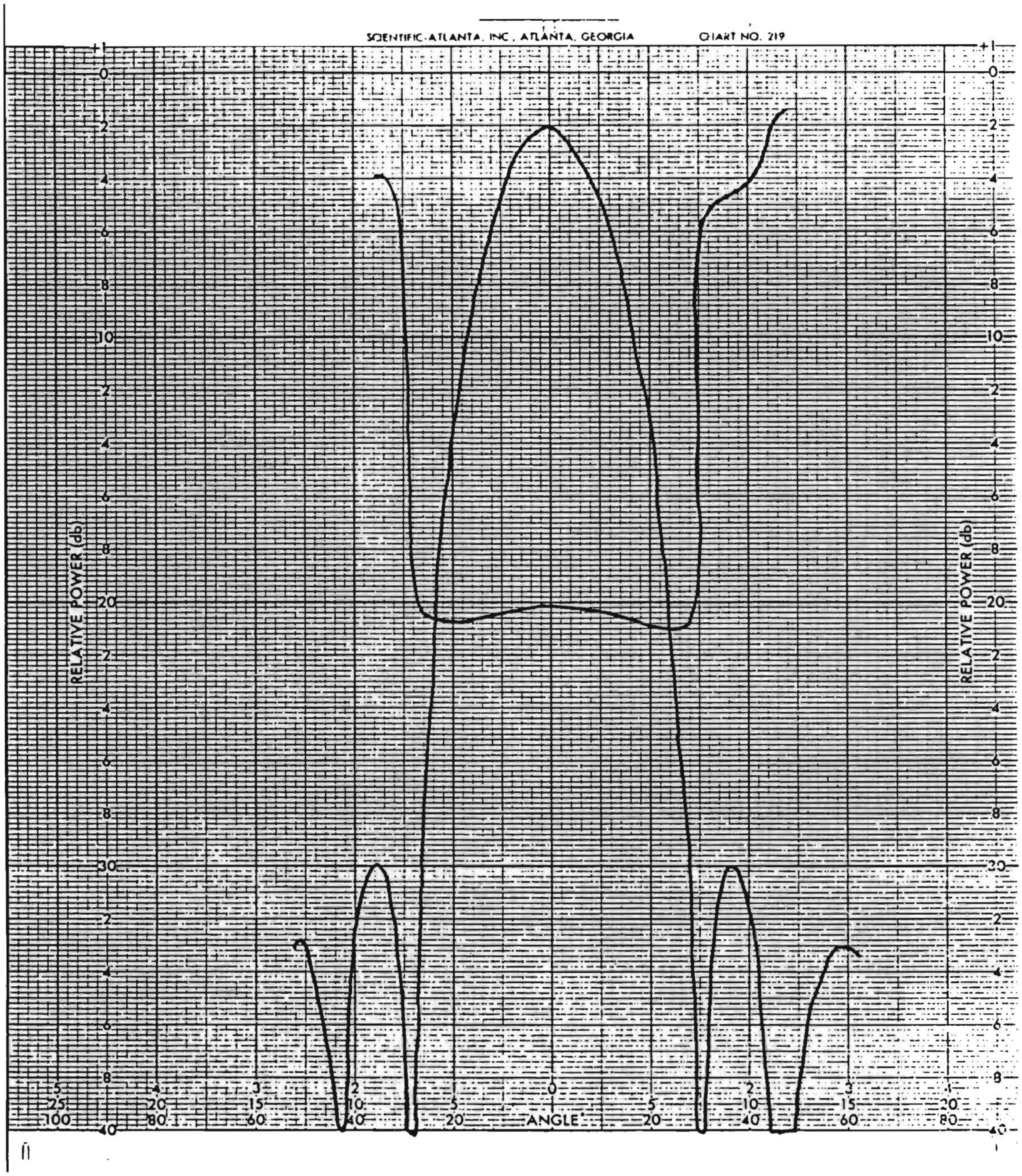

Figure 19. Feed E-plane pattern, f=2.79 GHz, (see caption on Figure 11).

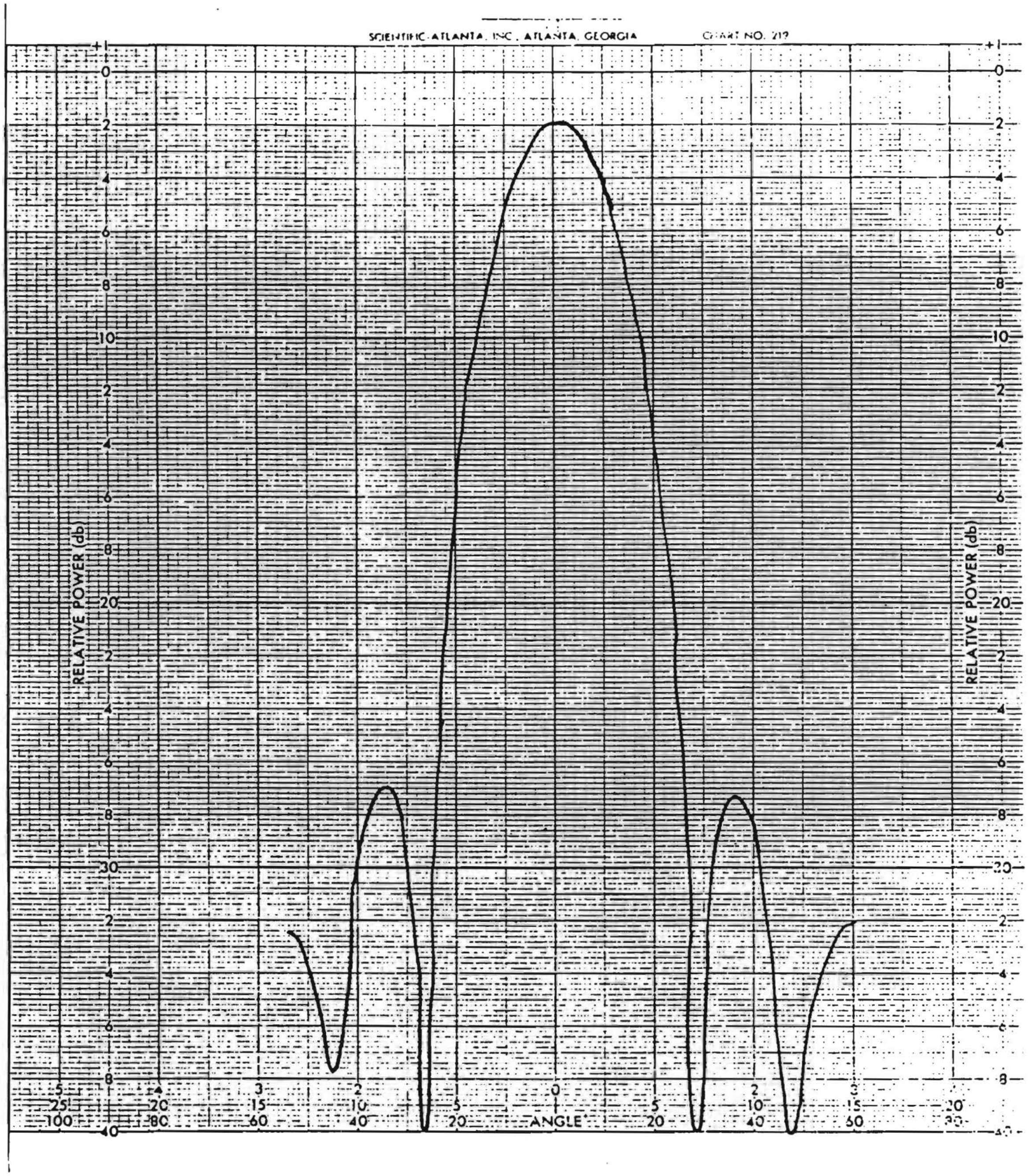

Figure 20. Feed E-plane pattern, f=2.8 GHz, (see caption on Figure 11).

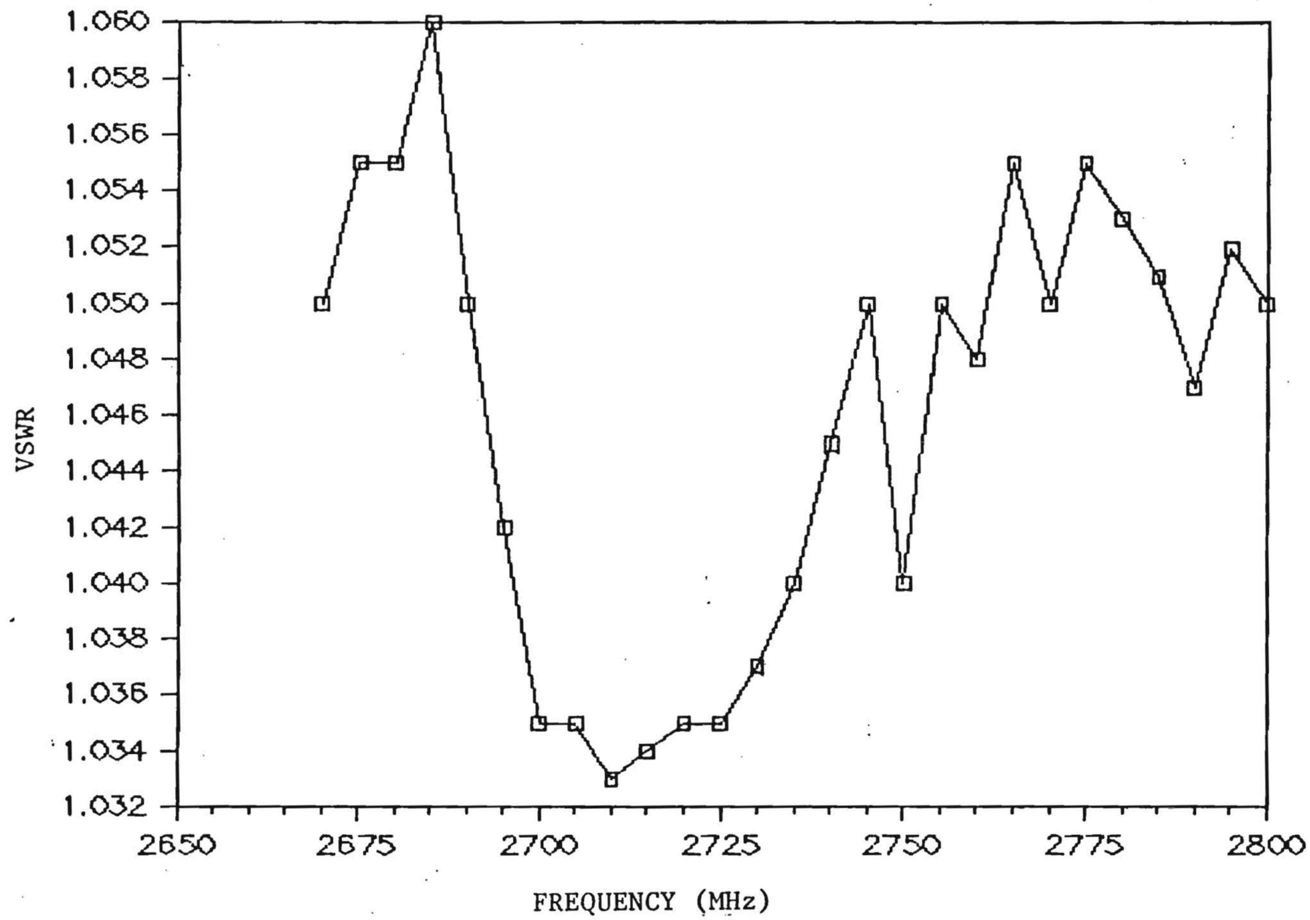

Figure 21. VSWR of circular load attached to rectangular-to-circular transition.

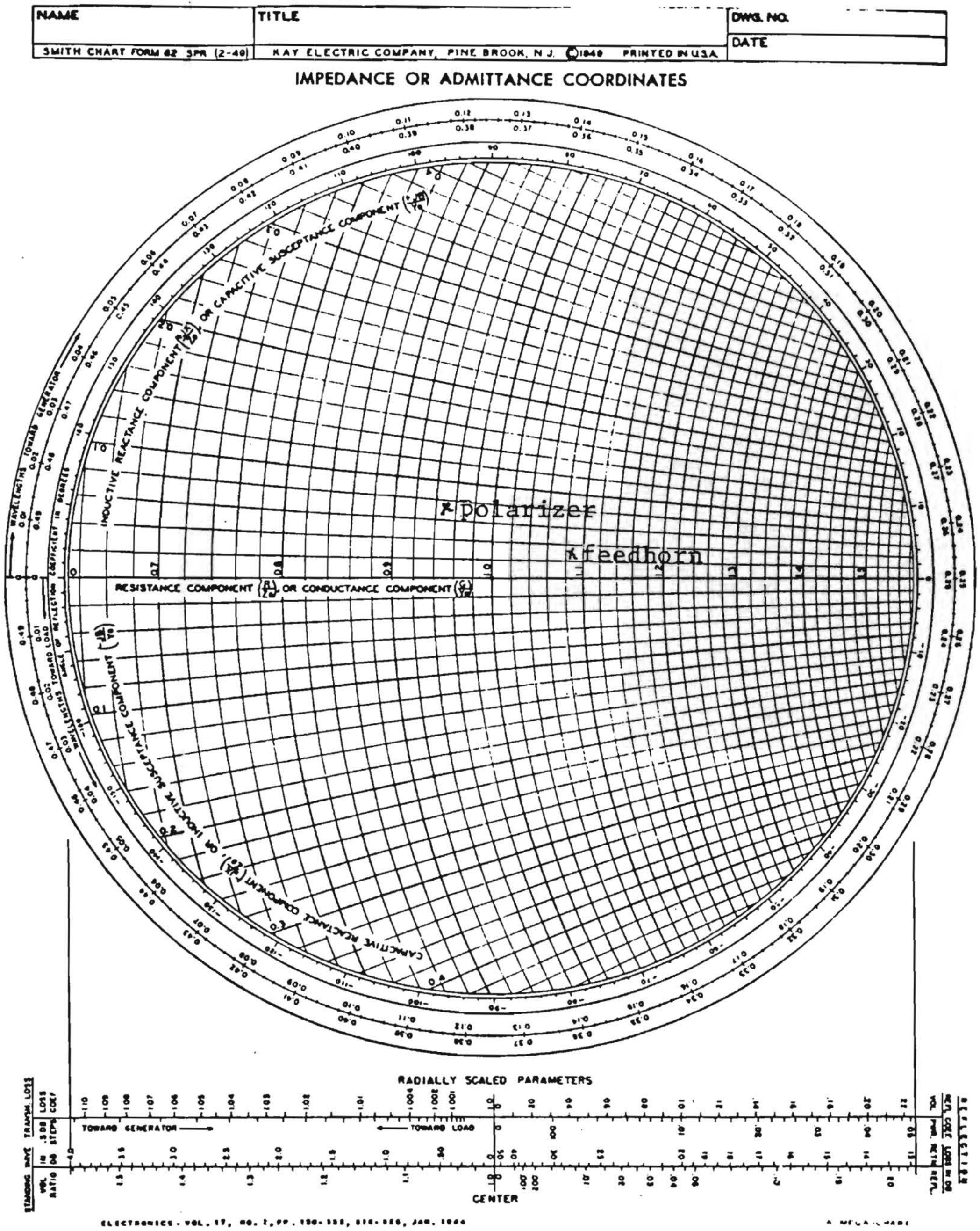

Figure 22. Impedance of feed horn only and of polarizer only at 2710 MHz (does not include transition between the horn and polarizer).

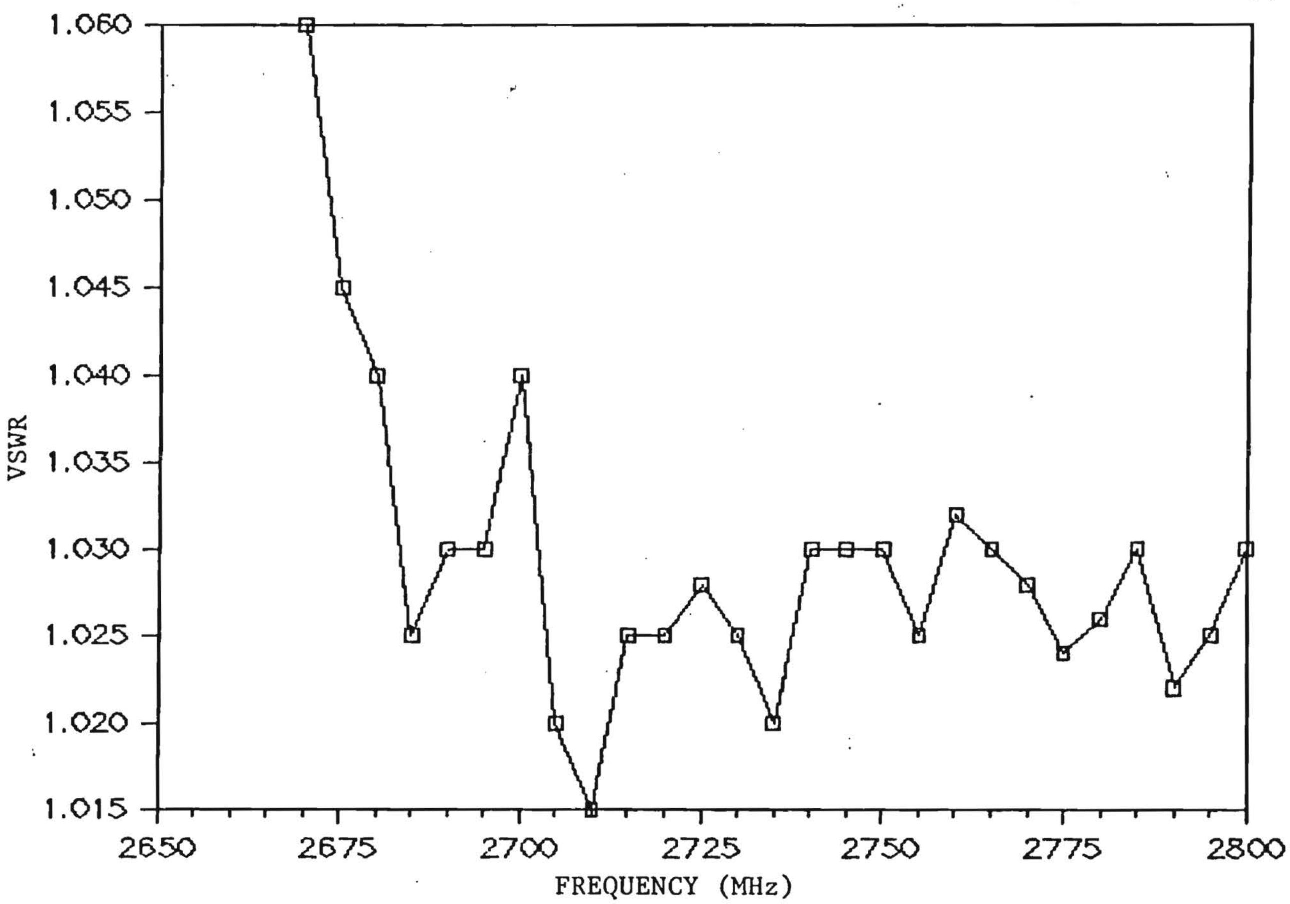

Figure 23. VSWR of polarizer with horn and load.

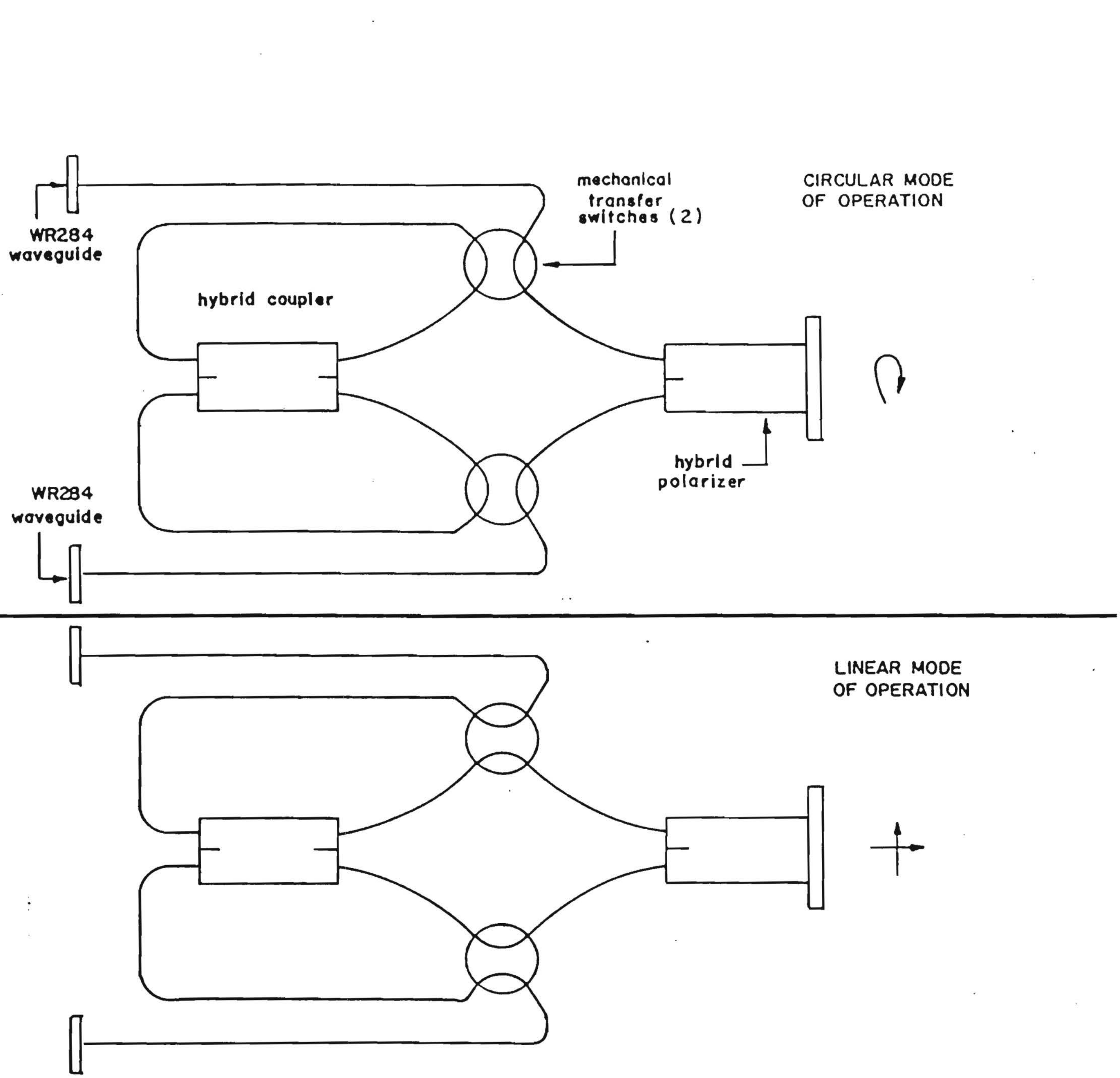

Figure 24. Circular/linear switchable antenna feed (from Atlantic Microwave Q-8442).

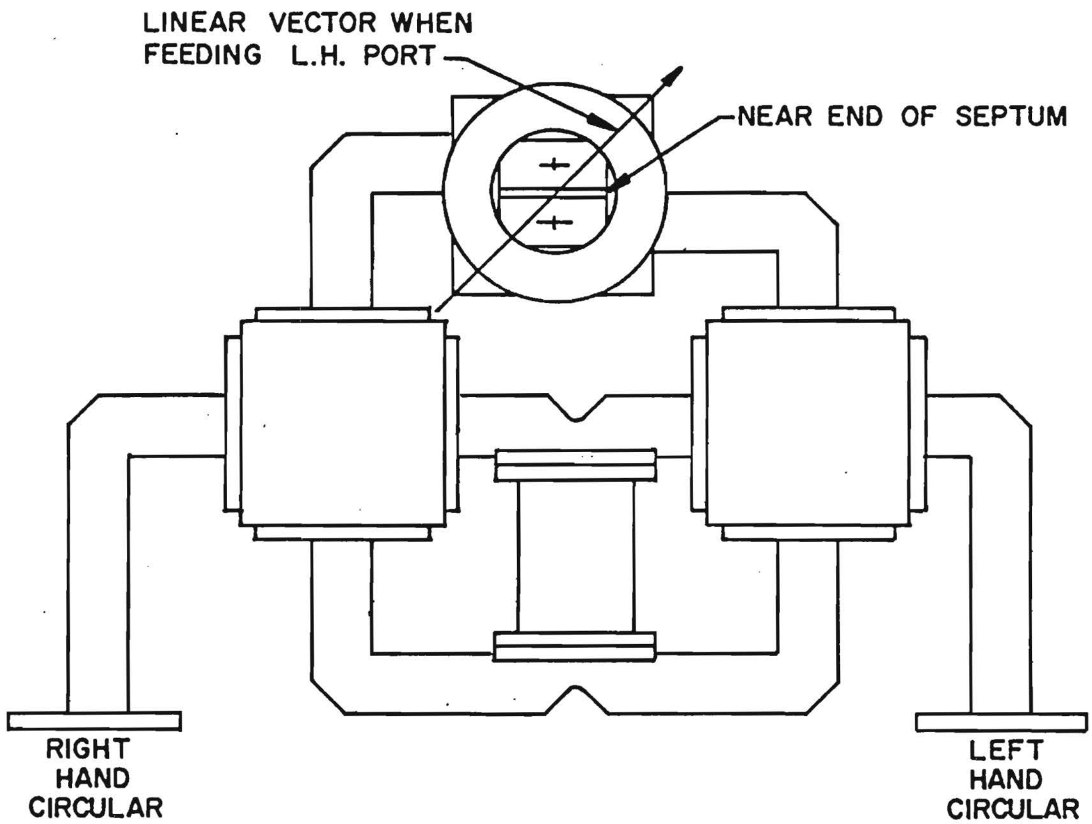

Figure 25 . Switchable antenna feed sector (from Atlantic Microwave A-20343).

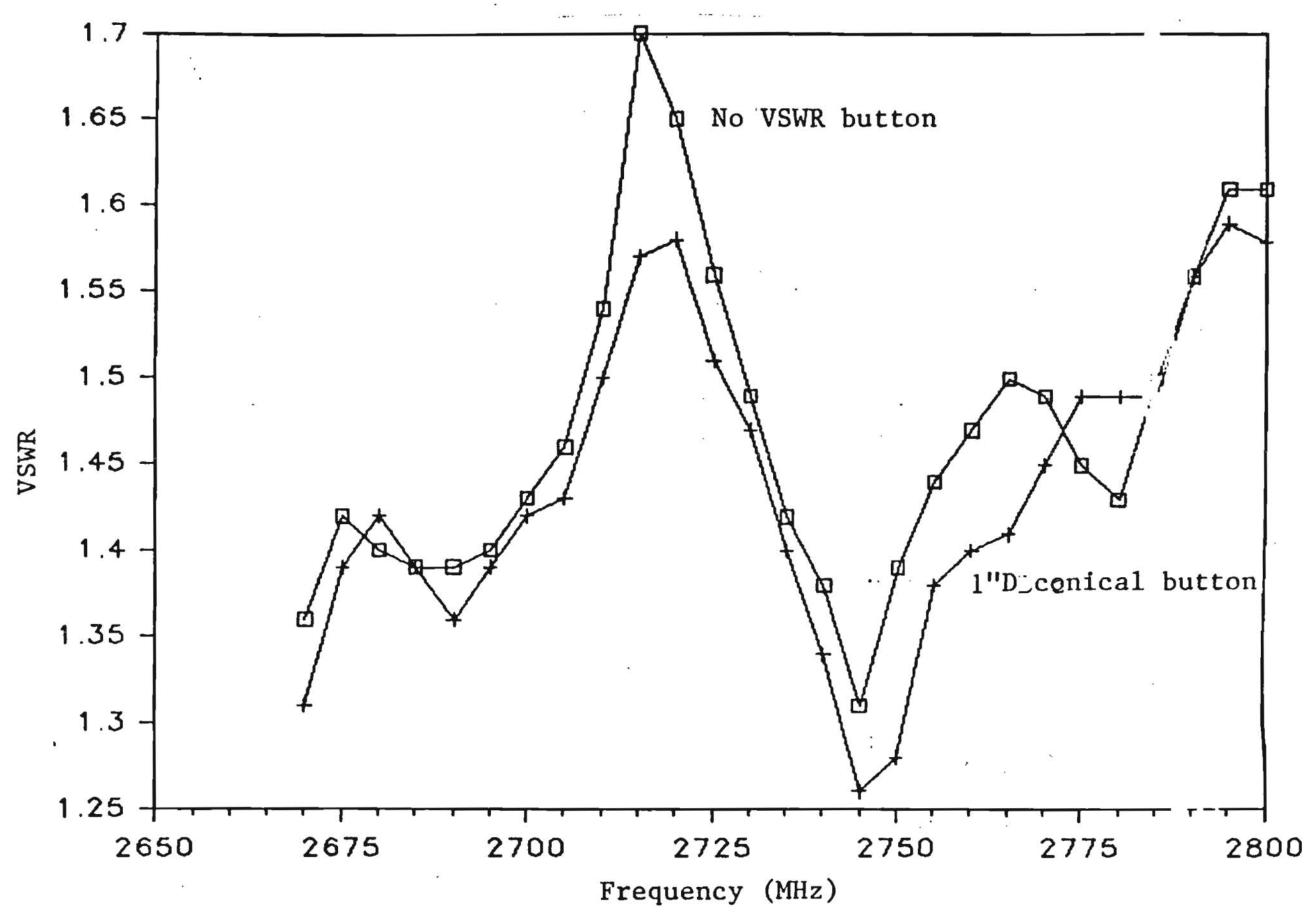

Figure 26. VSWR of AFGL antenna with subreflector and Potterhorn, without polarizer.

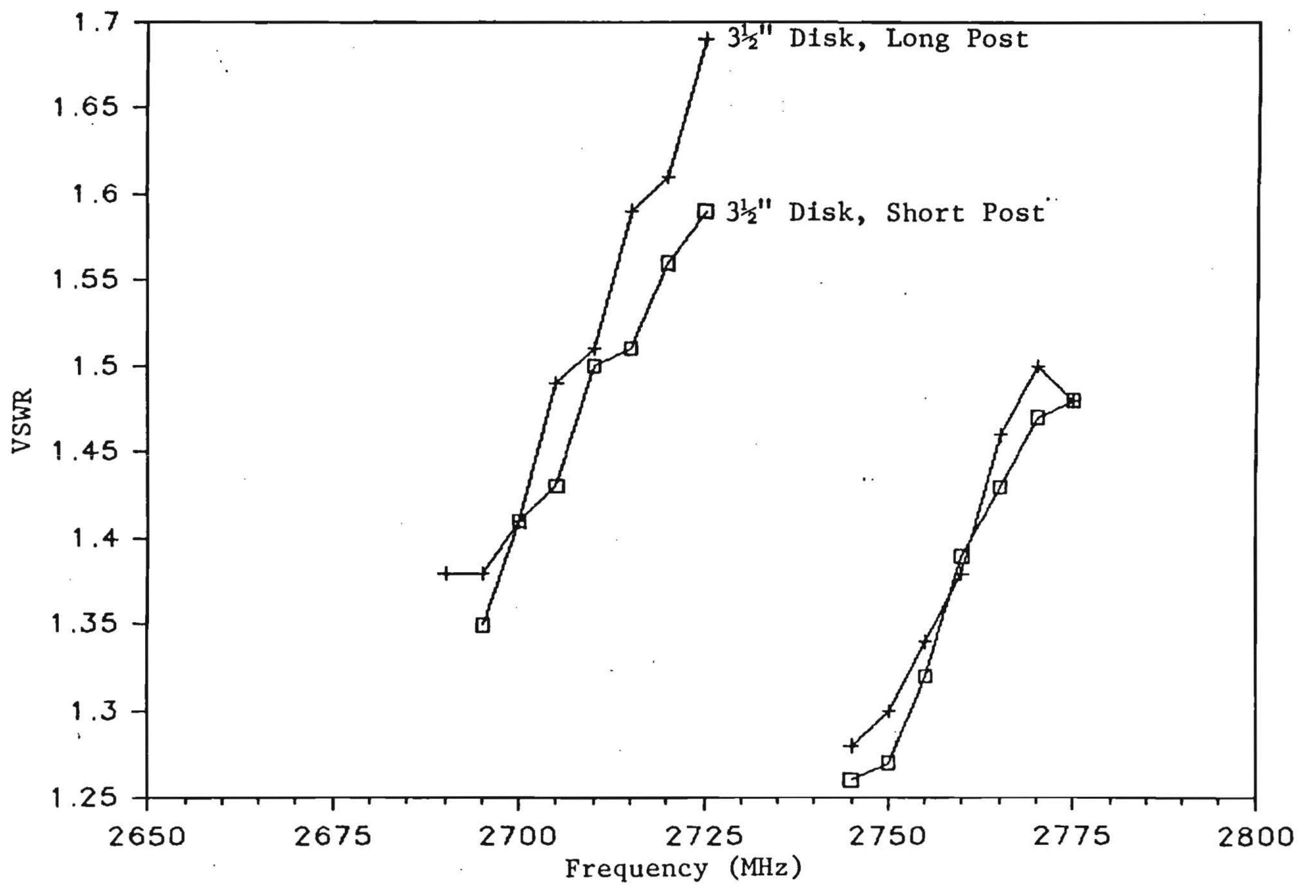

Figure 26 (continued). VSWR of AFGL antenna with subreflector and Potterhorn, without polarizer.

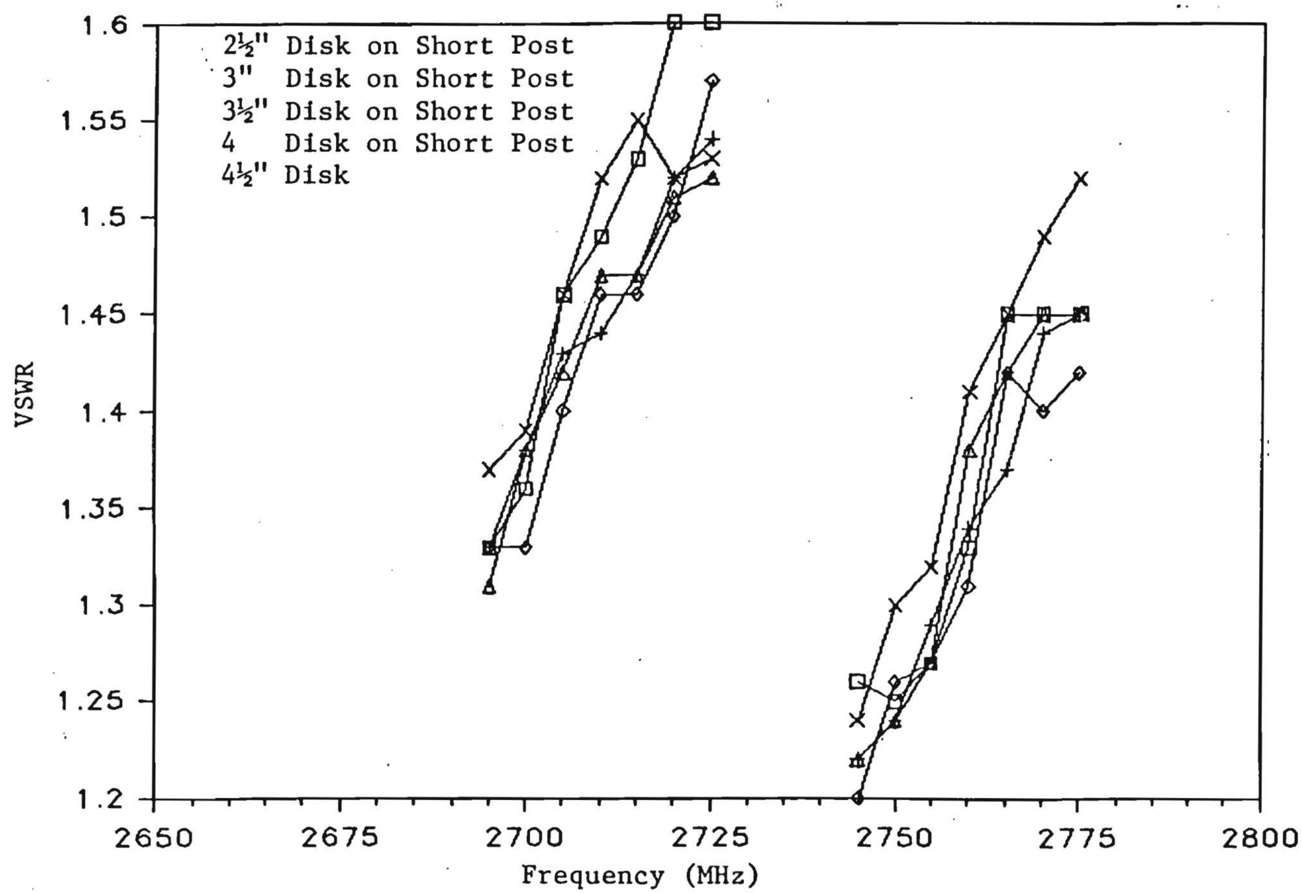

Figure 26 (continued). VSWR of AFGL antenna with subreflector and Potterhorn, without polarizer.

APPENDIX A

PAPER PRESENTED AT
21ST CONFERENCE ON
RADAR METEOROLOGY

ANALYSIS OF A POLARIZATION DIVERSITY
METEOROLOGICAL RADAR DESIGN

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1. INTRODUCTION

This work describes an ongoing design and modification to provide a polarization diversity addition for the Air Force Geophysics Laboratory (AFGL) 10 cm coherent weather radar. The unmodified radar is documented in Glover et al. (1981). Much of the information contained herein will be of interest as it is applicable to polarimetric radars in general.

In the fall of 1980, the Radar and Instrumentation Laboratory of the Engineering Experiment Station of the Georgia Institute of Technology received a contract from AFGL to perform a design study for this polarization diversity addition. The constraints of this effort were to retain, as much as possible, the present equipment and operating features, such as the antenna reflector, transmitters, microwave circuitry, and receivers while supplying a constructable design for the modification. The modified radar is to be ultimately capable of coherent operation in both the circular depolarization ratio (CDR) and differential reflectivity (Z_{DR}) modes. The radar is to provide significant new research information by exceeding the measurement capability of current systems.

One of the difficulties we encountered at the outset was the lack of uniformity of nomenclature between the radar engineering community and the meteorological community. To avoid possible misunderstandings, we present definitions of cross-polarization ratio terms in Table 1. Fundamental differences exist between the measurements performed by and the equipment required for CDR and Z_{DR} radars. Specifications for measurement of these parameters are given in Table 2, which includes traditional values as well as design goals for the AFGL radar. Some of the elements which determine these specifications, such as polarization isolation of the radio frequency (RF) switch or polarizer, are slightly beyond today's technology and require reasonable development efforts to attain, while other elements such as the effect of reflector surface errors, polarization isolation, or radome induced cross-polarization are at present not understood and will require a substantial development effort.

TABLE 1. DEFINITIONS OF CROSS-POLARIZATION RATIO TERMS

ICR_1	One-way integrated cancellation ratio: equal to the integrated cross-polarized energy emitted by a circular polarized antenna divided by the integrated co-polarized energy of the same antenna. Limits of integration are theoretically over 4π, in practice integration to the 3rd null of the co-polarized beam suffices.
ICR_2	Two-way integrated cancellation ratio: defined as above for transmission and reception through the same antenna.
$ICPR_1$	One-way integrated cross-polarization ratio: as ICR_1, but for linear polarization only.
$ICPR_2$	Two-way integrated cross-polarization ratio: as ICR_2, but for linear polarization only

TABLE 2. CDR, Z_{DR}, AND AFGL RADAR SPECIFICATIONS

	CDR		Z_{DR}		AFGL	
Specification	Trad.	Calc.	Trad.	Calc.	Composite	Goal
ICR_2	-40 dB	---	--	--	-35 dB	-37 dB
Error in ICR_2 Measurement	—	3 dB	—	—	3 dB	< 3 dB
$ICPR_2$ —	—	>-20 dB	>-26 dB	-26 dB	-30 dB	
Power Ratio Accuracy 0.1 dB	—	0.1-0.3 dB	—	0.2 dB	0.1 dB	
Amplitude Tracking Uncertainty	1.0 dB	< 0.23 dB	—	—	0.2 dB	0.1 dB
Receiver Phase Tracking Uncertainty	< 1.5°	—	—	—	< 1.5°	1.0°
Polarization Isolation	>-40 dB	—	>-20 dB	>-26 dB	-37 dB	-40 dB CP
					-26 dB	-30 dB LP

2. ANTENNA MODIFICATION

2.1 CROSS POLARIZATION OF REFLECTOR ANTENNAS, A REVIEW OF THE LITERATURE

A study of the literature of linear and circular cross-polarization of axisymmetric reflectors was undertaken that chronologically covered the past forty years. From this effort, it was initially determined that the cross-polarization pattern for linearly polarized antennas has maxima which lie in 45° planes between the principal axis of the antenna. These maxima consist of a set of pencil-beam lobes on each arm of these planes, with the first maxima occurring approximately at the first null of the co-polarized beam (Silver, 1949). Jones (1954) determined an exact solution for cross-polarization characteristics of the front fed paraboloid using an electric dipole, magnetic dipole, and Huygens or plane wave feed antenna. Here the results for the characteristics of a paraboloid excited by a short electric dipole or magnetic dipole were shown to be identical, with the sole exception that the E and H plane antenna patterns are to be interchanged when the dipoles are interchanged. Finally, for a plane wave feed chosen such that the E and H plane patterns are identical, he determined that the cross-polarized components of the fields are equal in magnitude and of opposite sign within each of the paraboloid quadrants so that, "it is noticed that the far zone field has no cross polarized radiation fields."

Watson and Ghobrial (1972) presented results which disagreed with the preceding profound statement by Jones and with future work by others including Ghobrial. In this paper it was shown that cross-polarization is a function of the electric field, the magnitude of the first cross-polarization lobe is far greater than that given by Jones, and the off-axis cross-polarization behavior of a Cassegrain antenna is superior to that of a front fed antenna, "due to the fact that the convex subreflector compensates to a high degree for cross-polarization caused by the concave main reflector." Later, Ghobrial and Futuh (1976) contradicted the last statement by showing that the polarization properties of Cassegrain antennas are identical to those of front fed antennas of equivalent focal length.

Prior to this, Ludwig (1973) presented three differing definitions of cross-polarization. According to the third definition, zero cross-polarization will result with a Huygens source feed (a physically circular feed with equal E and H amplitude patterns in all planes). Furthermore, he argued that the cross-polarization currents on a paraboloid illuminated by an infinitesimal electric dipole are often incorrectly attributed to reflector curvature. The electric dipole itself generates cross-polarization where it is viewed off axes by the reflector. Cross-polarization is then reduced by increasing the focal length of the paraboloid so that the reflector views less off-axis dipole energy.

We next examined the results of Dijk, et al. (1974). Here not only do the results for a short electric dipole feed agree with those of Jones, but also a practical example using an approximation of a Huygens source is given. Finally, polarization loss efficiency factor curves are presented for both open waveguide and electric dipole feeds as a function of subtended half-angle between the feed and the reflector. Polarization efficiency is defined as the ratio of total co-polarized antenna gain to the antenna gain if the cross-polarized energy were zero everywhere. This definition is in accordance with Potter (1967) and can be related to ICPR. Calculated examples were presented of polarization loss efficiency factor versus subtended half-angle for an electric dipole feed employed in a front fed paraboloid, Cassegrain antenna of various magnification factors, and a front fed paraboloid excited by an open waveguide structure operating in the TE_{10} mode. In the final example, it was shown that a Huygens source could not be attained with a rectangular or square aperture.

Finally, our investigation of linearly polarized reflector antennas continued to the effort of Ghobrial (1979) for an approximation to the cross-polarization calculations of Jones. Not only is there good agreement between these calculations, but also he derives an expression for peak cross-polarization which is related to the overall polarization efficiency, η,

$$\text{peak cross polarization (dB)} = 10 \ \mathrm{LOG}_{10} \left| 0.29 \ (1/\eta - 1) \right|. \qquad (1)$$

Our conclusion is that, for a theoretical axisymmetric reflector antenna without a feed support structure, the ICPR may be determined from a measurement of the level of one of the cross-polarization lobes.

Thus far, we have investigated reflector antennas with linearly polarized feeds. We conclude our review of the literature with an examination of a text by P. J. Wood (1980) which develops insight into the cross-polarization properties of reflector antennas with circularly polarized feeds. Wood has shown by his vector diffraction analysis method that circular cross-polarization lobes exist in phase quadrature with the co-polarized lobes and they have an absolute peak level of 8 dBi independent of reflector diameter. Obviously, these lobes vanish in the optical limit, $\lambda/D \to 0$. For the AFGL antenna, the amplitude of the peak lobe then is approximately 35 dB below the main beam.

2.2 ANTENNA CONFIGURATION CONSIDERATIONS

2.2.1 Waveguide Location

While consideration was given to the merits of the various antenna geometries, equal consideration must be given to the equipment configuration imposed by those geometries. If the AFGL front fed antenna configuration were retained, then either two phase matched waveguide runs from the back of the reflector to the polarizer and feed horn assembly would be required, or the entire assembly consisting of RF switch, microwave circuit, and receiver would have to be located at the prime focus. Obviously, the latter is impractical as it would impose severe antenna blockage. Less obvious is the impossibility of placing only the feed horn at the focus with the polarizer behind the main reflector, as this configuration would place unrealistic voltage standing wave ratio (VSWR) requirements and thermal requirements upon the waveguide connections. These constraints dictate the use of a Cassegrain antenna configuration so that these components may be contained in a relatively small, environmentally controlled package located behind the reflector.

2.2.2 Minimum Focal Length

During this effort we determined that $ICPR_1$ must be less than -32 dB. Employing Equation (1) in conjunction with the efforts of Dijk and Ghobrial for both an open WR-284 waveguide feed and an electric dipole feed, we considered the focal length to diameter ratio (f/D) required to achieve this value of $ICPR_1$. The results of this calculation are presented in Figure 1, together with the results of $ICPR_1$ determined by the Georgia Tech reflector antenna program, a computer program developed to calculate the co- and cross-polarized pattern performance of single reflector and double reflector antennas. This program has been validated over the past several years not only with data Georgia Tech has obtained, but also with other data that have appeared in the literature. The program was utilized to analyze the amount of anticipated cross-polarization as a function of various reflector focal lengths. The results show that, while a -20 dB $ICPR_1$ can be obtained with the existing AFGL reflector, which has an f/D of 0.4 further improvement requires a reflector with a longer focal length. Again, we are led toward a Cassegrain configuration as the focal length of the existing reflector can only be extended by employing a Cassegrain geometry.

2.2.3 Blockage and Unsymmetric Diffraction

Depending upon the feed arrangement and the choice of theory, the circular cross-polarization lobes should disappear or become almost insignificant; usually this is not the case. Experimentally, it can be shown that excessive aperture blockage will contribute diffracting surfaces which will increase cross-polarization as well as reduce overall antenna efficiency. Should a Cassegrain configuration be employed, reduction in antenna efficiency due to subreflector blockage can, in this instance, be discounted as it is given by the ratio of the square of the reflector diameters and for this antenna provides an almost unmeasurable effect on the total antenna gain. Diffraction from the main reflector edge, subreflector edge, feed horn edge, and support structure edges, on the other hand, can contribute energy into both the cross-polarized and co-polarized sidelobes. This diffraction contribution can be reduced by various methods, some of which are: (1) elimination of edges, (2) occultation of edges, and (3) employment of a symmetrical design. For the AFGL radar, the feed support will consist of a shroud wrapped around and behind the feed to occlude polarizer and feed reflecting surfaces. In the case of the latter consideration, detailed attention must be given to the overall axial symmetry of the entire antenna structure.

2.2.4 Antenna Configuration

Having considered the antenna geometries, we concluded that a Cassegrain affords the best compromise between focal length, feed location, blockage, and symmetry to produce favorable co-polarized and cross-polarized sidelobe architecture. We considered a third configuration, offset Cassegrain, as a possible geometry to eliminate illuminator blockage and further reduce these unwanted lobes.

In an axisymmetric antenna with a dipole feed, cross-polarization is generated in the aperture electric field by off-axis observation of the feed antenna; thus, cross-polarization has the property that it is oppositely directed in adjacent quadrants. Then by symmetry, cross-polarization cannot exist in the principal planes of the antenna, but does achieve a maximum value in the planes located midway between the principal planes. If a feed is constructed such that equal electric and magnetic dipole patterns are placed on the reflecting surface (Huygen's source), a second set of cross-polarized electric field vectors is generated by the magnetic field in the aperture which, in the case of axisymmetric reflectors, are equal and opposite to those generated by the electric field. In the case of an asymmetric reflector, an asymmetry exists because the distance between the subreflector and the upper main reflector quadrants is greater than the distance between the subreflector and the lower main reflector quadrants. In theory, this distance variation can be ameliorated by an offset subreflector. The best achievement of such an arrangement has yielded an antenna with two -34 dB cross-polarized lobes (relative to the main beam) symmetrically displaced from the antenna's principal axis (Wilkinson and Burdine, 1980). The virtue of such an antenna is its capacity for a great reduction in the near co-polarized sidelobes; for this example, a 17 dB improvement was achieved, compared to the level expected for a conventional axisymmetric Cassegrain antenna.

In light of these achievements, this geometry was considered, but the cost of an appropriate development program quickly dispelled further attention.

2.3 SUBREFLECTOR MOUNTING STRUCTURE

Although not a direct consideration of the specific antenna geometry, the feed and subreflector mounting structure has a significant influence upon the sidelobe and cross-polarization lobe integrity. Maintenance of overall antenna symmetry is the foremost requirement of cross-polarization reduction if the proper feed assembly is used. Because of the quadrapole nature of the cross-polarized antenna pattern, symmetry cannot be preserved with a tripod secondary reflector mount or with the existing tripod feed mount. Either a bipod with support wires or a quadrapod structure is required. Furthermore, the attachment points for the mount must be located as close to the rim of the main reflector as possible. This reduces lobe structure by reducing blockage from the spars and, when a reasonable illumination taper is employed, by reducing the scattered energy level from the attachment points.

No special spar cross-section has been shown to reduce cross-polarization backscatter from the support spars; however, the location of the quadrapod structure does affect the cross-polarized sidelobe structure. Since the cross-polarized lobes are located in planes rotated by $\pi/4$ with respect to the horizontal and vertical planes, the spars should be positioned in the horizontal and vertical planes to minimize scattering of the cross-polarized energy. When considering ICPR however, this attention to spar location may not be necessary.

2.4 SUBREFLECTOR

While the specific detail of design for the hyperbolic subreflector is not a subject of this paper, an interesting addition to the subreflector shape was provided by Wilkinson. The center of the subreflector employed in circularly polarized earth station antennas is conically shaped so that a "hole" exists in the reflected pattern. This "hole" prevents reflected energy from re-entering the feed by radiating that energy beyond the rim of the main reflector. This is an important consideration in the design of circularly polarized reflector antennas. Should a mismatch exist within the polarizer, any energy reflected into the polarizer from the feed will be reflected at the mismatch and retransmitted with the opposite polarization sense.

This conical section should have a smooth taper into the hyperbolic subsection of the subreflector to prevent diffraction effects. The use of absorbing material in place of the conical section cannot be considered as it would provide an additional diffracting edge. In other instances, this conical section is replaced by a button located at the center of the subreflector. This button serves the same purpose of scattering rather than returning energy into the feed.

2.5 POLARIZER ASSEMBLY

Three polarizers were considered for this modification: (1) short slot hybrid coupler, orthomode transducer combination, (2) lossless power divider with an orthomode transducer, and (3) sloped septum hybrid. Each concept (Figure 2) employs attending phase shifting devices and attenuators to accommodate both linearly or circularly polarized transmission as well as reception of the transmitted and orthogonal polarizations. The selection criteria were based upon the requirement of a minimum -37 dB isolation between polarizations for circular polarization and -26 dB isolation between polarizations for linear polarization.

Thus far, the general design has not shown ICR_2 to be bounded to less than -40 dB. However, if consideration is given to the VSWR of the components attached to the hybrid junction within any polarizer configuration and to the equivalence of hybrid junction isolation with ICR_2, then -40 dB isolation is most likely unachievable without VSWR improvement circuitry, while isolations of -35 dB to -37 dB are realistic, difficult-to-achieve anticipations. The validity of this realization exists because of the one-to-one mapping of VSWR and isolation of a hybrid junction (Riblet, 1952). A -40 dB polarizer isolation requires a VSWR $<$ 1.02:1 on all ports of the hybrid, which is generally unachievable for microwave components operating over any reasonable bandwidth.

In analyzing each polarizer configuration we assumed an attached corrugated or multitaper feed horn with a VSWR of 1.025:1, required a minimum isolation of -35 dB for circular polarization, and determined that the components attached to the polarizer input ports must have a VSWR of 1.05:1 or less.

2.5.1 Short Slot Hybrid and Orthomode Transducer Polarizer

The minimum achievable VSWR for the transducer ports of this polarizer (Figure 2a) is insufficient to provide better than -30 dB polarization isolation. Although the combined transducer, phase shifter, waveguide flanges, bends, and transfer switch VSWR may be significantly reduced by an appropriate choice and location of matching hardware, such a design would present a formidable construction task and, in the end, might have insufficient high-isolation bandwidth as well as excessive phase dispersion across the signal bandpass.

2.5.2 Lossless Power Divider and Orthomode Transducer Polarizer

The input E and H arms of the magic tee in the lossless power divider (Figure 2b) do not suffer the same isolation constraints as a hybrid junction unless the reflections from the colinear arms are in quadrature. The divider can certainly be constructed so that the reflections are in phase over a small bandwidth. However, taken as an entity, the lossless power divider exhibits the equivalent isolation and VSWR characteristics as the single hybrid junction, so that the same requirements are also enforced for the microwave components between the power divider and the orthodmode transducer. If less isolation could be tolerated, then this polarizer does offer the flexibility of transmission in any elliptical polarization and reception of that polarization and the orthogonal polarization.

2.5.3 Sloped Septum Polarizer

Obviously, the polarizer of choice, when operating in a circular mode, should involve as few microwave components as possible between the transmitter and the feed antenna so that full advantage of the low VSWR of the feed could be utilized. Therefore, such a device must be capable of directly generating the proper circular polarization from each waveguide input. A sloped septum polarizer (Figure 2c) is such a device. It is described in Chen and Tsandoulas (1973) and in Saltzberg (1978). The polarizer is a true hybrid coupler with two input ports and a common output port; exciting one input port causes the excitation voltage to be equally divided with one division receiving a 90° phase lag prior to entering the square output port; radiation exiting this port is circularly polarized. This device also obeys the VSWR versus isolation rule of the previous polarizers such that a minimum of attached components must exist in the high isolation circular polarization mode, while more attached components are tolerated in the less demanding linear polarization mode. Linear polarization is achieved by adding a hybrid coupler between the source and the polarizer to provide an appropriate 90° phase shift and allow equal amplitude excitation of the input ports (Figure 2c). Since transfer switches with a VSWR of less than 1.05:1 are obtainable, the possibility of constructing a -37 dB isolation feed assembly exists if a very low VSWR horn feed antenna is employed.

2.6 FEED ANTENNA

Various horn antennas were candidate feeds for this modification. The first consideration, a pyramidal horn, can be easily attached to the polarizer, requires no square-to-circular waveguide transition, and is inexpensive to manufacture. However, this feed can be shown to be equivalent to an orthogonal pair of magnetic dipoles and will give rise to high off-axis cross-polarization (Nelson, 1972). This effect has also been noted experimentally by Wilkinson. The second feed under consideration was a circular multitaper horn which can be designed with equal E and H plane patterns but only for a relatively narrow bandwidth. Since the third feed considered, a corrugated horn, can meet all the requirements of this design, but at a relatively high cost, the multitapered design was chosen for further investigation. An experimental multitaper horn was successfully constructed for 9.4 GHz in April 1983. Over a large portion of its pattern, it represents the attributes of a true Huygens source with equal E and H patterns in all planes.

2.7 ANTENNA SUMMARY

Using -32 dB as the $ICPR_1$ requirement, a minimum focal length of 230 inches is required (f/D = 0.8). This is based upon linear polarization considerations only; cross-polarization in the circularly polarized mode is only the result of antenna, feed and polarizer imperfections; it is independent of focal length.

A quadrapod mounting structure consisting of cylindrical spars attached near the reflector rim offers the optimal sidelobe and cross-polarization reduction condition. Furthermore, no structure visible to the subreflector should be employed to support the feed assembly as such a support would encourage scattering and might detract from overall symmetry. This requires the feed support be wholly contained within a shroud that is, with respect to the secondary reflector, occluded by the feed horn.

For high isolation in the circular mode and respectable isolation in linear polarization a sloped septum polarizer with a hybrid coupler or magic tee to provide linear polarization is the polarizer of choice. Finally, to maintain costs within reasonable bounds, for a relatively narrow high-isolation frequency band (±200 MHz at 9.4 GHz) a multitaper horn is the feed of choice. Specific recommendations for the antenna modification are presented in Table 3.

TABLE 3. RECOMMENDATIONS FOR ANTENNA MODIFICATION OF AFGL RADAR

Requirement	Recommendation
Antenna Configuration	Cassegrain with f/D > 0.8
Number of Support Spars	4
Support Spar Cross-Section	Circular
Feed/Polarizer Supports	Entire assembly must be covered by axisymmetric shroud
Secondary Reflector	Hyperbola with center half-conical section or VSWR button
Secondary Reflector Pattern Taper	About -10 dB on reflector edges
Feed Antenna	Multitaper horn or corrugated horn
Feed Antenna VSWR	< 1.025:1
Polarizer	Sloped septum
VSWR at Polarizer Input Ports	< 1.05:1
Anticipated ICR_2	> -35 dB
Anticipated $ICPR_2$	> -26 dB

3 MICROWAVE PACKAGE

3.1 THERMAL REQUIREMENTS

The microwave package contains those components which interface with the transmitter, receiver, and polarizer and, as such, must be capable of operating at the transmitter power level as well as be able to withstand heating due to losses. These components must critically maintain polarization isolation phase, and amplitude balance during transmission and reception. This can only be accomplished if the microwave package and non-video portions of the receiver are thermally stabilized and located as close as possible to the antenna feed assembly. In this instance, the operating temperature is dictated by the phase stability of the most unstable component. We believe that component to be the transmit-receive circulator and we have performed a cursory phase versus temperature experiment on the existing unit. The temperature at which the minimum phase change was observed was between 42.5°C and 45°C. Since this temperature is close to the expected maximum summer ambient temperature inside the radome, we recommend a complete heat exchanger system for the microwave package and receiver enclosure.

3.2 POLARIZATION ISOLATION IMPROVEMENT NETWORK

In an attempt to improve the polarization isolation, an improvement network has been conceptually included in the design. Various candidate VSWR reduction schemes are possible for the interconnections of the various microwave components, but the final choice of the specific solution will depend upon the achieved characteristics of the RF switch, polarizer, and feed antenna. One scheme under consideration (Hollis et al., 1980) is employed in the K_u-band radar at the National Research Council of Canada. We have confirmed that this scheme can be constructed to be effective over the required bandwidth; however, when the transmitter power of the AFGL radar was considered, little isolation improvement could be realized with reasonable component values.

VSWR improvement is also realizable by adding reactive devices into the microwave package. However, the magnitude and location of those devices can only be ascertained after the complex reflection values of the microwave components have been determined. The isolation improvement network, then, remains a concept; its necessity will be determined after the interconnected microwave components such as the antenna including the polarizer and high speed polarization switch are evaluated.

3.3 HIGH POWER RADIO FREQUENCY SWITCH

The RF polarization switch is the only other device currently thought to limit the polarization isolation performance of the modified radar. The basic high speed waveguide switch employs a configuration of phase shifters, magic tee, and short slot hybrid. Switching transmitted energy between output ports is achieved by appropriate setting of the phase shifters. Although reception of backscatter is available at orthogonal polarizations in the E and H arms of the magic tee, the polarization isolation at these ports may not be as great as that achieved upon transmission. In a more conservative design, backscatter is received through circulators located in each of the arms between the RF switch and polarizer.

Two designs have been proposed to realize the isolation requirement of the RF switch: (1) three switches connected in a series-parallel configuration and (2) a variation of a previously successful approach wherein a logic-based update network sampled the main and isolated ports and adjusted the current in each of the phase shifters to correct for isolation deficiency. Since all variations employ a hybrid coupler in their design, the isolation limitation is a function of VSWR, both external and internal to the switch. The VSWR presented to each port of the switch must be carefully controlled.

A mechanical switch was also considered. Of the varieties that exist, none can approach the switching time or other peformance characteristics of an electronic device. Shutter switches are available with switching speeds in the 10 millisecond region, rotary switches are an order of magnitude slower, and the ingeneous fast rotating devices employed on differential reflectivity radars do not afford the liberty of variable PRF and cannot attain the low VSWR demanded by the polarizer for circularly polarized modes.

4. RECEIVER

The general requirements of the receiver were considered up to, but not including, the processor. Of these, three unique critical requirements exist: phase tracking, amplitude tracking, and inter-channel isolation. Gross phase and amplitude balance will be maintained throughout by careful component selection, thermal control, and phase/amplitude trimmer assemblies inserted at strategic locations. Critical phase and amplitude tracking errors will be eliminated in software via a look-up table. While the object of this design was to retain a maximum of present components as well as present operating features, some existing hardware must be altered to maintain phase and amplitude tracking and to improve inter-channel isolation.

4.1 INTER-CHANNEL ISOLATION

To realize the full 37 dB isolation offered by the antenna feed assembly, the minimum receiver inter-channel isolation must be greater than 45 dB, a value confirmed by McCormick (1981). Furthermore, McCormick has suggested that to avoid a conspicuous data error, a minimum 55 dB isolation is necessary. Three paths which affect intra-channel isolation must be considered: (1) cross coupling in the local oscillator channel, (2) coupling via receiver coaxial cables, and (3) coupling via the DC power supply lines. The last two mechanisms can be reduced to insignificant levels by employing good engineering practices and, in the case of the RF signal path, employing copper semi-rigid cables. Cross-coupling via the local oscillator channel can be reduced by minimizing the VSWR seen by the hybrid couplers employed as power dividers and by the use of isolators prior to each of the mixers.

4.2 SENSITIVITY

Noise figure is a measure of overall system sensitivity. A low system noise figure is as important as an increase in transmitter power; an improvement in noise figure provides the same overall performance improvement as a likewise increase in tramsitter power, but at a considerably reduced cost.

The noise power level presented to antenna terminals of an ideal receiver is related to the source temperature, T_s, and the receiver effective temperature, T_{eff}, such that, for situations where $T_s = O(T_{eff})$, improvements in noise figure will yield slightly better improvements in overall sensitivity than would be expected from the noise figure improvement alone. In this design, for example, utilizing an overall 5 dB noise figure will result in a noise floor -109.2 dBm/MHz during observation of -40°C (223°K) ice clouds. Under the same conditions, however, a 3 dB improvement in overall noise figure will result in a 3.5 dB improvement in noise floor so that an observational sensitivity of approximately -112.7 dBm/MHz will be realized.

Another factor which will contribute to sensitivity degradation in the superheterodyne receiver is reception of the unwanted mixer sideband which contributes 3 dB of noise. This sideband can be suppressed either by a preselector, located either prior to the front-end low noise amplifier (LNA) or between the LNA and the mixer, or by a sideband suppression mixer. If a preselector is located prior to the LNA, it adds a front-end insertion loss which is equivalent to an increase in noise figure by the value of the insertion loss. Usually, however, the preselector loss is only on the order of 1 dB, so that an overall improvement results. On the other hand, if a preselecting filter is placed between the LNA and the mixer, little sensitivity degradation will result. While this location is appealing on the basis of sensitivity considerations, it does not preselect out-of-band signals from the LNA. Likewise, a sideband suppression mixer does not offer LNA preselection. Since intense out-of-band signals that would require LNA preselection do not normally exist at the site of the AFGL radar, post LNA preselection was chosen to simplify the design.

4.3 DYNAMIC RANGE

Two definitions of receiver dynamic range exist: (1) overall dynamic range, defined as the operating range of the receiver from the noise floor to the 1 dB signal compression point, and (2) the spurious free dynamic range (SFDR), defined as the operating range from the noise floor up to a power level at which spurious signals are processible.

The 1 dB compression point is an order of magnitude more coarse than our requirement. As a rule of thumb, the 0.1 dB compression point (the linearity requirement for this modification), is approximately 10 dB less than the 1 dB compression point. Furthermore, most amplifier manufacturers define the 1 dB compression point as an output value; the system designer must be careful to subtract the amplifier gain so that the 1 dB or 0.1 dB compression point is referenced to the amplifier input. From a calculation of the expected return energy from each form of hydrometeor, assuming a minimum radar range of 1 kilometer and using a transmitter level of +88 dBm with a two-way antenna gain of +84 dB, the maximum expected signal at the receiver input was determined to be -8 dBm. This design then requires a dynamic range of approximately 109 dB, which is impossible to achieve with present logarithmic amplifiers so an alternate method must be used to expand the receiver's dynamic range.

In most receivers, a form of automatic gain control (AGC) is available to reduce the RF and intermediate frequency (IF) amplifier gain as the return signal level is increased. However, AGC removes the power level measurement capabilities of the receiver unless the AGC voltage is carefully calibrated and monitored. Another method to increase overall dynamic range is to minimize the RF amplifier gain and electronically remove the IF preamplifier when the expected return approaches receiver compression; the computer, cognizant of this condition, adjusts its processing accordingly. We have chosen this latter method in conjunction with a logarithmic amplifier capable of a 90 dB dynamic range.

The dynamic range of a receiver is also limited by spurious responses which are accepted by the processor. These spurious responses, known as intermodulation products (IMP), are internally generated in the low noise amplifier and mixer from external sources. The frequencies of these products are given by (McVay, 1967)

$$F_{spur} = \pm\, nf_1 \pm mf_2, \qquad (2)$$

where n,m are integers.

In this design, only those values where n + m = 3 are of concern as the resultant signals are close to frequencies which can be received and converted to the intermediate frequency by the mixer. However, for these signals to be processible by the receiver of a pulsed radar, they must be the product of continuous carrier sources, in which case they may be characterized as such and reduced or eliminated.

Because of the dual transmitters employed in this radar (2710 MHz and 2760 MHz), a possible corruption of power channel data by velocity channel data, and vice versa, does exist, as the spurious frequency sideband energy generated from one channel is in the nearby spectrum receivable by the other channel. While this is a valid argument for LNA preselection, at present, only IF filtering has been considered for the elimination of this cross-channel IMP.

4.4 IF FILTER

The IF filter fulfills two missions: it determines the overall system noise floor and it provides the required selectivity. Exact choice of an IF filter is not a trivial task, as the filter and the RF amplifier essentially determine the receiver performance.

For optimum signal-to-noise receiver performance of a pulse modulated signal, the IF half-power bandwidth must be approximately 1.2 times the reciprocal of the transmitted pulse width or, in this design, 1.2 MHz. However, to minimize phase dispersion across the filter bandpass in the class of filters known as planar filters (Chebishev, Butterworth, and elliptic), a half-power IF bandwidth of 4 MHz is required.

The importance of filter skirt selectivity cannot be overstressed; many designs do not extend filter specifications beyond the bandwidth of the halfpower points which fails to specify the attenuation at frequencies further from the center frequency. If thought is given to the frequency sideband energy of the transmitted channel opposite to the receiver channel under consideration, then a moderate degree of data corruption may be caused by many factors such as the range, type of hydrometeors observed, and spectral distribution of the transmitter pulse. A moderate skirt selectivity requirement exists as some of the spurious frequencies generated within the LNA and given by Equation (2), which are the result of the two transmitted signals, are only 10 MHz removed from the anticipated received signal.

This condition exists when both the Doppler channel and the reflectivity channel return pulses are received simultaneously. We calculate that two -39 dBm signals into the low noise amplifier are required to generate an IMP at the receiver noise floor. Since a 1 dB increase in input level will cause a 3 dB increase in output level for third order IMP, returns greater than -36 dBm into the receiver will begin to degrade the data. We calculate that returns exceeding this level are expected infrequently. The elimination of this IMP then depends upon the filter skirt selectivity chosen so that the interfering pulse "sidebands" are attenuated into the noise. This condition may not be possible, as good skirt selectivity and phase dispersion are divergent from one another in planar filers.

4.5 LOCAL OSCILLATOR AND MIXER

While all of the present components are retained in the local oscillator chain, additional components are added to provide increased intra-channel isolation, phase balance, and amplitude balance. The increased losses of these items require a slight amplification of the local oscillator signal level so that the mixers may be operated in a lower distortion region. By further increasing this amplification, high intercept point mixers can be employed with the result that the overall receiver 1 dB compression point is sufficiently increased to be wholly determined by the RF amplifier. The original radar utilized phase locked loop oscillators. A filter following each oscillator is required to prevent the high spurious output of the oscillator from entering the mixer as these spurious components will allow the receiver to capture unwanted signals. Since spurious signals occur within 600 kHz of the local oscillator frequency, a high Q, thermally stable, cavity filter is required.

5 CONCLUSION

In the foregoing discussion we have presented the key design elements of the antenna, microwave package and receiver. Although we have considered only the highlights, we have concentrated on the antenna, as this appears to be the most critical component of the system. We have also shown that the radar, including all its components, must be considered as an entity.

Antenna cross-polarization
Depends on the waveguide location.
Is Cassegrain best?
Let's put it to test
To get us the most isolation.

The IF filter skirt selectivity
Should reduce the system proclivity
For frequencies spurious.
But don't let them worry us--
We'll cut down their net transmissivity.

Mother Nature, they say, is a bitch,
Always looking to find us a glitch.
And so, in the end,
Everything will depend
On the high power microwave switch.

6. ACKNOWLEDGEMENTS

The authors thank Mr. E. J. Wilkinson of GTE International Systems for insight into antenna cross-polarization. This effort was supported by AFGL Contract Nos. F19628-81-K-0027 and F19628-82-K-0038.

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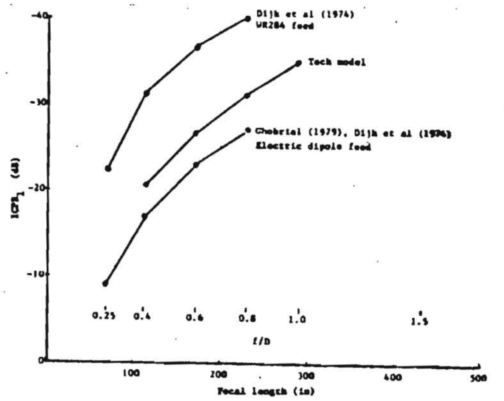
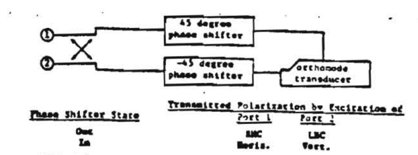
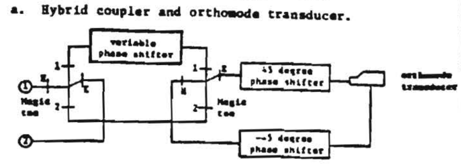


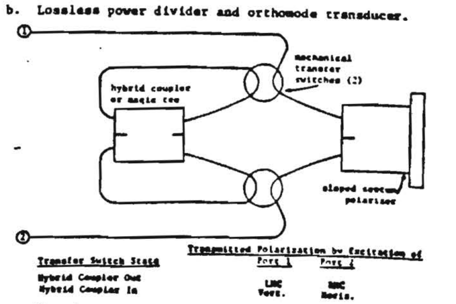
Figure 1. $ICPR_1$ for various feeds and f/D for an axisymmetric parabolic reflector antenna.



a. Hybrid coupler and orthomode transducer.



b. Lossless power divider and orthomode transducer.



c. Sloped septum.

Figure 2. Candidate polarizer configurations.

APPENDIX B

ANTENNA STATIC
AND
DYNAMIC STRUCTURAL ANALYSIS

ER - 100 - 1

DESIGN REVIEW

Prepared For

GEORGIA INSTITUTE OF TECHNOLOGY

Prepared By

H & W INDUSTRIES, INC.
COHASSET MASS.

Signed ____________________
Thomas P. Walsh, P.E.

TABLE OF CONTENTS

1.0 Specification Review

Paragraphs 2.2, 2.3 and 2.4 of the Contract Statement of Work comprise the specification for the work to be performed under the present contract. Those paragraphs are copied below.

2.2 STATIC AND DYNAMIC STRUCTURAL ANALYSIS

Upon receipt of initiation letter, contractor shall determine the reflector deformations that may occur as a result of various natural and operational effects upon the reflector, subreflector, subreflector support assembly, and feed support assembly. Contractor shall also determine deformations, if any, that may occur within the support spars and subreflector. The effects shall include, but not be limited to:

1. dead weight distortion as a function of elevation angle,
2. seasonal thermal charges both with and without the radome,
3. wind loading distortion,
4. thermal charges due to shadowing, (out)
5. inertial loading distortion in both azimuth and elevation planes and
6. vibrational characteristics including those of the spars created by vortex shedding.

Servo-Loop resonances shall also be considered. Contractor shall send a preliminary report of this information to Georgia Tech within 60 days of initiation. Georgia Tech shall determine the impact of such deformations upon antenna performance, and may at their opinion request further investigation should the present reflector appear unsuitable. Such further investigation may include, but not be limited to, consideration of different spar support systems, or the addition of strengthening members to the reflector support assembly.

2.3 FEED SUPPORT AND SUBREFLECTOR SUPPORT

Upon receipt of initiation letter, contractor shall design and construct a structure to support a multi-taper circular horn feed antenna whose exterior length is approximately 60" and maximum outside diameter approximately 32". Adjustment and adjustment locking devices shall be incorporated within the design to allow precise location of the feed horn. The exterior of the horn and support structure shall be surrounded by a concentric, axisymmetric shroud assembly.

The contractor shall also design and construct a quadrapod subreflector support assembly. This assembly shall attach as closely to the perimeter of the main reflector as practicable and shall be designed to minimize resonances due to vortex shedding and other effects. This assembly shall allow for a six (6) inch axial adjustment range and a three (3) inch radial adjustment range as well as adjustment locking devices so that one subreflector can be precisely located and locked in position. For the purposes of these designs, the contractor shall consider both the condition with, and the condition without a radome enclosure surrounding the antenna assembly.

Prior to design finalization of these assemblies, Georgia Tech shall supply the exact dimensions of the feed horn assembly as well as the exact size, shape, and location of the subreflector assembly.

2.4 SUBREFLECTOR

Upon receipt of initiation letter, contractor shall construct a hyperbolic subreflector of a size not to exceed three feet in diameter. The subreflector shall contain a VSWR reduction button; the subreflector shall interface with, and mount upon the subreflector support assembly. Georgia Tech shall determine the shape and size of the subreflector.

2.0 Analysis Review

The reflector structure from the base of the hub to the apex of the subreflector support was modeled and analyzed via the finite element computor program, "Stardyne". Both static and dynamic analyses were performed.

A. Static Analysis

The Static Analysis evaluated the following cases:

Case	Subject
1	Horizon Point, Dead Load Deflections & Stresses
2	Elevation = 30°, Dead Load Deflections
3	Elevation = 60°, Dead Load Deflections
4	Elevation = 90°, Dead Load Deflections
5	Elevation Rotation from 90° to 60°
6	Elevation Rotation from 90° to 30°
7	Elevation Rotation from 90° to 0°
8	Seasonal Temperature Change of 20°
9	Effects of a 30 MPH Frontal Wind
10	Effects of a 30 MPH Quartering Wind (120° off boresite)
11	Effects of a 10°/sec Rotational Accelleration

The input and output of the final run of the Static Analysis is included in Section 4. The output of this run was limited to deflections only. The output of the initial run is also included in Section 4. That run computed deflections for all cases and stresses for Cases 1, 8, 9, 10, and 11. The maximum stresses for those cases are listed below:

Case 1	1448 psi	due to dead load
Case 8	2750 psi	due to thermal effects
Case 9	192 psi	due to 30 mph frontal wind
Case 10	Negligible	due to 30 mph quartering wind
Case 11	Negligible	due to 10°/sec rotational inertia

Considering the Aluminum Association Specification, allowable stress for 6063-T5 Aluminum (lowest strength alloy in the reflector) is 6500 psi, we can consider the stress levels acceptable. Further considerations relative to stress levels are:

1. The spar cross-sectional area has increased from 2 x 2 x 1/8 wall square tube in the initial run to 4" OD x 3/16 wall round tube in the final run. This change was implemented to lower the subreflector support deflections. An attendant stress effect is to halve the Case 1 stress of 1448 psi.

2. The math model assumed the base of the reflector hub to be fixed. In fact, the hub is attached to a steel structure. The thermal effects, therefore, are based on an aluminum structure with a coefficient of thermal expansion of 13×10^{-6} in/in/deg, expanding relative to a base interface with an expansion of zero. This analysis has utilized the most conservative possible end condition. In fact, the end condition could be either a continuous steel structure with a coefficient of thermal expansion of 8.6×10^{-6} in/in/deg or a steel structure with one end attached to a floating bearing. That is, the continuous structure would be one where both elevation bearings react loads parallel to the elevation shaft vs. one where one bearing takes radial load only. In the first case, the deflections and stresses of Case 8 would become $\left(1 - \frac{8.6}{13}\right)$ or 34% of the calculated values; and in the second case, they would approach zero.

The above calculations and observations result in reflector stresses which are acceptable for all combinations of position, wind and thermal effects.

The significant reflector deflections of Cases 5 through 11 are plotted in Figures B.a. through B.f. These topographic plots are made joining points of equal deflections. Plots B.a., B.b., B.c. and B.f. are characteristically horizontal plot lines indicating the reflector is deflecting so as to generate an elevation pointing error. Plots B.d. and B.e. are characteristically polar deflection plots indicating a defocusing effect. We have RMS(ed) the nodal deflections parallel to the boresight for the reflecting surface and tabulated the results below:

Case	RMS (Nodes 1 - 96, Deflection X3)
5	.0035"
6	.0062"
7	.0074"
8	.0031"
9	.0019"
10	< .001
11	< .001

All the above can be decreased by best fitting the data. Cases 5, 6, and 7 can be improved by rotating the coordinate system about the elevation axis and Cases 8 and 9 can be improved by calculating a change in the best fitting focal length. The magnitude of the tabulated date precludes the necessity of best fitting.

The subreflector support deflections due to elevation rotation can be obtained by reviewing deflections for Nodes 211, 222, 233 and 244.

Case	X_2 Deflection - Final Run
5	-.022
6	-.037
7	-.041

These deflections are approximately 1/2 the magnitude of their values for the initial run. The deflections appear acceptable in all cases.

B. Dynamic Analysis

The Dynamic Analysis extracted the first seven modes of vibration. See Section 4C. Since vibrations above 10HZ will have little or no effect on the servo band pass, the computor was programmed to extract and define all mode shapes with a frequency of 10HZ or less. Only one mode was found less than 10HZ at 7.799 HZ. The mode shape is defined in figures C.a., C.b. and C.c. In addition, the next six modal frequencies were calculated, (between 13 and 24 HZ). A review of the fundamental frequency mode shape shows it to be the torsional mode with the reflector structural components rotating around the hub. It is interesting to note that for this case, the spars do not depart greatly from their undeformed straight line shape. We can therefore expect the spars not to vibrate until at least 13 CPS.

The calculated individual spar resonant frequency is 27 HZ. Given a Strouhal number of .2 (tubes) the vortex street shedding frequency will coincide with the spar natural frequency at wind velocities about 30 MPH. The forces transmitted to the structure at this wind velocity will be sufficient to cause problems. We recommend that if the unit is to be used without the radome, a helical wind of small dia tube (approx. 5/8 dia) be wound along each spar at a pitch of approximately 2 feet.

The dynamic characteristics in all other respects are acceptable.

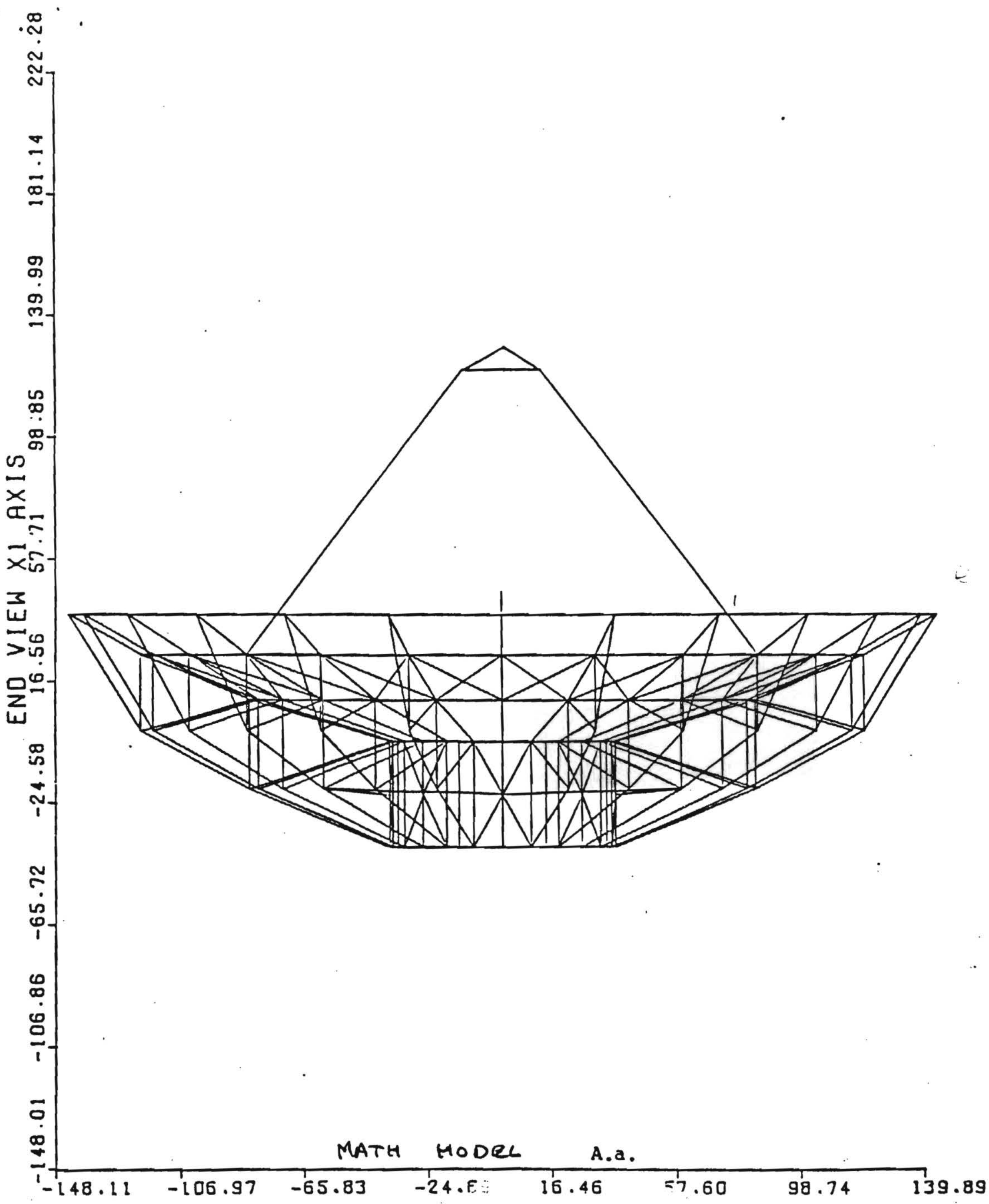


Figure A.a. The Math Model, Side Elevation View.

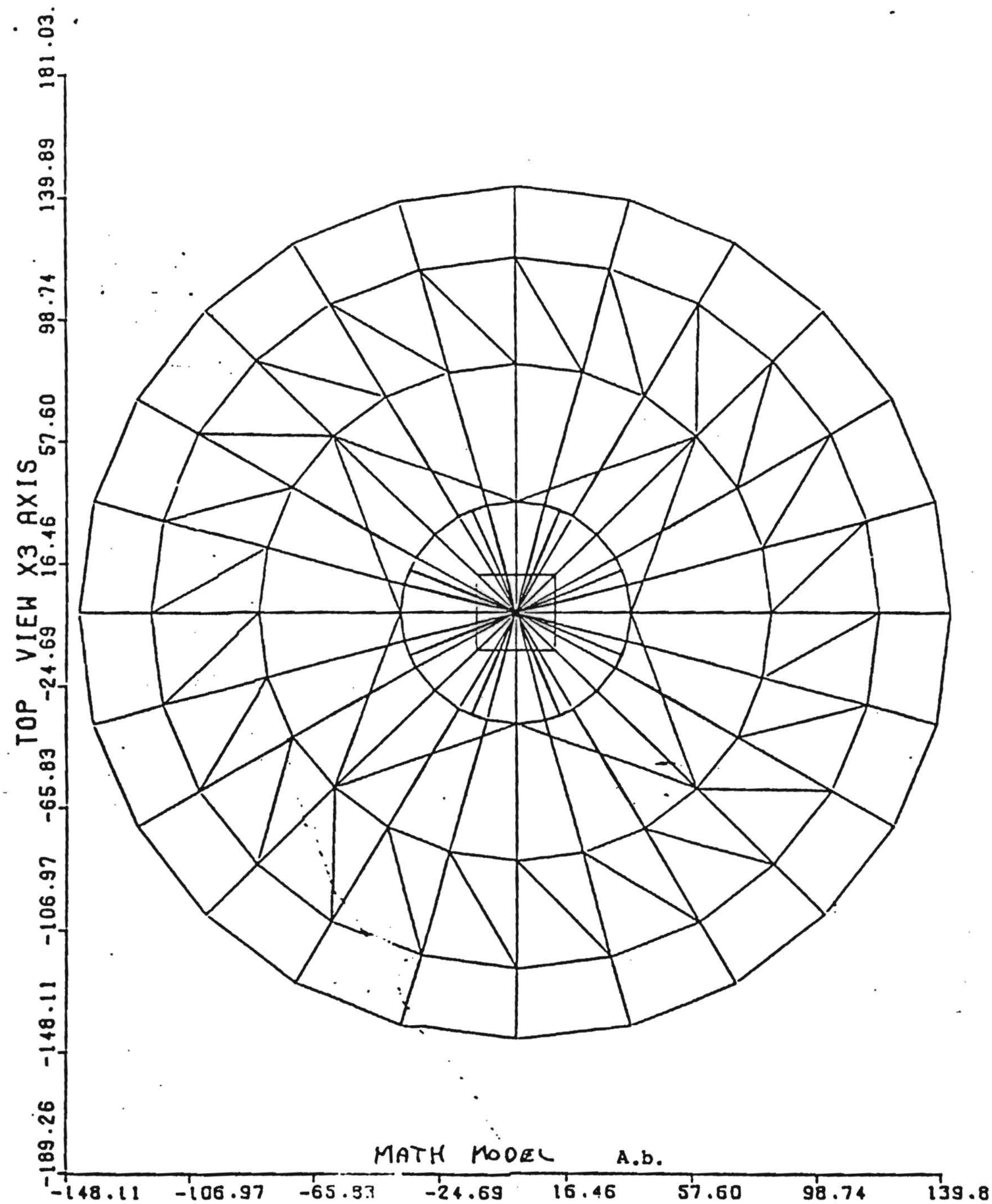


Figure A.b. The Math Model, Face View.

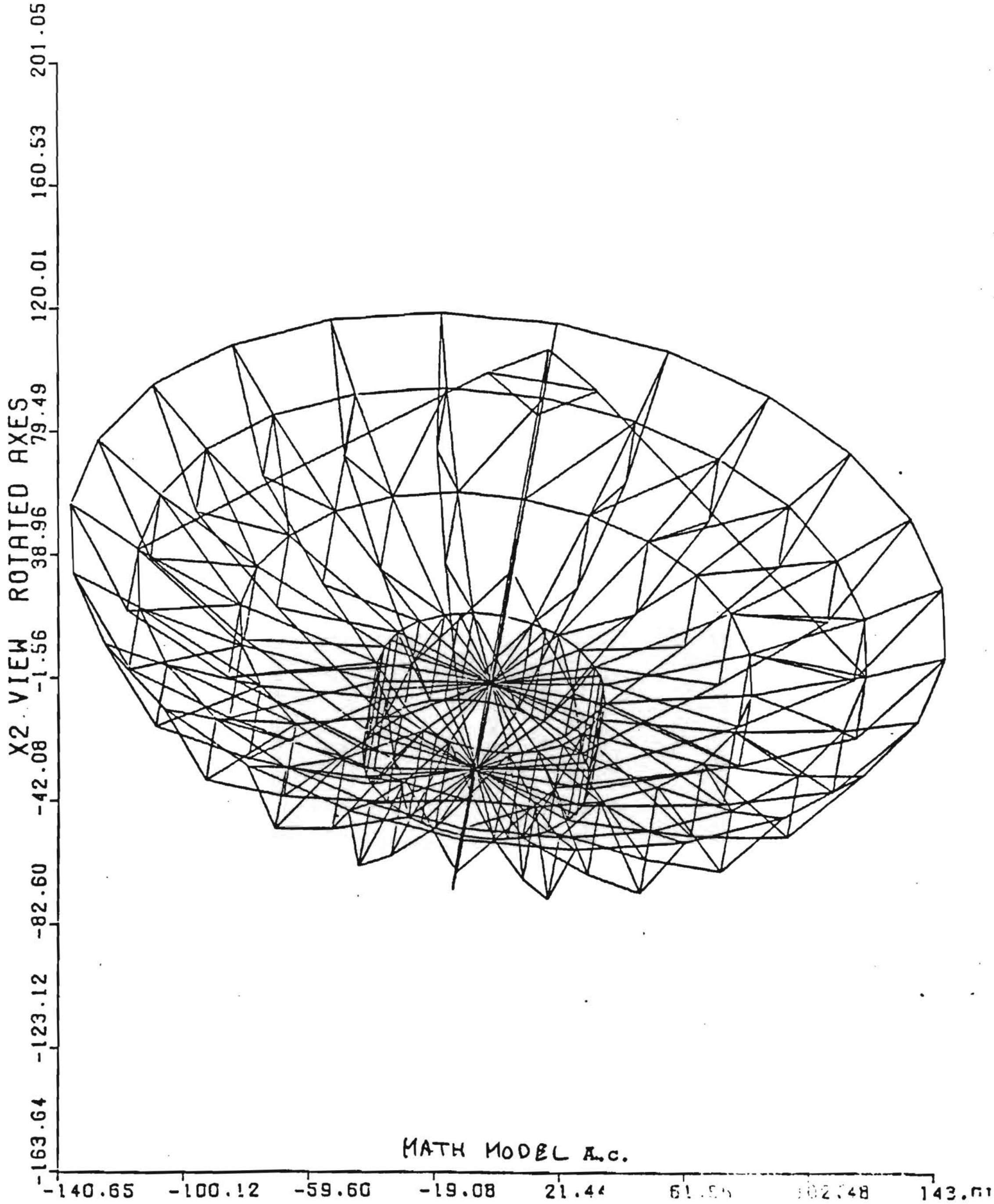


Figure A.c. The Math Model, Isometric.

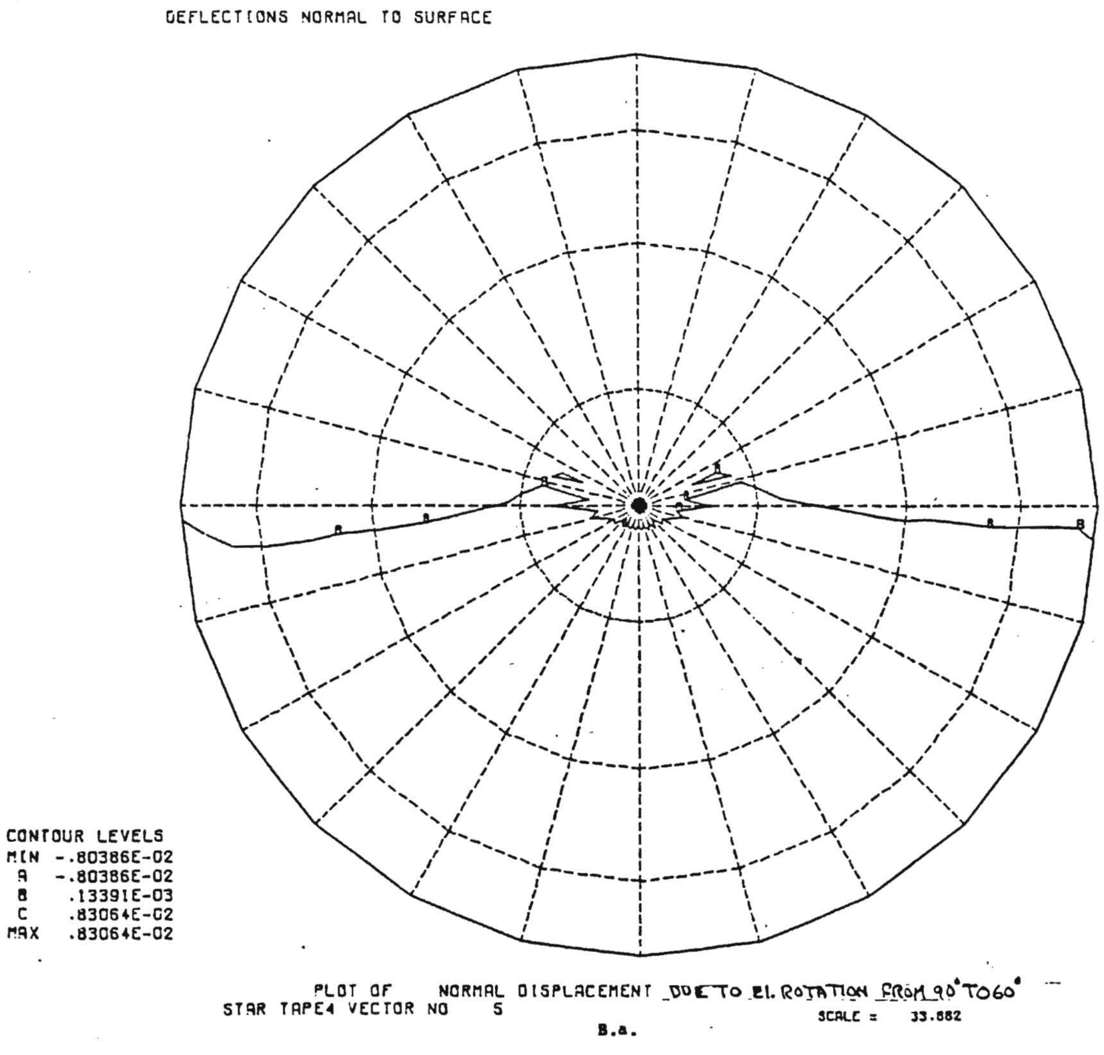


Figure B.a. Static Deflection, Plot of Normal Displacement due to Elevation Rotation 90° to 60°.

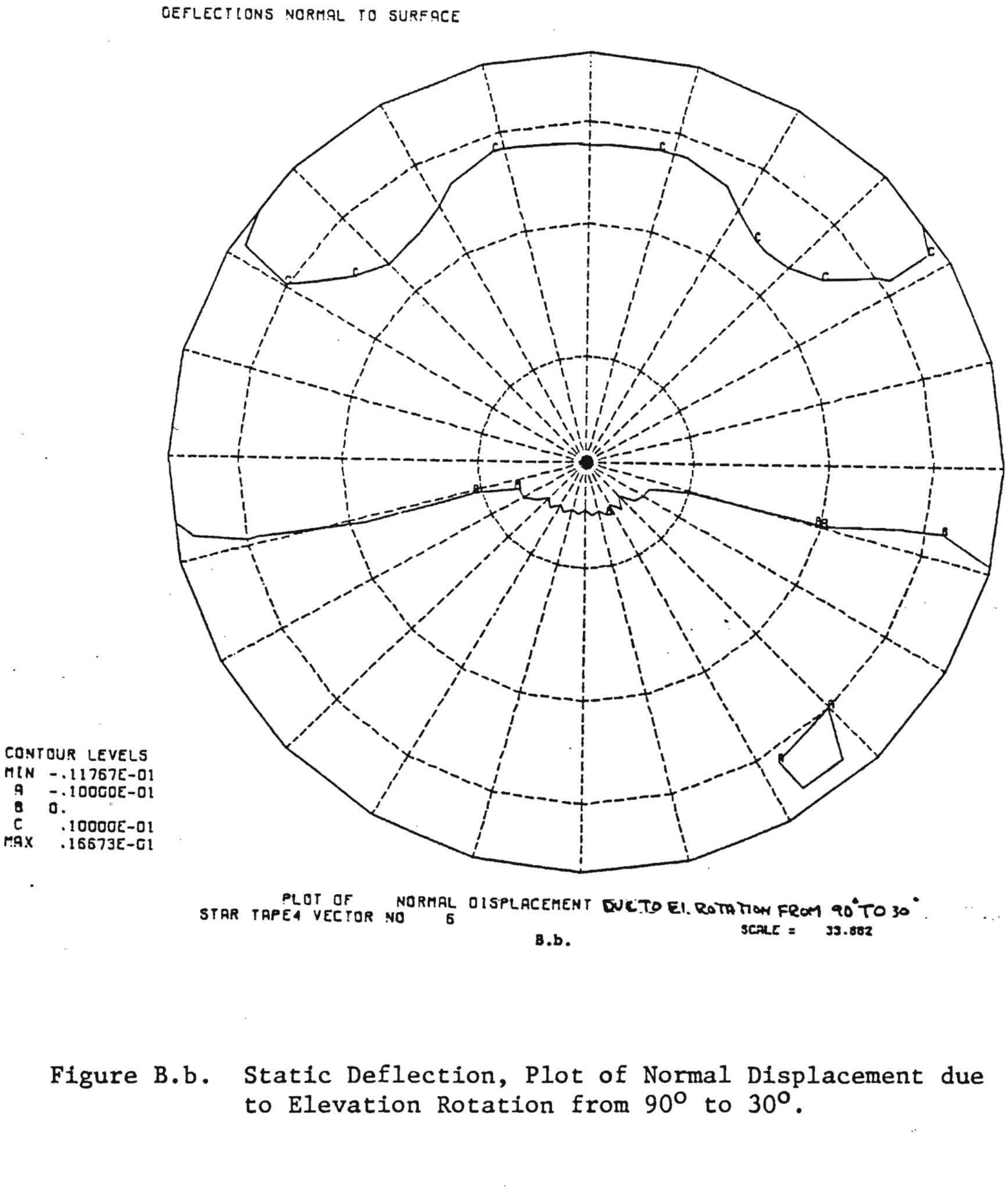


Figure B.b. Static Deflection, Plot of Normal Displacement due to Elevation Rotation from 90° to 30°.

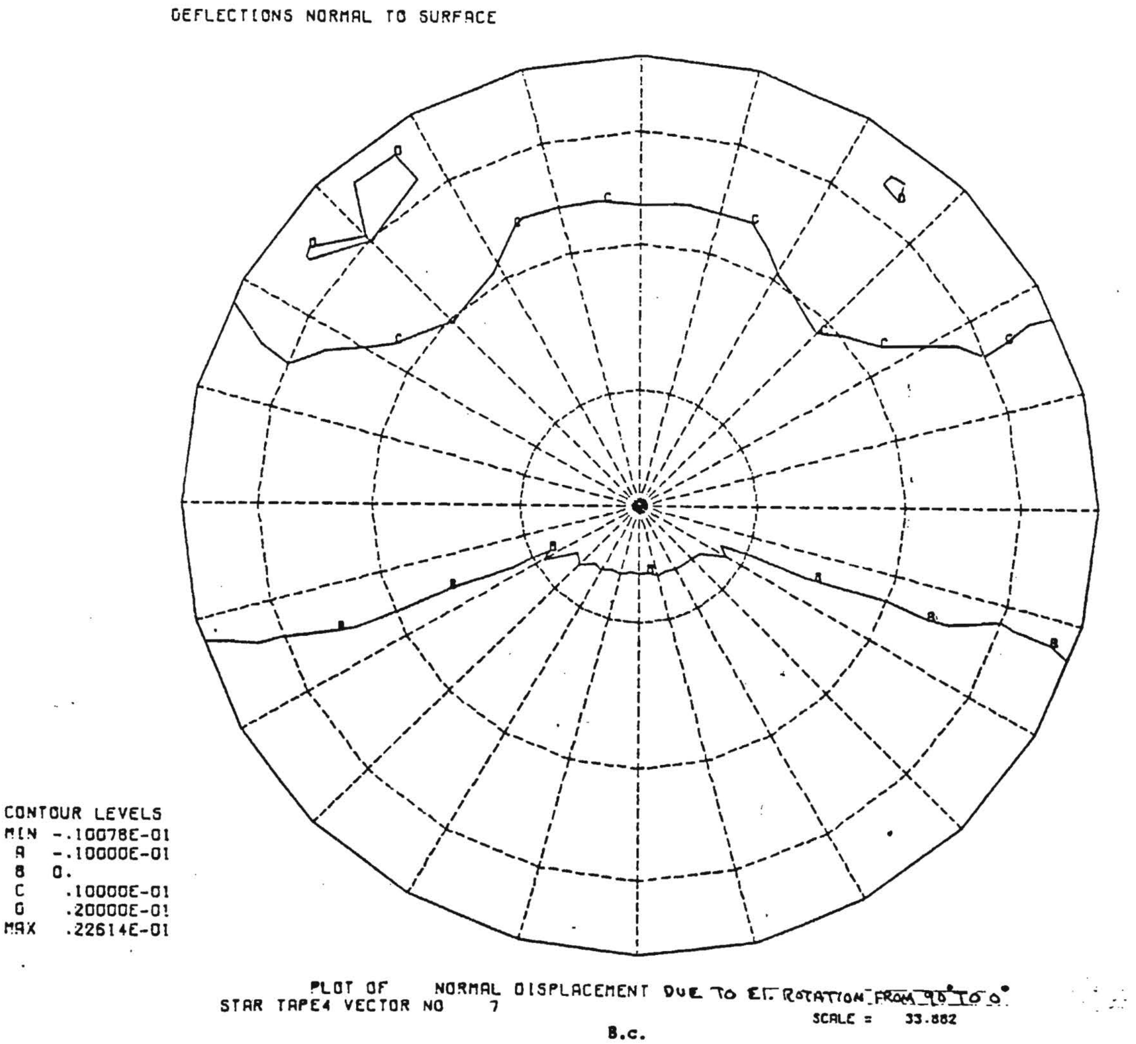


Figure B.c. Static Deflection, Plot of Normal Displacement due to Elevation Rotation from 90° to 0°.

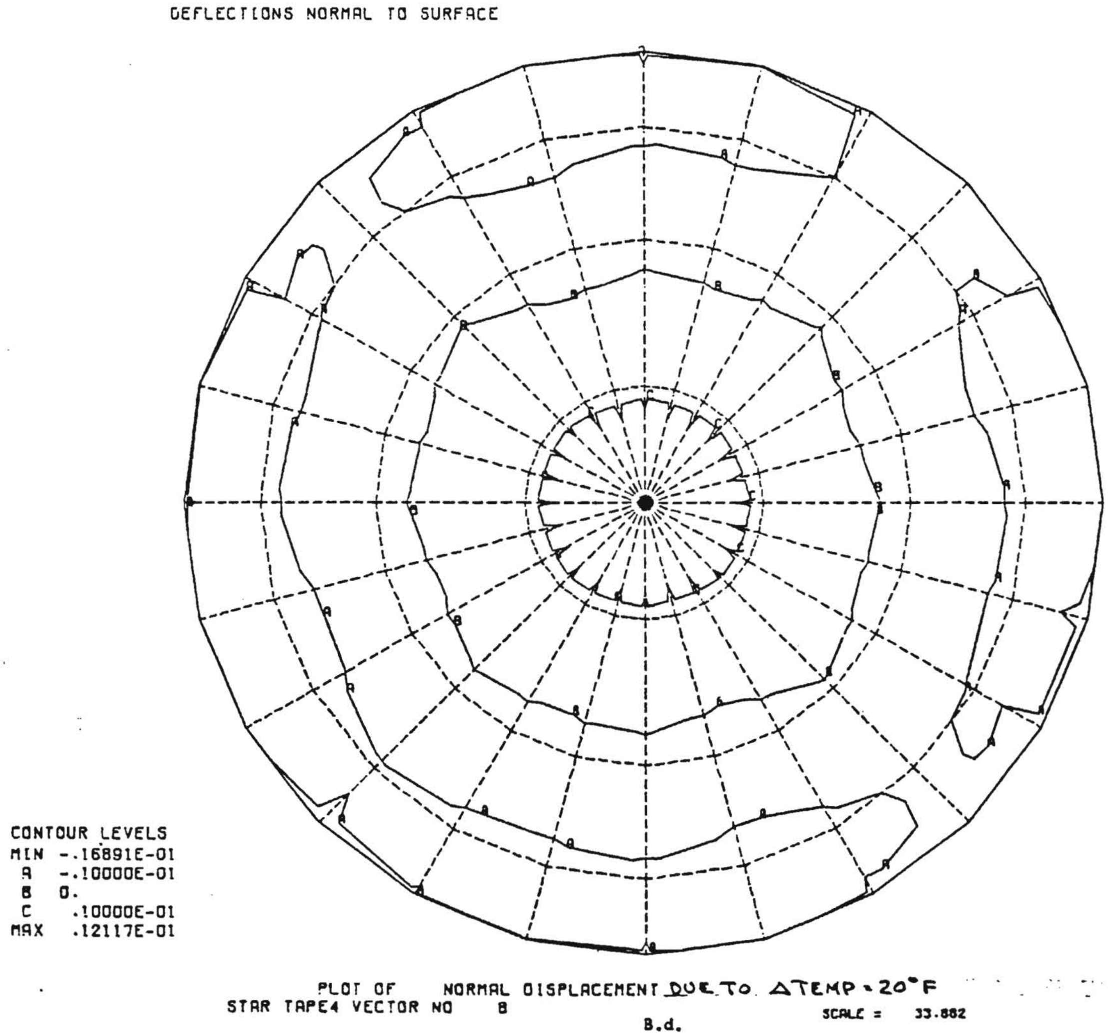


Figure B.d. Static Deflection, Plot of Normal Displacement due to Δ Temperature = 20°F.

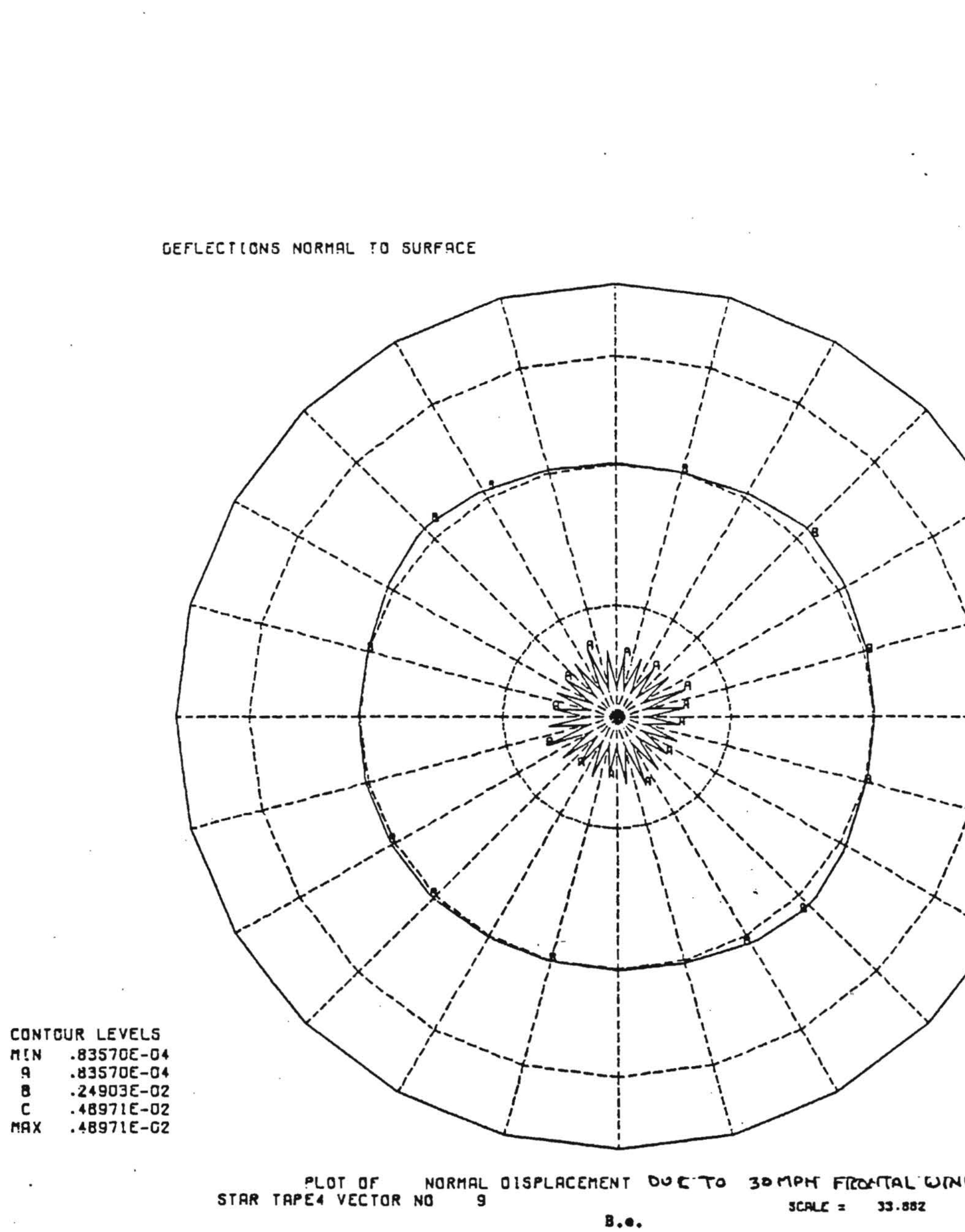


Figure B.e. Static Deflection, Plot of Normal Displacement due to 30 MPH Frontal Wind.

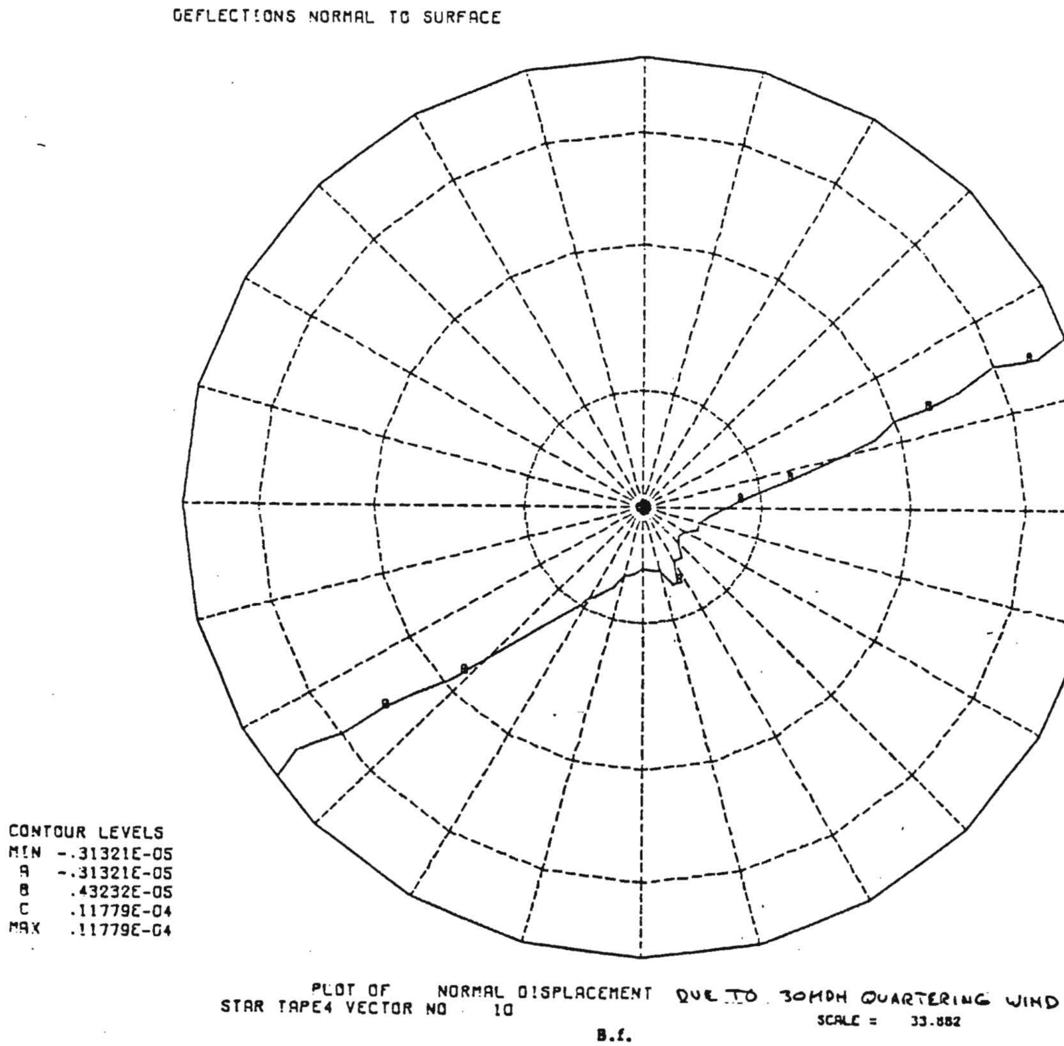
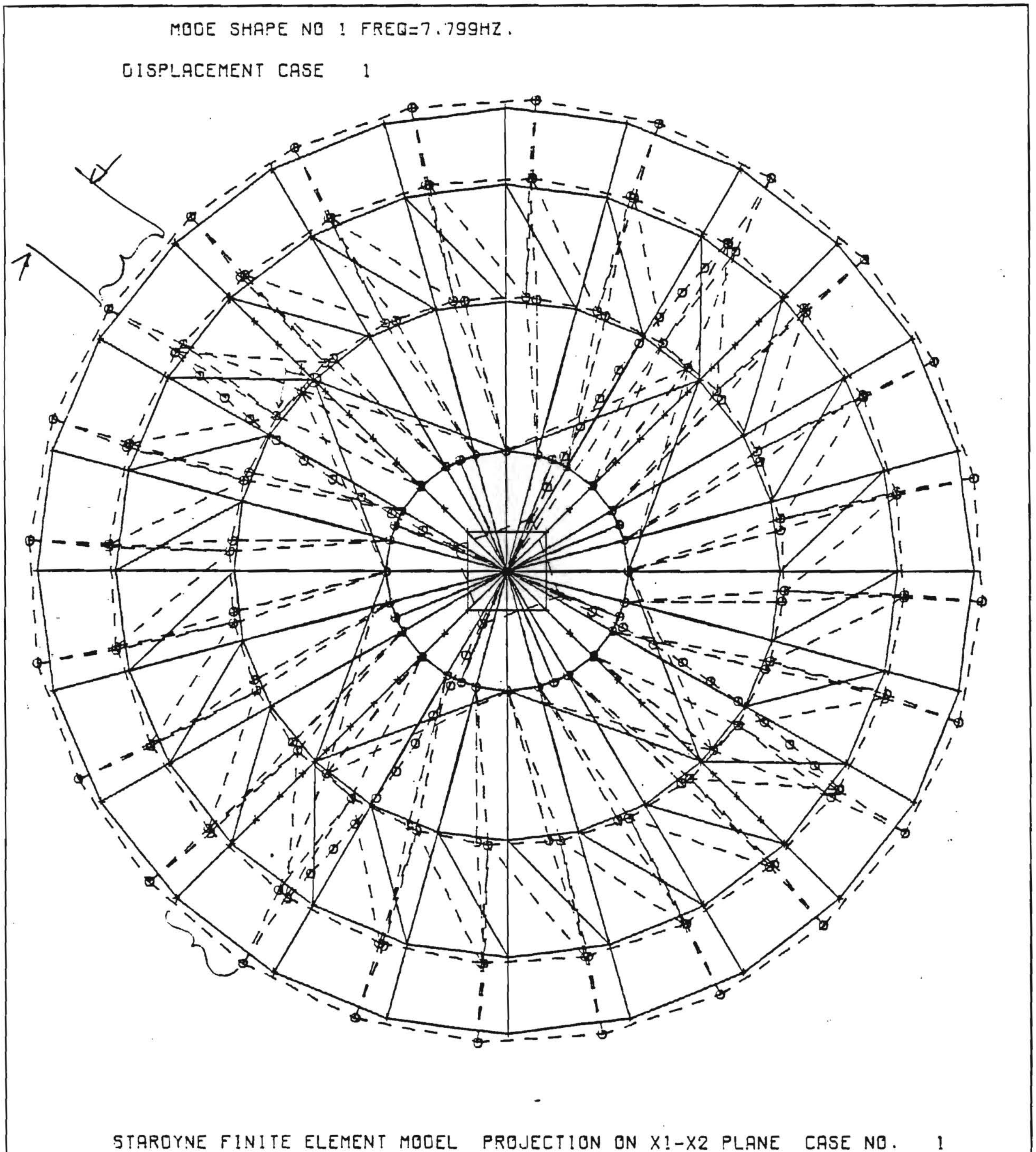
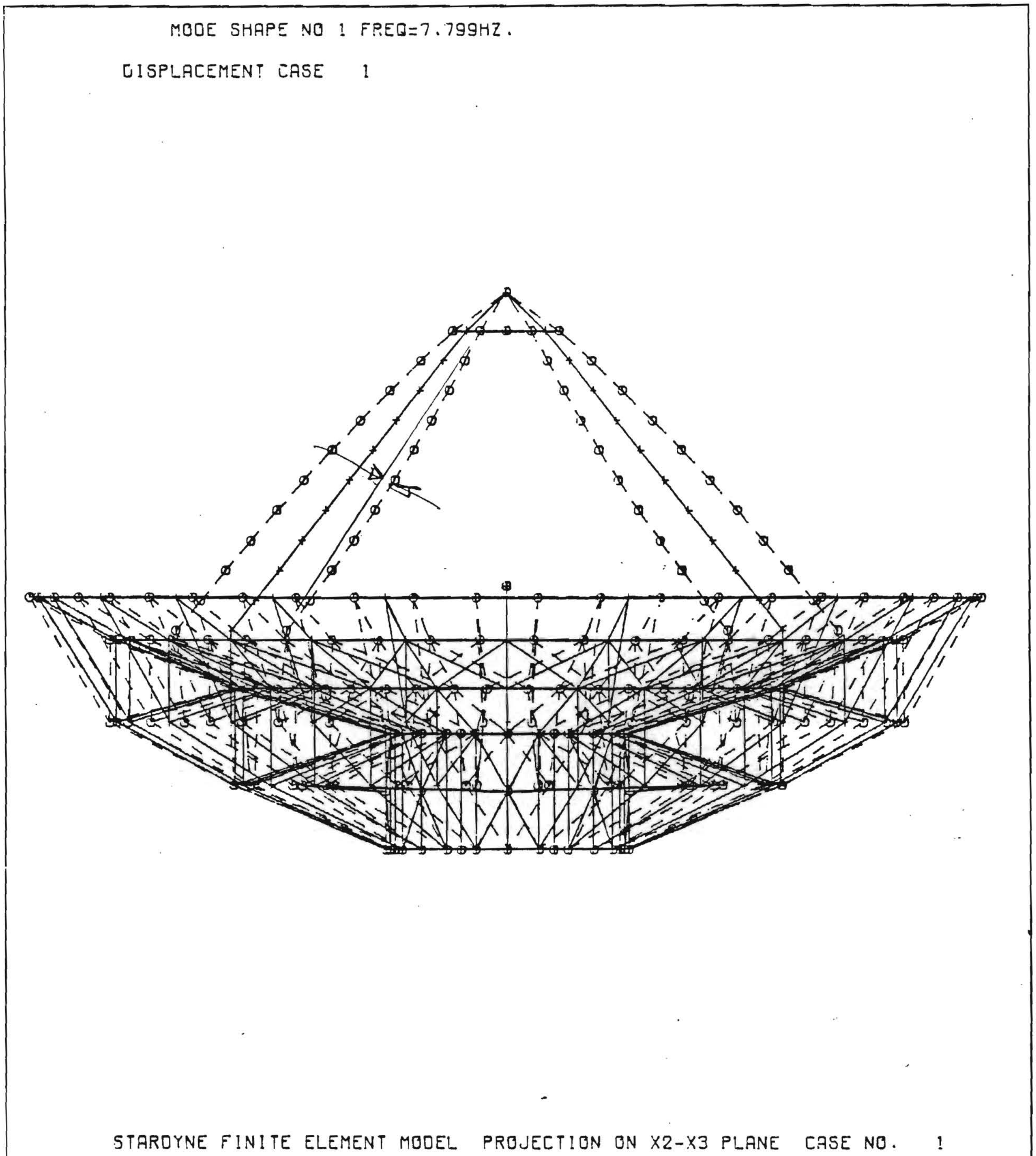


Figure B.f. Static Deflection, Plot of Normal Displacement due to 30 MPH Quartering Wind.

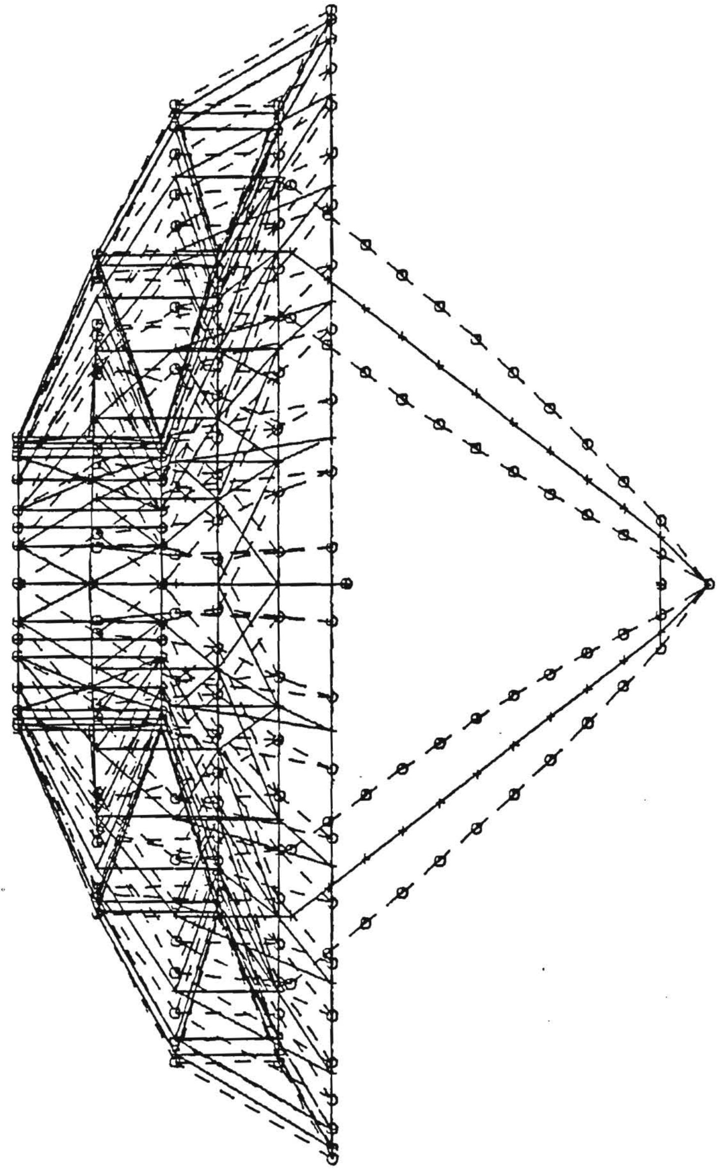

MODE SHAPE NO 1 FREQ=7.799HZ.
DISPLACEMENT CASE 1
STARDYNE FINITE ELEMENT MODEL PROJECTION ON X1-X2 PLANE CASE NO. 1

C.a.


MODE SHAPE NO 1 FREQ=7.799HZ.
DISPLACEMENT CASE 1
STARDYNE FINITE ELEMENT MODEL PROJECTION ON X2-X3 PLANE CASE NO. 1
C.b.

MODE SHAPE NO 1 FREQ=7.799HZ.

DISPLACEMENT CASE 1



STARDYNE FINITE ELEMENT MODEL PROJECTION ON X3-X1 PLANE CASE NO. 1

C.c.

Figure C.c. Dynamic Mode Shape, Plan View.

A-3226

FINAL REPORT
AFLG-TR-84-0239

POLARIZATION DIVERSITY ADDITION TO THE 10 CENTIMETER DOPPLER WEATHER RADAR

James S. Ussailis
Harold L. Bassett

Report Period 1 April 1982 through 31 July 1984

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BSTRACT (Continue on reverse if necessary and identify by block number)

The research performed was that of providing antenna modifications for a polarization ersity addition to the AFGL 10 centimeter DOPPLER WEATHER RADAR. Described within are ANTENNA FEED DESIGN (POTTER HORN), the conversion of the antenna from a prime focus to assegrain Configuration, the results of the feed horn RF measurements, the construction the POLARIZER ASSEMBLY, and the installation and testing of the antenna system.

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10 CENTIMETER DOPPLER WEATHER RADAR

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Atlanta, Georgia 30332

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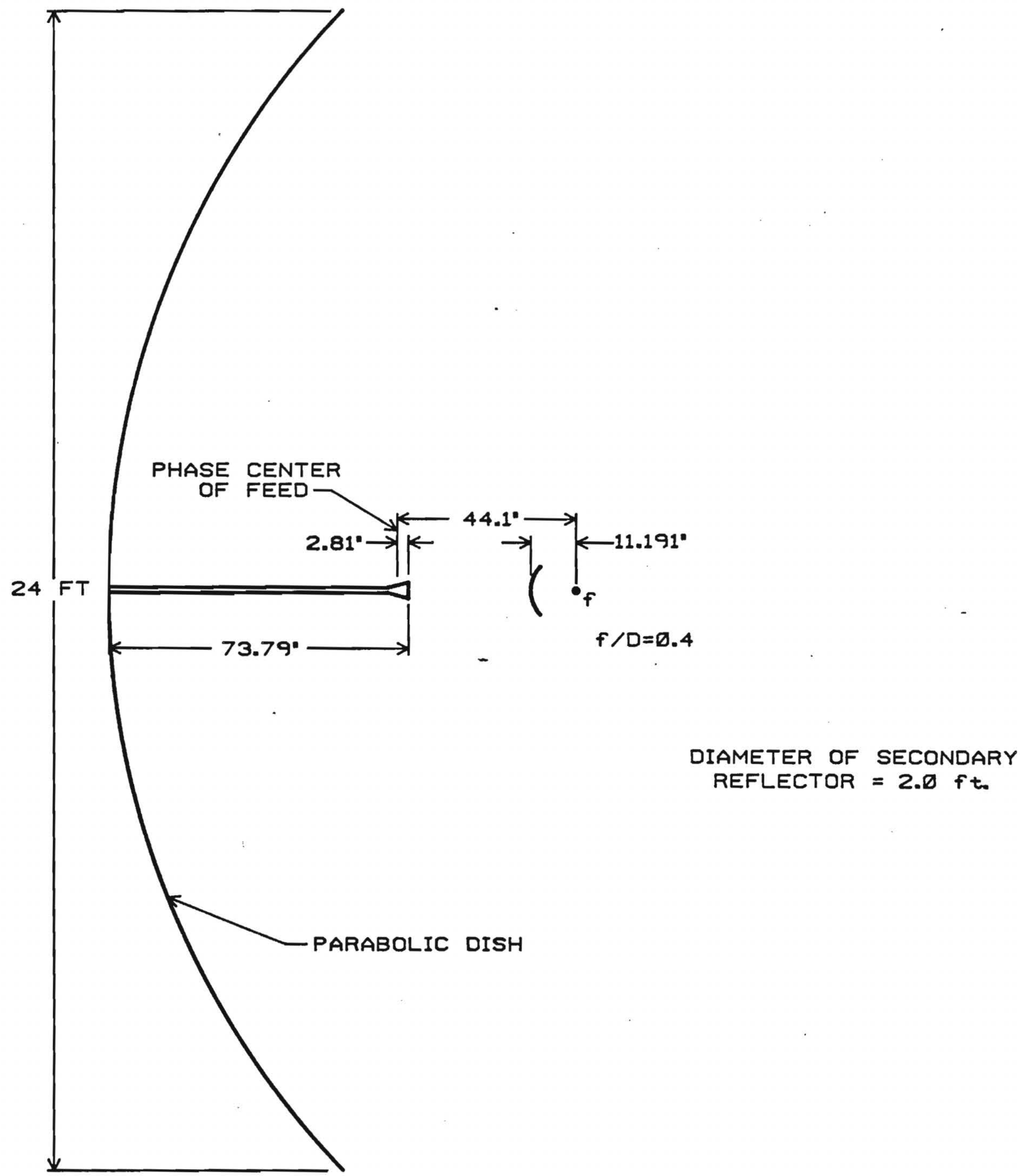
TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES



Positions of feed horn, phase center of feed, and subreflector.

SECTION 1
INTRODUCTION

The objective of this research program was to provide antenna modifications for a polarization diversifying addition to the AFGL 10 cm Doppler weather radar.

This addition, together with a subsequent receiver addition, will allow measurement of the coherent linear or circular monostatic scattering matrix of meteorological phenomena. The observations provided by the modified radar will allow for more direct (rather than inferred) measurement of these phenomena than has been heretofore possible. Examples of these additional observations include measurement of mean particle size, mean particle shape, and thermodynamic phase. The purpose of this report is to discuss the actual antenna modification; the interested reader should review References [1] and [2] to gain insight into the radar measurables as well as the specifications required to attain a reasonable measurement accuracy. Reference [2] is included as Appendix A.

In Section 2 the radar modifications and the installation of the feed horn and associated microwave circuitry are discussed. A conclusion is drawn in Section 3.

SECTION 2
RADAR MODIFICATIONS

2.1 STRUCTURAL ANALYSIS

A structural analysis of the existing reflector together with the proposed subreflector, support span assembly, feed support assembly, and feed horn was performed by Mr. T. Walsh, P.E., of H & W Industries, Inc., Cohassett, Mass. This effort, consisting of both static and dynamic analyses, determined the distortional effects of dead weight, seasonal thermal changes, wind distortion, and inertial loading. The results of these analyses are included as Appendix B.

2.2 CONVERSION TO CASSEGRAIN CONFIGURATION

The antenna was converted from a prime focus configuration to a Cassegrain configuration. This conversion extended the focal length to diameter ratio (f/D) of the main reflector and thus reduced the anticipated linear cross-polarization to acceptable levels. The conversion was accomplished by adding a subreflector and feed support assembly. The existing tripod feed support was replaced with a relocated quadrapod support, not only to provide sufficient latitude to adjust the subreflector, but also to ensure a reduction of both circular and linear cross-polarized levels. The design and fabrication of these items, including the subreflector, was provided by H & W Industries under a Georgia Tech subcontract.

2.3 FABRICATION OF A HUYGENS SOURCE FEED

A Huygens source feed which radiates equal amplitude, TE_{11} and TM_{11} circular waveguide modes (also known as the hybrid or HE_{11} mode) will theoretically induce no cross-polarization when properly illuminating a reflector antenna. All non-Huygens source feeds, including dipoles, magnetic dipoles (slots), and crossed dipoles, will produce off-axis cross-polarization from the reflector. This is true for both linearly and circularly polarized systems.

A few antennas will generate the HE_{11} mode. On this project both a corrugated horn and a multitaper or Potter horn were considered. The Potter horn was chosen on the basis of cost. Because of a lack of design data in the literature, it was decided to construct a scaled feed operating at 9.4 GHz before proceeding with a full sized S-band feed. Five iterations of various tapers and phasing sections were constructed before the final configuration was fabricated. This feed achieved equal E and H phase patterns (Figures 1 and 2) over a 60 degree angular extent. By symmetry of its circular aperture, it can be proclaimed a Huygens source over this angular area. Figures 3 to 8 show that it is also a functional design from 9.3 to 9.7 GHz inclusive.

The dimensions of the successful 9.4 GHz feed were then scaled to 2.735 GHz, the mid-band operating frequency of the radar. Fabrication of the full size feed proceeded with a different mechanical technology; rather than machine a full size horn from a large cylinder of aluminium, the various sections were rolled from thick aluminum stock and machined. This provided a lighter weight, lower cost structure and allowed for modification. This latter benefit was fortunate since the initial full size model did not provide equal E- and H-plane patterns over a reasonable extent, nor did it have a sufficiently low VSWR ($<$ 1.02:1) for circular polarimetric operation.

An attempt was made to understand equalization of the patterns by extending the horn's phasing section in three incremental steps of 1/2 inch. This also had little effect on performance. Finally, after an analysis of the unit's characteristics, a front phasing section was added which succeeded in providing equal E & H phase patterns at 2.710 GHz (Figures 9 and 10). E-plane pattern measurements were also recorded from 2.67 GHz to 2.80 GHz for future reference (Figures 11 through 20).

While initial VSWR measurements were undertaken at this time, final VSWR measurements were accomplished during installation. Initially the VSWR of the final feed horn was unacceptably high. An attempt was made to reduce the reflections by use of an iris, but it was decided to limit the effort in this area since the significant VSWR specification was applicable only at the polarizer-horn junction and not between the test equipment-horn junction. VSWR measurements were performed with various sized irises placed between the feed horn and rectangular waveguide to circular waveguide transition. Minimum VSWR was attained with a 2.60 inch iris.

During component installation on the reflector in Sudbury, Mass., the feed VSWR measurements were repeated. This was done to re-establish horn baseline data to: (1) show that no damage occurred in transit from Atlanta and (2) to complete the data package. The following paragraphs summarize the entire set of measurements.

A. The loss of the rectangular to circular transition was measured so that the actual VSWR at the horn could be determined. The loss was determined by placing a short circuit at the input and then at the output of the transition and by measuring the return loss. The transition was found to have 1.0 dB two-way loss which implies a 0.5 dB one-way loss.

B. VSWR of the transition was measured. These measurements depended on the reflection from Atlantic Microwave circular load which was attached to the transition. One cannot separate or isolate these reflections from the data. The data may not be useful, but are presented in Figure 21.

C. Peak and null measurements were made by using a short circuit on a slotted line and a short circuit on a slotted line plus the rectangular to circular transition. These data may be utilized with following measurements to determine the complex value of reflection coefficient. The data are presented as Table 1.

D. Horn and transition VSWR measurements were made to not only ensure that no electrical damage occurred to the feed horn during shipment but also to acquire complex reflection coefficient data so a scientific approach to VSWR reduction could be performed. The data are presented in Table 2.

E. VSWR of the polarizer and transition assembly was measured. Only a few data points were taken with this combination to ensure a reasonable conjugate match between the polarizer and horn. The remainder of the data requires completion of the polarizer. These data are required before installation so that the best possible match can be ensured. The available data are presented in Table 3 while the match with the tuning screws in the optimum position is shown in Figure 22. The Smith chart shows the reasonableness of the match between the polarizer and horn. The final match can be improved, but required the final polarizer configuation.

F. VSWR measurements of the horn plus the polarizer were made with the opposite polarizer port terminated (Figure 23). These measurements established that the horn reasonably matched the incomplete polarizer. The addition of the tuning screws improves the junction match sufficiently to be better than the rquirement at 2710 MHz.

TABLE 1. SLOTTED LINE PEAK AND NULL POSITION DATA

FREQUENCY MHz	SLOTTED SECTION PEAK POSITION cm	SLOTTED SECTION NULL POSITION cm	SLOTTED SECTION & TRANSITION PEAK POSITION cm	SLOTTED SECTION & TRANSITION NULL POSITION cm
2670	13.39	8.97	14.66	10.20
2675	13.30	8.90	14.34	9.90
2680	13.37	8.88	13.96	9.55
2685	13.23	8.77	13.69	9.23
2690	13.14	8.75	13.14	8.95
2695	13.04	8.71	12.87	8.62
2700	13.06	8.75	12.63	8.33
2705	13.04	8.66	12.23	8.05
2710	12.97	8.64	12.15	7.69
2715	12.78	8.60	11.90	7.40
2720	12.67	8.58	11.44	7.14
2725	12.77	8.50	11.02	6.83
2730	12.73	8.44	10.90	6.50
2735	12.46	8.44	10.54	6.20
2740	12.53	8.42	10.19	5.88
2745	12.43	8.36	9.96	5.64
2750	12.41	8.35	9.50	5.35
2755	12.32	8.33	9.05	13.30
2760	12.38	8.22	8.89	12.97
2765	12.48	8.30	8.74	12.72
2770	12.14	8.18	8.42	12.43
2775	12.20	8.21	7.90	12.05
2780	12.20	8.19	7.69	11.81
2785	12.20	8.10	7.45	11.45
2790	11.95	8.09	7.10	11.20
2795	11.87	8.00	6.94	10.98
2800	11.83	7.95	6.53	10.49

TABLE 2. VSWR OF HORN AND TRANSITION

FREQUENCY MHz	PEAK POSITION cm	NULL POSITION cm	VSWR
2670.05	12.44	8.23	1.055
2675.00	12.10	7.13	1.070
2680.03	12.04	7.50	1.030
2685.01	10.27	15.43	1.020
2690.08	9.00	12.88	1.012
2695.09	8.03	11.66	1.025
2700.09	6.70	11.53	1.050
2705.07	6.60	11.06	1.080
2710.06	6.24	10.30	1.095
2715.00	5.70	10.00	1.122
2719.98	5.40	9.80	1.138
2725.00	13.60	9.28	1.155
2730.03	13.25	9.02	1.162
2735.06	12.84	8.60	1.173
2740.02	12.65	8.33	1.157
2745.03	12.05	8.00	1.160
2750.02	11.87	7.69	1.148
2755.04	11.40	7.35	1.135
2759.98	11.27	7.38	1.120
2765.02	10.66	6.68	1.100
2770.02	10.30	6.57	1.095
2775.05	10.20	6.10	1.080
2780.02	10.03	5.80	1.077
2785.01	9.65	13.70	1.073
2790.04	8.98	12.80	1.069
2795.08	8.56	12.74	1.082
2800.00	8.10	11.96	1.090

TABLE 3. VSWR OF POLARIZER AND TRANSITION
(PORTS TERMINATED WITH MATCHED LOADS)

FREQUENCY MHz	PEAK POSITION cm	NULL POSITION cm	VSWR
Tuning Screws Out 1 Turn.			
2705.00	13.25	8.69	1.096
2710.02	13.27	8.60	1.095
2715.02	12.80	8.22	1.095
Tuning Screws Out 2 Turns.			
2700.04	13.03	8.36	1.10
2705.01	13.36	8.36	1.095
2710.00	13.04	8.34	1.10
2715.02	12.80	8.24	1.09
Tuning Screws Out 3 Turns.			
2705.00	12.90	8.57	1.10
2710.03	12.90	8.52	1.09
2715.00	12.66	8.25	1.085

2.4 POLARIZER ASSEMBLY

A device, known as a polarizer, was required to generate the various linear and circular polarizations of operation. The unit of choice is a sloped septum polarizer because this device can directly generate each state of circular polarization from a single waveguide input, thus minimizing the number of waveguide junctions in this mode of operation. This is essential, as the circular polarization scattering matrix measurments require the most polarization isolation, and as high polarization isolation implies a minimum VSWR ($<$ 1.02:1) on all polarizer ports. Minimizing the number of waveguide junctions is necessary to reduce VSWR.

In the less critical linear polarization diversity mode of operation, a topwall hybrid coupler is added to the circuit (Figures 24 and 25). Here the VSWR requirements are $<$ 1.1:1. However, reconsideration of the differential reflectivity polarization isolation requirements has indicated that a further reduction in the VSWR requirement may be applicable [3].

The polarizer assembly including polarizer, switches, topwall coupler, square waveguide section, square waveguide to circular waveguide section, and assorted waveguide pieces was supplied to Atlantic Microwave Corp., of Bolton, Mass., under a subcontract issued by Georgia Tech.

2.5 INSTALLATION

The final step to the antenna modification was the installation and testing of the antenna system. While the installation proceeded in an orderly fashion, the system tests had to be abbreviated due to prior commitments of the radar.

Georgia Tech began installing the antenna hardware on 9 August 1983. Between 9 August and 18 August the existing feed and tripod support assembly were removed and four reflector panels were drilled, pinned, and removed. Following this, the quadrapod subreflector mount and feed mount were installed, and the modified reflector was assembled. Throughout this operation, Georgia Tech was assisted by a mechanical technician from H & W Industries and by AFGL personnel.

Hardware installation was completed during the period from 22 August to 26 August 1983. After the feed horn was installed, the subreflector and feed horn were mechanically aligned, and initial pattern measurements were performed. Azimuth sidelobes were measured between 18 dB and 19 dB below the main lobe peak at 2.710 GHz and between 16 dB and 17 dB at 2.760 GHz.

During the initial pattern measurements, moderate swings in boresight amplitude were noticed. AFGL believed that the amplitude change was due to shifting of the transmitting antenna. This antenna is a 10 foot prime focus reflector mounted approximately at the 40 foot level of a tower located on Nobscot Hill, at a range of 4.9 miles. Since the owner of the tower (Raytheon Co.) donated the space with the provision that any attachment would employ no welding or drilled holes, a clamping arrangement was devised. Before these tests, the prevailing wind had sufficiently distorted the mount so that the antenna was no longer rigidly held.

Pattern measurements taken by AFGL personnel during the period from 29 August to 12 September indicated that all azimuthal patterns had asymmetrical first nulls. Upon investigation, a drooping of the feed was discovered when the antenna axis was rotated from the vertical to the horizontal. This droop was due to insufficient feed support. H & W Industries then fabricated and assisted in the installation of four feed support spars.

On 17 September 1983, VSWR measurements of the antenna were performed. Two methods were attempted to reduce subreflector VSWR: (1) the addition of a small conically shaped VSWR reduction button at the center of the subreflector and (2) the addition of a post and reactive plate at the same location. The theory of operation of these devices is straightforward. The former attempts to reflect toward the side of the antenna those rays which may otherwise reflect from the subreflector into the feed horn. The latter introduces an out-of-phase component to the electric field to cancel this undesired reflected ray.

Both devices were inefficient at reducing antenna VSWR (Figures 26, 27, and 28). However, since the post reduced VSWR somewhat, it was left on the subreflector. During the following two weeks, antenna patterns were measured by AFGL personnel. Very high sidelobe levels were noted which were eventually determined to be a result of the VSWR reduction post. The post was removed and replaced by a conical VSWR reduction button of 3-inch diameter.

No further testing was possible in 1983 because of prior commitments of the radar system. Subsequently, it was also discovered that the feed support assembly placed the feed one inch closer to the subreflector than required. This overextension was corrected in August 1984 so that the antenna assembly can be properly focused.

SECTION 3
CONCLUSION

The antenna of the AFGL S-band Doppler weather radar has been modified for dual polarization operations, and its proper operation has been partially confirmed. Final focusing and overall VSWR reduction are required before cross-polarization levels can be determined. A reduction of the first sidelobe levels is also required before polarimetric measurements are made. Possible methods for accomplishing this include modification of the shape of the subreflector support spars and modification of the illumination of the main reflector by means of microwave absorbing material.

SECTION 4
PERSONNEL

The following scientists and engineers contributed to the research reported in this document.

Person	Contribution and Affiliation
James S. Ussailis	Project Director; Georgia Tech
Joseph M. Newton	Electrical Design of Feed Horn; Georgia Tech
Donal Gallentine	Mechanical Design of Feed Horn; Georgia Tech
Keith D. Vaughn	Testing of Feed Horn, Installation; Georgia Tech
Edward Salzberg	Polarizer Design and Manufacture; Atlantic Microwave Corp. Rt. 117, Bolton, Mass. 01740
Robert Dalton	Polarizer Mechanical Design; Atlantic Microwave Corp.
Thomas P. Walsh, PE	Mechanical Analysis of Antenna Design; H & W Industries, Inc. Cohassett, Mass.
James Hayes	Mechanical Design of Antenna; H & W Industries, Inc.
Graham Armstrong	Contract Monitor Air Force Geophysics Laboratory Ground Based Remote Sensing Branch Hanscom AFB, Mass. 01730
Alexander Bishop	Testing Assistance; AFGL
James I. Metcalf	Technical Assistance; AFGL

SECTION 5

PREVIOUS CONTRACT AND PUBLICATION

Previous Related Contract:	F19628-81-K-0027
Final Report:	"Analysis of a Polarization Diversity Weather Radar Design"; Ussailis, J. S., Leiker, L. A., Goodman, R. M. IV, and Metcalf, J. I., Georgia Institute of Technology, Engineering Experiment Station, Project A-2807, Atlanta, GA, 2 July 1982. Report No. AFGL-TR-82-02344, Air Force Geophysics Laboratory.

SECTION 6

PUBLICATIONS PARTIALLY SPONSORED BY THIS CONTRACT

1. "System Errors in Polarimetric Radar Backscatter Measurements", Ussailis, J. S., and Metcalf, J. I., Proceedings of 2nd Workshop on Polarimetric Radar Technology, Redstone Arsenal, AL, 3-5 May 1983.

2. "Radar System Errors in Polarization Diversity Measurements", Metcalf, J. I. and Ussailis, J. S., Preprints, 21st Conference on Radar Meteorology, Edmonton, Alberta, Canada, 19-23 September 1983.

3. "Analysis of a Polarization Diversity Meteorological Radar Design", Ussailis, J. S., and Metcalf, J. I., Preprints, 21st Conference on Radar Meteorology, Edmonton, Alberta, Canada, 19-23 September 1983.

4. "Radar System Errors in Polarization Diversity Measurements:, Metcalf, J. I., and Ussailis, J. S., Journal of Atmospheric and Oceanic Technology, Vol. 1, No. 2, 105-114 (1984).

SECTION 7

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1. Ussailis, J. S., Leiker, L. A., Goodman, R. M. IV, and Metcalf, J. I. "Analysis of a Polarization Diversity Weather Radar Design, Final Report, Project A-2807, Georgia Institute of Technology; AFGL-TR-82-0234, Air Force Geophysics Laboratory, July 1982. AD121666.

2. Ussailis, J. S., and Metcalf, J. I. "Analysis of a Polarization Diversity Meteorological Radar Design," Preprints, 21st Conference on Radar Meteorology, Edmonton, Alberta, Canada, 19-23 September 1983.

3. Metcalf, J. I., and Ussailis, J. S. "Radar System Errors in Polarization Diversity Measurements", Journal of Atmospheric and Oceanic Technology, Vol. 1, in press (1984).

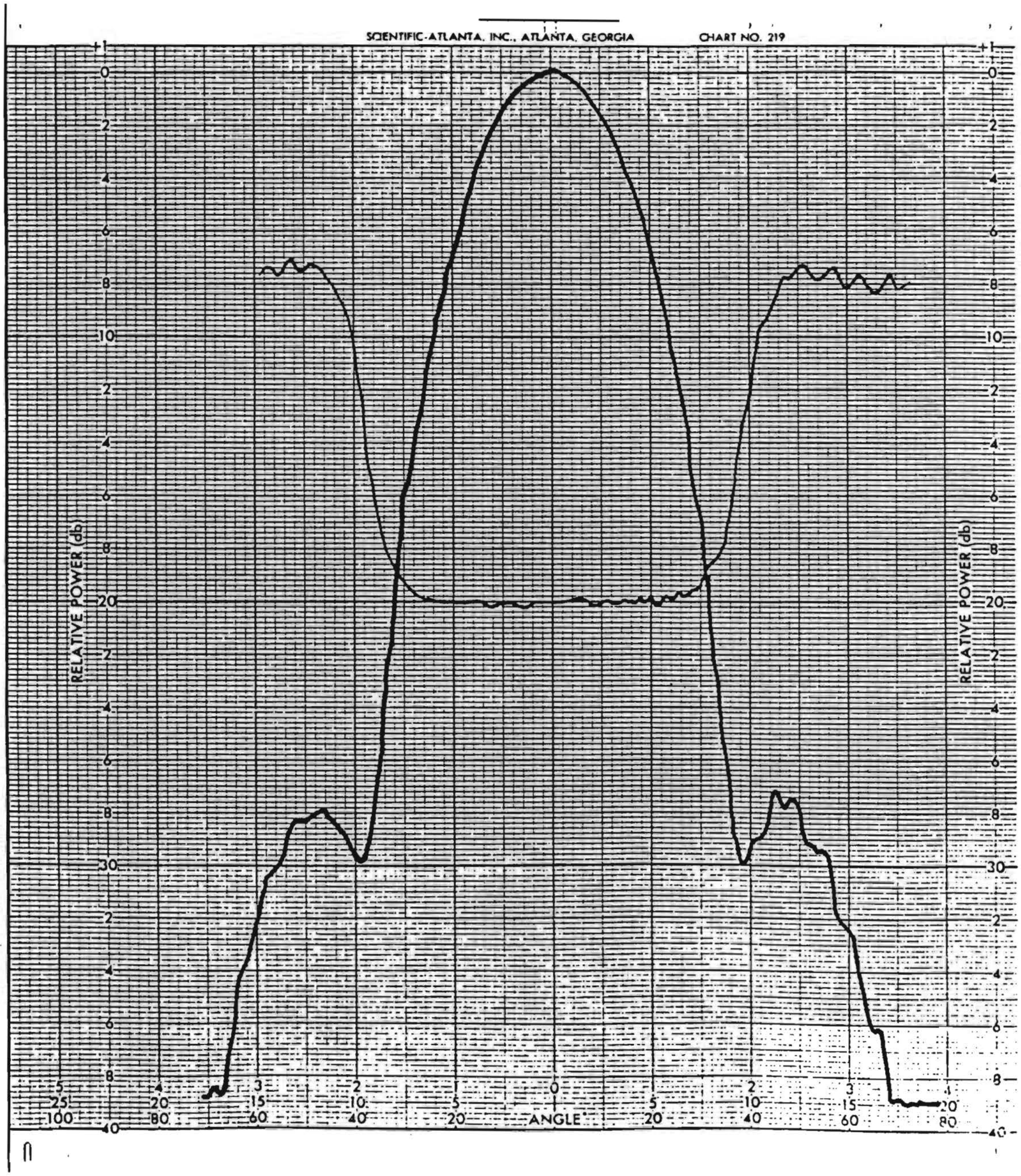

Figure 1. Pattern of scaled feed horn, E-plane, f = 9.4 GHz.

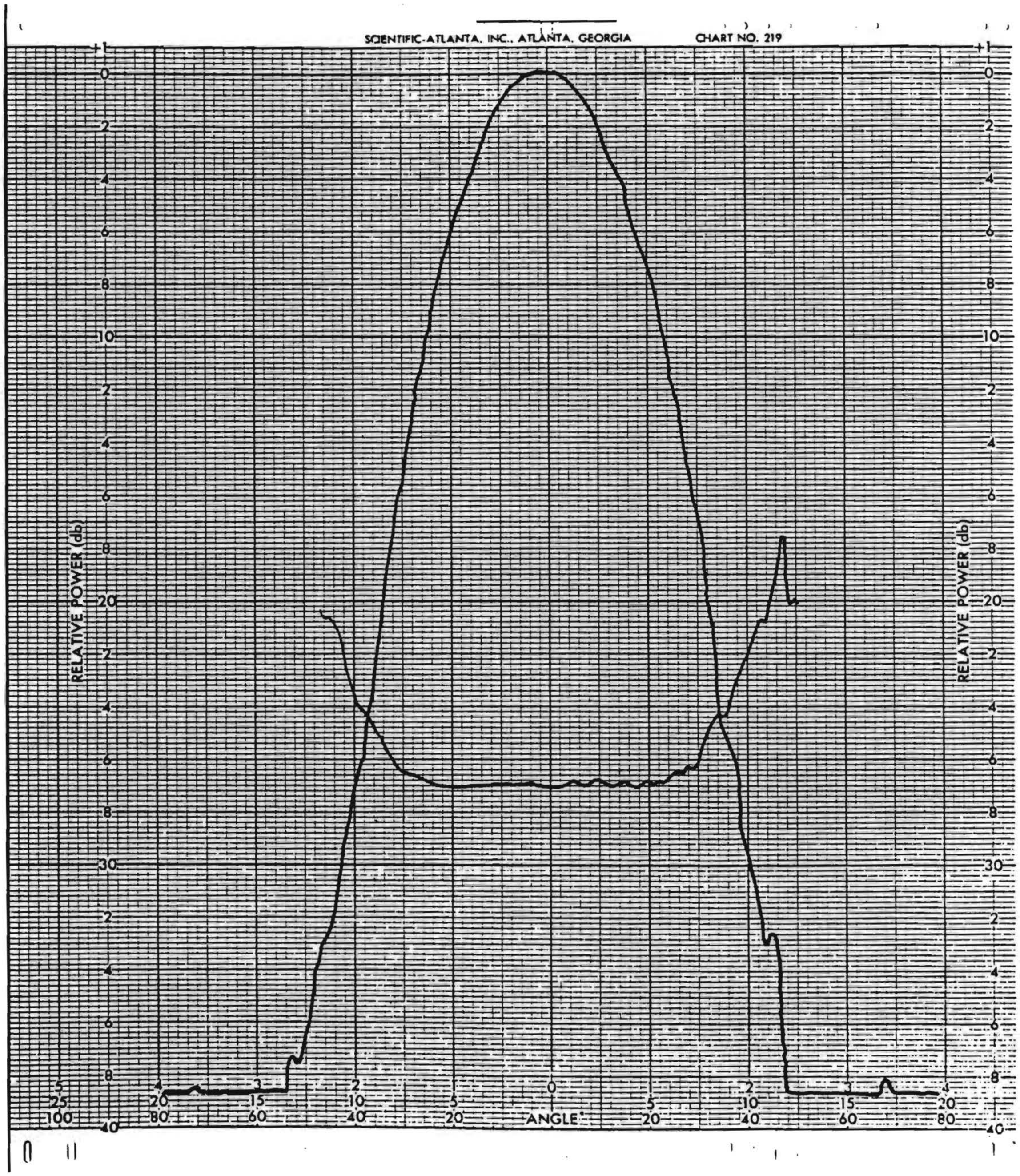

Figure 2. Pattern of scaled feed horn, H-plane, f = 9.4 GHz.

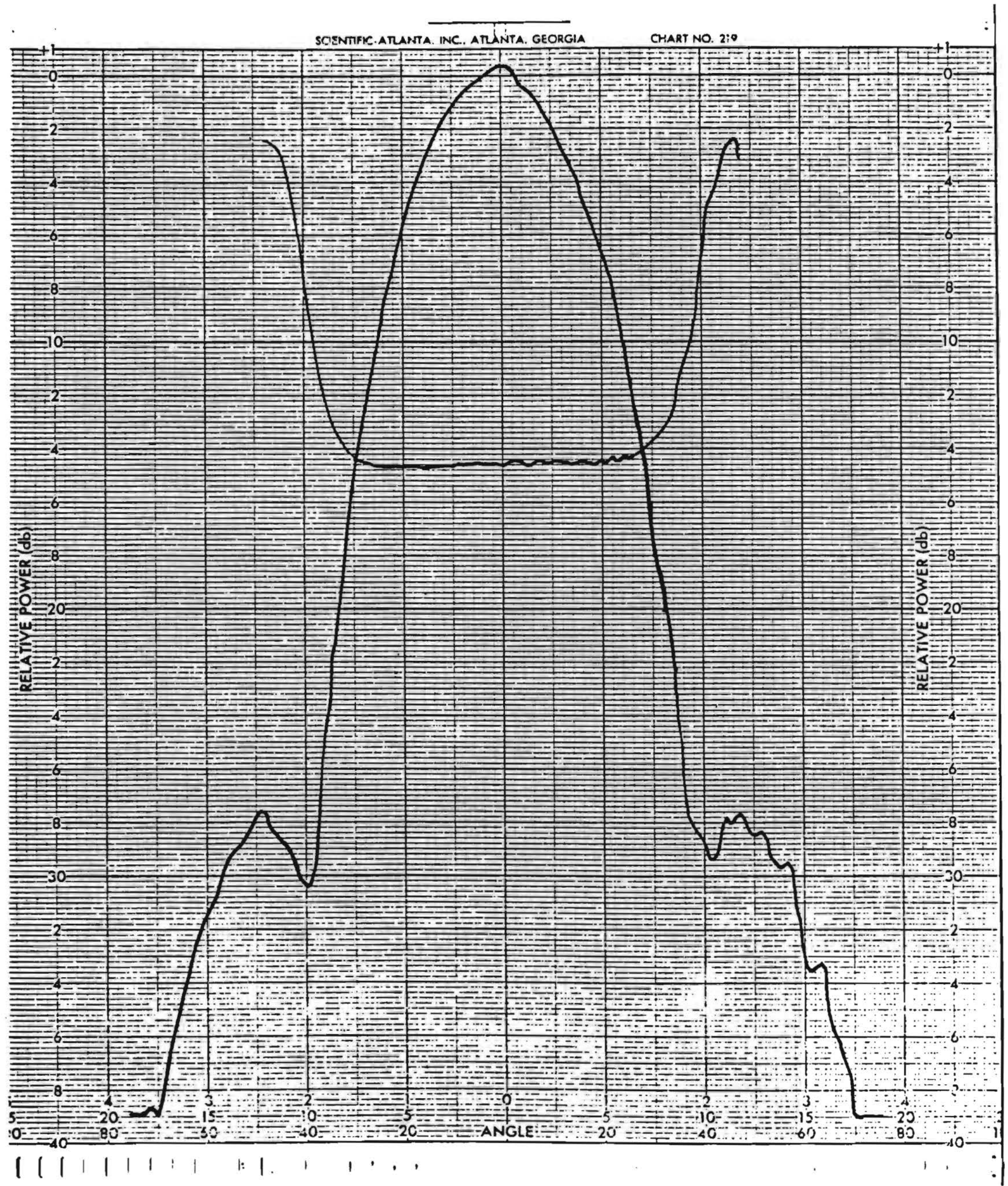

Figure 3. Pattern of scaled feed horn, E-plane, f = 9.3 GHz.

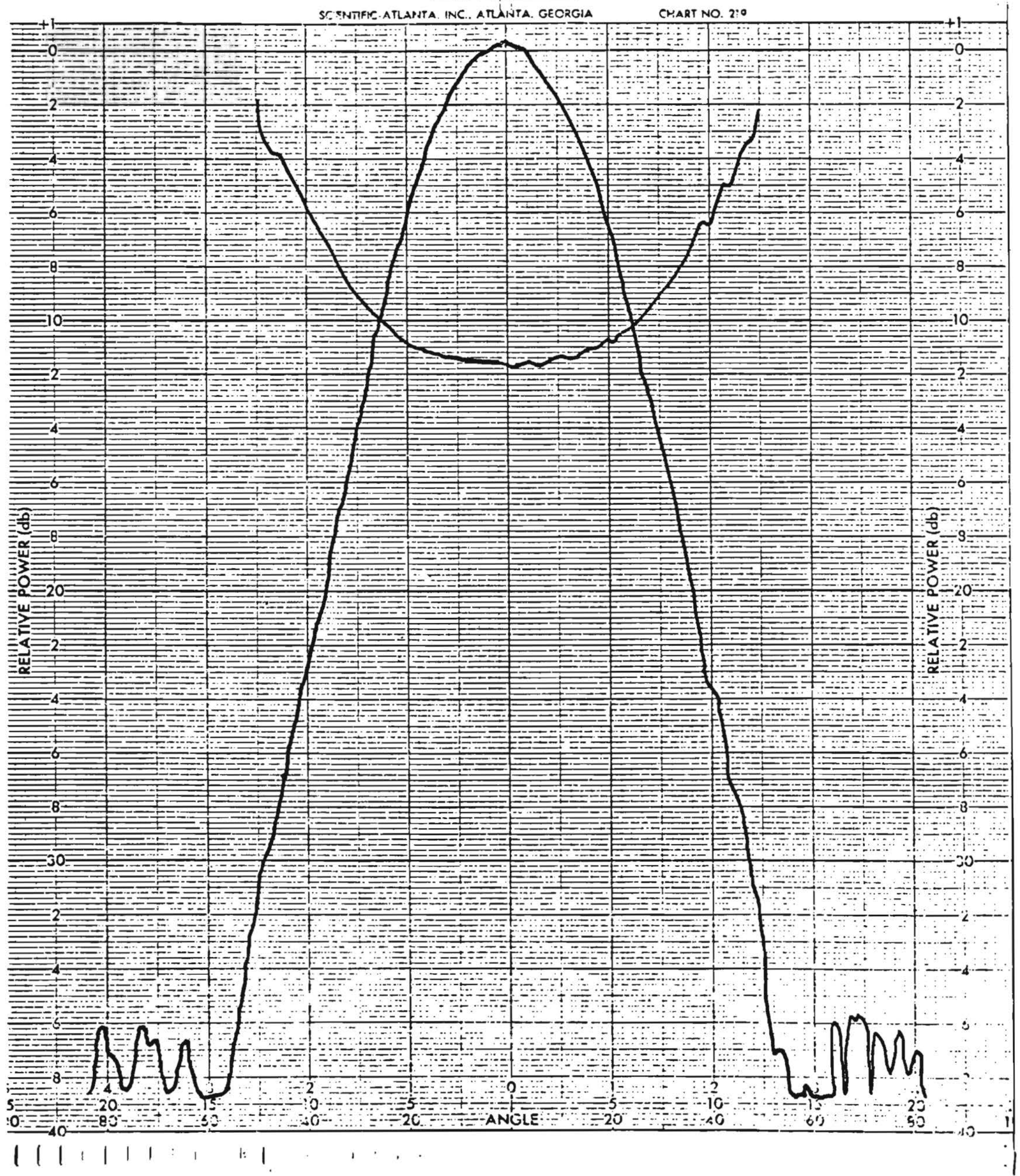

Figure 4. Pattern of scaled feed horn, H-plane, f = 9.3 GHz.

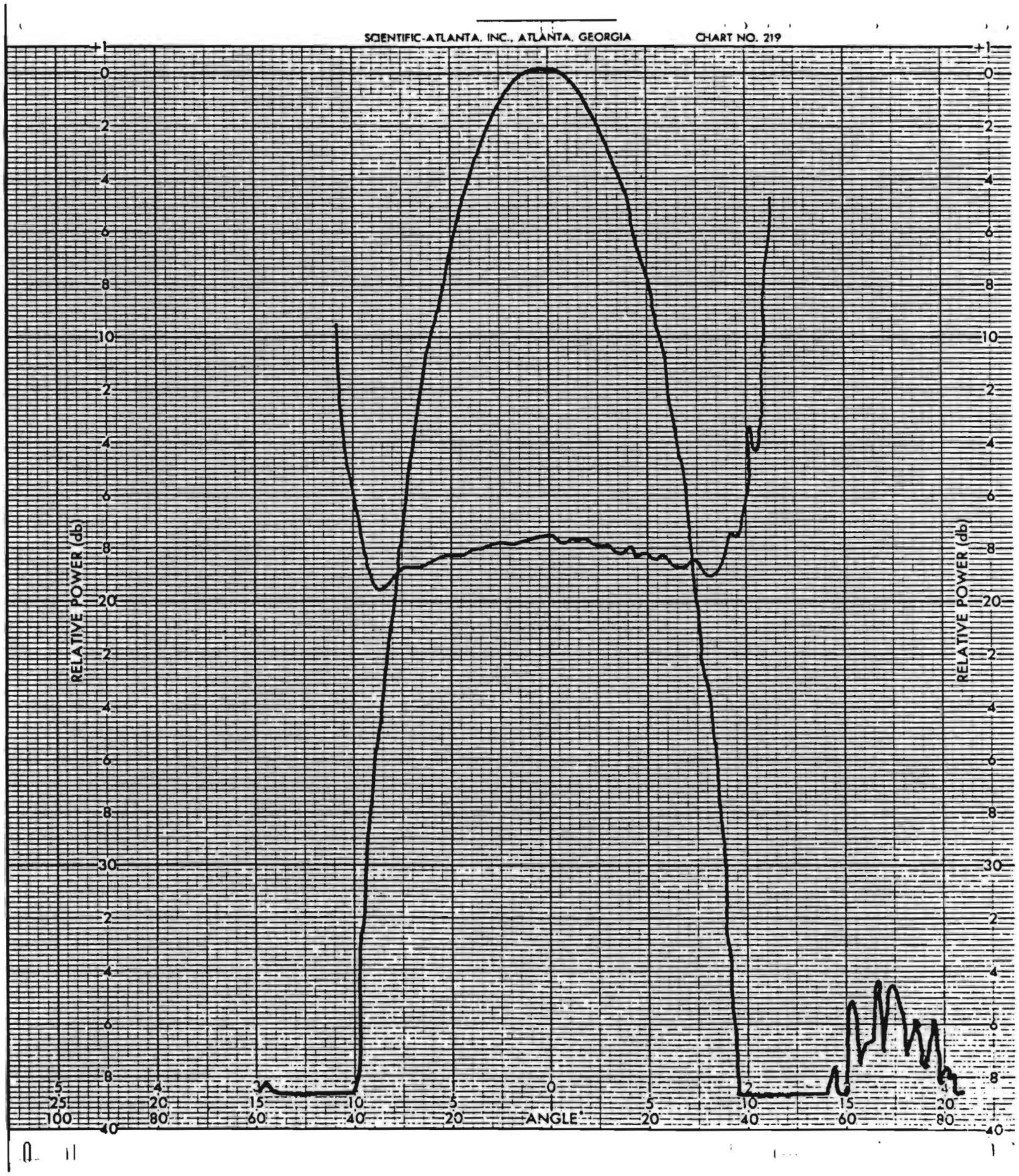

Figure 5. Pattern of scaled feed horn, H-plane, f = 9.5 GHz.

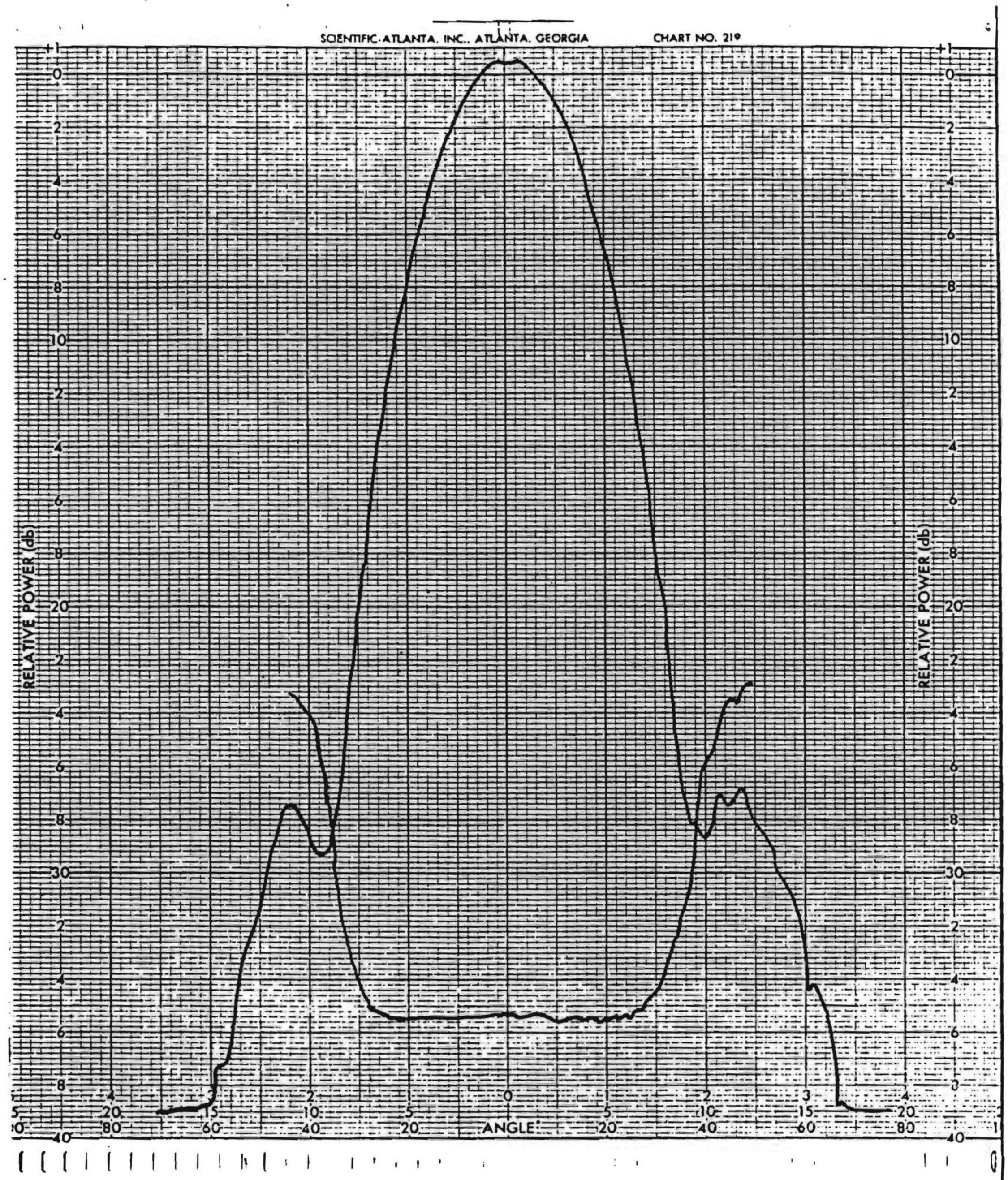

Figure 6. Pattern of scaled feed horn, E-plane, f = 9.5 GHz.

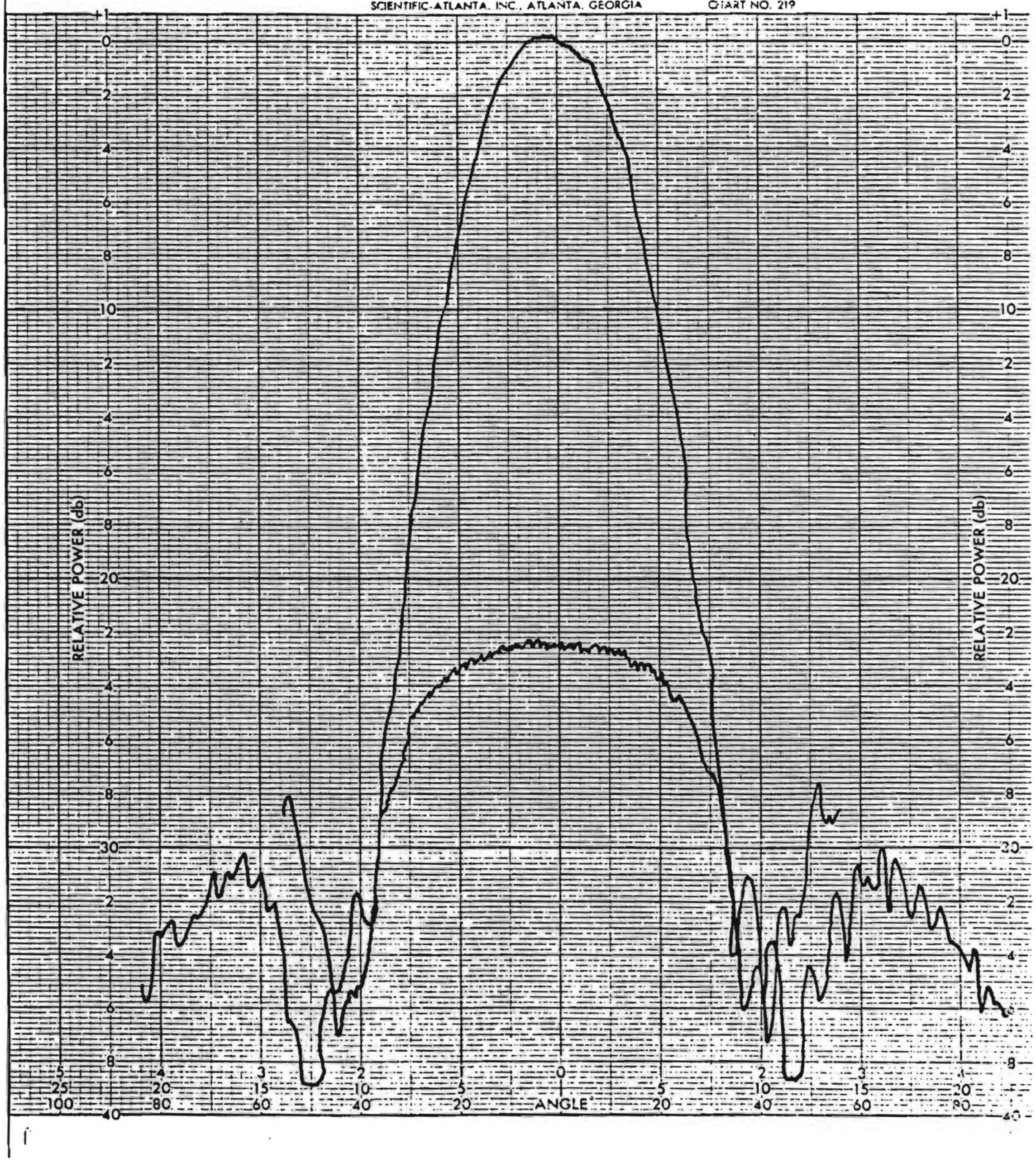

Figure 7. Pattern of scaled feed horn, H-plane, f = 9.6 GHz.

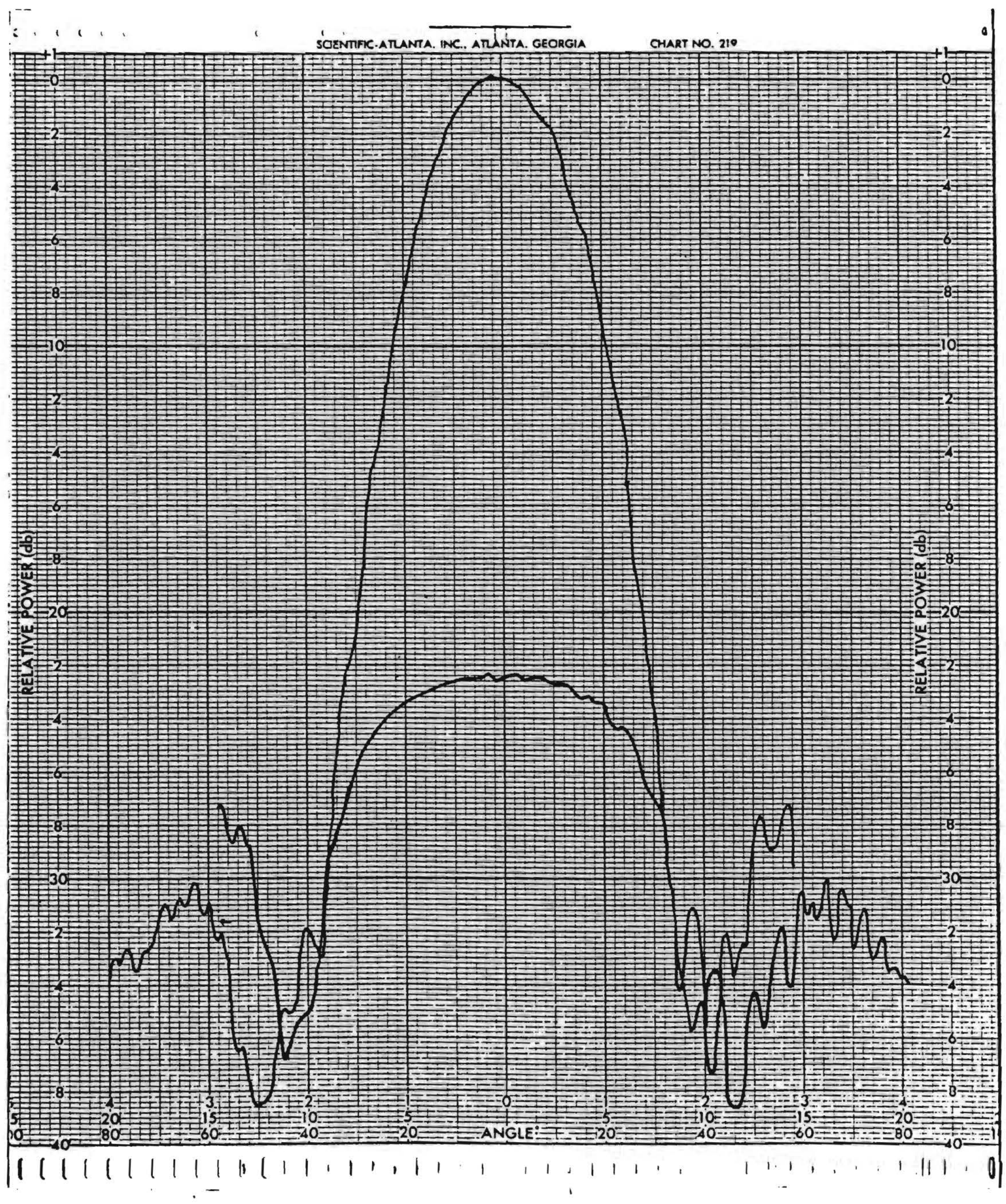

Figure 8. Pattern of scaled feed horn, H-plane, f = 9.7 GHz.

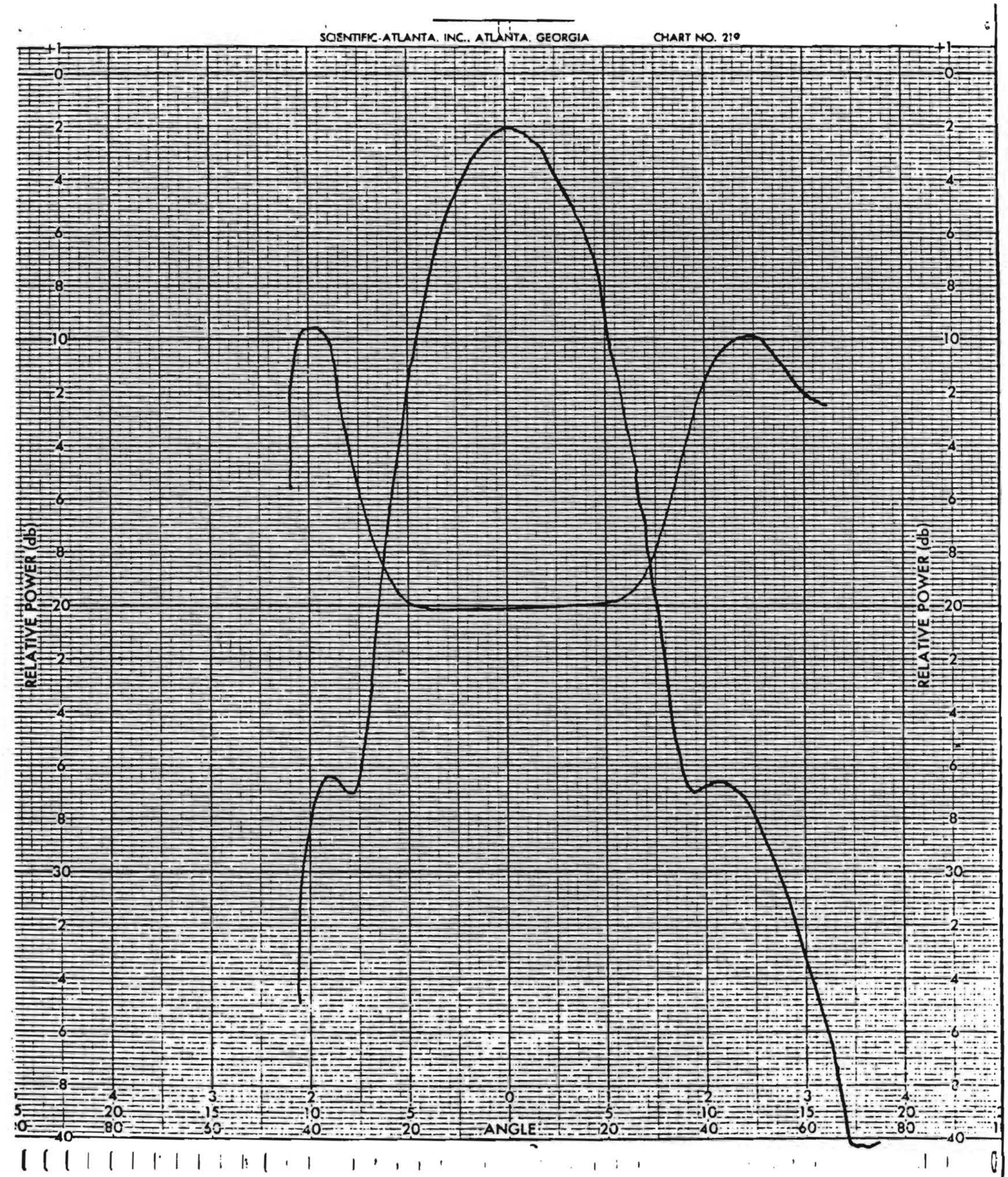

Figure 9. H-plane pattern of full-size feed in final configuration, f = 2.71 GHz. Phase center is 2-5/8 inches inside aperture.

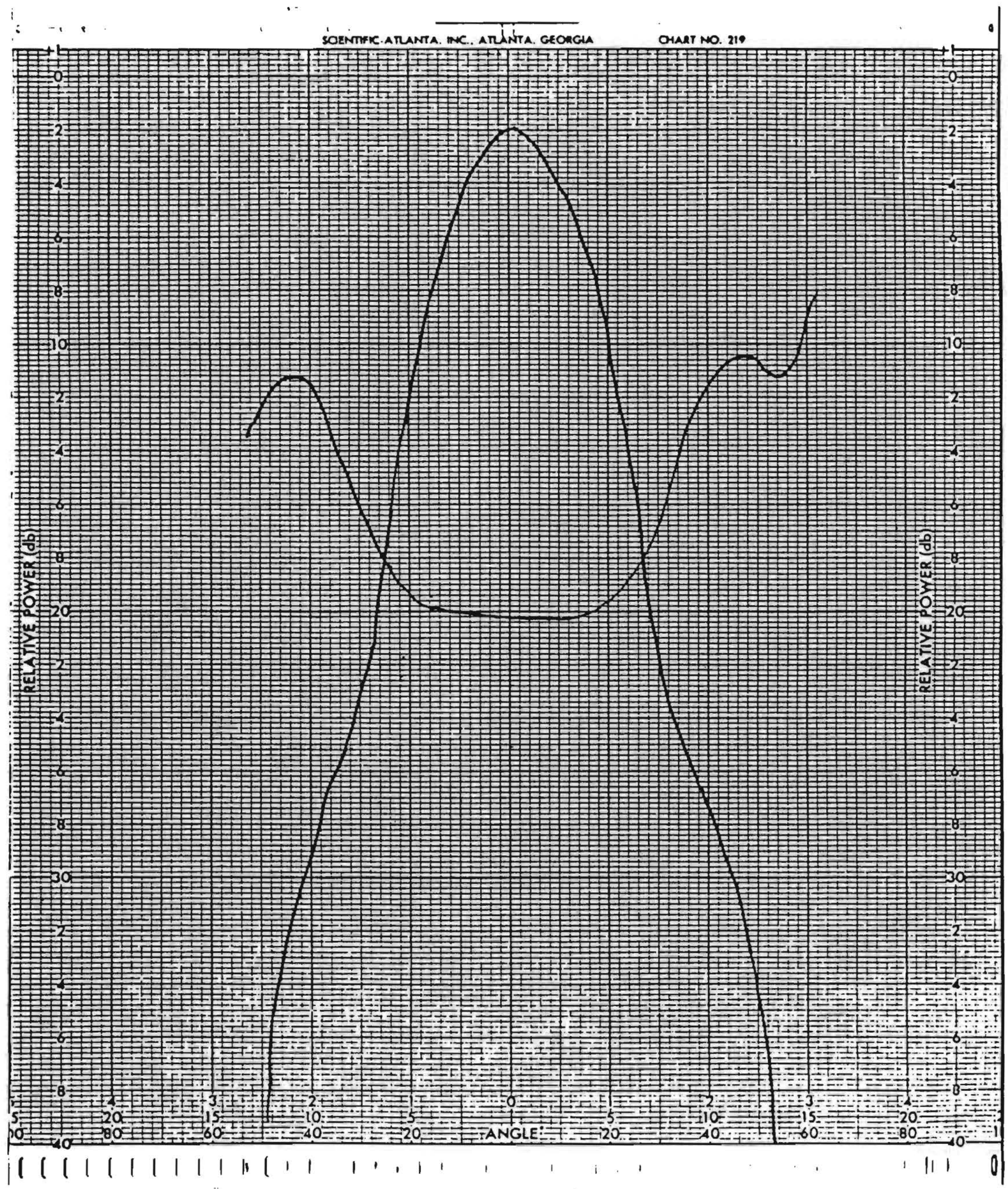

Figure 10. E-plane pattern, f = 2.71 GHz; same conditions as Figure 9.

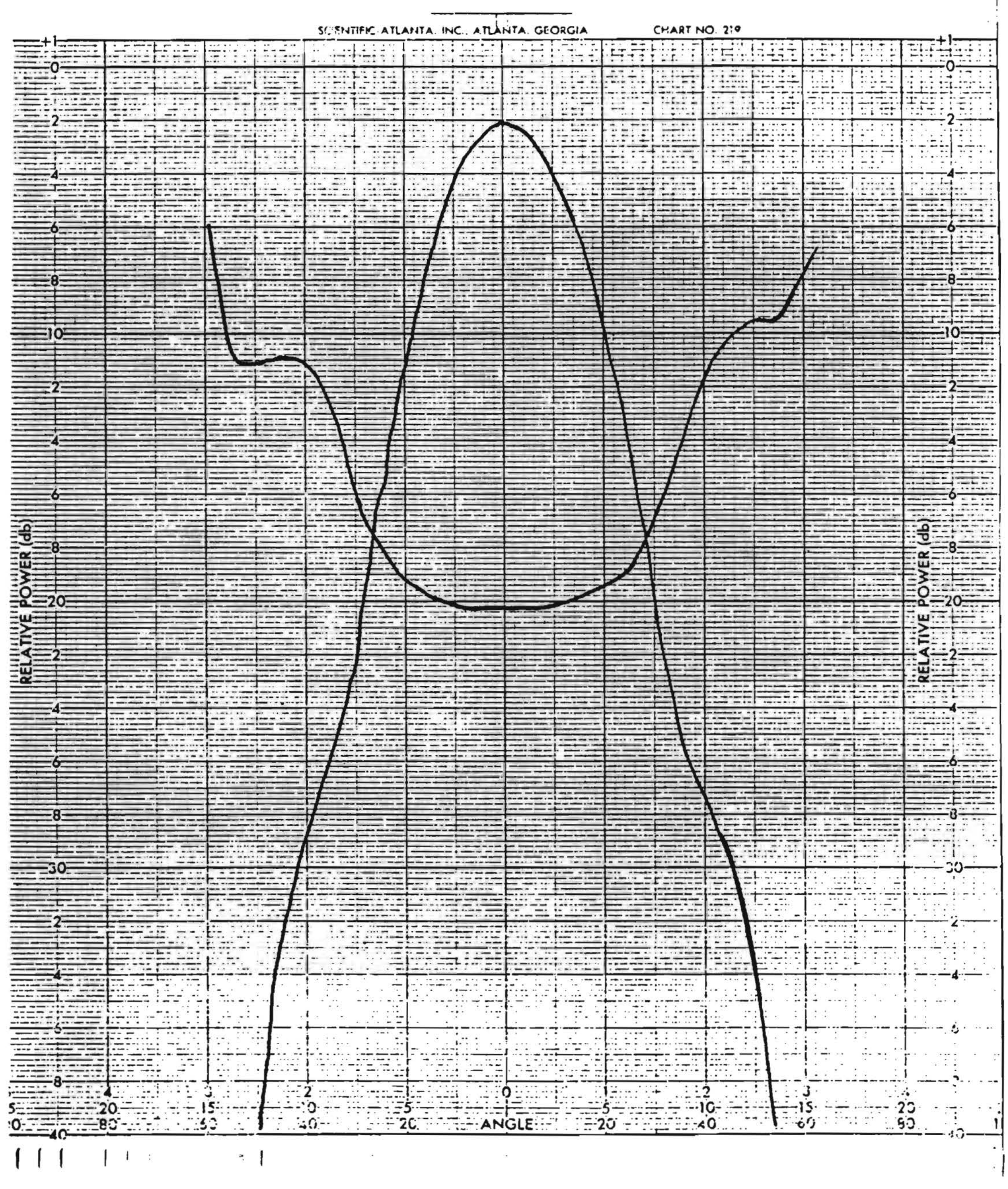

Figure 11. E-plane pattern of full-size feed in final configuration, f = 2.71 GHz. Phase center is 2-13/16 inches inside the aperture.

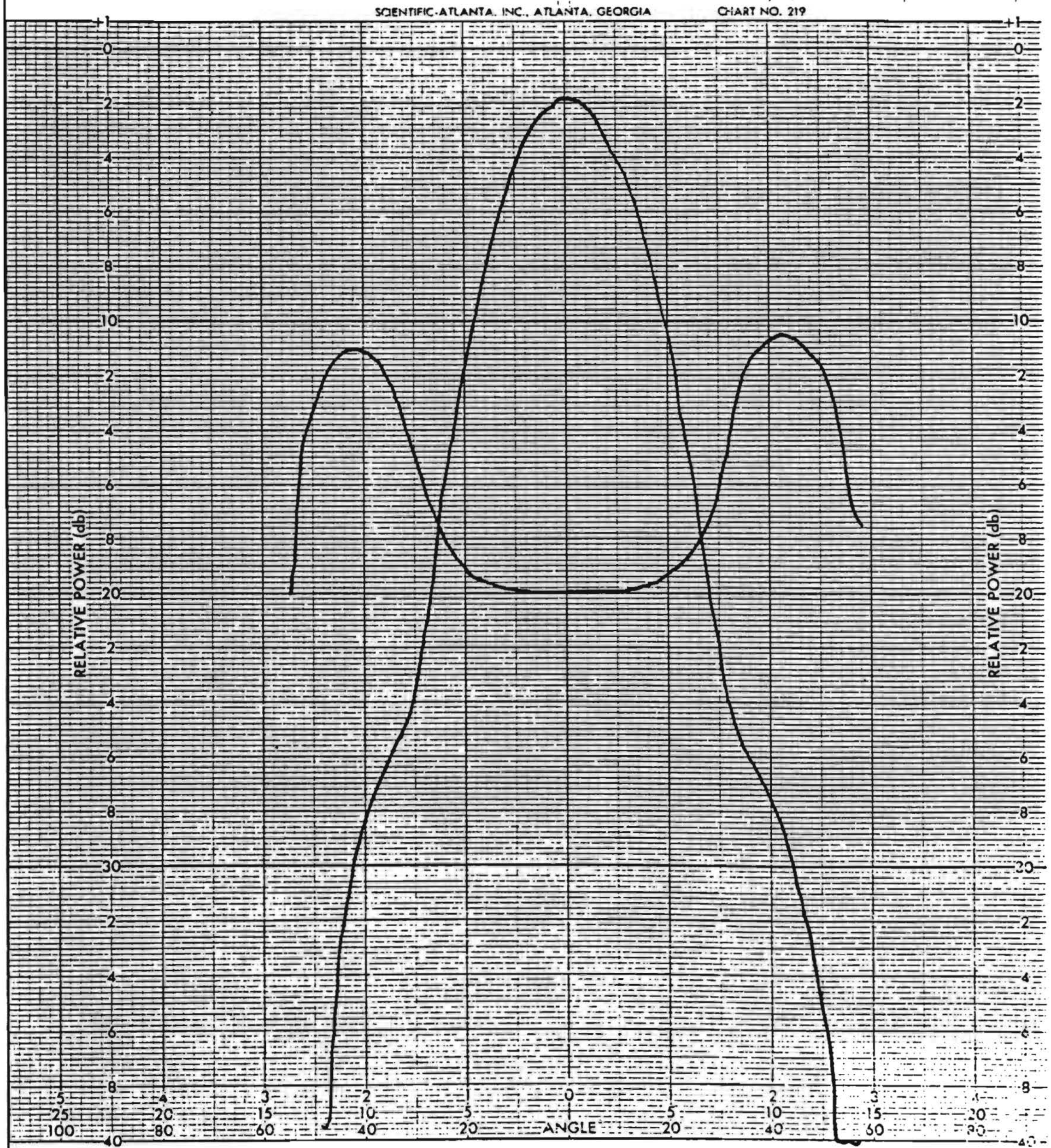

Figure 12. E-plane pattern, f = 2.7 GHz; same condition as Figure 11.

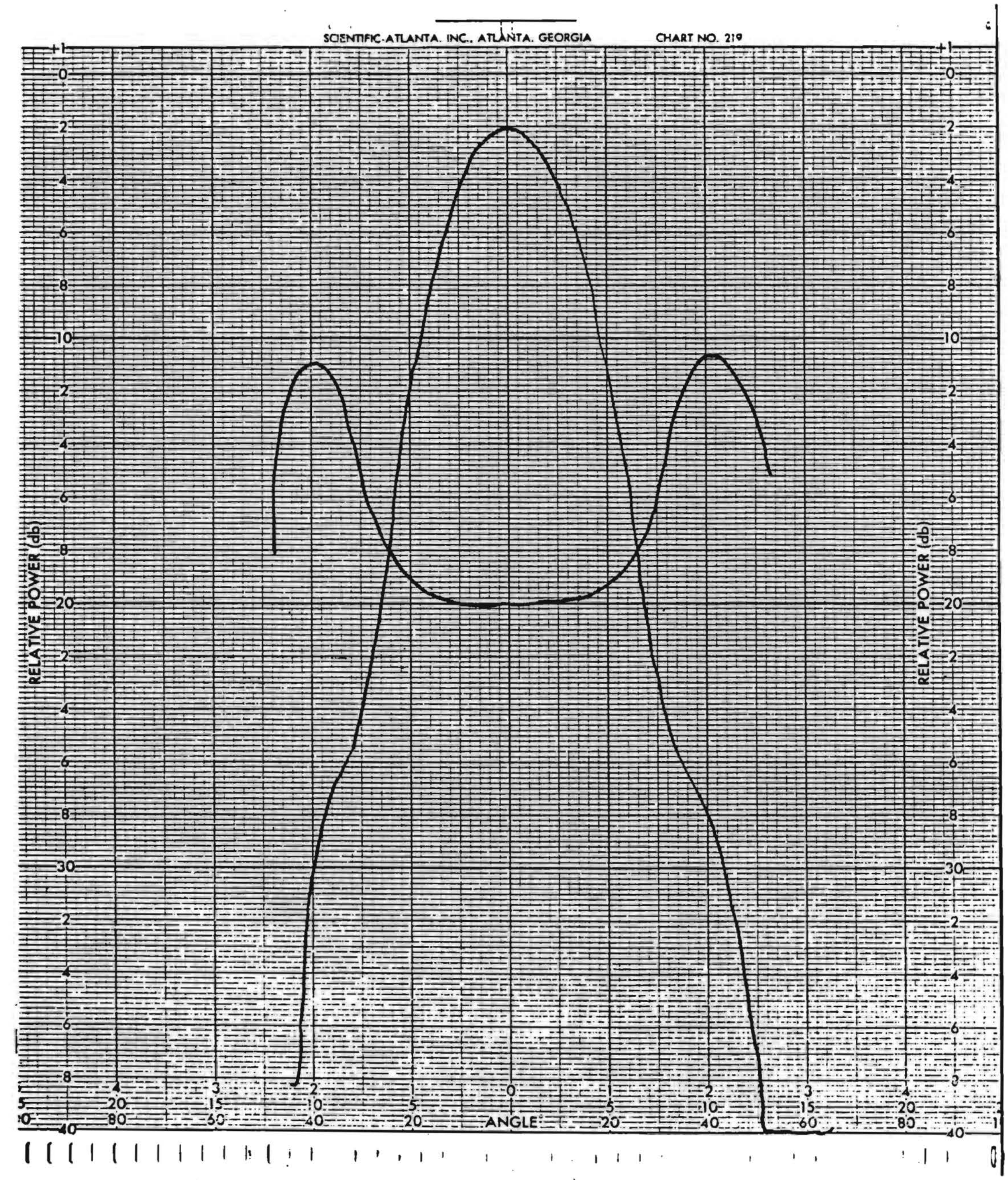

Figure 13. E-plane pattern, f = 2.72 GHz; same conditions as Figure 11.

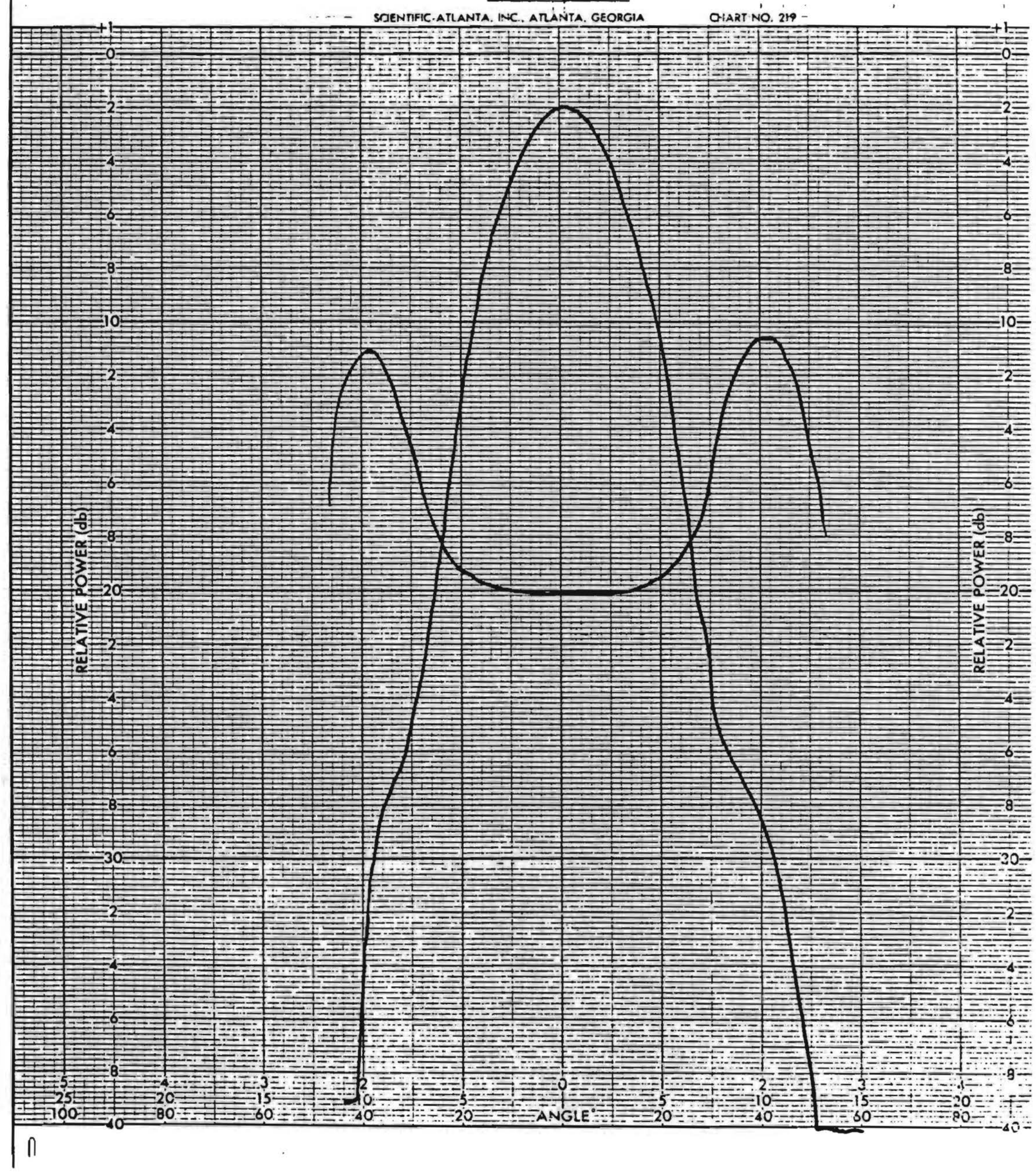

Figure 14. E-plane pattern, f = 2.73 GHz; same conditions as Figure 11.

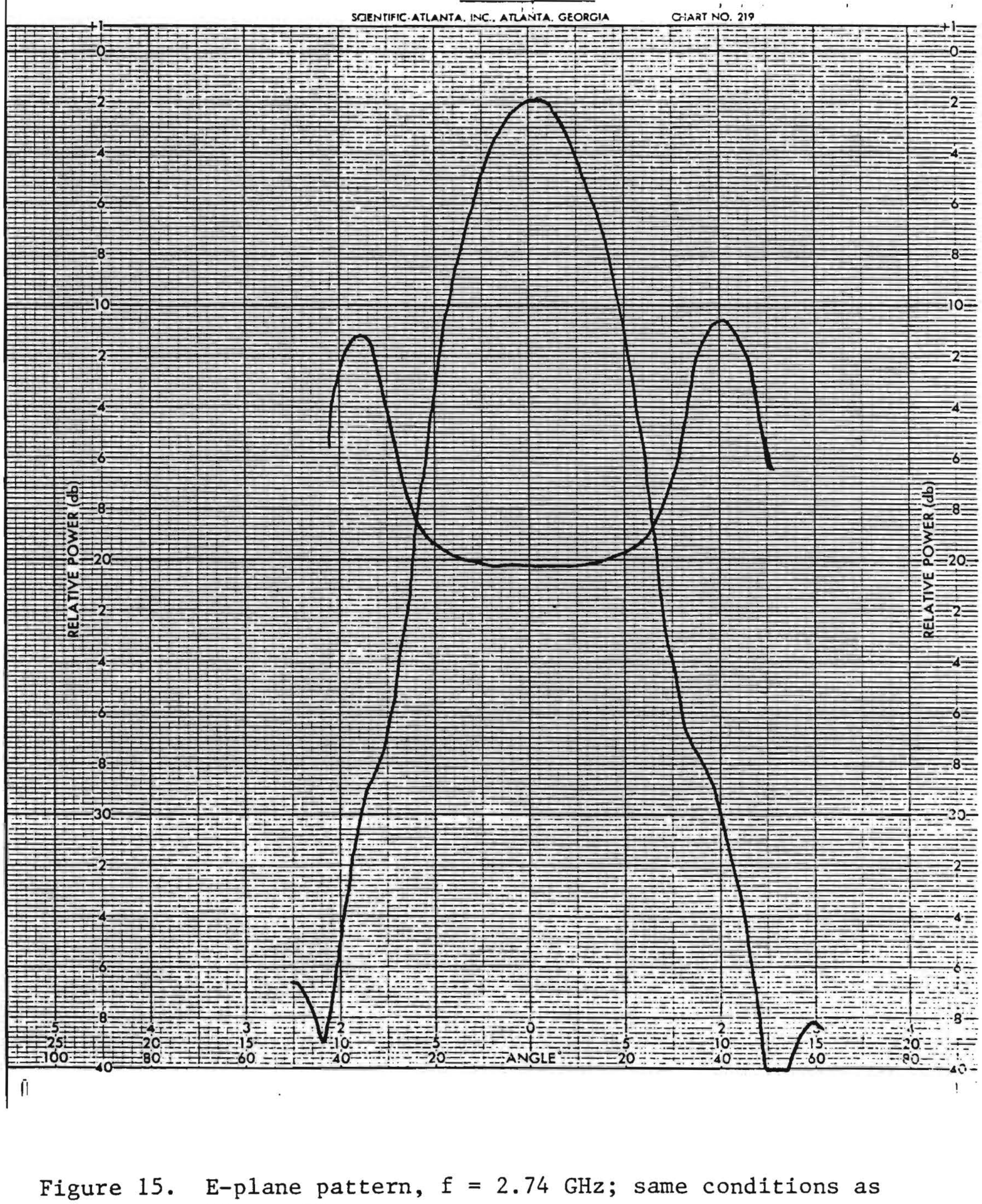

Figure 15. E-plane pattern, f = 2.74 GHz; same conditions as Figure 11.

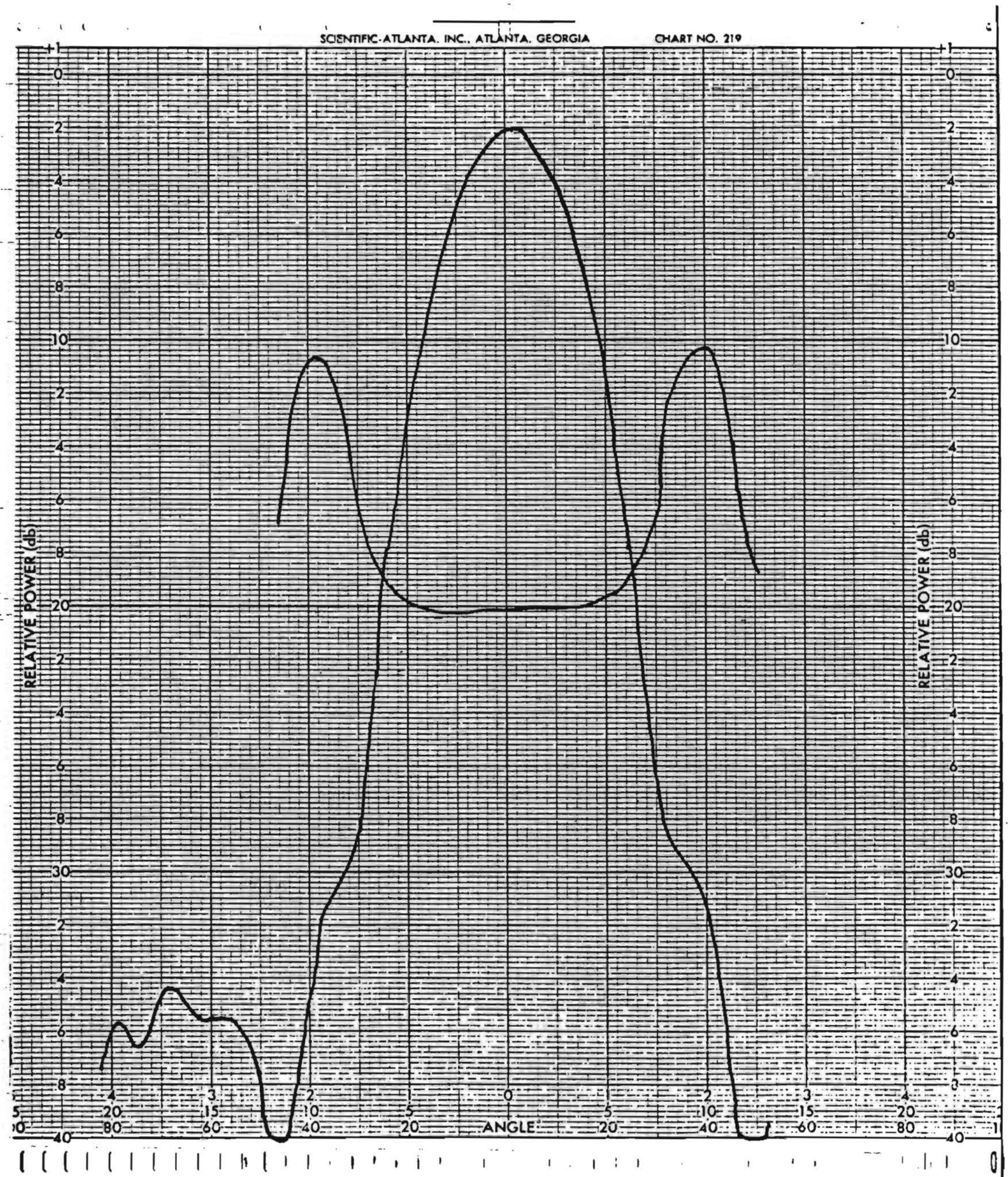

Figure 16. E-plane pattern, f = 2.75 GHz; same conditions as Figure 11.

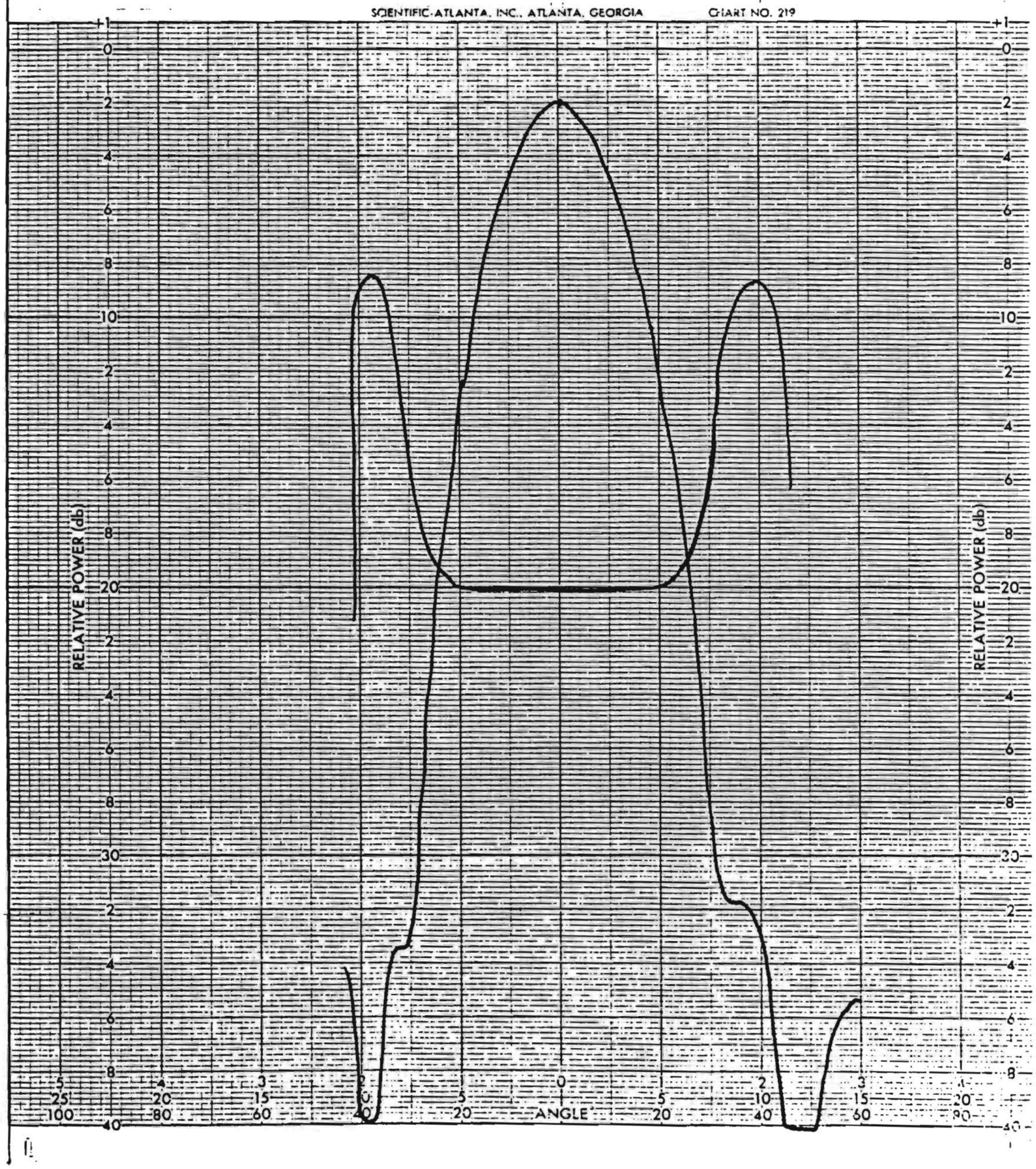

Figure 17. E-plane pattern, f = 2.76 GHz; same conditions as Figure 11.

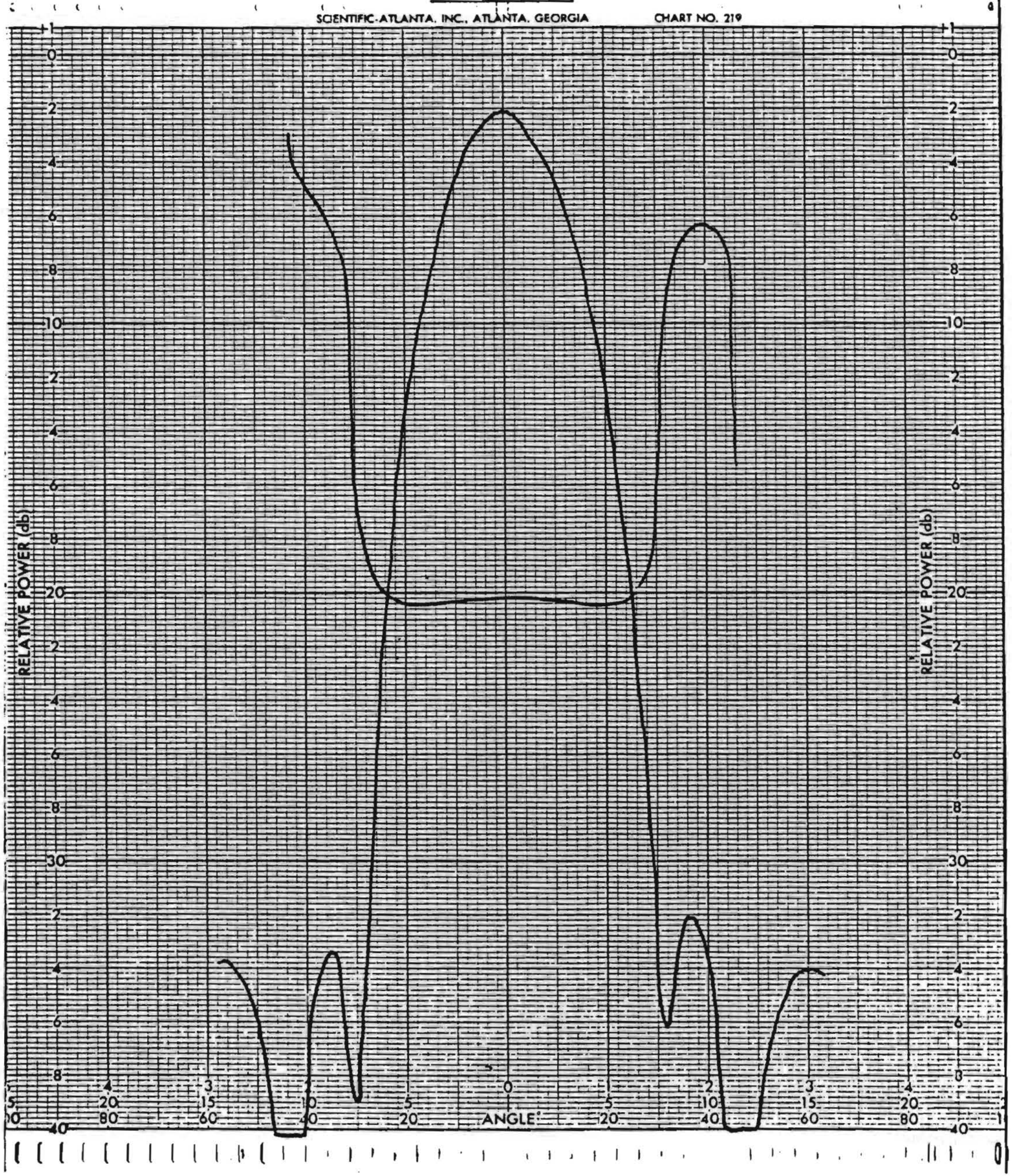

Figure 18. E-plane pattern, f = 2.77 GHz; same conditions as Figure 11.

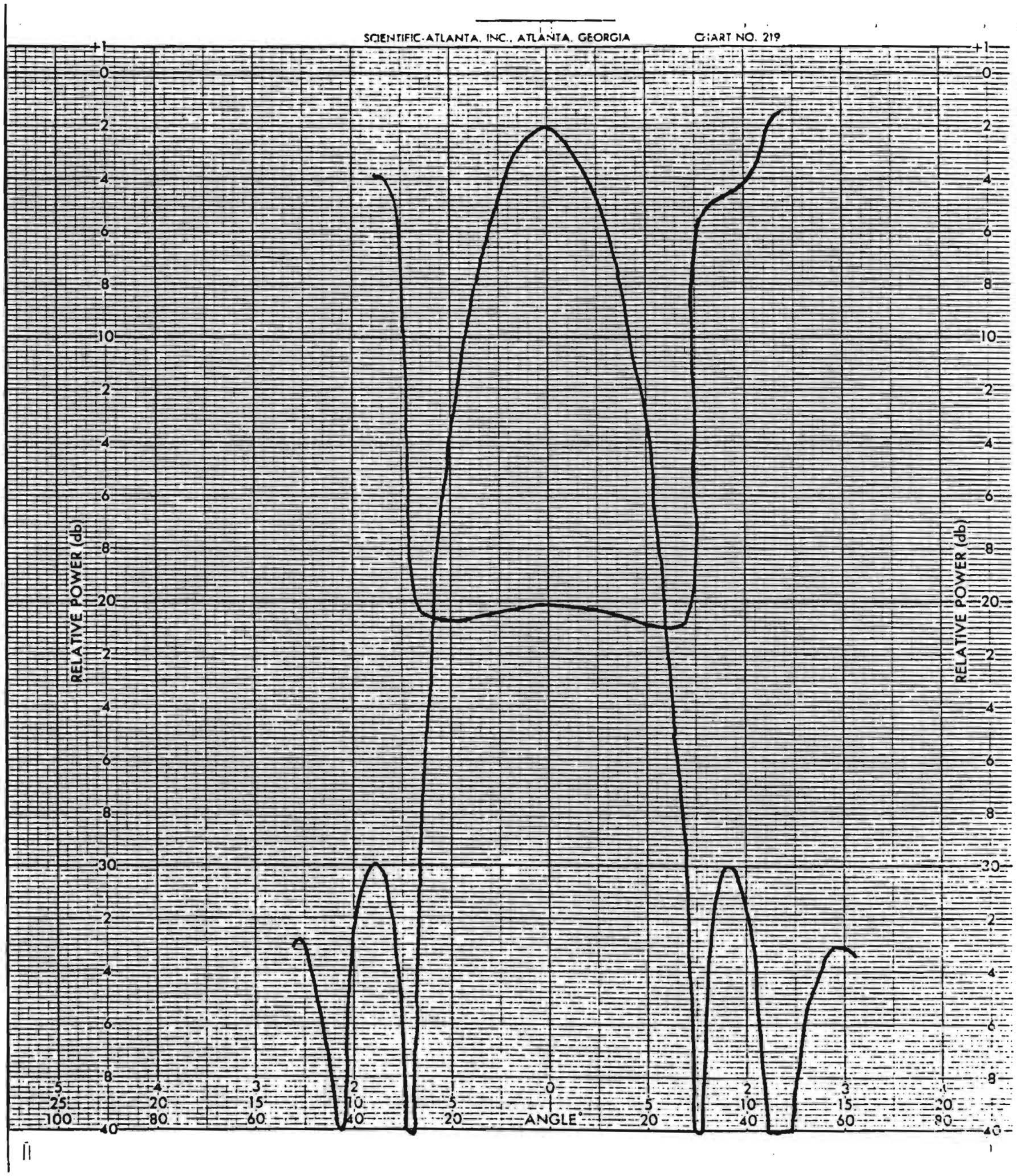

Figure 19. E-plane pattern, f = 2.78 GHz; same conditions as Figure 11.

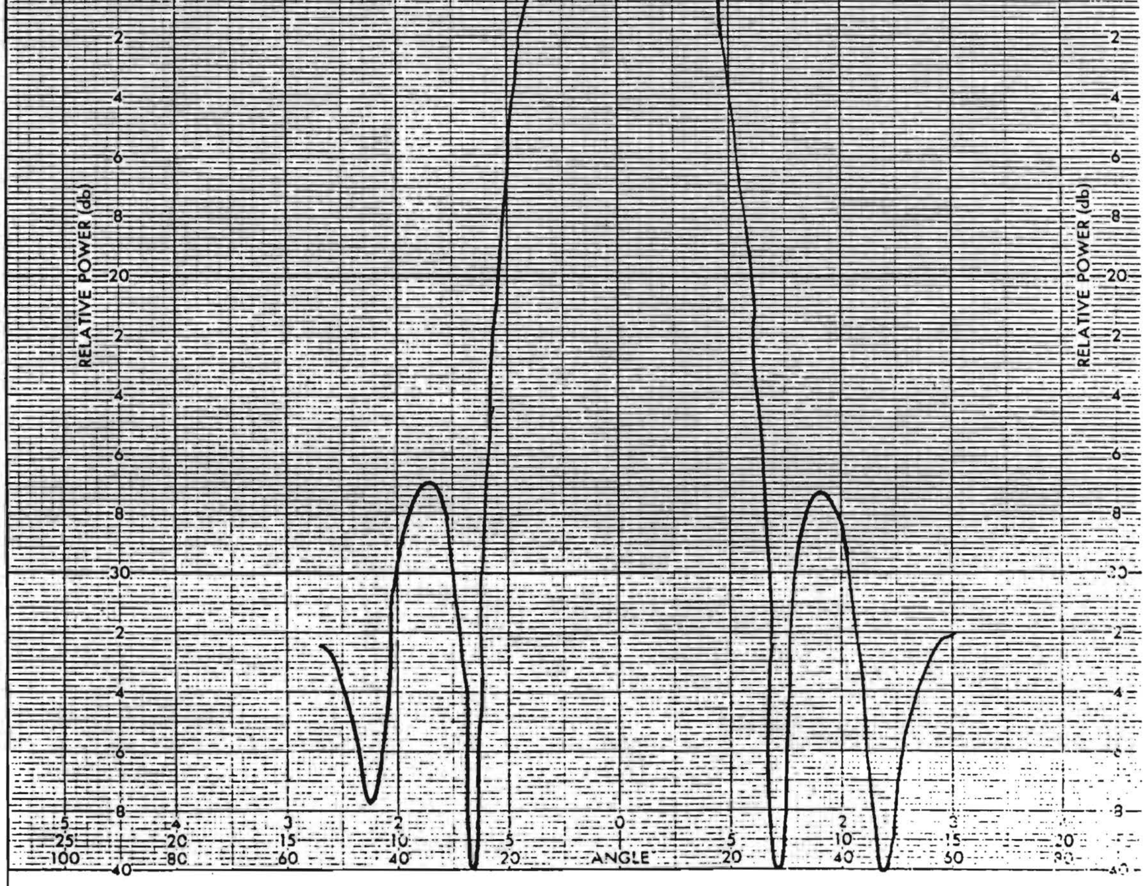

Figure 20. E-plane pattern, f = 2.79 GHz; same conditions as Figure 11.

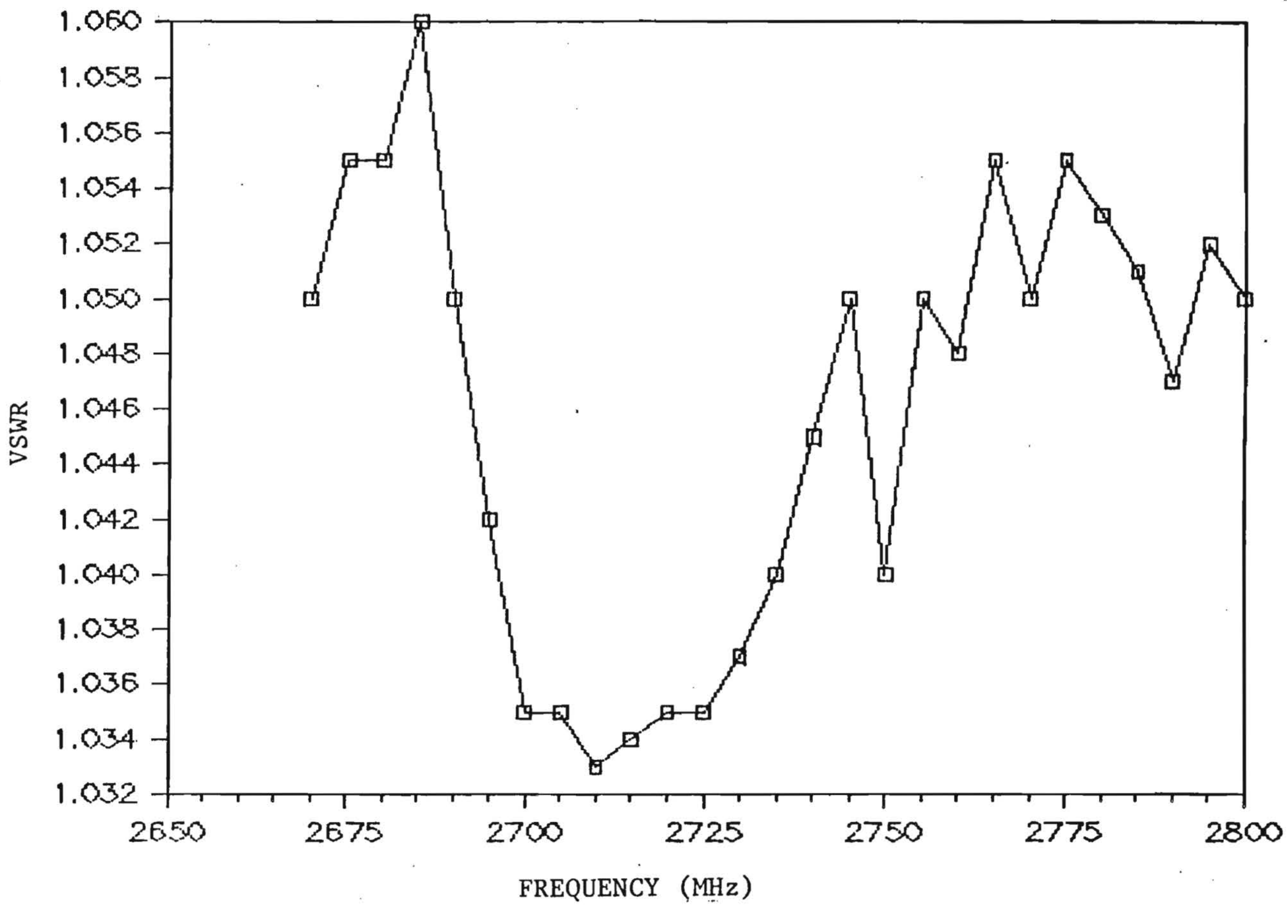

Figure 21. VSWR of rectangular-to-circular transition with circular load attached.

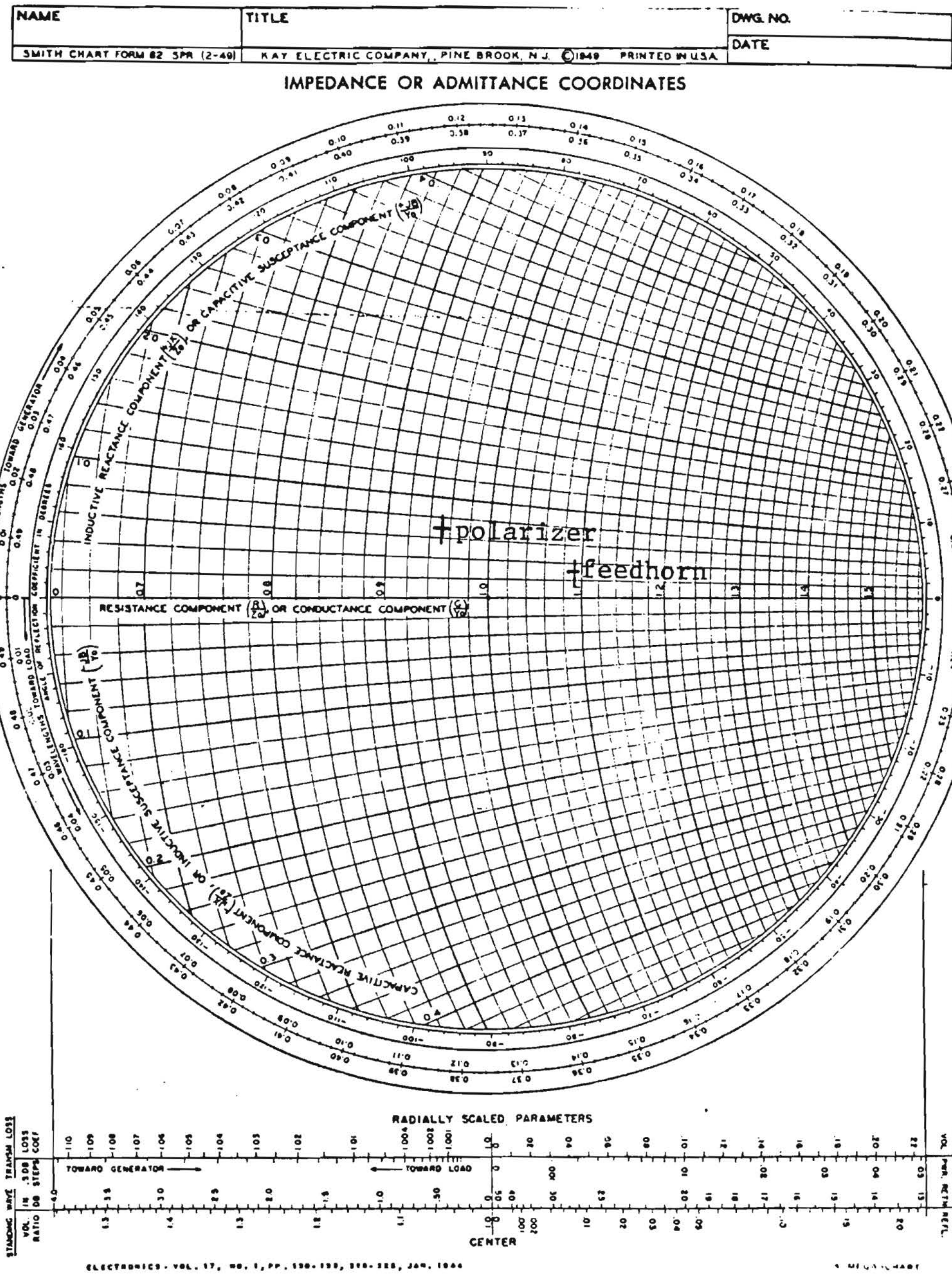

Figure 22. Normalized impedance of feed horn and of polarizer at 2710 MHz.

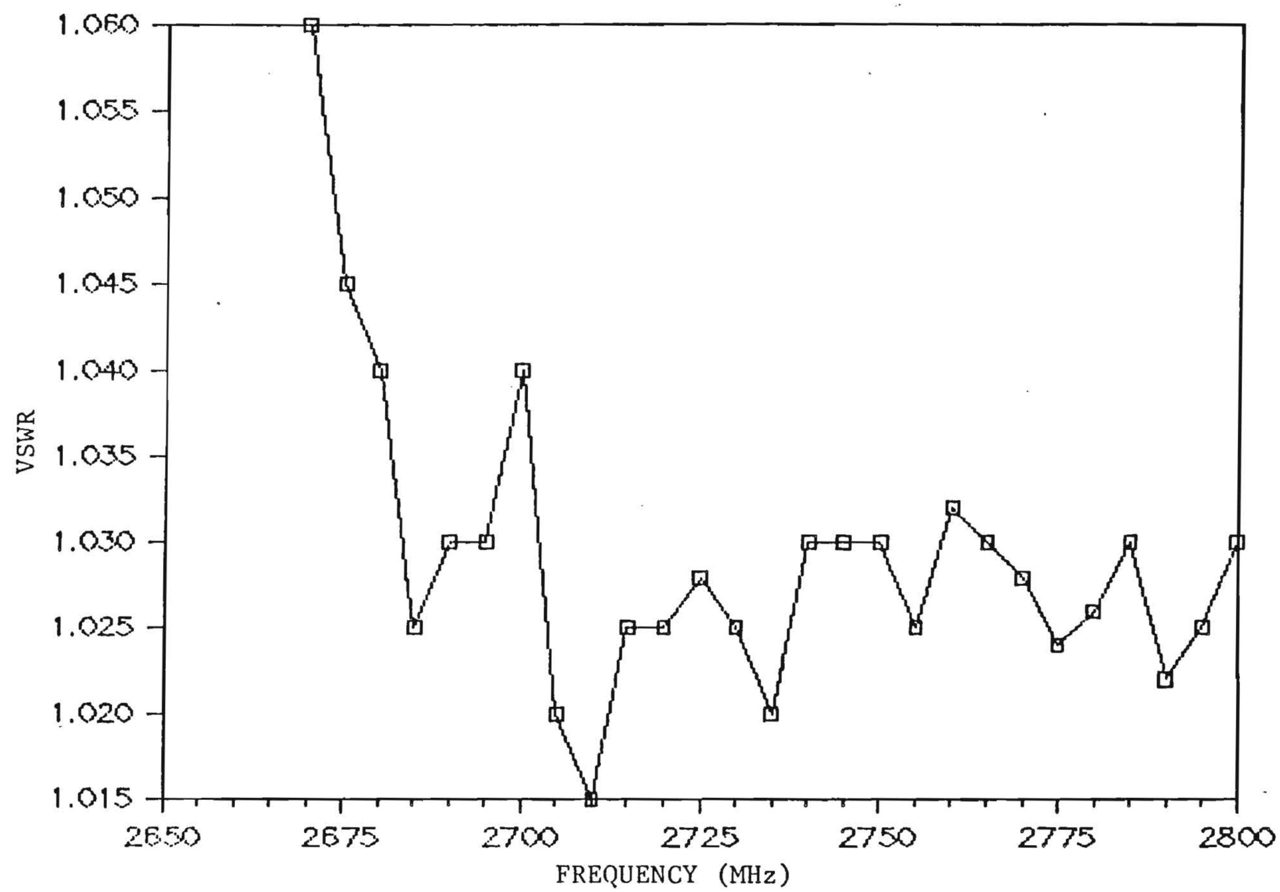

Figure 23. Input VSWR of polarizer with horn attached to circular port and load attached to unused input port.

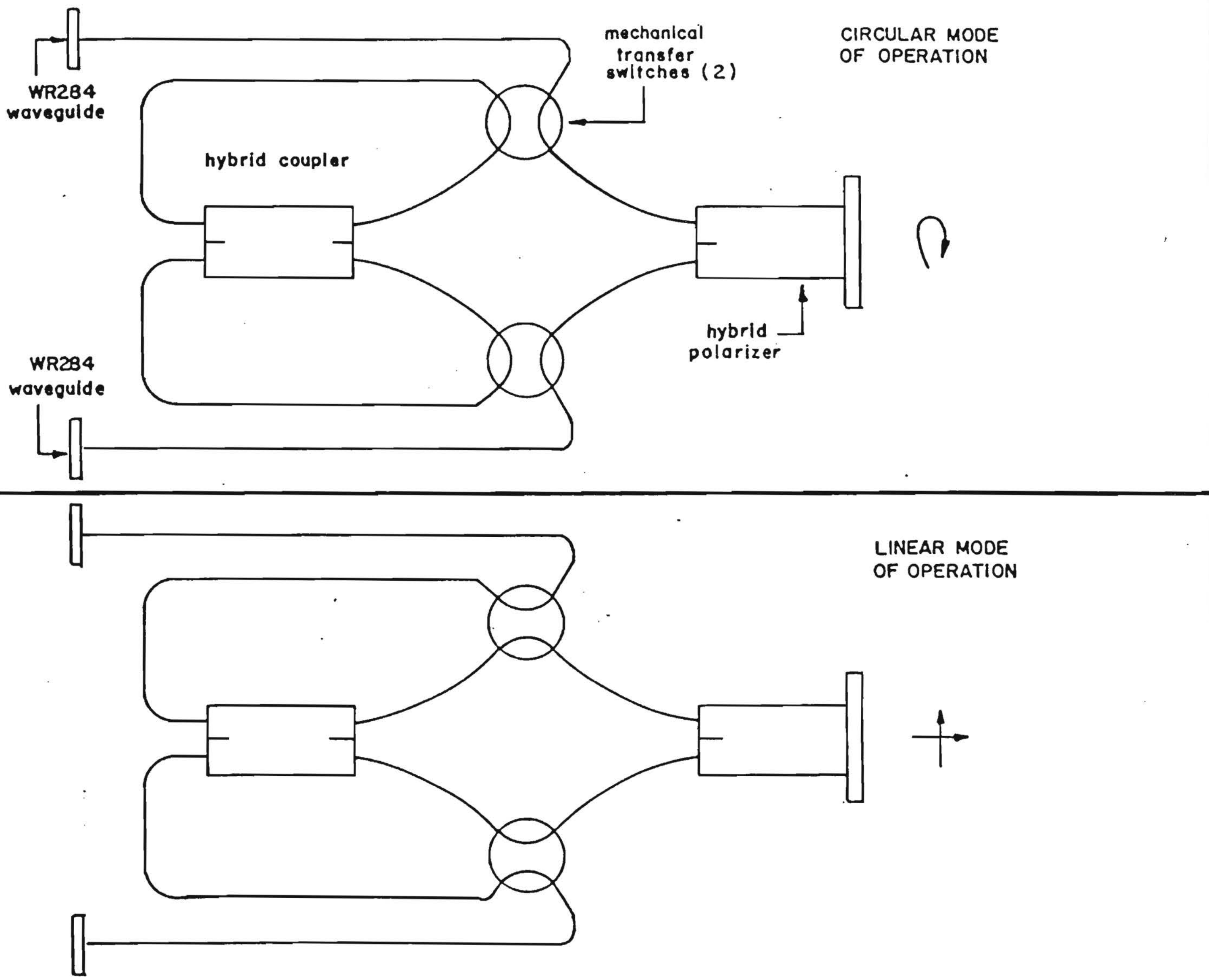

Figure 24. Schematic representation of circular/linear switchable antenna polarizer.

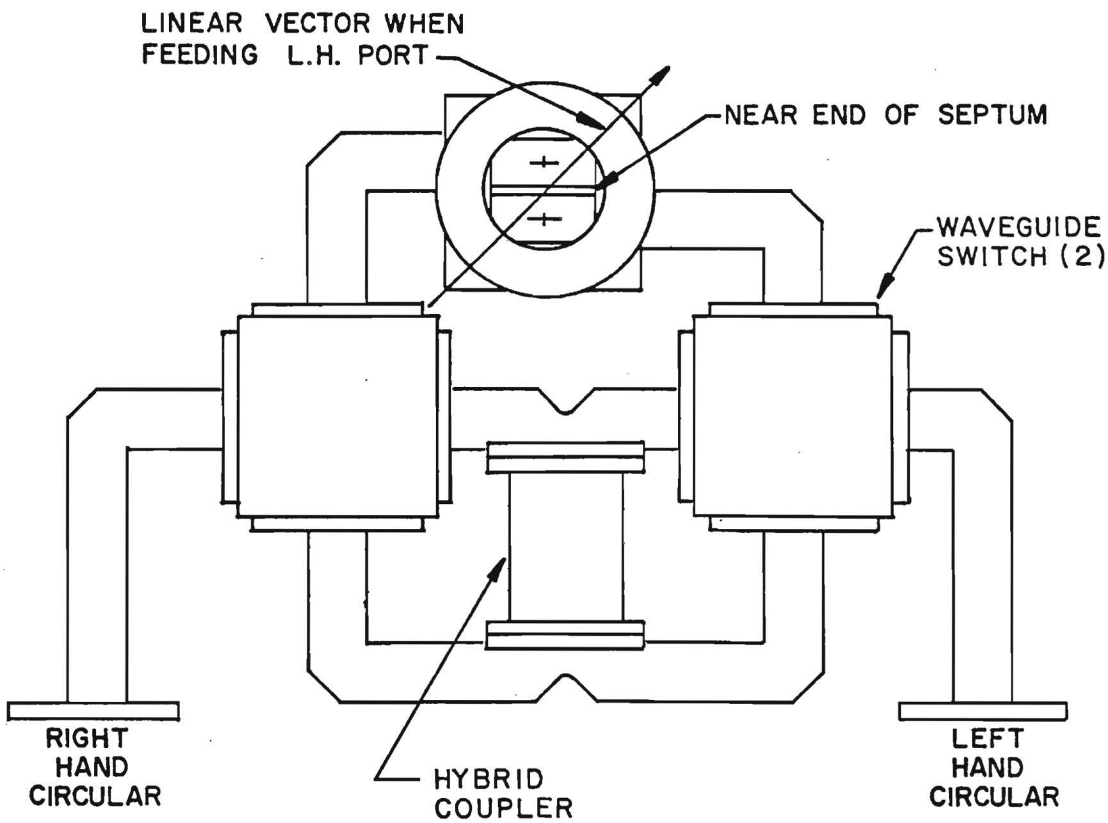

Figure 25. Rear mechanical detail of antenna polarizer.

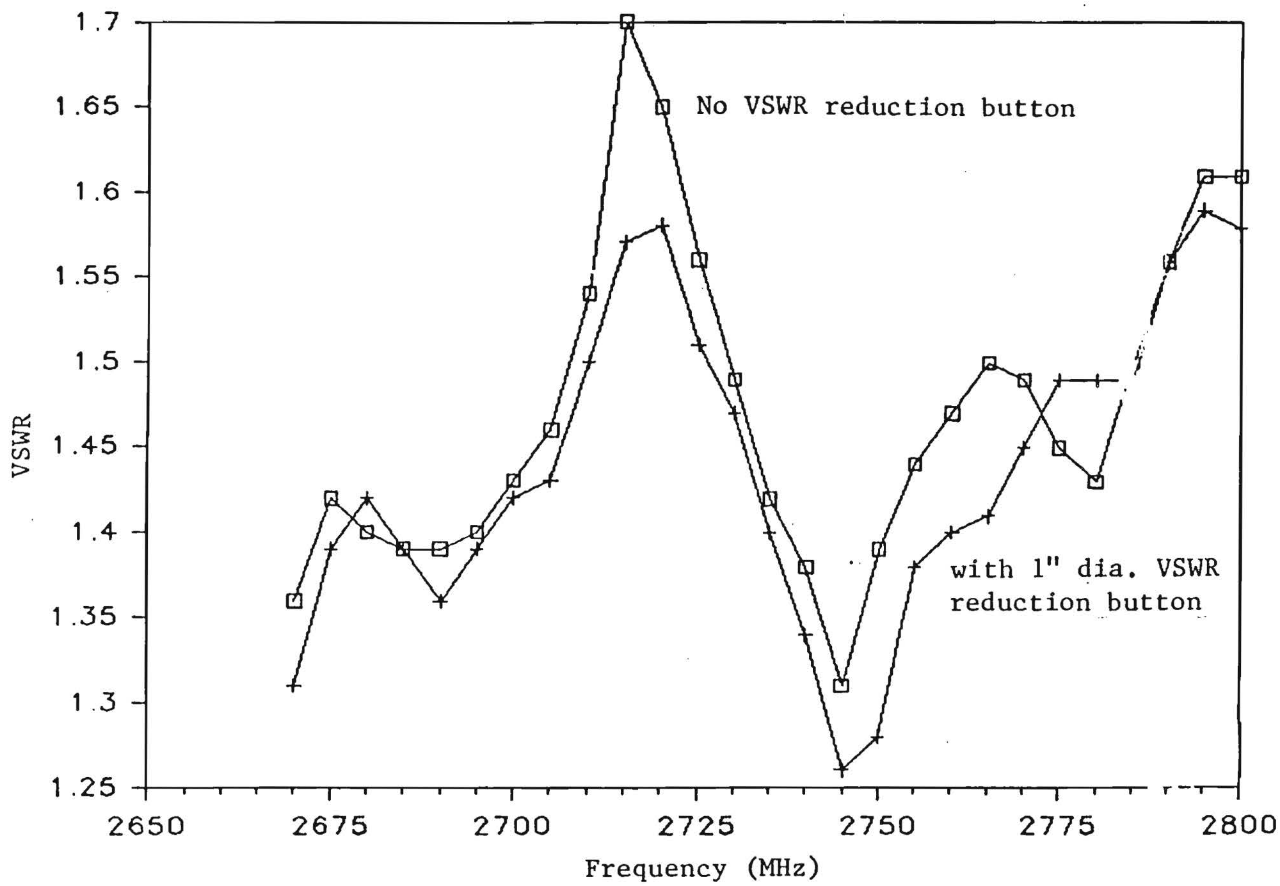

Figure 26. VSWR of modified AFGL antenna showing effect of 1-inch diameter VSWR reduction button.

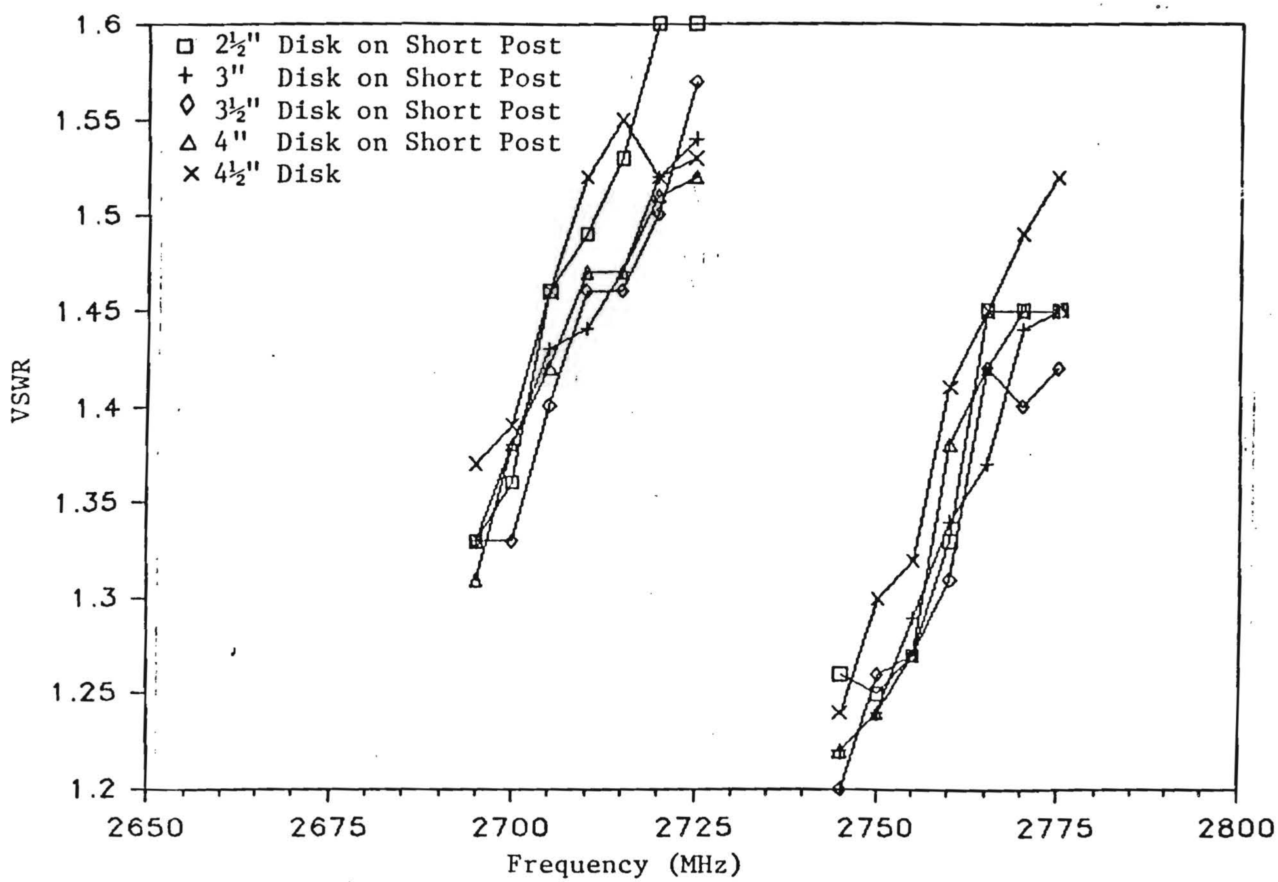

Figure 27. VSWR of modified AFGL antenna showing effect of post and disk VSWR reduction method.

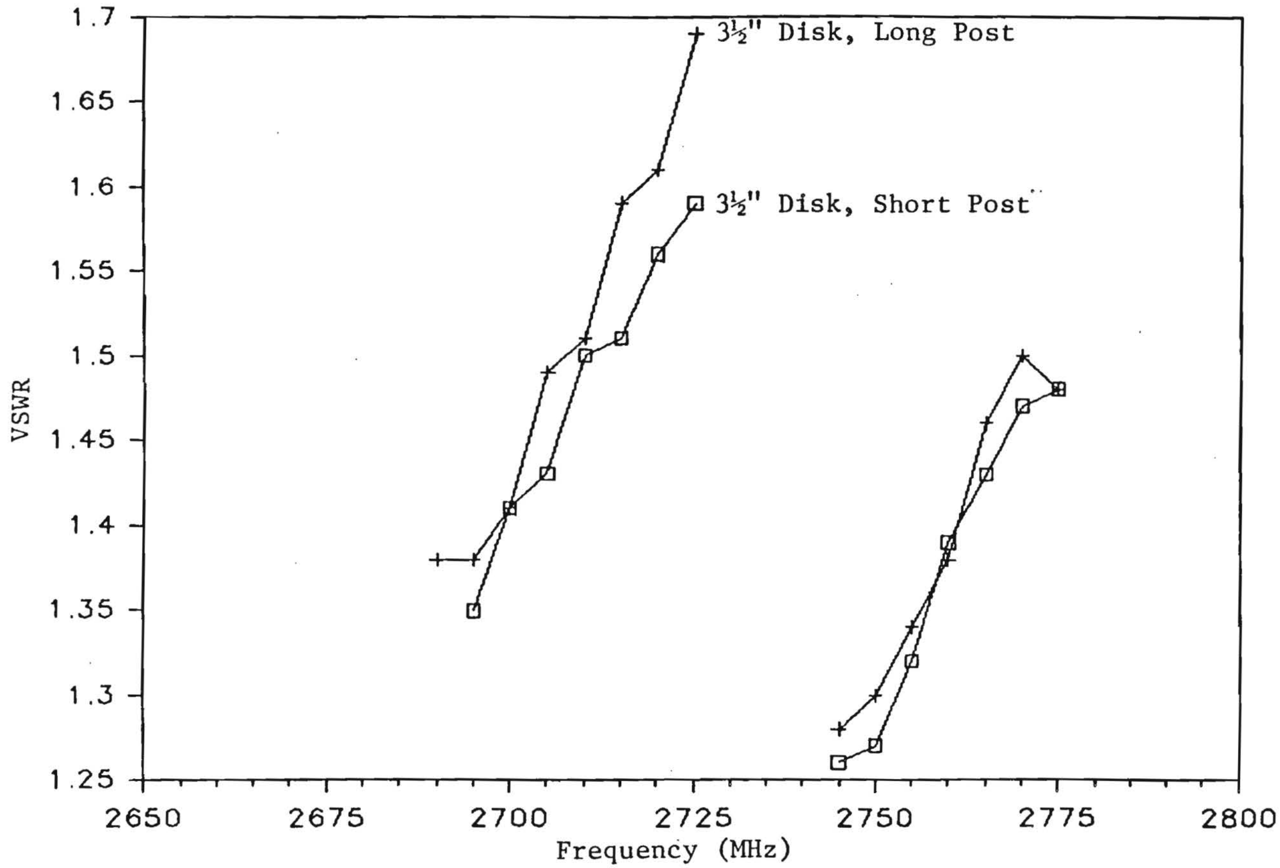

Figure 28. VSWR of modified AFGL antenna showing effect of differing post length.

APPENDIX A

PAPER PRESENTED AT
21ST CONFERENCE ON
RADAR METEOROLOGY

ANALYSIS OF A POLARIZATION DIVERSITY
METEOROLOGICAL RADAR DESIGN

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1. INTRODUCTION

This work describes an ongoing design and modification to provide a polarization diversity addition for the Air Force Geophysics Laboratory (AFGL) 10 cm coherent weather radar. The unmodified radar is documented in Glover et al. (1981). Much of the information contained herein will be of interest as it is applicable to polarimetric radars in general.

In the fall of 1980, the Radar and Instrumentation Laboratory of the Engineering Experiment Station of the Georgia Institute of Technology received a contract from AFGL to perform a design study for this polarization diversity addition. The constraints of this effort were to retain, as much as possible, the present equipment and operating features, such as the antenna reflector, transmitters, microwave circuitry, and receivers while supplying a constructable design for the modification. The modified radar is to be ultimately capable of coherent operation in both the circular depolarization ratio (CDR) and differential reflectivity (Z_{DR}) modes. The radar is to provide significant new research information by exceeding the measurement capability of current systems.

One of the difficulties we encountered at the outset was the lack of uniformity of nomenclature between the radar engineering community and the meteorological community. To avoid possible misunderstandings, we present definitions of cross-polarization ratio terms in Table 1. Fundamental differences exist between the measurements performed by and the equipment required for CDR and Z_{DR} radars. Specifications for measurement of these parameters are given in Table 2, which includes traditional values as well as design goals for the AFGL radar. Some of the elements which determine these specifications, such as polarization isolation of the radio frequency (RF) switch or polarizer, are slightly beyond today's technology and require reasonable development efforts to attain, while other elements such as the effect of reflector surface errors, polarization isolation, or radome induced cross-polarization are at present not understood and will require a substantial development effort.

TABLE 1. DEFINITIONS OF CROSS-POLARIZATION RATIO TERMS

ICR_1	One-way integrated cancellation ratio: equal to the integrated cross-polarized energy emitted by a circular polarized antenna divided by the integrated co-polarized energy of the same antenna. Limits of integration are theoretically over 4π, in practice integration to the 3rd null of the co-polarized beam suffices.
ICR_2	Two-way integrated cancellation ratio: defined as above for transmission and reception through the same antenna.
$ICPR_1$	One-way integrated cross-polarization ratio: as ICR_1, but for linear polarization only.
$ICPR_2$	Two-way integrated cross-polarization ratio: as ICR_2, but for linear polarization only

TABLE 2. CDR, Z_{DR}, AND AFGL RADAR SPECIFICATIONS

	CDR		Z_{DR}		AFGL	
Specification	Trad.	Calc.	Trad.	Calc.	Composite	Goal
ICR_2	-40 dB	---	--	--	-35 dB	-37 dB
Error in ICR_2 Measurement	--	3 dB	--	--	3 dB	< 3 dB
$ICPR_2$ --	—	>-20 dB	>-26 dB	-26 dB	-30 dB	
Power Ratio Accuracy 0.1 dB	--	0.1-0.3 dB	--	0.2 dB	0.1 dB	
Amplitude Tracking Uncertainty	1.0 dB	< 0.23 dB	--	--	0.2 dB	0.1 dB
Receiver Phase Tracking Uncertainty	< 1.5°	--	--	--	< 1.5°	1.0°
Polarization Isolation	>-40 dB	--	>-20 dB	>-26 dB	-37 dB	-40 dB CP
					-26 dB	-30 dB LP

2. ANTENNA MODIFICATION

2.1 CROSS POLARIZATION OF REFLECTOR ANTENNAS, A REVIEW OF THE LITERATURE

A study of the literature of linear and circular cross-polarization of axisymmetric reflectors was undertaken that chronologically covered the past forty years. From this effort, it was initially determined that the cross-polarization pattern for linearly polarized antennas has maxima which lie in 45° planes between the principal axis of the antenna. These maxima consist of a set of pencil-beam lobes on each arm of these planes, with the first maxima occurring approximately at the first null of the co-polarized beam (Silver, 1949). Jones (1954) determined an exact solution for cross-polarization characteristics of the front fed paraboloid using an electric dipole, magnetic dipole, and Huygens or plane wave feed antenna. Here the results for the characteristics of a paraboloid excited by a short electric dipole or magnetic dipole were shown to be identical, with the sole exception that the E and H plane antenna patterns are to be interchanged when the dipoles are interchanged. Finally, for a plane wave feed chosen such that the E and H plane patterns are identical, he determined that the cross-polarized components of the fields are equal in magnitude and of opposite sign within each of the paraboloid quadrants so that, "it is noticed that the far zone field has no cross polarized radiation fields."

Watson and Ghobrial (1972) presented results which disagreed with the preceding profound statement by Jones and with future work by others including Ghobrial. In this paper it was shown that cross-polarization is a function of the electric field, the magnitude of the first cross-polarization lobe is far greater than that given by Jones, and the off-axis cross-polarization behavior of a Cassegrain antenna is superior to that of a front fed antenna, "due to the fact that the convex subreflector compensates to a high degree for cross-polarization caused by the concave main reflector." Later, Ghobrial and Futuh (1976) contradicted the last statement by showing that the polarization properties of Cassegrain antennas are identical to those of front fed antennas of equivalent focal length.

Prior to this, Ludwig (1973) presented three differing definitions of cross-polarization. According to the third definition, zero cross-polarization will result with a Huygens source feed (a physically circular feed with equal E and H amplitude patterns in all planes). Furthermore, he argued that the cross-polarization currents on a paraboloid illuminated by an infinitesimal electric dipole are often incorrectly attributed to reflector curvature. The electric dipole itself generates cross-polarization where it is viewed off axes by the reflector. Cross-polarization is then reduced by increasing the focal length of the paraboloid so that the reflector views less off-axis dipole energy.

We next examined the results of Dijk, et al. (1974). Here not only do the results for a short electric dipole feed agree with those of Jones, but also a practical example using an approximation of a Huygens source is given. Finally, polarization loss efficiency factor curves are presented for both open waveguide and electric dipole feeds as a function of subtended half-angle between the feed and the reflector. Polarization efficiency is defined as the ratio of total co-polarized antenna gain to the antenna gain if the cross-polarized energy were zero everywhere. This definition is in accordance with Potter (1967) and can be related to ICPR. Calculated examples were presented of polarization loss efficiency factor versus subtended half-angle for an electric dipole feed employed in a front fed paraboloid, Cassegrain antenna of various magnification factors, and a front fed paraboloid excited by an open waveguide structure operating in the TE_{10} mode. In the final example, it was shown that a Huygens source could not be attained with a rectangular or square aperture.

Finally, our investigation of linearly polarized reflector antennas continued to the effort of Ghobrial (1979) for an approximation to the cross-polarization calculations of Jones. Not only is there good agreement between these calculations, but also he derives an expression for peak cross-polarization which is related to the overall polarization efficiency, η,

$$\text{peak cross polarization (dB)} = 10\ \mathrm{LOG}_{10}\left|0.29\ (1/\eta - 1)\right|. \qquad (1)$$

Our conclusion is that, for a theoretical axisymmetric reflector antenna without a feed support structure, the ICPR may be determined from a measurement of the level of one of the cross-polarization lobes.

Thus far, we have investigated reflector antennas with linearly polarized feeds. We conclude our review of the literature with an examination of a text by P. J. Wood (1980) which develops insight into the cross-polarization properties of reflector antennas with circularly polarized feeds. Wood has shown by his vector diffraction analysis method that circular cross-polarization lobes exist in phase quadrature with the co-polarized lobes and they have an absolute peak level of 8 dBi independent of reflector diameter. Obviously, these lobes vanish in the optical limit, $\lambda/D \to 0$. For the AFGL antenna, the amplitude of the peak lobe then is approximately 35 dB below the main beam.

2.2 ANTENNA CONFIGURATION CONSIDERATIONS

2.2.1 Waveguide Location

While consideration was given to the merits of the various antenna geometries, equal consideration must be given to the equipment configuration imposed by those geometries. If the AFGL front fed antenna configuration were retained, then either two phase matched waveguide runs from the back of the reflector to the polarizer and feed horn assembly would be required, or the entire assembly consisting of RF switch, microwave circuit, and receiver would have to be located at the prime focus. Obviously, the latter is impractical as it would impose severe antenna blockage. Less obvious is the impossibility of placing only the feed horn at the focus with the polarizer behind the main reflector, as this configuration would place unrealistic voltage standing wave ratio (VSWR) requirements and thermal requirements upon the waveguide connections. These constraints dictate the use of a Cassegrain antenna configuration so that these components may be contained in a relatively small, environmentally controlled package located behind the reflector.

2.2.2 Minimum Focal Length

During this effort we determined that $ICPR_1$ must be less than -32 dB. Employing Equation (1) in conjunction with the efforts of Dijk and Ghobrial for both an open WR-284 waveguide feed and an electric dipole feed, we considered the focal length to diameter ratio (f/D) required to achieve this value of $ICPR_1$. The results of this calculation are presented in Figure 1, together with the results of $ICPR_1$ determined by the Georgia Tech reflector antenna program, a computer program developed to calculate the co- and cross-polarized pattern performance of single reflector and double reflector antennas. This program has been validated over the past several years not only with data Georgia Tech has obtained, but also with other data that have appeared in the literature. The program was utilized to analyze the amount of anticipated cross-polarization as a function of various reflector focal lengths. The results show that, while a -20 dB $ICPR_1$ can be obtained with the existing AFGL reflector, which has an f/D of 0.4 further improvement requires a reflector with a longer focal length. Again, we are led toward a Cassegrain configuration as the focal length of the existing reflector can only be extended by employing a Cassegrain geometry.

2.2.3 Blockage and Unsymmetric Diffraction

Depending upon the feed arrangement and the choice of theory, the circular cross-polarization lobes should disappear or become almost insignificant; usually this is not the case. Experimentally, it can be shown that excessive aperture blockage will contribute diffracting surfaces which will increase cross-polarization as well as reduce overall antenna efficiency. Should a Cassegrain configuration be employed, reduction in antenna efficiency due to subreflector blockage can, in this instance, be discounted as it is given by the ratio of the square of the reflector diameters and for this antenna provides an almost unmeasurable effect on the total antenna gain. Diffraction from the main reflector edge, subreflector edge, feed horn edge, and support structure edges, on the other hand, can contribute energy into both the cross-polarized and co-polarized sidelobes. This diffraction contribution can be reduced by various methods, some of which are: (1) elimination of edges, (2) occultation of edges, and (3) employment of a symmetrical design. For the AFGL radar, the feed support will consist of a shroud wrapped around and behind the feed to occlude polarizer and feed reflecting surfaces. In the case of the latter consideration, detailed attention must be given to the overall axial symmetry of the entire antenna structure.

2.2.4 Antenna Configuration

Having considered the antenna geometries, we concluded that a Cassegrain affords the best compromise between focal length, feed location, blockage, and symmetry to produce favorable co-polarized and cross-polarized sidelobe architecture. We considered a third configuration, offset Cassegrain, as a possible geometry to eliminate illuminator blockage and further reduce these unwanted lobes.

In an axisymmetric antenna with a dipole feed, cross-polarization is generated in the aperture electric field by off-axis observation of the feed antenna; thus, cross-polarization has the property that it is oppositely directed in adjacent quadrants. Then by symmetry, cross-polarization cannot exist in the principal planes of the antenna, but does achieve a maximum value in the planes located midway between the principal planes. If a feed is constructed such that equal electric and magnetic dipole patterns are placed on the reflecting surface (Huygen's source), a second set of cross-polarized electric field vectors is generated by the magnetic field in the aperture which, in the case of axisymmetric reflectors, are equal and opposite to those generated by the electric field. In the case of an asymmetric reflector, an asymmetry exists because the distance between the subreflector and the upper main reflector quadrants is greater than the distance between the subreflector and the lower main reflector quadrants. In theory, this distance variation can be ameliorated by an offset subreflector. The best achievement of such an arrangement has yielded an antenna with two -34 dB cross-polarized lobes (relative to the main beam) symmetrically displaced from the antenna's principal axis (Wilkinson and Burdine, 1980). The virtue of such an antenna is its capacity for a great reduction in the near co-polarized sidelobes; for this example, a 17 dB improvement was achieved, compared to the level expected for a conventional axisymmetric Cassegrain antenna.

In light of these achievements, this geometry was considered, but the cost of an appropriate development program quickly dispelled further attention.

2.3 SUBREFLECTOR MOUNTING STRUCTURE

Although not a direct consideration of the specific antenna geometry, the feed and subreflector mounting structure has a significant influence upon the sidelobe and cross-polarization lobe integrity. Maintenance of overall antenna symmetry is the foremost requirement of cross-polarization reduction if the proper feed assembly is used. Because of the quadrapole nature of the cross-polarized antenna pattern, symmetry cannot be preserved with a tripod secondary reflector mount or with the existing tripod feed mount. Either a bipod with support wires or a quadrapod structure is required. Furthermore, the attachment points for the mount must be located as close to the rim of the main reflector as possible. This reduces lobe structure by reducing blockage from the spars and, when a reasonable illumination taper is employed, by reducing the scattered energy level from the attachment points.

No special spar cross-section has been shown to reduce cross-polarization backscatter from the support spars; however, the location of the quadrapod structure does affect the cross-polarized sidelobe structure. Since the cross-polarized lobes are located in planes rotated by $\pi/4$ with respect to the horizontal and vertical planes, the spars should be positioned in the horizontal and vertical planes to minimize scattering of the cross-polarized energy. When considering ICPR however, this attention to spar location may not be necessary.

2.4 SUBREFLECTOR

While the specific detail of design for the hyperbolic subreflector is not a subject of this paper, an interesting addition to the subreflector shape was provided by Wilkinson. The center of the subreflector employed in circularly polarized earth station antennas is conically shaped so that a "hole" exists in the reflected pattern. This "hole" prevents reflected energy from re-entering the feed by radiating that energy beyond the rim of the main reflector. This is an important consideration in the design of circularly polarized reflector antennas. Should a mismatch exist within the polarizer, any energy reflected into the polarizer from the feed will be reflected at the mismatch and retransmitted with the opposite polarization sense.

This conical section should have a smooth taper into the hyperbolic subsection of the subreflector to prevent diffraction effects. The use of absorbing material in place of the conical section cannot be considered as it would provide an additional diffracting edge. In other instances, this conical section is replaced by a button located at the center of the subreflector. This button serves the same purpose of scattering rather than returning energy into the feed.

2.5 POLARIZER ASSEMBLY

Three polarizers were considered for this modification: (1) short slot hybrid coupler, orthomode transducer combination, (2) lossless power divider with an orthomode transducer, and (3) sloped septum hybrid. Each concept (Figure 2) employs attending phase shifting devices and attenuators to accommodate both linearly or circularly polarized transmission as well as reception of the transmitted and orthogonal polarizations. The selection criteria were based upon the requirement of a minimum -37 dB isolation between polarizations for circular polarization and -26 dB isolation between polarizations for linear polarization.

Thus far, the general design has not shown ICR_2 to be bounded to less than -40 dB. However, if consideration is given to the VSWR of the components attached to the hybrid junction within any polarizer configuration and to the equivalence of hybrid junction isolation with ICR_2, then -40 dB isolation is most likely unachievable without VSWR improvement circuitry, while isolations of -35 dB to -37 dB are realistic, difficult-to-achieve anticipations. The validity of this realization exists because of the one-to-one mapping of VSWR and isolation of a hybrid junction (Riblet, 1952). A -40 dB polarizer isolation requires a VSWR $\leq$ 1.02:1 on all ports of the hybrid, which is generally unachievable for microwave components operating over any reasonable bandwidth.

In analyzing each polarizer configuration we assumed an attached corrugated or multitaper feed horn with a VSWR of 1.025:1, required a minimum isolation of -35 dB for circular polarization, and determined that the components attached to the polarizer input ports must have a VSWR of 1.05:1 or less.

2.5.1 Short Slot Hybrid and Orthomode Transducer Polarizer

The minimum achievable VSWR for the transducer ports of this polarizer (Figure 2a) is insufficient to provide better than -30 dB polarization isolation. Although the combined transducer, phase shifter, waveguide flanges, bends, and transfer switch VSWR may be significantly reduced by an appropriate choice and location of matching hardware, such a design would present a formidable construction task and, in the end, might have insufficient high-isolation bandwidth as well as excessive phase dispersion across the signal bandpass.

2.5.2 Lossless Power Divider and Orthomode Transducer Polarizer

The input E and H arms of the magic tee in the lossless power divider (Figure 2b) do not suffer the same isolation constraints as a hybrid junction unless the reflections from the colinear arms are in quadrature. The divider can certainly be constructed so that the reflections are in phase over a small bandwidth. However, taken as an entity, the lossless power divider exhibits the equivalent isolation and VSWR characteristics as the single hybrid junction, so that the same requirements are also enforced for the microwave components between the power divider and the orthodmode transducer. If less isolation could be tolerated, then this polarizer does offer the flexibility of transmission in any elliptical polarization and reception of that polarization and the orthogonal polarization.

2.5.3 Sloped Septum Polarizer

Obviously, the polarizer of choice, when operating in a circular mode, should involve as few microwave components as possible between the transmitter and the feed antenna so that full advantage of the low VSWR of the feed could be utilized. Therefore, such a device must be capable of directly generating the proper circular polarization from each waveguide input. A sloped septum polarizer (Figure 2c) is such a device. It is described in Chen and Tsandoulas (1973) and in Saltzberg (1978). The polarizer is a true hybrid coupler with two input ports and a common output port; exciting one input port causes the excitation voltage to be equally divided with one division receiving a 90° phase lag prior to entering the square output port; radiation exiting this port is circularly polarized. This device also obeys the VSWR versus isolation rule of the previous polarizers such that a minimum of attached components must exist in the high isolation circular polarization mode, while more attached components are tolerated in the less demanding linear polarization mode. Linear polarization is achieved by adding a hybrid coupler between the source and the polarizer to provide an appropriate 90° phase shift and allow equal amplitude excitation of the input ports (Figure 2c). Since transfer switches with a VSWR of less than 1.05:1 are obtainable, the possibility of constructing a -37 dB isolation feed assembly exists if a very low VSWR horn feed antenna is employed.

2.6 FEED ANTENNA

Various horn antennas were candidate feeds for this modification. The first consideration, a pyramidal horn, can be easily attached to the polarizer, requires no square-to-circular waveguide transition, and is inexpensive to manufacture. However, this feed can be shown to be equivalent to an orthogonal pair of magnetic dipoles and will give rise to high off-axis cross-polarization (Nelson, 1972). This effect has also been noted experimentally by Wilkinson. The second feed under consideration was a circular multitaper horn which can be designed with equal E and H plane patterns but only for a relatively narrow bandwidth. Since the third feed considered, a corrugated horn, can meet all the requirements of this design, but at a relatively high cost, the multitapered design was chosen for further investigation. An experimental multitaper horn was successfully constructed for 9.4 GHz in April 1983. Over a large portion of its pattern, it represents the attributes of a true Huygens source with equal E and H patterns in all planes.

2.7 ANTENNA SUMMARY

Using -32 dB as the $ICPR_1$ requirement, a minimum focal length of 230 inches is required (f/D = 0.8). This is based upon linear polarization considerations only; cross-polarization in the circularly polarized mode is only the result of antenna, feed and polarizer imperfections; it is independent of focal length.

A quadrapod mounting structure consisting of cylindrical spars attached near the reflector rim offers the optimal sidelobe and cross-polarization reduction condition. Furthermore, no structure visible to the subreflector should be employed to support the feed assembly as such a support would encourage scattering and might detract from overall symmetry. This requires the feed support be wholly contained within a shroud that is, with respect to the secondary reflector, occluded by the feed horn.

For high isolation in the circular mode and respectable isolation in linear polarization a sloped septum polarizer with a hybrid coupler or magic tee to provide linear polarization is the polarizer of choice. Finally, to maintain costs within reasonable bounds, for a relatively narrow high-isolation frequency band (±200 MHz at 9.4 GHz) a multitaper horn is the feed of choice. Specific recommendations for the antenna modification are presented in Table 3.

TABLE 3. RECOMMENDATIONS FOR ANTENNA MODIFICATION OF AFGL RADAR

Requirement	Recommendation
Antenna Configuration	Cassegrain with f/D > 0.8
Number of Support Spars	4
Support Spar Cross-Section	Circular
Feed/Polarizer Supports	Entire assembly must be covered by axisymmetric shroud
Secondary Reflector	Hyperbola with center half-conical section or VSWR button
Secondary Reflector Pattern Taper	About -10 dB on reflector edges
Feed Antenna	Multitaper horn or corrugated horn
Feed Antenna VSWR	< 1.025:1
Polarizer	Sloped septum
VSWR at Polarizer Input Ports	< 1.05:1
Anticipated ICR_2	> -35 dB
Anticipated $ICPR_2$	> -26 dB

3 MICROWAVE PACKAGE

3.1 THERMAL REQUIREMENTS

The microwave package contains those components which interface with the transmitter, receiver, and polarizer and, as such, must be capable of operating at the transmitter power level as well as be able to withstand heating due to losses. These components must critically maintain polarization isolation phase, and amplitude balance during transmission and reception. This can only be accomplished if the microwave package and non-video portions of the receiver are thermally stabilized and located as close as possible to the antenna feed assembly. In this instance, the operating temperature is dictated by the phase stability of the most unstable component. We believe that component to be the transmit-receive circulator and we have performed a cursory phase versus temperature experiment on the existing unit. The temperature at which the minimum phase change was observed was between 42.5°C and 45°C. Since this temperature is close to the expected maximum summer ambient temperature inside the radome, we recommend a complete heat exchanger system for the microwave package and receiver enclosure.

3.2 POLARIZATION ISOLATION IMPROVEMENT NETWORK

In an attempt to improve the polarization isolation, an improvement network has been conceptually included in the design. Various candidate VSWR reduction schemes are possible for the interconnections of the various microwave components, but the final choice of the specific solution will depend upon the achieved characteristics of the RF switch, polarizer, and feed antenna. One scheme under consideration (Hollis et al., 1980) is employed in the K_u-band radar at the National Research Council of Canada. We have confirmed that this scheme can be constructed to be effective over the required bandwidth; however, when the transmitter power of the AFGL radar was considered, little isolation improvement could be realized with reasonable component values.

VSWR improvement is also realizable by adding reactive devices into the microwave package. However, the magnitude and location of those devices can only be ascertained after the complex reflection values of the microwave components have been determined. The isolation improvement network, then, remains a concept; its necessity will be determined after the interconnected microwave components such as the antenna including the polarizer and high speed polarization switch are evaluated.

3.3 HIGH POWER RADIO FREQUENCY SWITCH

The RF polarization switch is the only other device currently thought to limit the polarization isolation performance of the modified radar. The basic high speed waveguide switch employs a configuration of phase shifters, magic tee, and short slot hybrid. Switching transmitted energy between output ports is achieved by appropriate setting of the phase shifters. Although reception of backscatter is available at orthogonal polarizations in the E and H arms of the magic tee, the polarization isolation at these ports may not be as great as that achieved upon transmission. In a more conservative design, backscatter is received through circulators located in each of the arms between the RF switch and polarizer.

Two designs have been proposed to realize the isolation requirement of the RF switch: (1) three switches connected in a series-parallel configuration and (2) a variation of a previously successful approach wherein a logic-based update network sampled the main and isolated ports and adjusted the current in each of the phase shifters to correct for isolation deficiency. Since all variations employ a hybrid coupler in their design, the isolation limitation is a function of VSWR, both external and internal to the switch. The VSWR presented to each port of the switch must be carefully controlled.

A mechanical switch was also considered. Of the varieties that exist, none can approach the switching time or other peformance characteristics of an electronic device. Shutter switches are available with switching speeds in the 10 millisecond region, rotary switches are an order of magnitude slower, and the ingeneous fast rotating devices employed on differential reflectivity radars do not afford the liberty of variable PRF and cannot attain the low VSWR demanded by the polarizer for circularly polarized modes.

4. RECEIVER

The general requirements of the receiver were considered up to, but not including, the processor. Of these, three unique critical requirements exist: phase tracking, amplitude tracking, and inter-channel isolation. Gross phase and amplitude balance will be maintained throughout by careful component selection, thermal control, and phase/amplitude trimmer assemblies inserted at strategic locations. Critical phase and amplitude tracking errors will be eliminated in software via a look-up table. While the object of this design was to retain a maximum of present components as well as present operating features, some existing hardware must be altered to maintain phase and amplitude tracking and to improve inter-channel isolation.

4.1 INTER-CHANNEL ISOLATION

To realize the full 37 dB isolation offered by the antenna feed assembly, the minimum receiver inter-channel isolation must be greater than 45 dB, a value confirmed by McCormick (1981). Furthermore, McCormick has suggested that to avoid a conspicuous data error, a minimum 55 dB isolation is necessary. Three paths which affect intra-channel isolation must be considered: (1) cross coupling in the local oscillator channel, (2) coupling via receiver coaxial cables, and (3) coupling via the DC power supply lines. The last two mechanisms can be reduced to insignificant levels by employing good engineering practices and, in the case of the RF signal path, employing copper semi-rigid cables. Cross-coupling via the local oscillator channel can be reduced by minimizing the VSWR seen by the hybrid couplers employed as power dividers and by the use of isolators prior to each of the mixers.

4.2 SENSITIVITY

Noise figure is a measure of overall system sensitivity. A low system noise figure is as important as an increase in transmitter power; an improvement in noise figure provides the same overall performance improvement as a likewise increase in tramsitter power, but at a considerably reduced cost.

The noise power level presented to antenna terminals of an ideal receiver is related to the source temperature, T_s, and the receiver effective temperature, T_{eff}, such that, for situations where $T_s = O(T_{eff})$, improvements in noise figure will yield slightly better improvements in overall sensitivity than would be expected from the noise figure improvement alone. In this design, for example, utilizing an overall 5 dB noise figure will result in a noise floor -109.2 dBm/MHz during observation of -40°C (223°K) ice clouds. Under the same conditions, however, a 3 dB improvement in overall noise figure will result in a 3.5 dB improvement in noise floor so that an observational sensitivity of approximately -112.7 dBm/MHz will be realized.

Another factor which will contribute to sensitivity degradation in the superheterodyne receiver is reception of the unwanted mixer sideband which contributes 3 dB of noise. This sideband can be suppressed either by a preselector, located either prior to the front-end low noise amplifier (LNA) or between the LNA and the mixer, or by a sideband suppression mixer. If a preselector is located prior to the LNA, it adds a front-end insertion loss which is equivalent to an increase in noise figure by the value of the insertion loss. Usually, however, the preselector loss is only on the order of 1 dB, so that an overall improvement results. On the other hand, if a preselecting filter is placed between the LNA and the mixer, little sensitivity degradation will result. While this location is appealing on the basis of sensitivity considerations, it does not preselect out-of-band signals from the LNA. Likewise, a sideband suppression mixer does not offer LNA preselection. Since intense out-of-band signals that would require LNA preselection do not normally exist at the site of the AFGL radar, post LNA preselection was chosen to simplify the design.

4.3 DYNAMIC RANGE

Two definitions of receiver dynamic range exist: (1) overall dynamic range, defined as the operating range of the receiver from the noise floor to the 1 dB signal compression point, and (2) the spurious free dynamic range (SFDR), defined as the operating range from the noise floor up to a power level at which spurious signals are processible.

The 1 dB compression point is an order of magnitude more coarse than our requirement. As a rule of thumb, the 0.1 dB compression point (the linearity requirement for this modification), is approximately 10 dB less than the 1 dB compression point. Furthermore, most amplifier manufacturers define the 1 dB compression point as an output value; the system designer must be careful to subtract the amplifier gain so that the 1 dB or 0.1 dB compression point is referenced to the amplifier input. From a calculation of the expected return energy from each form of hydrometeor, assuming a minimum radar range of 1 kilometer and using a transmitter level of +88 dBm with a two-way antenna gain of +84 dB, the maximum expected signal at the receiver input was determined to be -8 dBm. This design then requires a dynamic range of approximately 109 dB, which is impossible to achieve with present logarithmic amplifiers so an alternate method must be used to expand the receiver's dynamic range.

In most receivers, a form of automatic gain control (AGC) is available to reduce the RF and intermediate frequency (IF) amplifier gain as the return signal level is increased. However, AGC removes the power level measurement capabilities of the receiver unless the AGC voltage is carefully calibrated and monitored. Another method to increase overall dynamic range is to minimize the RF amplifier gain and electronically remove the IF preamplifier when the expected return approaches receiver compression; the computer, cognizant of this condition, adjusts its processing accordingly. We have chosen this latter method in conjunction with a logarithmic amplifier capable of a 90 dB dynamic range.

The dynamic range of a receiver is also limited by spurious responses which are accepted by the processor. These spurious responses, known as intermodulation products (IMP), are internally generated in the low noise amplifier and mixer from external sources. The frequencies of these products are given by (McVay, 1967)

$$F_{spur} = \pm nf_1 \pm mf_2, \qquad (2)$$

where n,m are integers.

In this design, only those values where n + m = 3 are of concern as the resultant signals are close to frequencies which can be received and converted to the intermediate frequency by the mixer. However, for these signals to be processible by the receiver of a pulsed radar, they must be the product of continuous carrier sources, in which case they may be characterized as such and reduced or eliminated.

Because of the dual transmitters employed in this radar (2710 MHz and 2760 MHz), a possible corruption of power channel data by velocity channel data, and vice versa, does exist, as the spurious frequency sideband energy generated from one channel is in the nearby spectrum receivable by the other channel. While this is a valid argument for LNA preselection, at present, only IF filtering has been considered for the elimination of this cross-channel IMP.

4.4 IF FILTER

The IF filter fulfills two missions: it determines the overall system noise floor and it provides the required selectivity. Exact choice of an IF filter is not a trivial task, as the filter and the RF amplifier essentially determine the receiver performance.

For optimum signal-to-noise receiver performance of a pulse modulated signal, the IF half-power bandwidth must be approximately 1.2 times the reciprocal of the transmitted pulse width or, in this design, 1.2 MHz. However, to minimize phase dispersion across the filter bandpass in the class of filters known as planar filters (Chebishev, Butterworth, and elliptic), a half-power IF bandwidth of 4 MHz is required.

The importance of filter skirt selectivity cannot be overstressed; many designs do not extend filter specifications beyond the bandwidth of the halfpower points which fails to specify the attenuation at frequencies further from the center frequency. If thought is given to the frequency sideband energy of the transmitted channel opposite to the receiver channel under consideration, then a moderate degree of data corruption may be caused by many factors such as the range, type of hydrometeors observed, and spectral distribution of the transmitter pulse. A moderate skirt selectivity requirement exists as some of the spurious frequencies generated within the LNA and given by Equation (2), which are the result of the two transmitted signals, are only 10 MHz removed from the anticipated received signal.

This condition exists when both the Doppler channel and the reflectivity channel return pulses are received simultaneously. We calculate that two -39 dBm signals into the low noise amplifier are required to generate an IMP at the receiver noise floor. Since a 1 dB increase in input level will cause a 3 dB increase in output level for third order IMP, returns greater than -36 dBm into the receiver will begin to degrade the data. We calculate that returns exceeding this level are expected infrequently. The elimination of this IMP then depends upon the filter skirt selectivity chosen so that the interfering pulse "sidebands" are attenuated into the noise. This condition may not be possible, as good skirt selectivity and phase dispersion are divergent from one another in planar filers.

4.5 LOCAL OSCILLATOR AND MIXER

While all of the present components are retained in the local oscillator chain, additional components are added to provide increased intra-channel isolation, phase balance, and amplitude balance. The increased losses of these items require a slight amplification of the local oscillator signal level so that the mixers may be operated in a lower distortion region. By further increasing this amplification, high intercept point mixers can be employed with the result that the overall receiver 1 dB compression point is sufficiently increased to be wholly determined by the RF amplifier. The original radar utilized phase locked loop oscillators. A filter following each oscillator is required to prevent the high spurious output of the oscillator from entering the mixer as these spurious components will allow the receiver to capture unwanted signals. Since spurious signals occur within 600 kHz of the local oscillator frequency, a high Q, thermally stable, cavity filter is required.

5 CONCLUSION

In the foregoing discussion we have presented the key design elements of the antenna, microwave package and receiver. Although we have considered only the highlights, we have concentrated on the antenna, as this appears to be the most critical component of the system. We have also shown that the radar, including all its components, must be considered as an entity.

Antenna cross-polarization
Depends on the waveguide location.
Is Cassegrain best?
Let's put it to test
To get us the most isolation.

The IF filter skirt selectivity
Should reduce the system proclivity
For frequencies spurious.
But don't let them worry us--
We'll cut down their net transmissivity.

Mother Nature, they say, is a bitch,
Always looking to find us a glitch.
And so, in the end,
Everything will depend
On the high power microwave switch.

6. ACKNOWLEDGEMENTS

The authors thank Mr. E. J. Wilkinson of GTE International Systems for insight into antenna cross-polarization. This effort was supported by AFGL Contract Nos. F19628-81-K-0027 and F19628-82-K-0038.

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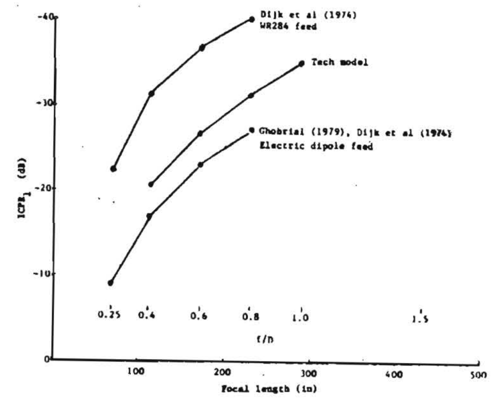
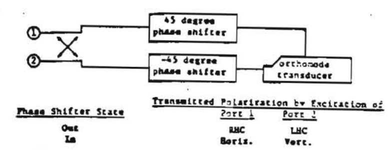
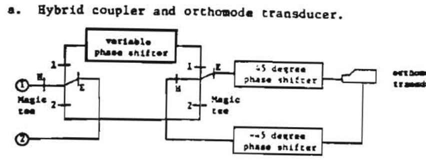


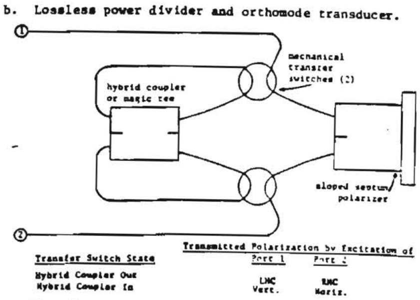
Figure 1. $ICPR_I$ for various feeds and f/D for an axisymmetric parabolic reflector antenna.



a. Hybrid coupler and orthomode transducer.



b. Lossless power divider and orthomode transducer.



c. Sloped septum.

Figure 2. Candidate polarizer configurations.

APPENDIX B

ANTENNA STATIC

AND

DYNAMIC STRUCTURAL ANALYSIS

ER - 100 - 1

DESIGN REVIEW

Prepared For

GEORGIA INSTITUTE OF TECHNOLOGY

Prepared By

H & W INDUSTRIES, INC.
COHASSET MASS.

Signed ______________________

Thomas P. Walsh, R.P.E.

TABLE OF CONTENTS

1.0 Specification Review

Paragraphs 2.2, 2.3 and 2.4 of the Contract Statement of Work comprise the specification for the work to be performed under the present contract. Those paragraphs are copied below.

2.2 STATIC AND DYNAMIC STRUCTURAL ANALYSIS

Upon receipt of initiation letter, contractor shall determine the reflector deformations that may occur as a result of various natural and operational effects upon the reflector, subreflector, subreflector support assembly, and feed support assembly. Contractor shall also determine deformations, if any, that may occur within the support spars and subreflector. The effects shall include, but not be limited to:

1. dead weight distortion as a function of elevation angle,
2. seasonal thermal charges both with and without the radome,
3. wind loading distortion,
4. thermal charges due to shadowing, (out)
5. inertial loading distortion in both azimuth and elevation planes and
6. vibrational characteristics including those of the spars created by vortex shedding.

Servo-Loop resonances shall also be considered. Contractor shall send a preliminary report of this information to Georgia Tech within 60 days of initiation. Georgia Tech shall determine the impact of such deformations upon antenna performance, and may at their opinion request further investigation should the present reflector appear unsuitable. Such further investigation may include, but not be limited to, consideration of different spar support systems, or the addition of strengthening members to the reflector support assembly.

2.3 FEED SUPPORT AND SUBREFLECTOR SUPPORT

Upon receipt of initiation letter, contractor shall design and construct a structure to support a multi-taper circular horn feed antenna whose exterior length is approximately 60" and maximum outside diameter approximately 32". Adjustment and adjustment locking devices shall be incorporated within the design to allow precise location of the feed horn. The exterior of the horn and support structure shall be surrounded by a concentric, axisymmetric shroud assembly.

The contractor shall also design and construct a quadrapod subreflector support assembly. This assembly shall attach as closely to the perimeter of the main reflector as practicable and shall be designed to minimize resonances due to vortex shedding and other effects. This assembly shall allow for a six (6) inch axial adjustment range and a three (3) inch radial adjustment range as well as adjustment locking devices so that one subreflector can be precisely located and locked in position. For the purposes of these designs, the contractor shall consider both the condition with, and the condition without a radome enclosure surrounding the antenna assembly.

Prior to design finalization of these assemblies, Georgia Tech shall supply the exact dimensions of the feed horn assembly as well as the exact size, shape, and location of the subreflector assembly.

2.4 SUBREFLECTOR

Upon receipt of initiation letter, contractor shall construct a hyperbolic subreflector of a size not to exceed three feet in diameter. The subreflector shall contain a VSWR reduction button; the subreflector shall interface with, and mount upon the subreflector support assembly. Georgia Tech shall determine the shape and size of the subreflector.

2.0 Analysis Review

The reflector structure from the base of the hub to the apex of the subreflector support was modeled and analyzed via the finite element computor program, "Stardyne". Both static and dynamic analyses were performed.

A. Static Analysis

The Static Analysis evaluated the following cases:

Case	Subject
1	Horizon Point, Dead Load Deflections & Stresses
2	Elevation = 30°, Dead Load Deflections
3	Elevation = 60°, Dead Load Deflections
4	Elevation = 90°, Dead Load Deflections
5	Elevation Rotation from 90° to 60°
6	Elevation Rotation from 90° to 30°
7	Elevation Rotation from 90° to 0°
8	Seasonal Temperature Change of 20°
9	Effects of a 30 MPH Frontal Wind
10	Effects of a 30 MPH Quartering Wind (120° off boresite)
11	Effects of a 10°/sec Rotational Accelleration

The input and output of the final run of the Static Analysis is included in Section 4. The output of this run was limited to deflections only. The output of the initial run is also included in Section 4. That run computed deflections for all cases and stresses for Cases 1, 8, 9, 10, and 11. The maximum stresses for those cases are listed below:

Case 1	1448 psi	due to dead load
Case 8	2750 psi	due to thermal effects
Case 9	192 psi	due to 30 mph frontal wind
Case 10	Negligible	due to 30 mph quartering wind
Case 11	Negligible	due to 10°/sec rotational inertia

Considering the Aluminum Association Specification, allowable stress for 6063-T5 Aluminum (lowest strength alloy in the reflector) is 6500 psi, we can consider the stress levels acceptable. Further considerations relative to stress levels are:

1. The spar cross-sectional area has increased from 2 x 2 x 1/8 wall square tube in the initial run to 4" OD x 3/16 wall round tube in the final run. This change was implemented to lower the subreflector support deflections. An attendant stress effect is to halve the Case 1 stress of 1448 psi.

2. The math model assumed the base of the reflector hub to be fixed. In fact, the hub is attached to a steel structure. The thermal effects, therefore, are based on an aluminum structure with a coefficient of thermal expansion of 13×10^{-6} in/in/deg, expanding relative to a base interface with an expansion of zero. This analysis has utilized the most conservative possible end condition. In fact, the end condition could be either a continuous steel structure with a coefficient of thermal expansion of 8.6×10^{-6} in/in/deg or a steel structure with one end attached to a floating bearing. That is, the continuous structure would be one where both elevation bearings react loads parallel to the elevation shaft vs. one where one bearing takes radial load only. In the first case, the deflections and stresses of Case 8 would become $\left(1 - \frac{8.6}{13}\right)$ or 34% of the calculated values; and in the second case, they would approach zero.

The above calculations and observations result in reflector stresses which are acceptable for all combinations of position, wind and thermal effects.

The significant reflector deflections of Cases 5 through 11 are plotted in Figures B.a. through B.f. These topographic plots are made joining points of equal deflections. Plots B.a., B.b., B.c. and B.f. are characteristically horizontal plot lines indicating the reflector is deflecting so as to generate an elevation pointing error. Plots B.d. and B.e. are characteristically polar deflection plots indicating a defocusing effect. We have RMS(ed) the nodal deflections parallel to the boresight for the reflecting surface and tabulated the results below:

Case	RMS (Nodes 1 - 96, Deflection X3)
5	.0035"
6	.0062"
7	.0074"
8	.0031"
9	.0019"
10	$<$ .001
11	$<$ .001

All the above can be decreased by best fitting the data. Cases 5, 6, and 7 can be improved by rotating the coordinate system about the elevation axis and Cases 8 and 9 can be improved by calculating a change in the best fitting focal length. The magnitude of the tabulated date precludes the necessity of best fitting.

The subreflector support deflections due to elevation rotation can be obtained by reviewing deflections for Nodes 211, 222, 233 and 244.

Case	X_2 Deflection - Final Run
5	-.022
6	-.037
7	-.041

These deflections are approximately 1/2 the magnitude of their values for the initial run. The deflections appear acceptable in all cases.

B. Dynamic Analysis

The Dynamic Analysis extracted the first seven modes of vibration. See Section 4C. Since vibrations above 10HZ will have little or no effect on the servo band pass, the computor was programmed to extract and define all mode shapes with a frequency of 10HZ or less. Only one mode was found less than 10HZ at 7.799 HZ. The mode shape is defined in figures C.a., C.b. and C.c. In addition, the next six modal frequencies were calculated, (between 13 and 24 HZ). A review of the fundamental frequency mode shape shows it to be the torsional mode with the reflector structural components rotating around the hub. It is interesting to note that for this case, the spars do not depart greatly from their undeformed straight line shape. We can therefore expect the spars not to vibrate until at least 13 CPS.

The calculated individual spar resonant frequency is 27 HZ. Given a Strouhal number of .2 (tubes) the vortex street shedding frequency will coincide with the spar natural frequency at wind velocities about 30 MPH. The forces transmitted to the structure at this wind velocity will be sufficient to cause problems. We recommend that if the unit is to be used without the radome, a helical wind of small dia tube (approx. 5/8 dia) be wound along each spar at a pitch of approximately 2 feet.

The dynamic characteristics in all other respects are acceptable.

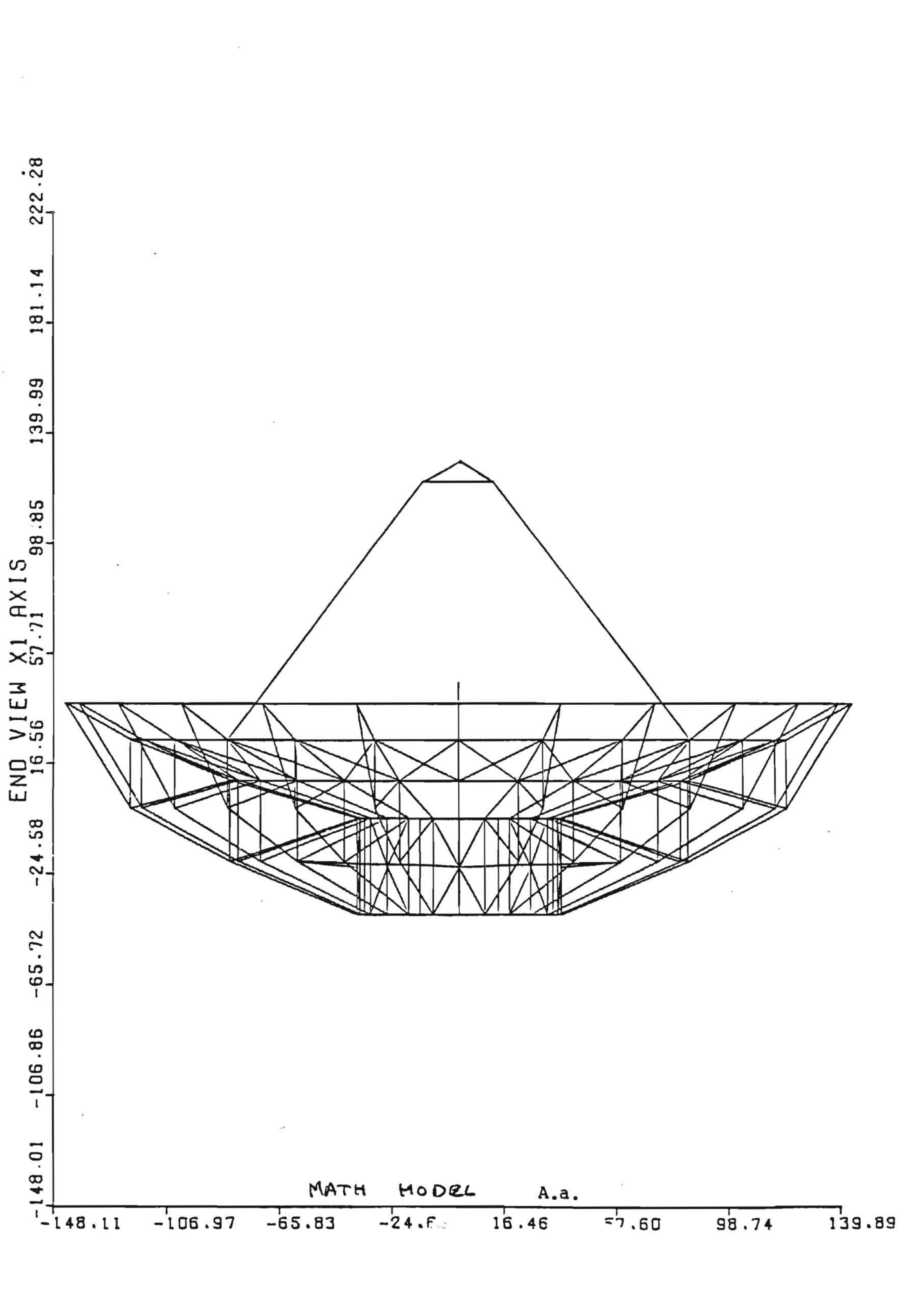


Figure A.a. The mathematical model, elevation view.

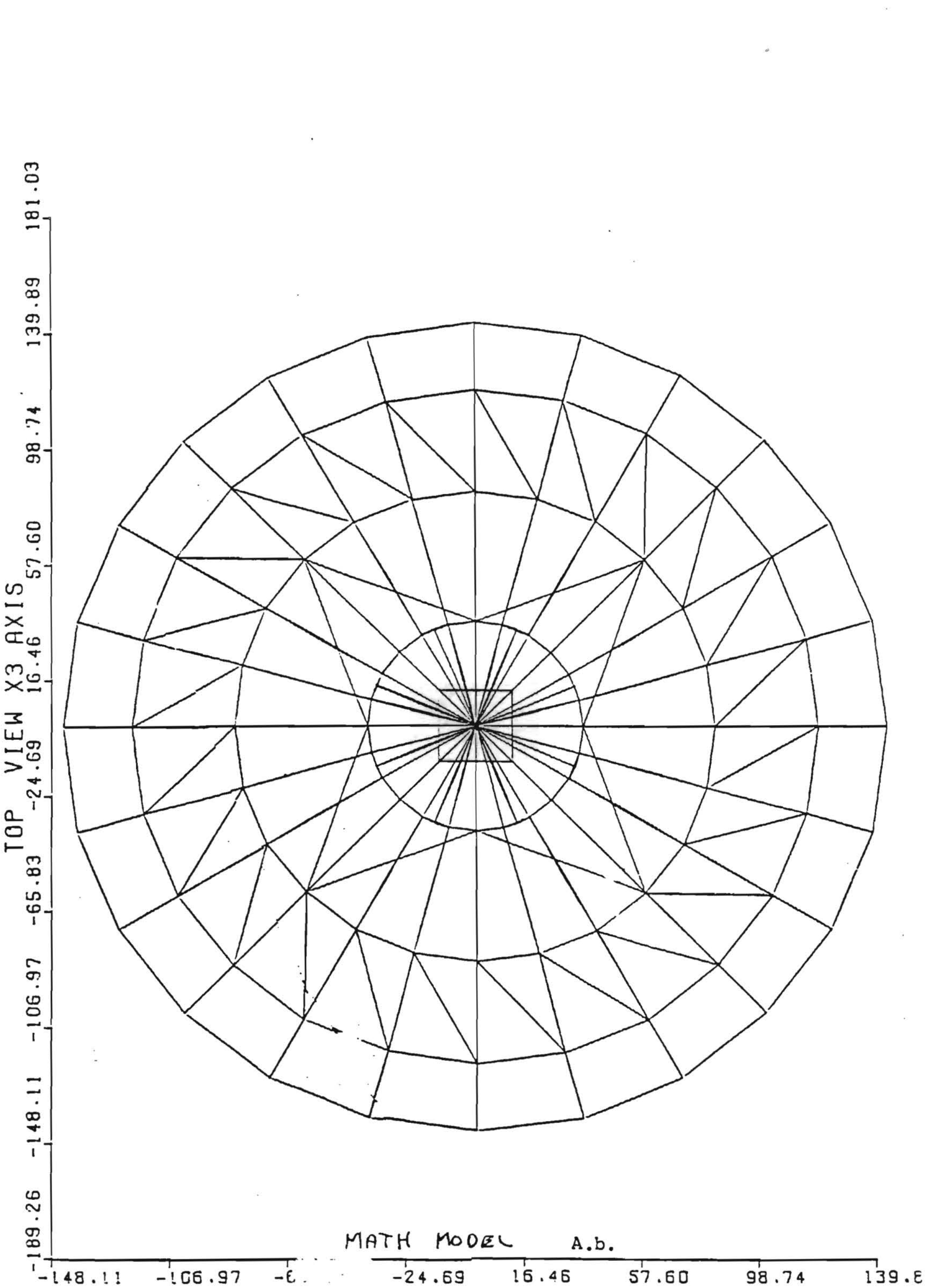


Figure A.b. The mathematical model, face view.

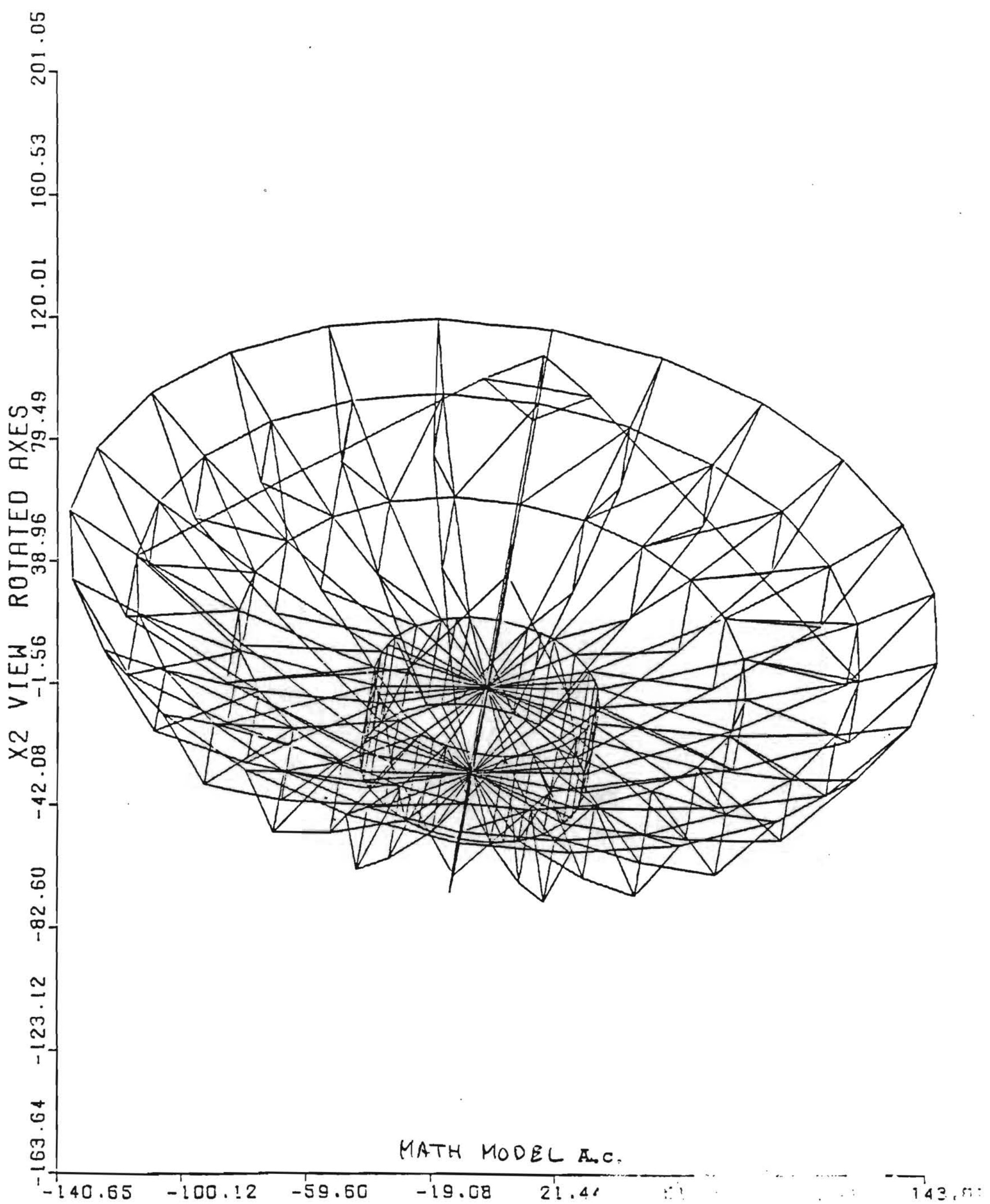


Figure A.c. The mathematical model, isometric view.

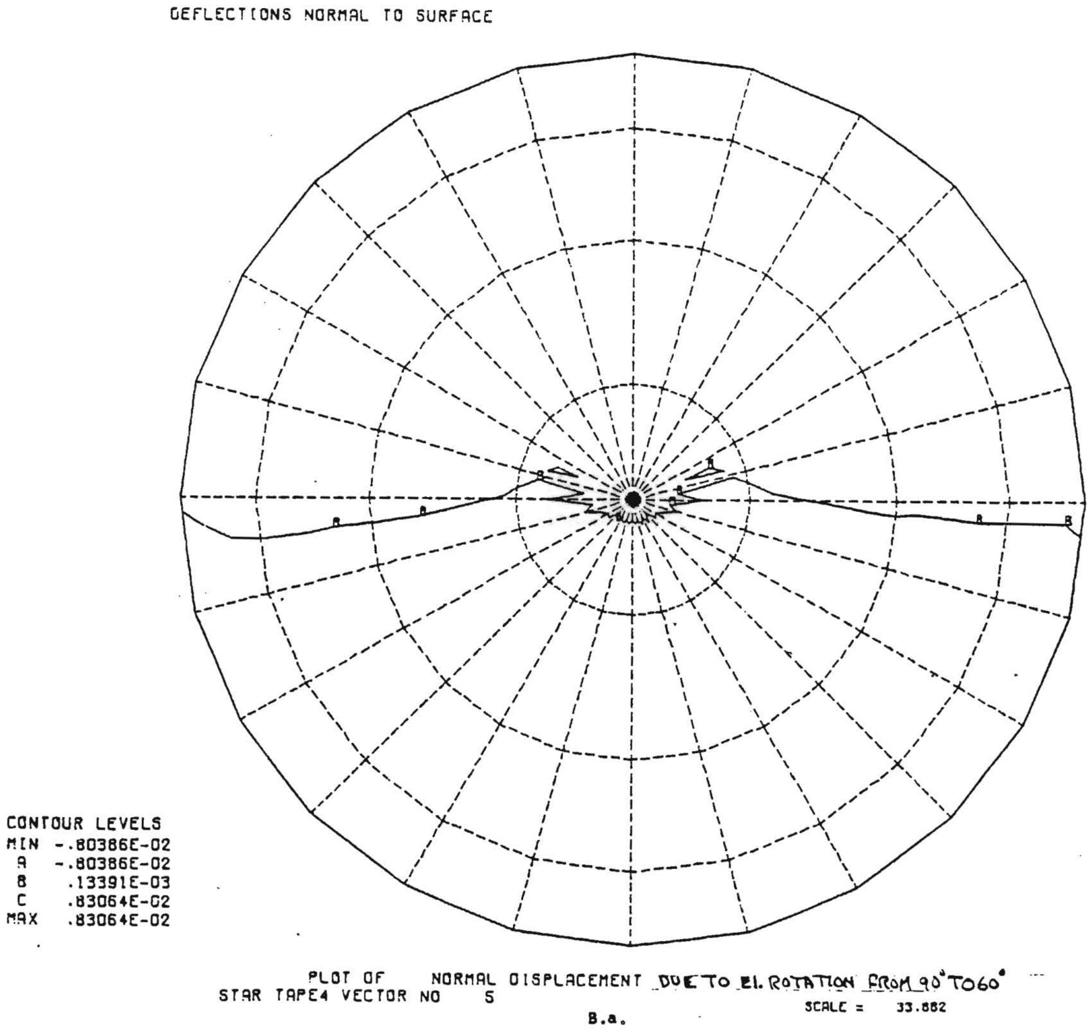


Figure B.a. Static Deflection, Plot of Normal Displacement due to Elevation Rotation 90° to 60°.

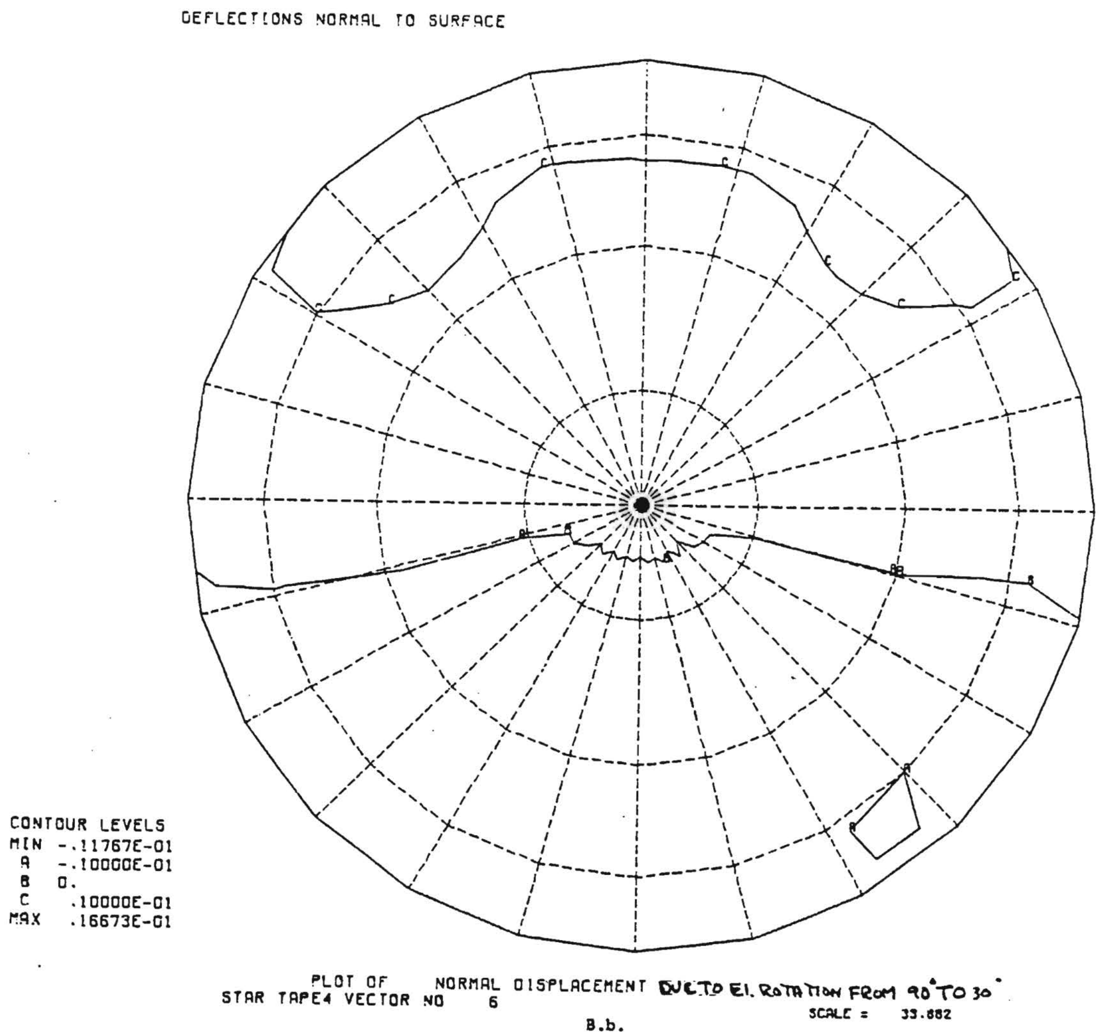


Figure B.b. Static Deflection, Plot of Normal Displacement due to Elevation Rotation from 90° to 30°.

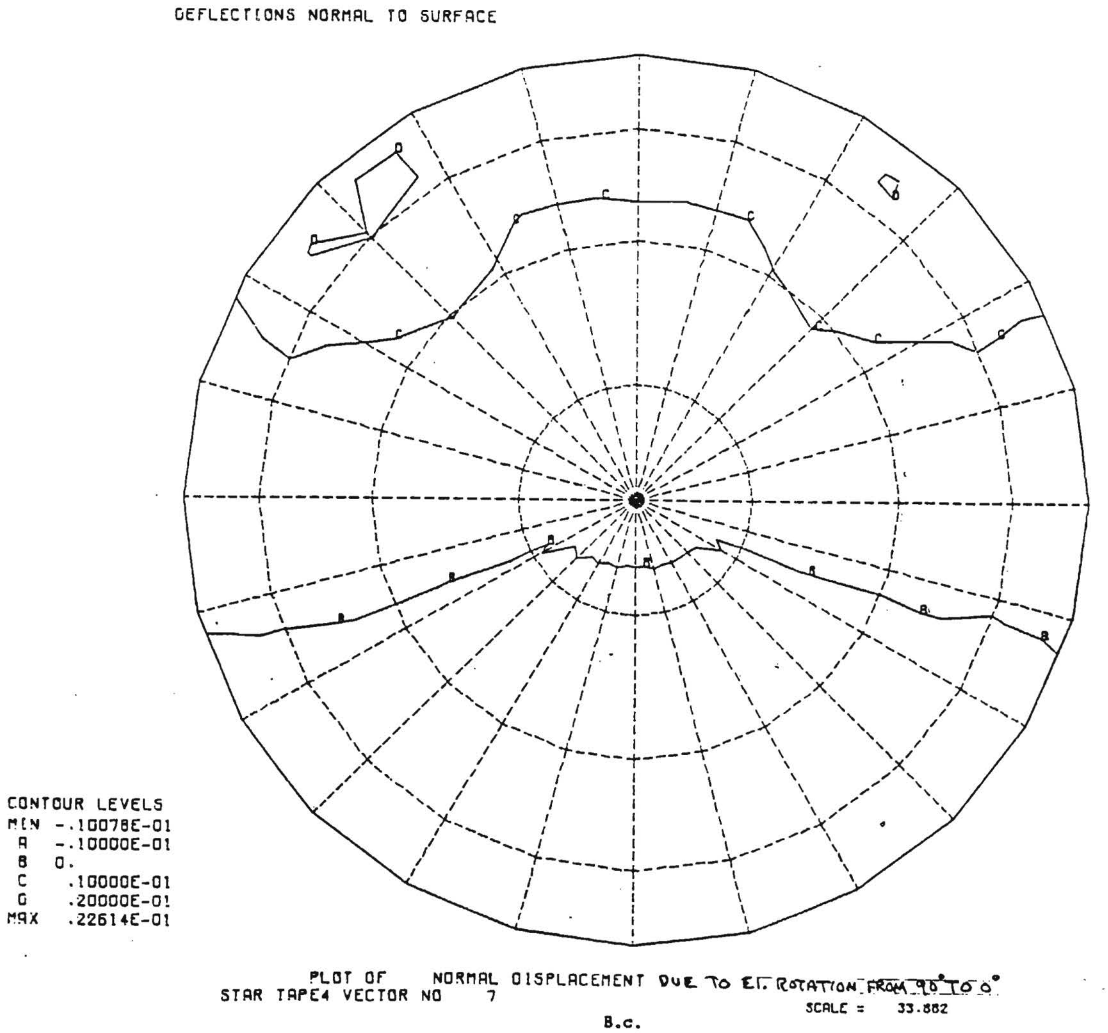


Figure B.c. Static Deflection, Plot of Normal Displacement due to Elevation Rotation from 90° to 0°.

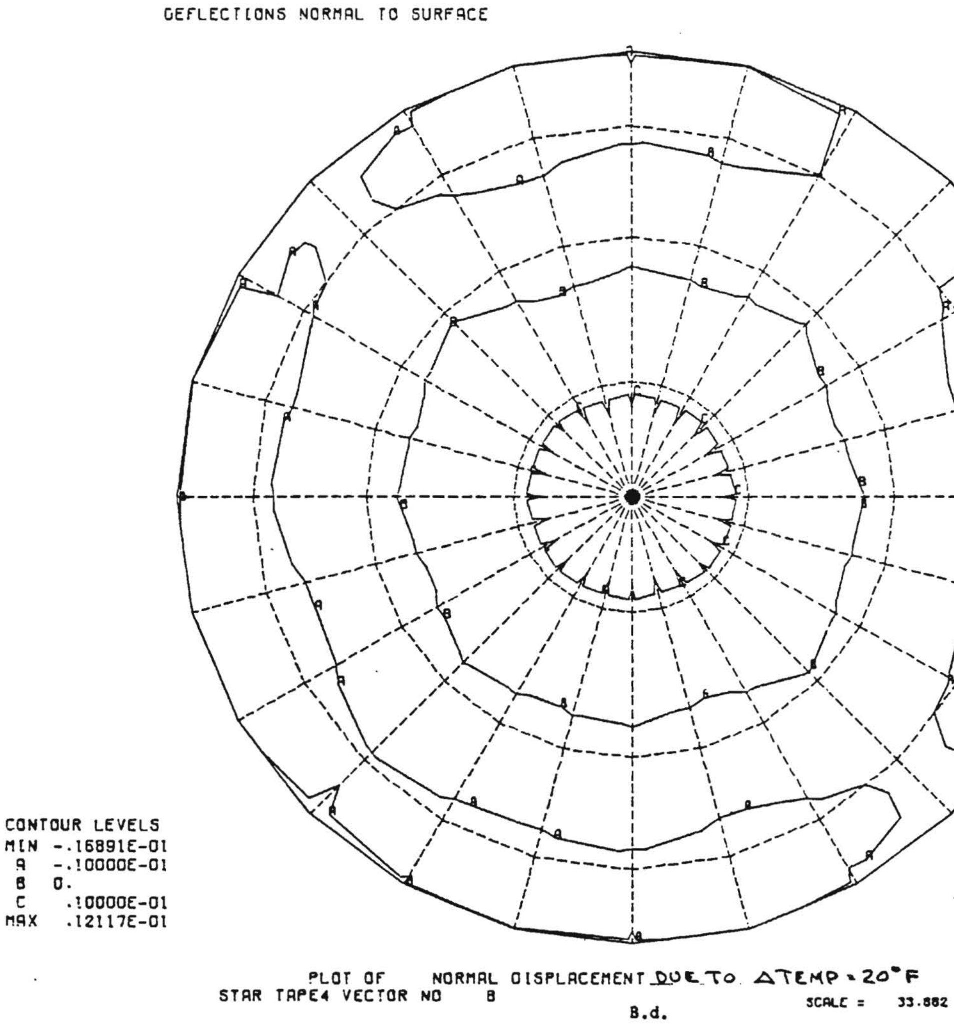


Figure B.d. Static Deflection, Plot of Normal Displacement due to Δ Temperature = 20°F.

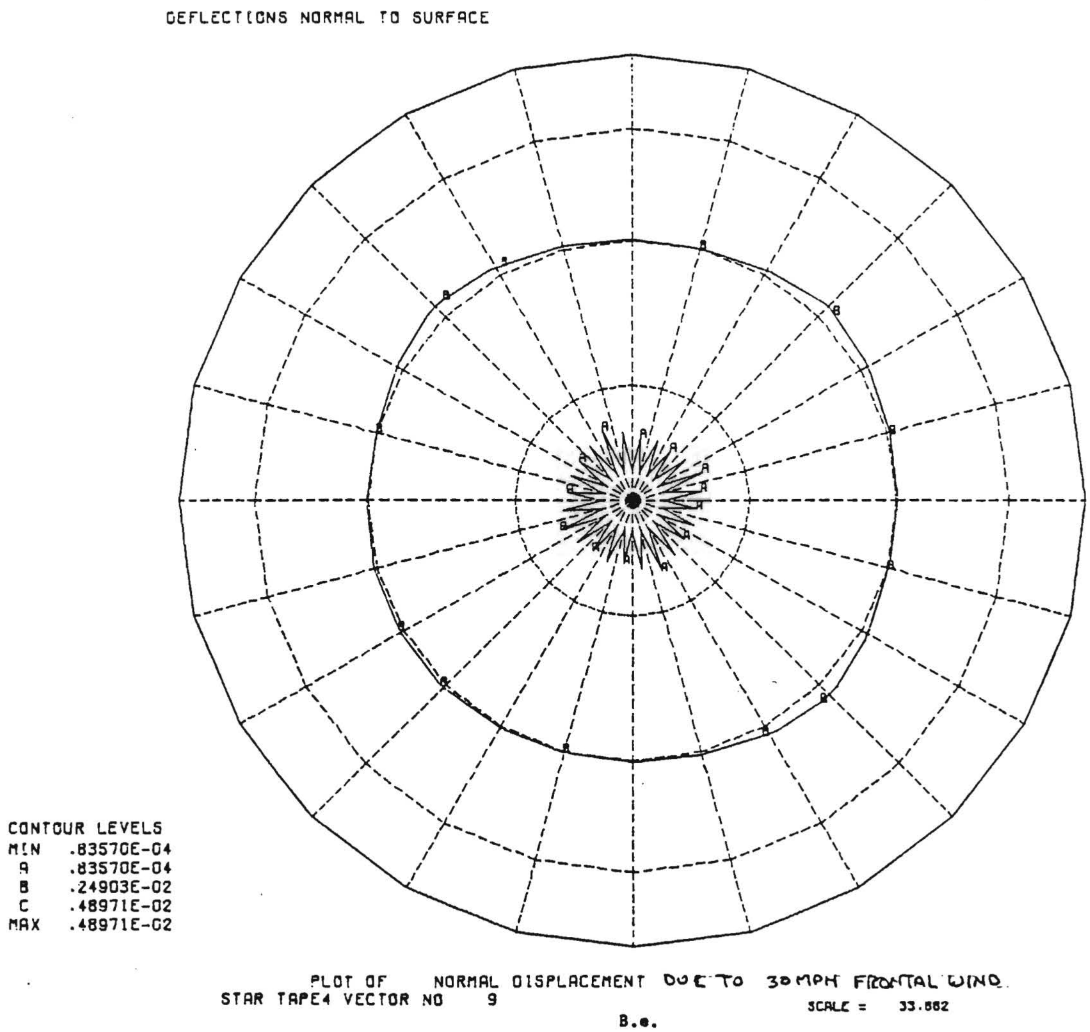


Figure B.e. Static Deflection, Plot of Normal Displacement due to 30 MPH Frontal Wind.

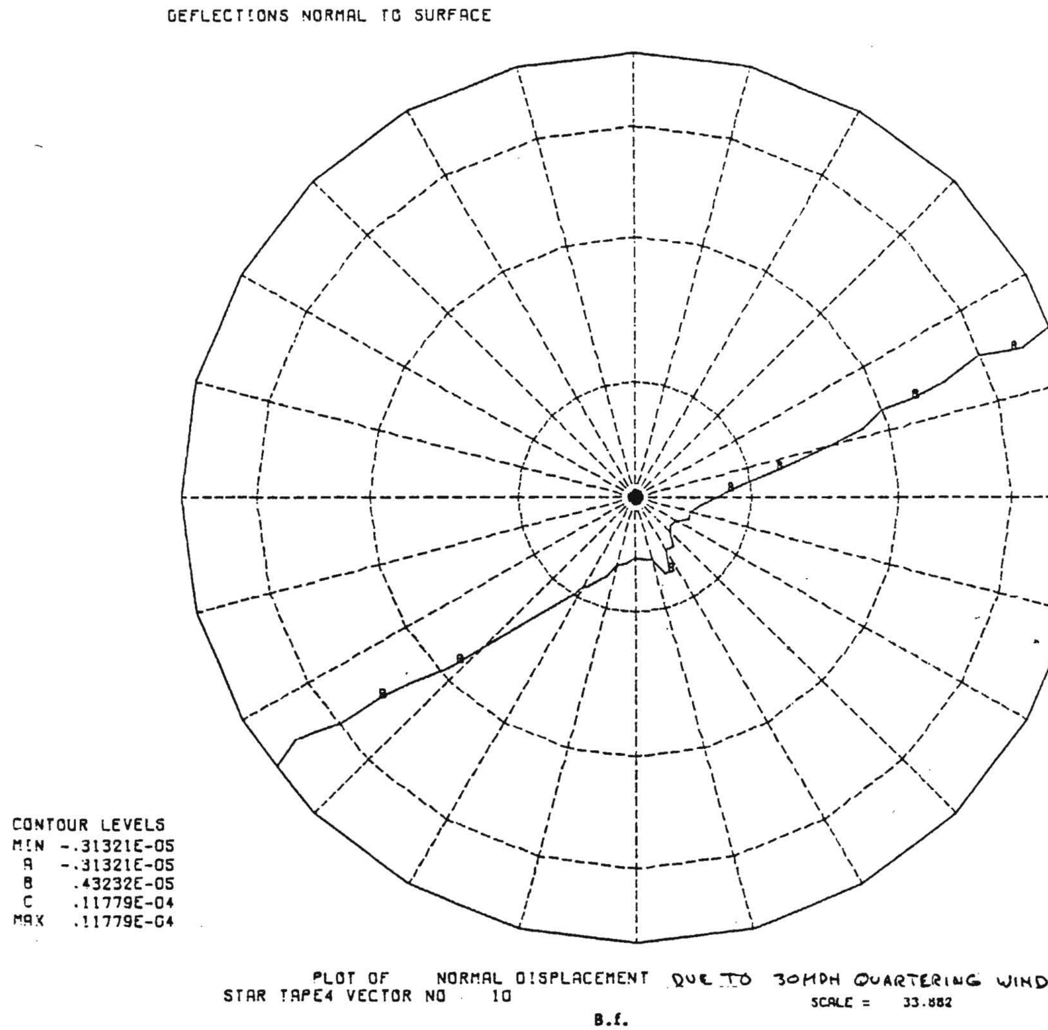
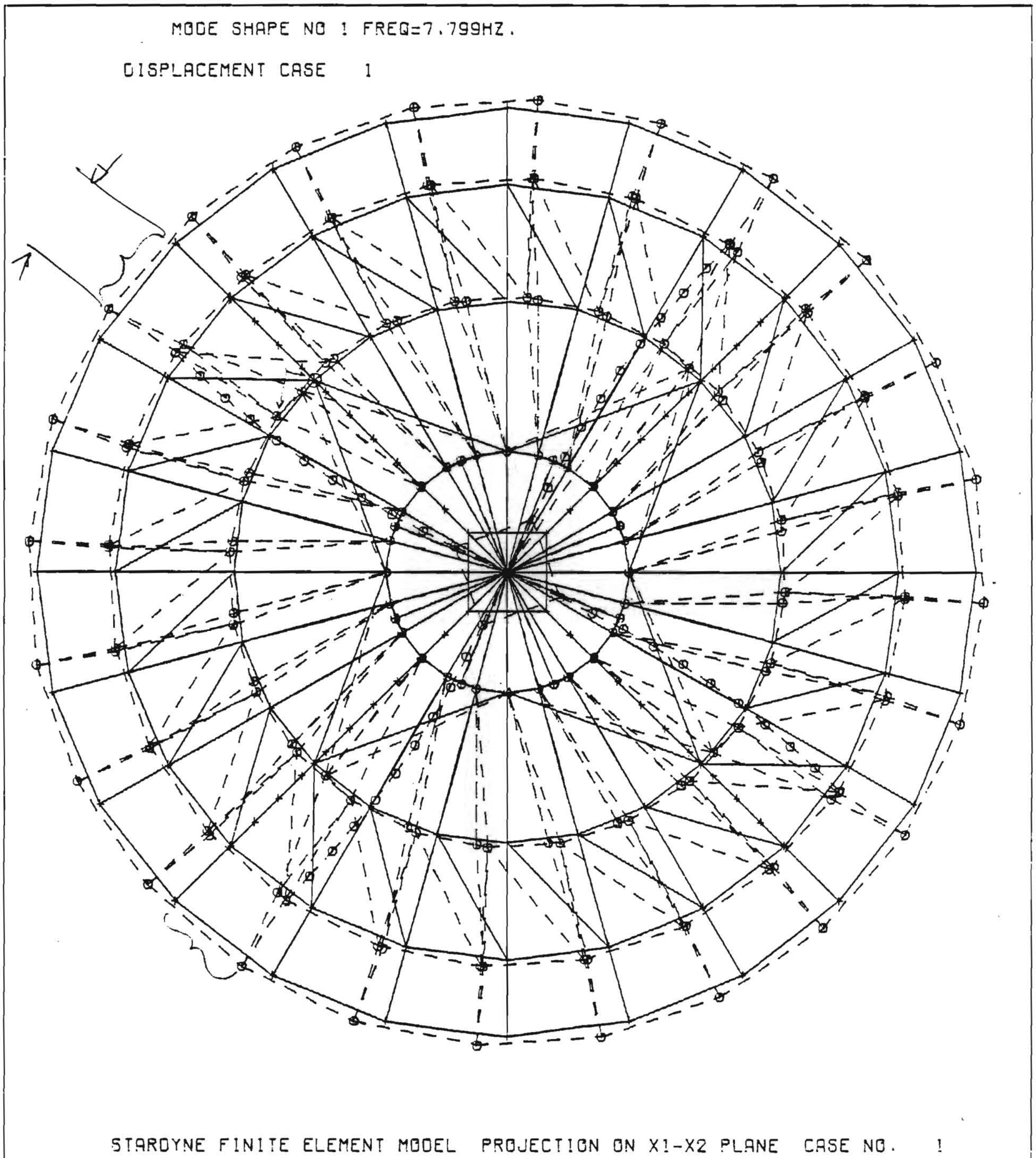
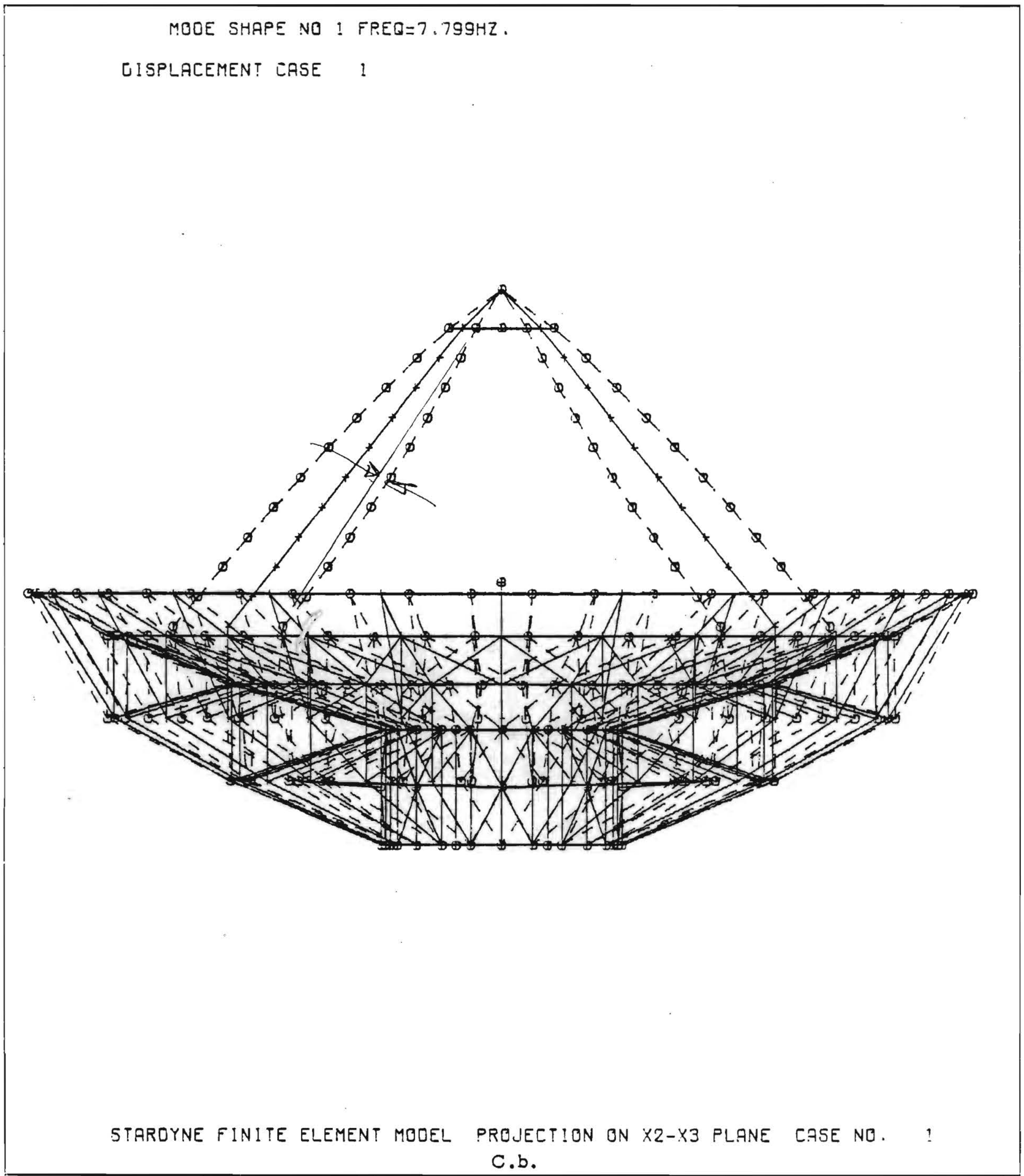


Figure B.f. Static Deflection, Plot of Normal Displacement due to 30 MPH Quartering Wind.


MODE SHAPE NO 1 FREQ=7.799HZ.
DISPLACEMENT CASE 1
STARDYNE FINITE ELEMENT MODEL PROJECTION ON X1-X2 PLANE CASE NO. 1

C.a.


MODE SHAPE NO 1 FREQ=7.799HZ.
DISPLACEMENT CASE 1
STARDYNE FINITE ELEMENT MODEL PROJECTION ON X2-X3 PLANE CASE NO. 1
C.b.

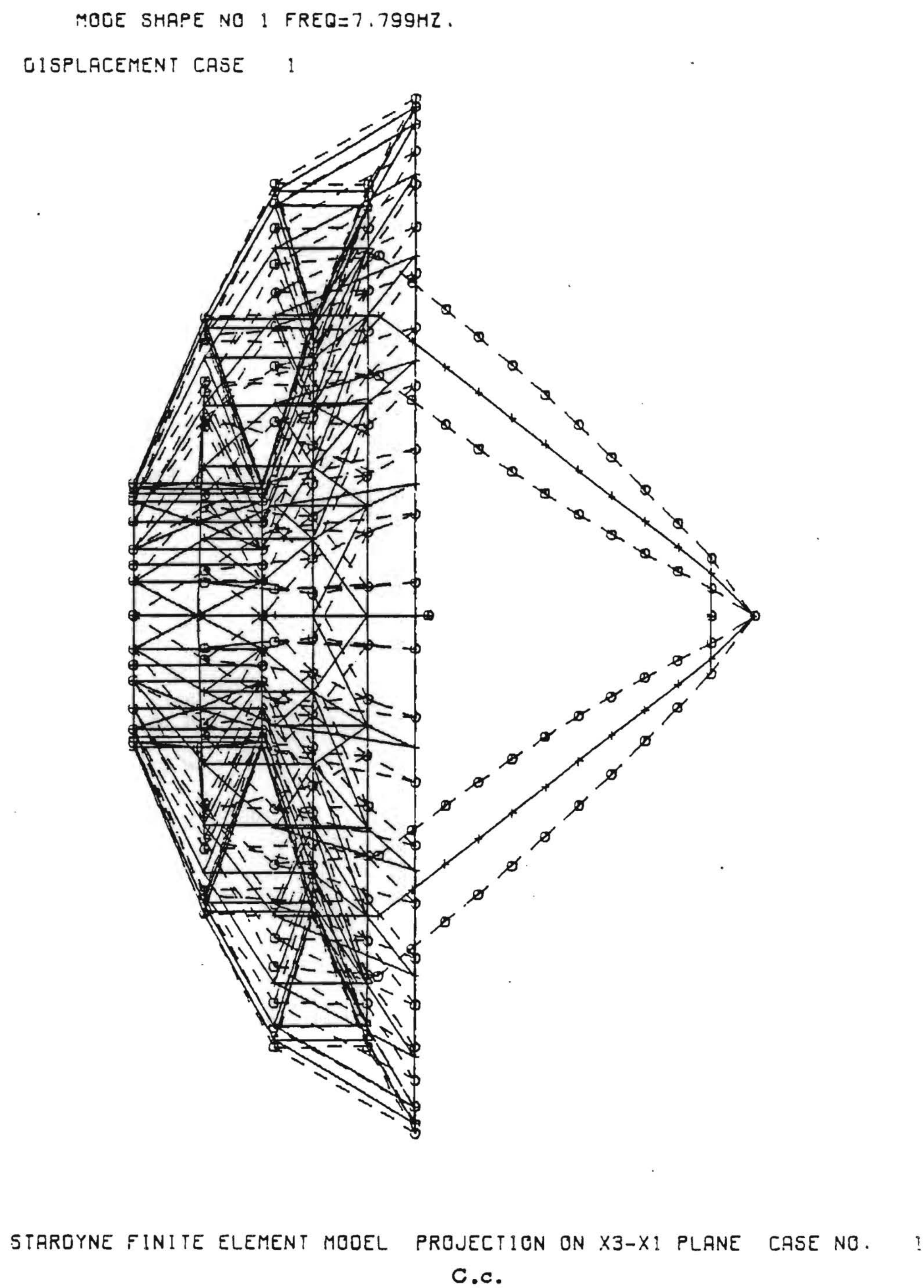


Figure C.c. Dynamic Mode Shape, Plan View.