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THE SELECTION OF GLIDE SLOPE ANTENNA PATTERNS FOR USE IN THE FREQUENCY ASSIGNMENT PROCESS

Mark Lopez

July 1979

Final Report

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FEDERAL AVIATION ADMINISTRATION

Systems Research & Development Service

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16. Abstract

The frequency assignment process is meant to preclude harmful interference within service volumes. This is done by choosing frequencies in a manner which provides certain minimum cochannel and adjacent channel desired to undesired signal ratios at critical points of the service volume. One of the factors which affects a station's signal strength in space is its horizontal antenna pattern. Consequently, the horizontal pattern can have a substantial effect onthe separation required between glide slope frequency assignments. In some cases, it is desirable to consider the actual antenna patterns involved rather than using worstcase station separations. This report has been assembled so that the directivity of the horizontal pattern may be considered in the assignment process. For each antenna type, a particular antenna pattern is recommended.

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SPECTRUM MANAGEMENT STAFF

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The mission of the Spectrum Management Staff is to assist the Department of State, National Telecommunications and Information Administration, and the Federal Communications Commission in assuring the FAA's and the nation's aviation interests with sufficient protected electromagnetic telecommunications resources throughout the world and to provide for the safe conduct of aeronautical flight by fostering effective and efficient use of a natural resource - the electromagnetic radio frequency spectrum.

This objective is achieved through the following services:

- Planning and defending the acquisition and retention of sufficient radio frequency spectrum to support the aeronautical interests of the nation, at home and abroad, and spectrum standardization for the world's aviation community.

- Providing research, analysis, engineering, and evaluation in the development of spectrum related policy, planning, standards, criteria, measurement equipment, and measurement techniques.

- Conducting electromagnetic compatibility analyses to determine intra/intersystem viability and design parameters, to assure certification of adequate spectrum to support system operational use and projected growth patterns, to defend aeronautical services spectrum from encroachment by others, and to provide for the efficient use of the aeronautical spectrum.

- Developing automated frequency selection computer programs/routines to provide frequency planning, frequency assignment, and spectrum analysis capabilities in the spectrum supporting the National Airspace System.

- Providing spectrum management consultation, assistance, and guidance to all aviation interests, users, and providers of equipment and services, both national and international.

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INTRODUCTION

In the past, separation of frequency assignments for associated facilities has not considered the individual system components. Consideration of these components (VOR, DME, TACAN, LOCALIZER, GLIDESLOPE) had been included in the overall separation criteria. Separations required between VORTAC Stations did not require that VOR and TACAN separations be considered separately. Separations required between ILS stations did not require that LOCALIZER, GLIDESLOPE, and DME separations be considered separately. Years ago, there was enough standardization among facilities that this could be done. In recent years, however, the use of many stations types and the variation in the radiated powers of stations has lead us to reexamine old assumptions and conclusions. As a result of this examination, we have concluded that separation of frequency assignments for associated facilities should consider the individual system components.

The use of directional antennas can have a substantial effect on the separation required between ILS Localizer frequency assignments. Since cochannel separations are larger, the effect will be greater for them than for adjacent channel separations.

Consideration of horizontal glide slope antenna directivity is not expected to have a substantial effect on the separation required between cochannel ILS systems. Since the glide slope service volume is substantially smaller than the localizer service volume, localizer separation requirements are still expected to dominate in almost all circumstances. A similar statement could be made for those first adjacent channel glide slope which are paired with first adjacent channel localizers (example: 18x and 18y).

The situation is somewhat different for second adjacent channel glide slope stations and for those first adjacent channel glide slopes not paired with first adjacent channel localizers (example: 18y and 38x). In these cases, the glide slope separation requirement must naturally be examined individually. The horizontal antenna patterns of the glide slope antennas may have a significant effect on separation required in these cases. Consideration of the antenna pattern may be preferable to using worst case separations.

We have assembled data from a number of sources. For antenna type where horizontal patterns were not available, we have made use of NAFEC's ability to measure them. Wherever possible, comparisons have been made between the following types of information:

___ Theoretical Antenna Patterns

___ Measured Antenna Patterns

___ Applicable FAA Antenna Specifications

Data for each antenna type is included in the appendixes. On the basis of these data, antenna patterns have been chosen for use in the frequency assignment process. These patterns are shown in the report conclusions.

DISCUSSION

Rationale for Antenna Pattern Choices

From the information available, three types of antenna data have been compared: theoretical, measured, and FAA Specifications. Ideally, agreement would be expected among these types of data. Practically, this is not always the case. For some antennas, all three types of data are not available. In reviewing what was available, we used the following general glide lines in choosing horizontal antenna patterns for the frequency assignment process.

- ___ If an FAA Antenna Specification was found to be applicable for an antenna type and if both the theoretical and the measured data compared reasonably well with it, we depended largely on the specification in choosing the pattern to be used in the frequency assignment process.
- ___ If an FAA Antenna Specification was found to be applicable and it did not compare well with the measured data, we chose a conservative frequency assignment pattern based on a carefully chosen mixture of specification and measured data. An example of this method is seen in the frequency assignment pattern chosen for the type I and type II antennas.
- ___ If no FAA Antenna Specification was applicable and if theoretical data was only available for some portion of a pattern, we tried to get as much measured data as possible before choosing a conservative pattern.
- ___ If no FAA Antenna Specification was found to be applicable

and if no theoretical pattern was available, we chose a frequency assignment pattern on the basis of the measured data. The patterns chosen for the Stan-38, End-Fire Slotted-Cable, and the A.I.L. Type 55 Glide Slope Antennas are examples of this method.

CONCLUSIONS

1. The difference between the horizontal antenna patterns of various ILS glide slope antenna types are not as large as what has been found for ILS localizers. Nevertheless, some differences are apparent. In some cases, it may be desirable to take these differences into account in the frequency assignment process.

2. Recommended antenna patterns are shown in figures 1 thru 7. These patterns are intended as tools for avoiding interference between ILS glide slopes. In some cases, those are not the best patterns to use as tools for avoiding interferences between ILS glide slopes and other types of radio services. Should the need arise to make such an analysis, discussion with the Spectrum Management Staff (ARD-60) is recommended.

3. A frequency assignment antenna pattern is not included for the wave-glide antenna since no horizontal antenna patterns were found. Antenna data on this system is therefore still required. Additional data would also be helpful on the A.I.L. Type 55 glide slope and the end-fire slotted cable system.

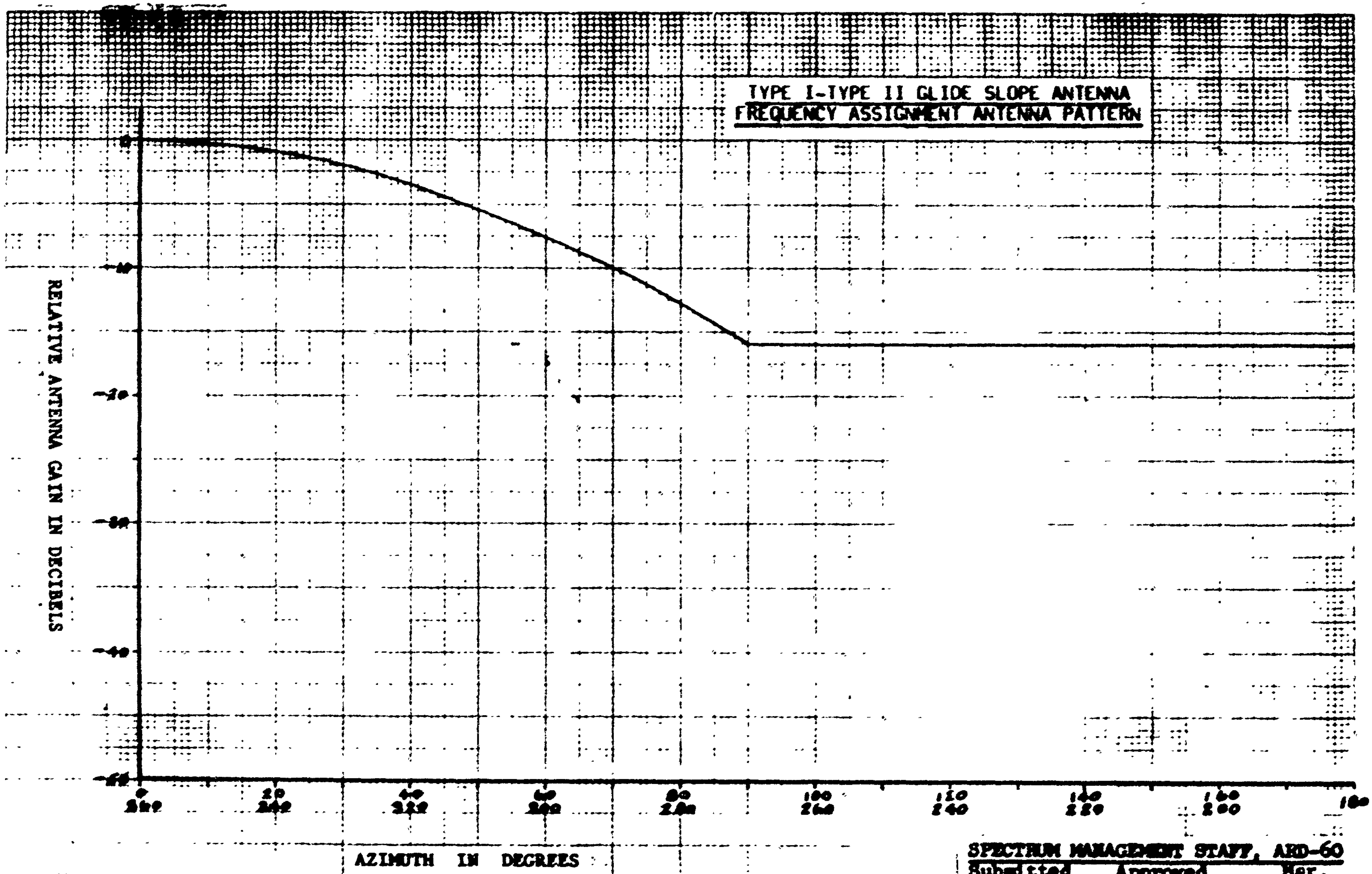

FIGURE 1

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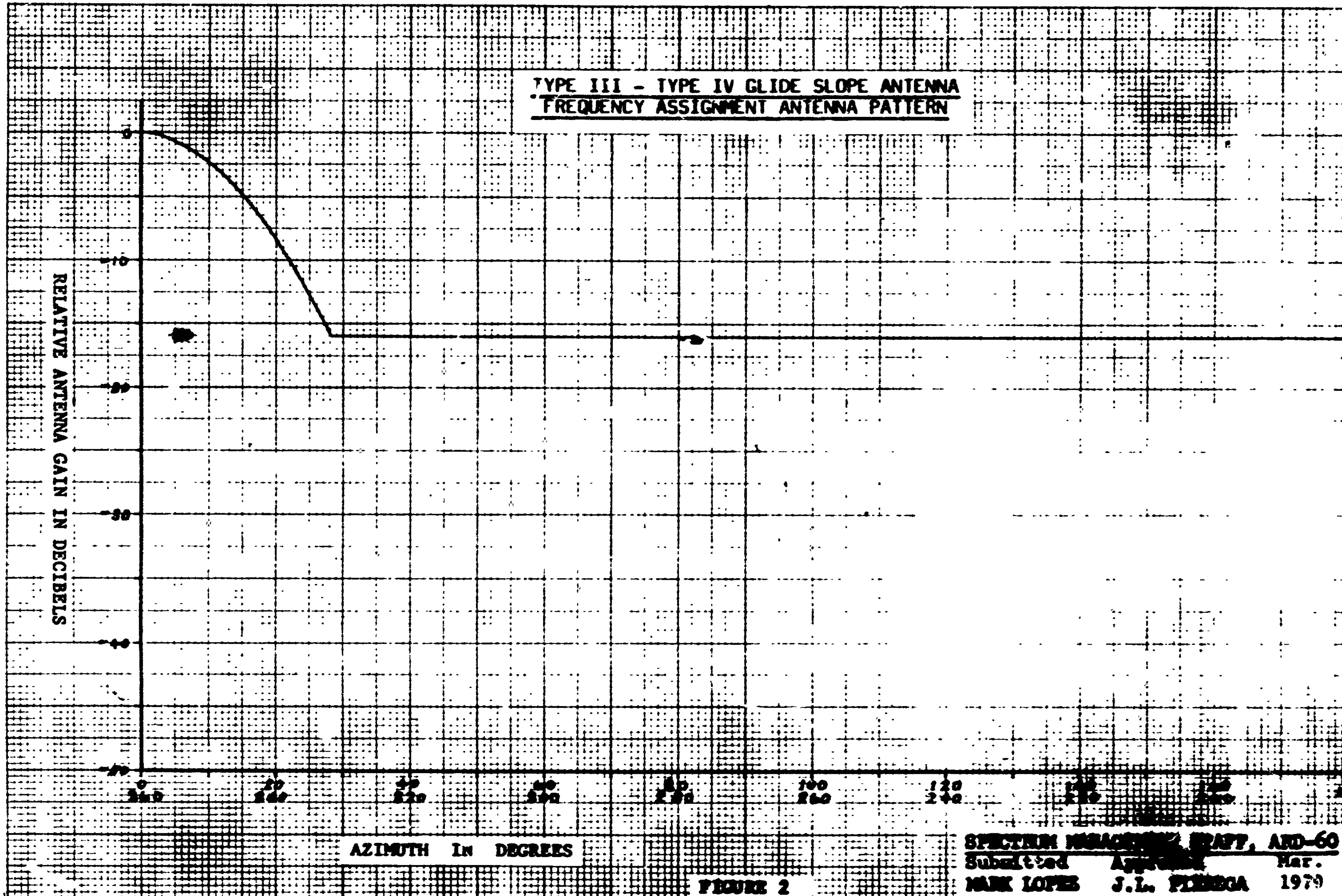
TYPE III - TYPE IV GLIDE SLOPE ANTENNA
FREQUENCY ASSIGNMENT ANTENNA PATTERN
RELATIVE ANTENNA GAIN IN DECIBELS
0
-10
-20
-30
-40
-50
0
360
20
340
40
320
60
300
80
280
100
260
120
240
AZIMUTH IN DEGREES
Submitted
Mar.
MARK LOPEZ
1979

FIGURE 2

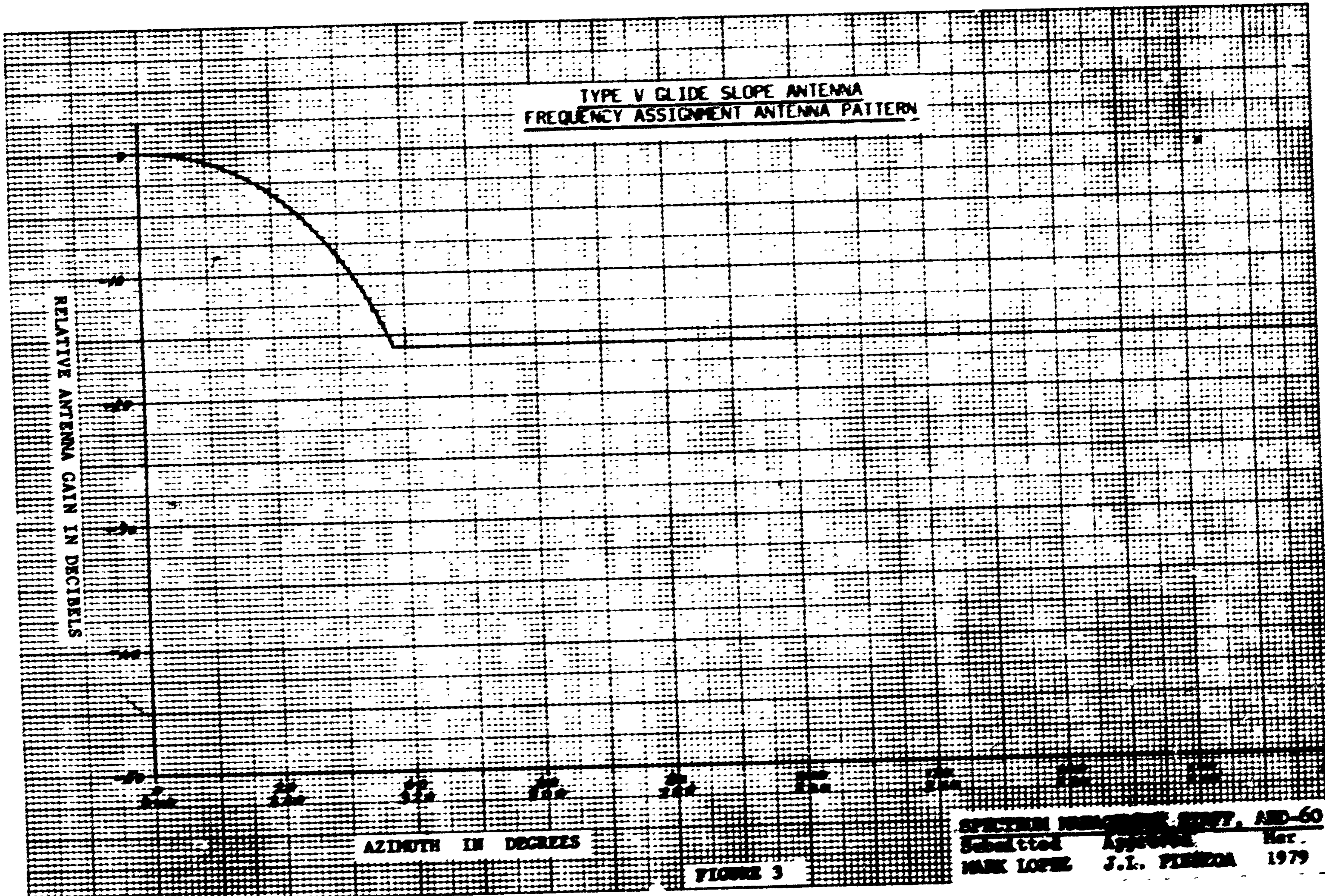
TYPE V GLIDE SLOPE ANTENNA
FREQUENCY ASSIGNMENT ANTENNA PATTERN
RELATIVE ANTENNA GAIN IN DECIBELS
AZIMUTH IN DEGREES
Submitted
Mar.
1979

FIGURE 3

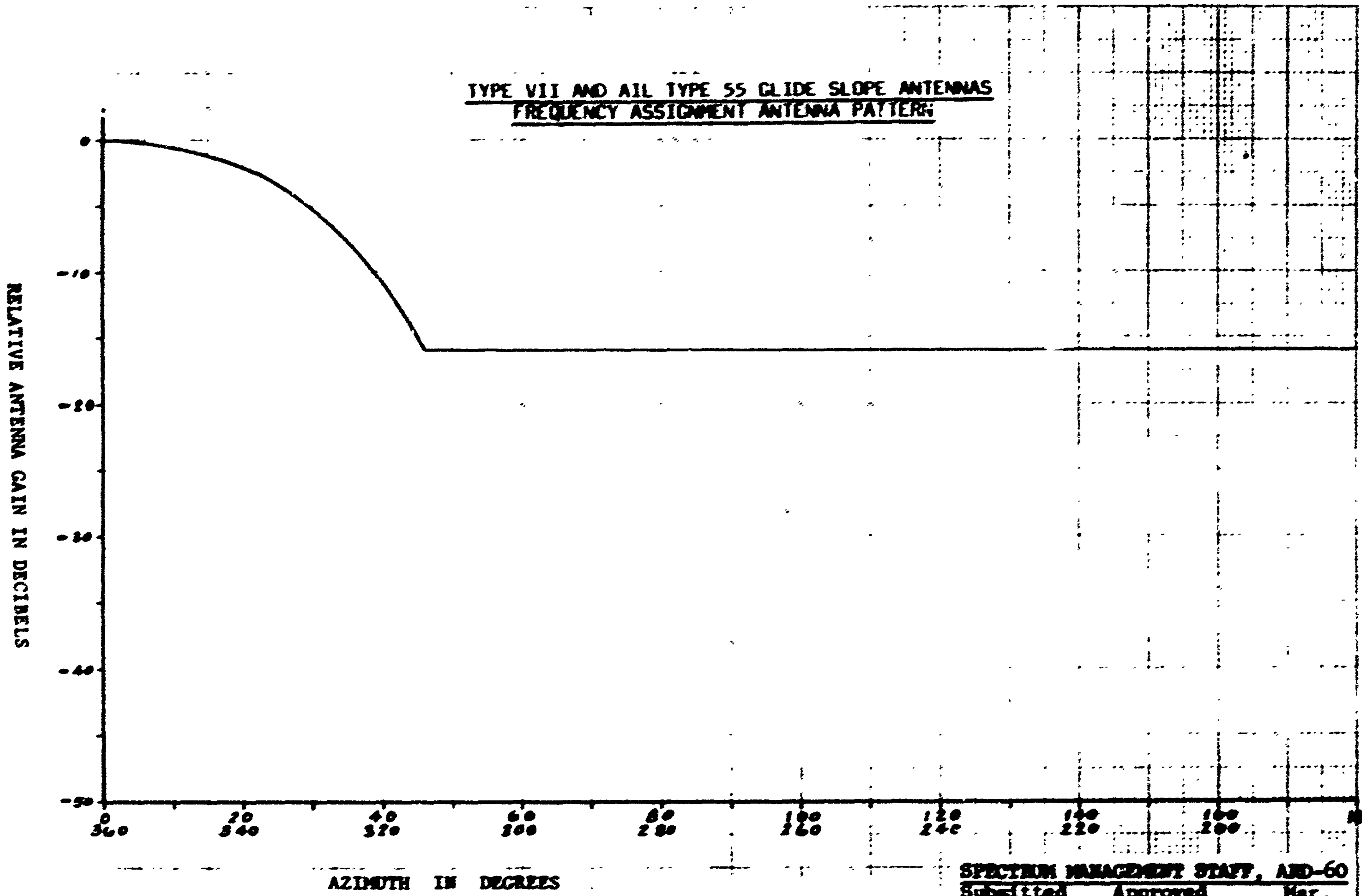

FIGURE 4

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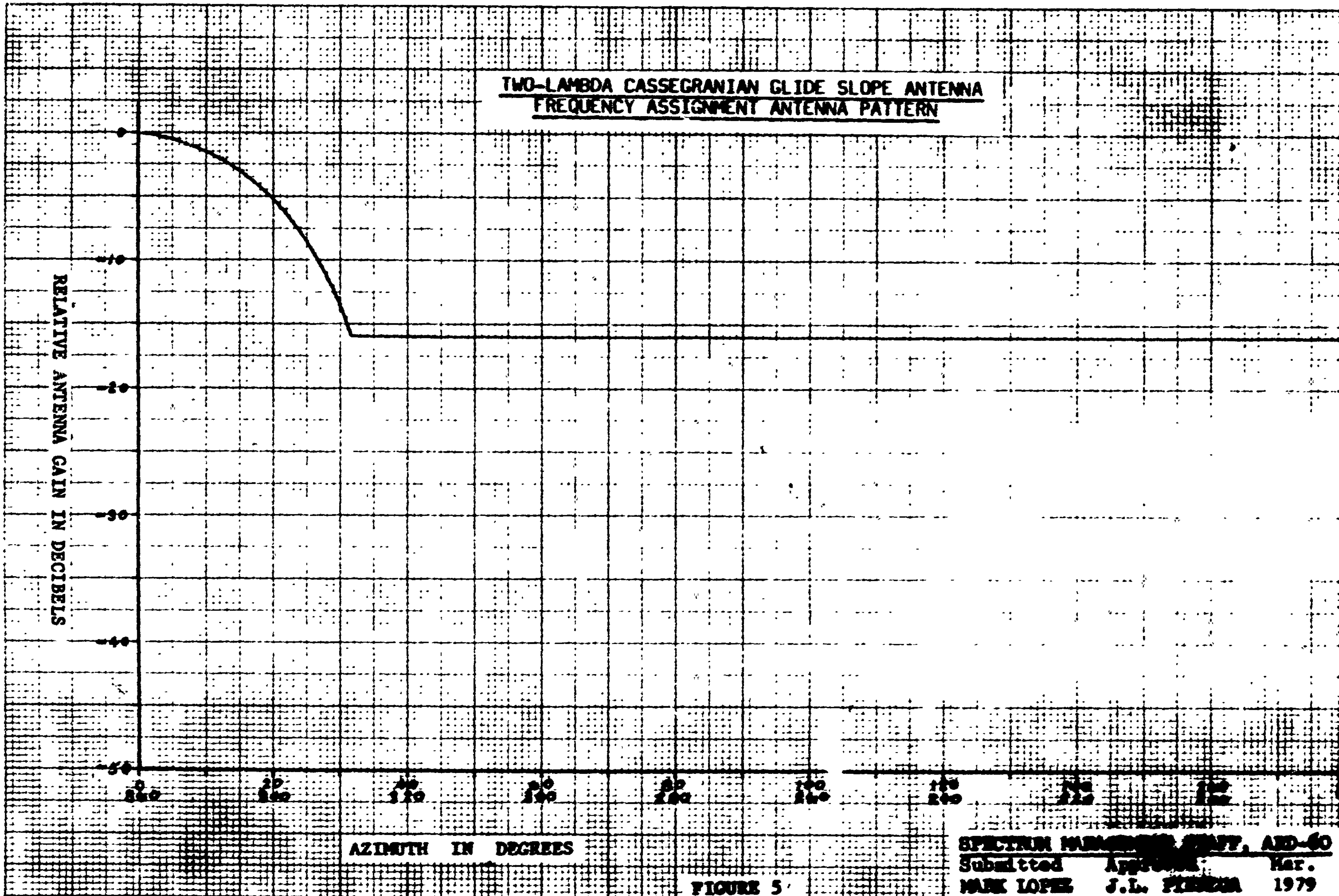

TWO-LAMBDA CASSEGRANIAN GLIDE SLOPE ANTENNA
FREQUENCY ASSIGNMENT ANTENNA PATTERN
RELATIVE ANTENNA GAIN IN DECIBELS
-10
-20
-30
-40
-50
0
20
40
60
80
100
AZIMUTH IN DEGREES
Submitted
Mar.
MARK LOPEZ
1979

FIGURE 5

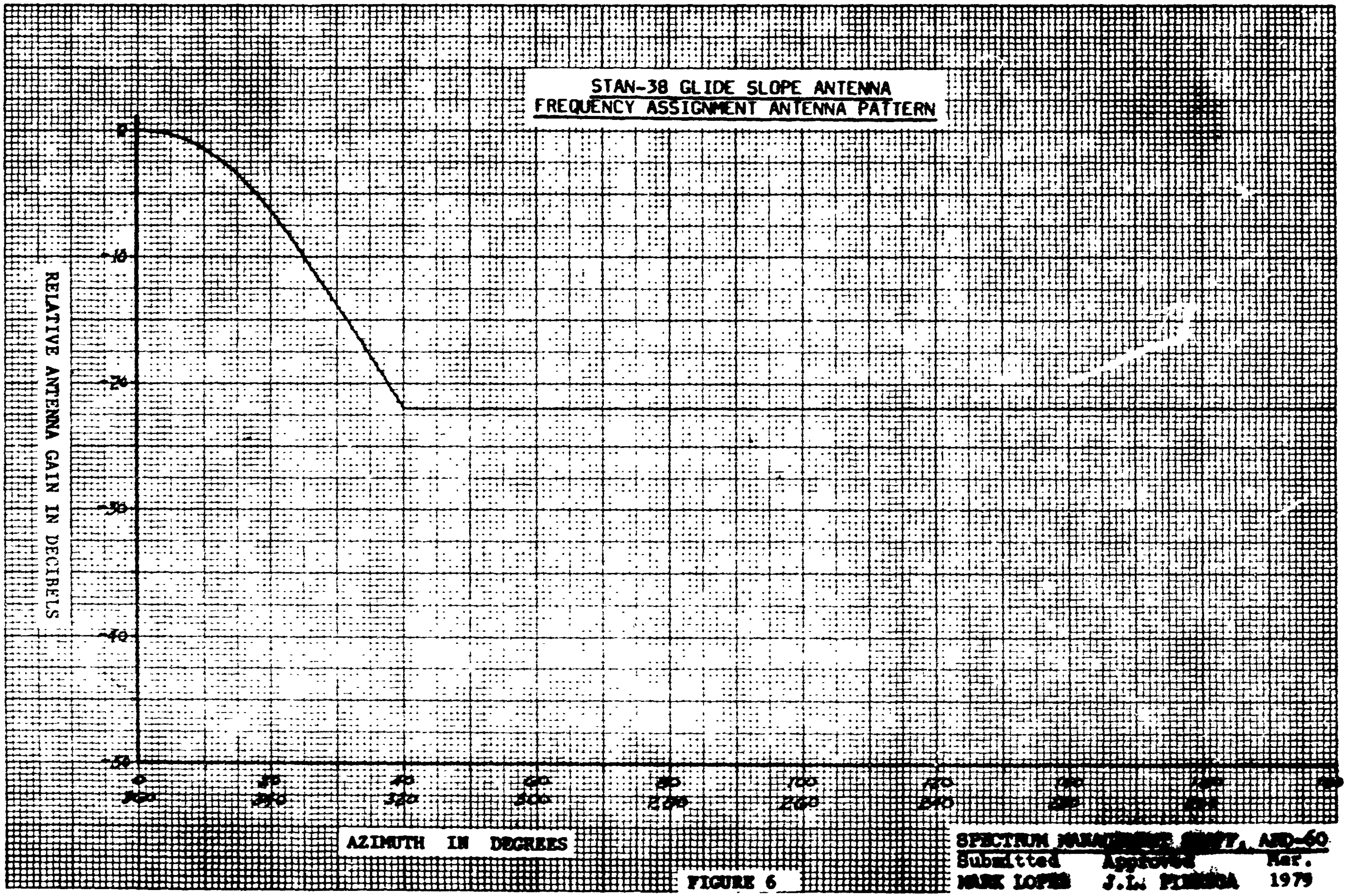

STAN-38 GLIDE SLOPE ANTENNA
FREQUENCY ASSIGNMENT ANTENNA PATTERN
RELATIVE ANTENNA GAIN IN DECIBELS
0
-10
-20
-30
-40
-50
AZIMUTH IN DEGREES
Submitted
Mar.
1979

FIGURE 6

TYPE VII AND AIL TYPE 55 GLIDE SLOPE ANTENNAS
FREQUENCY ASSIGNMENT ANTENNA PATTERN

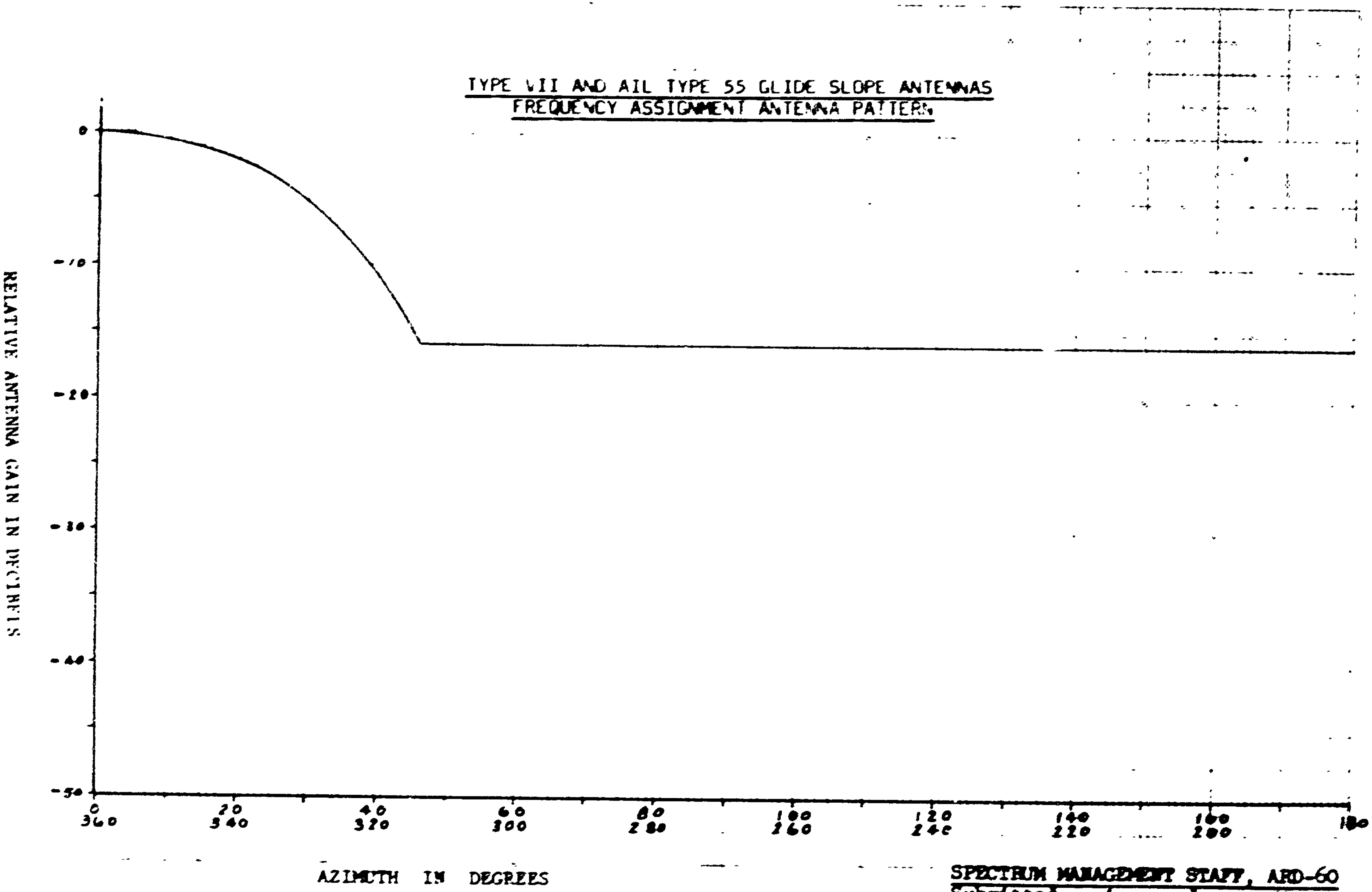


FIGURE 4

SPECTRUM MANAGEMENT STAFF, ARD-60

Submitted	Approved	Mar.
MARK LOPEZ	J.L. PIERZGA	1979

RELATED DOCUMENTS

1. FAA Handbook 6050.5A, "Frequency Management Engineering Principles, Geographical Separation Criteria for VOR, DME, TACAN, ILS, and VOT Frequency Assignments," March 12, 1969.
2. FAA Instruction Booklet TI 6750.9, "Antenna, Glide Slope Type FA-8090," FAA Contract FA68WA-1969, Scanwell Laboratories Inc., May 9, 1968.
3. Wilcox American Standard Co., Instruction Book TI 6750.21, "Glide Slope Antenna (Type III) Type FA-8021," FAA Contract FA68WA-1890, Wilcox American Standard Co., April 30, 1968.
4. FAA Preliminary Instruction Book TI 6750.32, "Glide Slope Antenna System Type FA-8730," FAA Contract DOT-FA70WA-2451, Scanwell Laboratories Inc., June 30, 1970.
5. FAA Preliminary Instruction Book TI 6750.44, "Glide Slope Antenna System, Part of Mark I Instrument Landing System," FAA Contract DOT-FA69WA-2196, A.I.L. Cutler Hammer, June 30, 1969.
6. FAA Preliminary Instruction Book TI 6750.63, "Glide Slope Antenna System Type FA-8870," FAA Contract FA71WA-2525, Scanwell Laboratories Inc., December 30, 1970.
7. FAA Instruction Book, Book I TI 6750.69, "Glideslope Station, One Frequency Type AN/GRN-27(V)," FAA Contract F33657-71-C-0103, Texas Instruments, June 1, 1974.
8. FAA Instruction Book, Book I TI 6750.70, "Glideslope Station, Two Frequency Type AN/GRN-27 (V)," FAA Contract F33657-71-C-0103, Texas Instruments, June 1, 1974.

9. FAA Instruction Book TI6750.76, "Glide Slope Antenna System FA-8976," FAA Contract FA73WA-3176, February 9, 1973 and FA73WA-3358, Antenna Products Co., October 16, 1973.

10. FAA Preliminary Instruction Book TI6750.83, "Glide Slope Antenna Type FA-9373," FAA Contract FA74WA-3364, Antenna Products Co., October 18, 1973.

11. FAA Instruction Book, "Mark III Instrument Landing System Glide Slope Station NAFEC," FAA Contract DOT-FA73WA-3289, Texas Instruments.

12. FAA Order 6750.6B, "Installation Instructions for Category I and Category II ILS Glide Slopes," July 9, 1976.

13. FAA Order 6750.16A, "Sitting Criteria for Instrument Landing Systems," August 18, 1973.

14. FAA Order 6750.17, "Maintenance of ILS Glide Slope Equipment," August 25, 1971, Reprinted September 14, 1976 (Includes Changes 1 through 4).

15. FAA Order 6750.32, "Maintenance of Null Reference Glide Slope Equipment," August 9, 1976.

16. FAA Report No. RD-64-11, "Analysis of ILS Glide Slope Antennas in Operation and Under Development," FAA Contract FA-WA-4391, National Engineering Science Co., February 1964.

17. FAA Report No. RD-65-46," A Waveguide Glide Slope Antenna," FAA Contract FAA/BRD-317, A.I.L. Cutler Hammer, July 1965.

18. FAA Report No. FAA-RD-71-30," Instrument Landing System Improvement Program," FAA Contract FA69WA-2066, Avionics Research Group, Department of Electrical Engineering, October 1971.

19. FAA Report No. FAA-RD-72-139, "Analysis of Instrument Landing System Glide Slope Broadside Antennas," FAA Contract DOT-FA71WA-2666, Aerospace

and Electronics Systems Division of Westinghouse Defense and Electronics Systems Center, August 1972.

20. FAA, Phase II Interim Report No. FAA-RD-73-78, "Modification and Test Instrument Landing System Glide Slope Waveguide Antenna," FAA Contract DOT-FA71WA-2666, Aerospace and Electronics Systems Division of Westinghouse Defense and Electronic Systems Center, June 1973.

21. FAA Interim Report No. FAA-RD-76-9, "Installation and Test of the Compensated Waveguide Antenna at Buffalo, New York, Runway 23. Glide Slope 23," FAA Contract DOT-FA74WA-3360, Aerospace and Electronic Systems Division of Westinghouse Defense and Electronics Systems Center, February 1976.

22. FAA Report No. FAA-RD-77-130, "The Selection of ILS Localizer Antenna Patterns for use in the Frequency Assignment Process," Robert D. Smith, September 1978.

23. FAA Specification FAA-E-2245, "Antennas, Glide Slope," March 11, 1966, Amendment-3, March 24, 1969.

24. FAA Specification FAA-E-2429, "Antenna System, Glide Slope," January 2, 1970, Amendment-2, November 14, 1973.

25. FAA Specification FAA-E-2557, "Amplitude and Phase Control Unit, Sideband Reference Glide Slope," April 2, 1973, Amendment-1, May 11, 1973.

26. Photographs Obtained from Robert Littlepage, Program Manager, Glide Slope Antenna Systems, Westinghouse Electric Corp., Letter To ARD-60 Dated December 20, 1977.

27. Scanwell Laboratories, Inc., "Instruction Manual for Glide Slope Antenna System Type 4400," Prepared for Pueblo Memorial Airport to Serve Runway 25R, July, 1970.

28. Technical Manual TTH 309, "Instrument Landing System Equipment Glide Path Type Stan 38," British Document HB. 1268/2-A Issue 1, June 1968.

29. Unpublished Measured Data Obtained from Neil Creedon, A.I.L. Cutler Hammmer, Letter To ARD-60 Dated December 19, 1977.

30. Watts Jr., C.B., "Description of the End-Fire Slotted-Cable Glide Slope, Medium Aperture," January 1977.

ACRONYMS AND ABBREVIATIONS

AGL	Above Ground Level
A.I.L.	Airborne Instrument Laboratory
A.P.C.	Antenna Products Company
CE	Capture Effect Glide Slope System
dB	Decibel
DWG	Drawing
FAA	Federal Aviation Administration
G/S	Glide Slope
ILS	Instrument Landing System
kHz	Kilohertz
km	Kilometer
MHz	Megahertz
NAFEC	National Aviation Facilities Experimental Center
nmi	Nautical Miles
NR	Null Reference Glide Slope System
RF	Radio Frequency
RWY	Runway
SBR	Sideband Reference Glide Slope System
SRDS	Systems Research and Development Service
T.I.	Texas Instruments
TTH	Telecommunication Technical Handbook

APPENDIX A

TYPE I AND TYPE II ANTENNAS

The Type I antenna consists of a half - wave dipole mounted on an elliptical ground plane and enclosed in a radome. The Type II antenna is the same as the Type I, except it is equipped with a heater. The addition of the heater does not affect the antenna pattern. These antennas have primarily been used with the older tube type transmitters. They are gradually being phased out in favor of antennas with a more directional azimuthal pattern. Only limited measured data was found on these antennas.

The measured data taken at NAFEC (Fig. A3) compares well with the theoretical patterns. In addition, it compares reasonably well with the requirements of specification FAA-E-2245 (Fig. G1). The measured data from Trenton (Fig. A4) does not compare quite as well. The main lobe of the pattern is somewhat narrower and the pattern slightly exceeds the -16dB limit between 242 and 264 degrees. No explanation was available for these discrepancies. The frequency assignment antenna pattern recommended for the Type I and Type II Glideslope Antennas (Fig. 1) is based on the specification (FAA-E-2245) and figures in Appendix A.

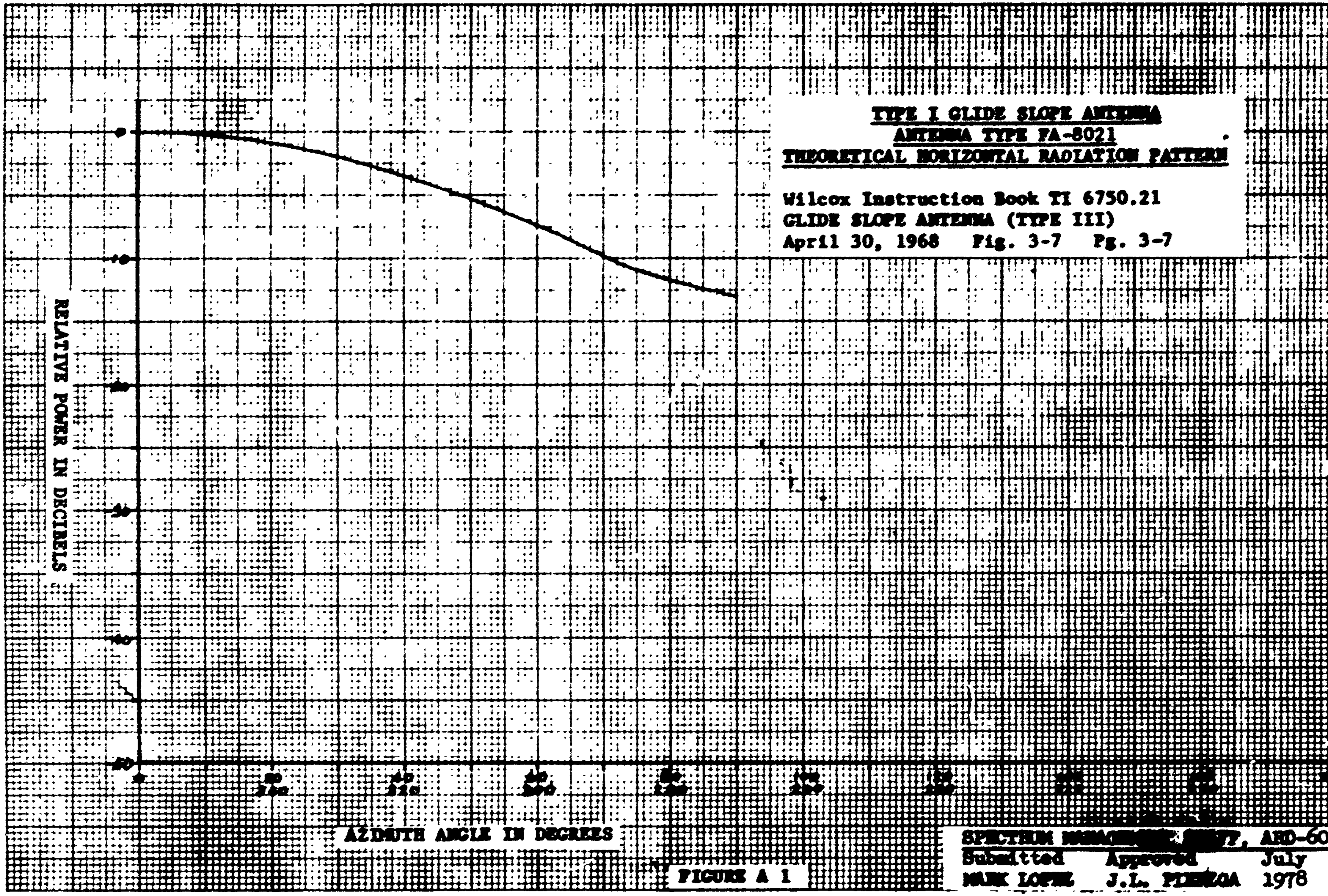

TYPE I GLIDE SLOPE ANTENNA
ANTENNA TYPE FA-8021
THEORETICAL HORIZONTAL RADIATION PATTERN
Wilcox Instruction Book TI 6750.21
GLIDE SLOPE ANTENNA (TYPE III)
April 30, 1968 Fig. 3-7 Pg. 3-7
RELATIVE POWER IN DECIBELS
AZIMUTH ANGLE IN DECREES
ARD-60
Submitted Approved July
1978

FIGURE A 1

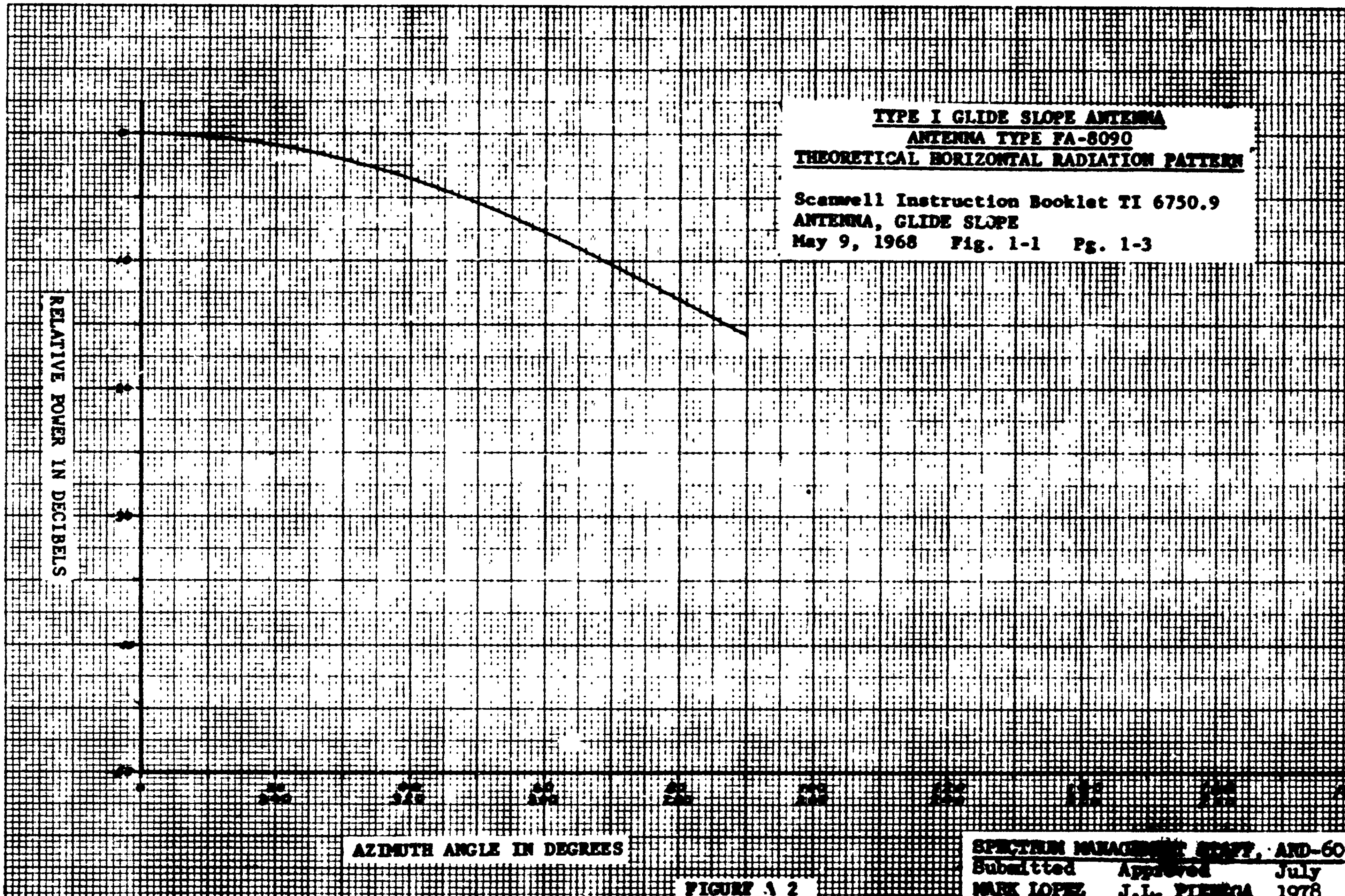
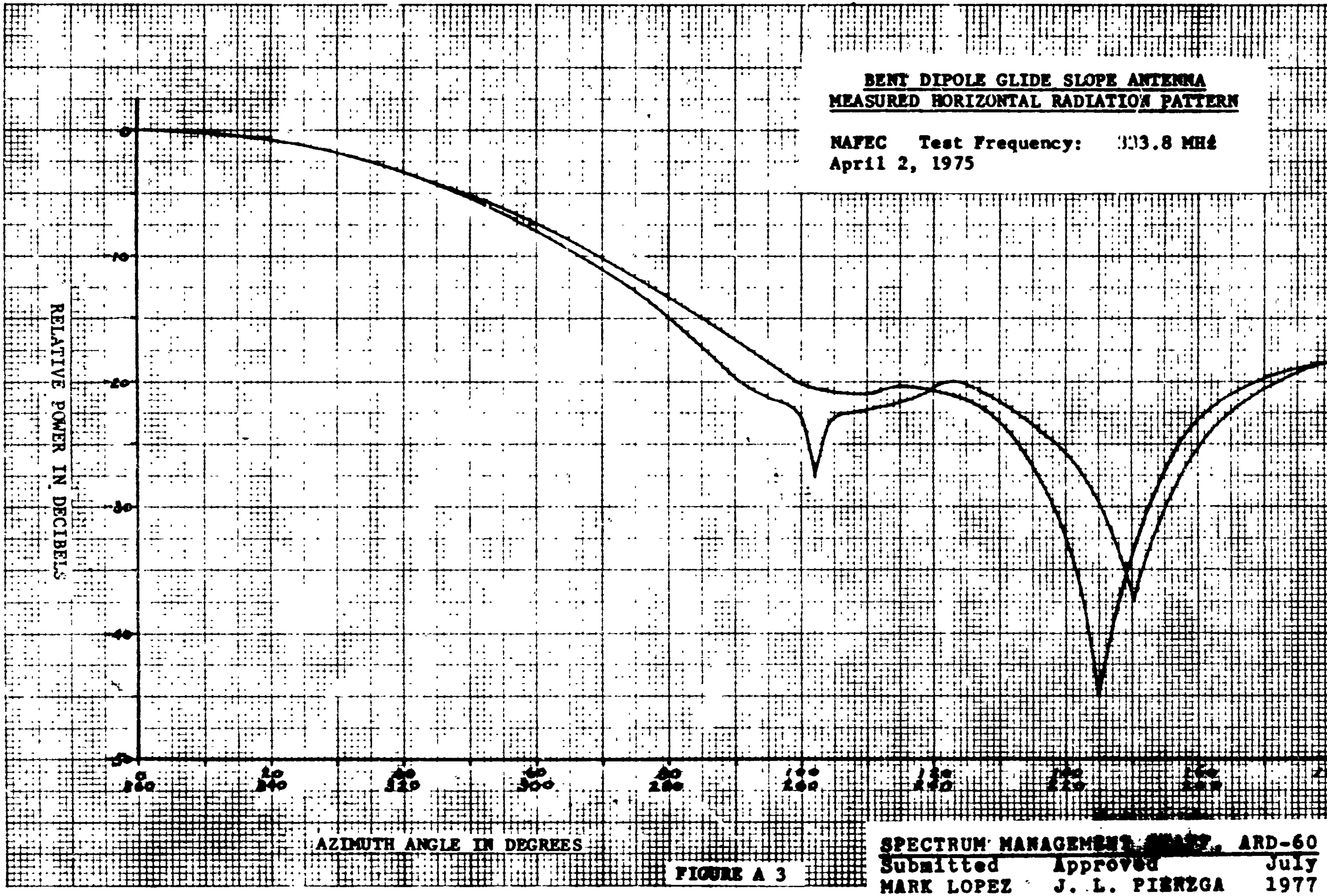

TYPE I GLIDE SLOPE ANTENNA
ANTENNA TYPE FA-8090
THEORETICAL HORIZONTAL RADIATION PATTERN
Scanwell Instruction Booklet TI 6750.9
ANTENNA, GLIDE SLOPE
May 9, 1968 Fig. 1-1 Pg. 1-3
RELATIVE POWER IN DECIBELS
AZIMUTH ANGLE IN DEGREES
Submitted
MARK LOPEZ
July
1978

FIGURE A 2



BENT DIPOLE GLIDE SLOPE ANTENNA
MEASURED HORIZONTAL RADIATION PATTERN
NAFEC Test Frequency: 333.8 MHz
April 2, 1975
RELATIVE POWER IN DECIBELS
0
10
20
30
40
50
0
360
20
340
40
320
60
300
80
280
100
260
120
240
140
220
160
200
180
AZIMUTH ANGLE IN DEGREES
SPECTRUM MANAGEMENT [illegible], ARD-60
Submitted Approved July
MARK LOPEZ J. L. PIERZGA 1977

FIGURE A 3

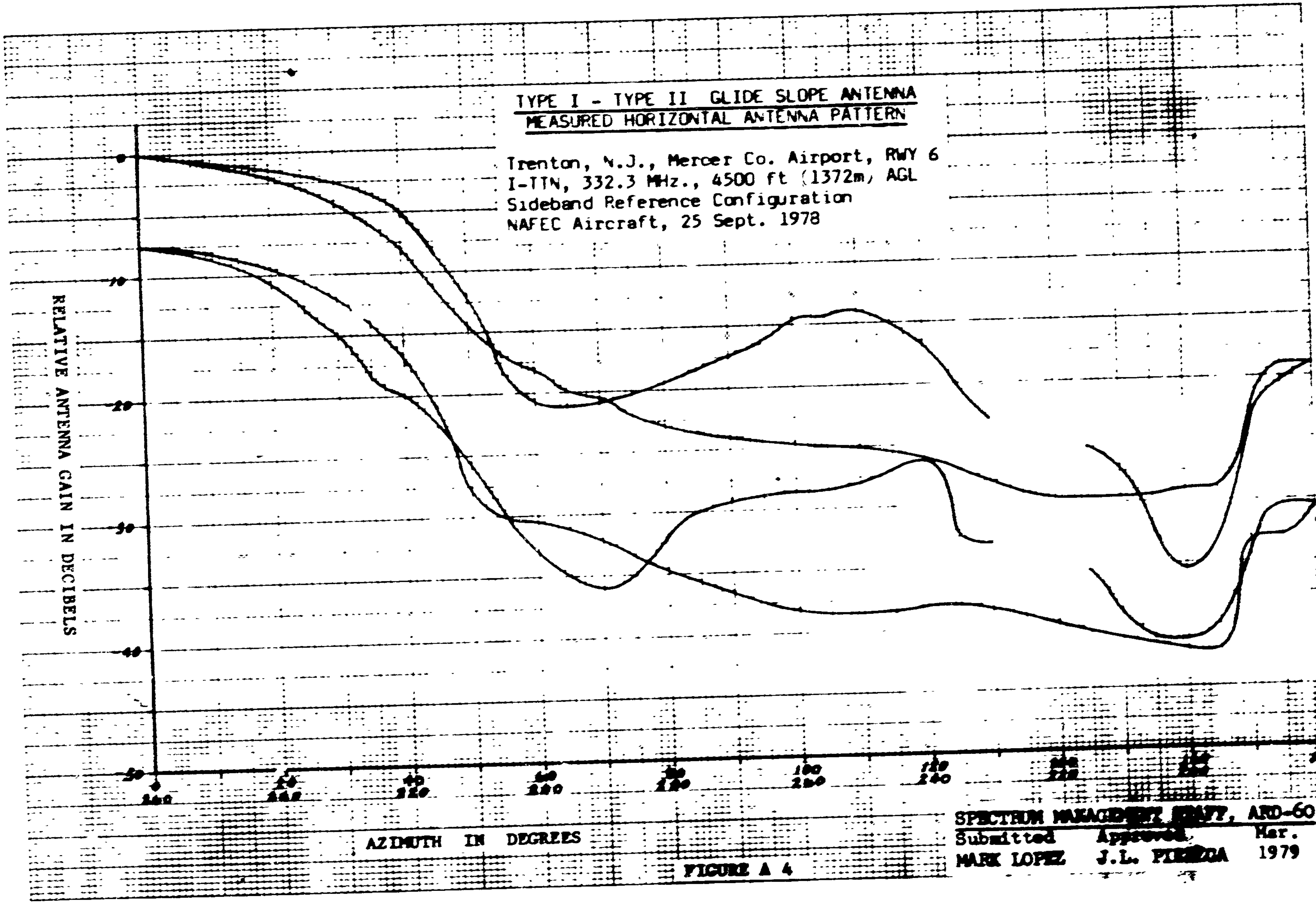

TYPE I - TYPE II GLIDE SLOPE ANTENNA
MEASURED HORIZONTAL ANTENNA PATTERN
Trenton, N.J., Mercer Co. Airport, RWY 6
I-TTN, 332.3 MHz., 4500 ft (1372m) AGL
Sideband Reference Configuration
NAFEC Aircraft, 25 Sept. 1978
RELATIVE ANTENNA GAIN IN DECIBELS
AZIMUTH IN DEGREES
SPECTRUM MANAGEMENT STAFF, ARD-60
Submitted
Approved
Mar. 1979
MARK LOPEZ
J.L. PIRENGA

FIGURE A 4

APPENDIX B

TYPE III AND TYPE IV ANTENNAS

The Type III antenna is composed of three Type I antennas mounted on an iron frame with an array spacing of approximately 0.75 wave lengths at the mid-band frequency (332.0 MHz). The Type IV antenna is similar to the Type III antenna, except it contains three Type II antennas. (This amounts to the addition of 3 heaters and does not affect the horizontal antenna pattern). These two types are the most widely used glide slope antennas.

The available data includes nine theoretical and measured patterns taken from various publications (Figs. B1 thru B8 and B11). These data compare reasonably well with the applicable specifications; FAA-E-2245 and FAA-E-2429 (Figs. G2 and G5). An additional five measured patterns were obtained from NAFEC data (Figs. B9, B10, B12, B13, and B14). These patterns show some discrepancies. Allentown and Hagerstown compare well with both the theoretical pattern and the specifications, but don't appear to meet the modified requirement of the contract specification with regard to the lower limit of the antenna pattern between 0 and 50 degrees. Dulles does not compare well with either the theoretical pattern or the two specifications. No explanation for this disagreement is available at this time. Allegheny County compares reasonably well with the recommended Type III - Type IV frequency assignment pattern, but contains an unexplained peak between 60 and 85 degrees where the data exceeds the -16dB maximum. Reading agrees well with the Type III - Type IV pattern in the front course, but contains some unusual variations in the data outside 20 degrees. NAFEC could provide no explanations for these irregularities. The frequency assignment antenna pattern recommended for the Type III and

Type IV glide slope antennas is based on specification FAA-E-2245 (Fig. G2) and the material in Appendix B.

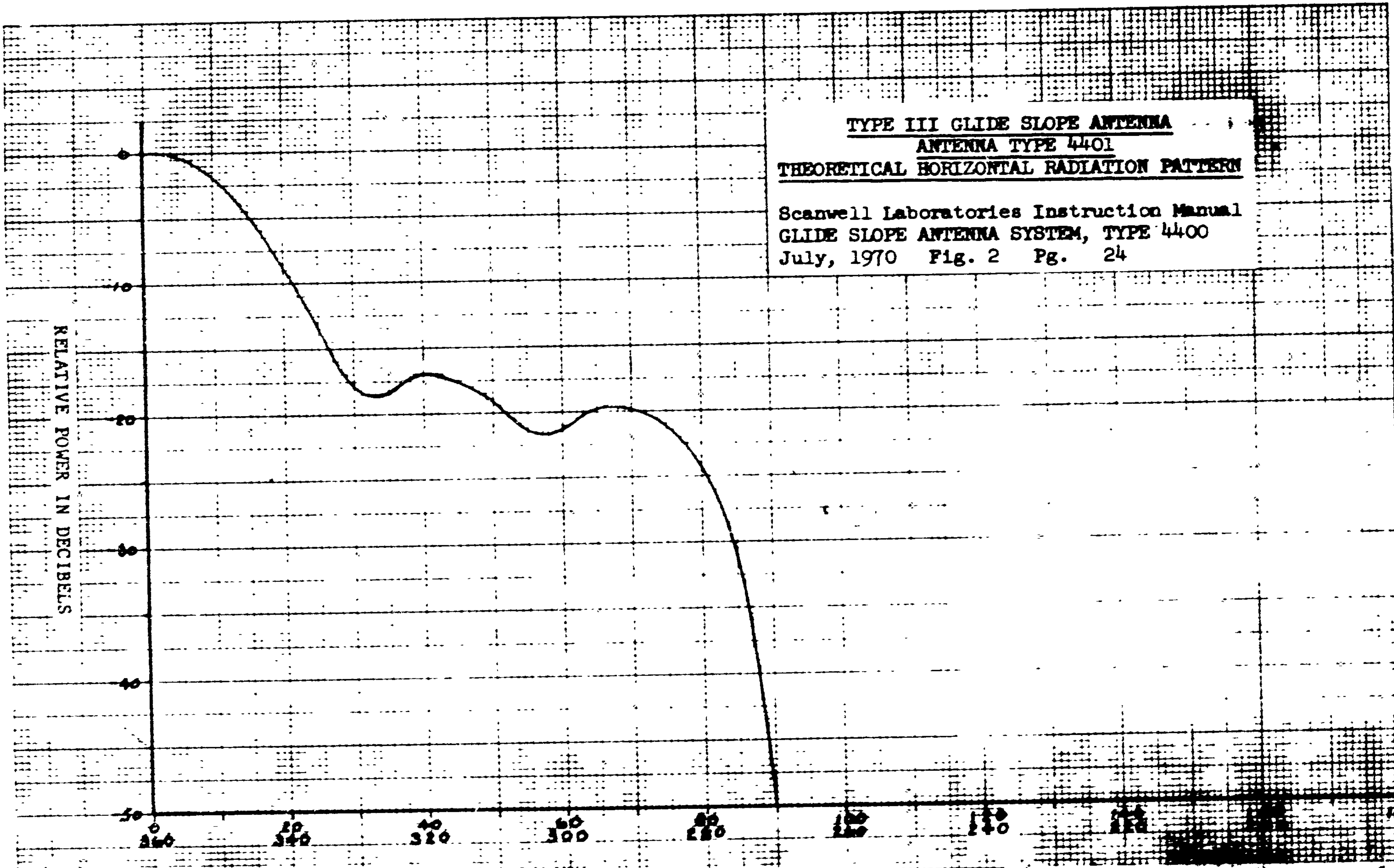


FIGURE B 1

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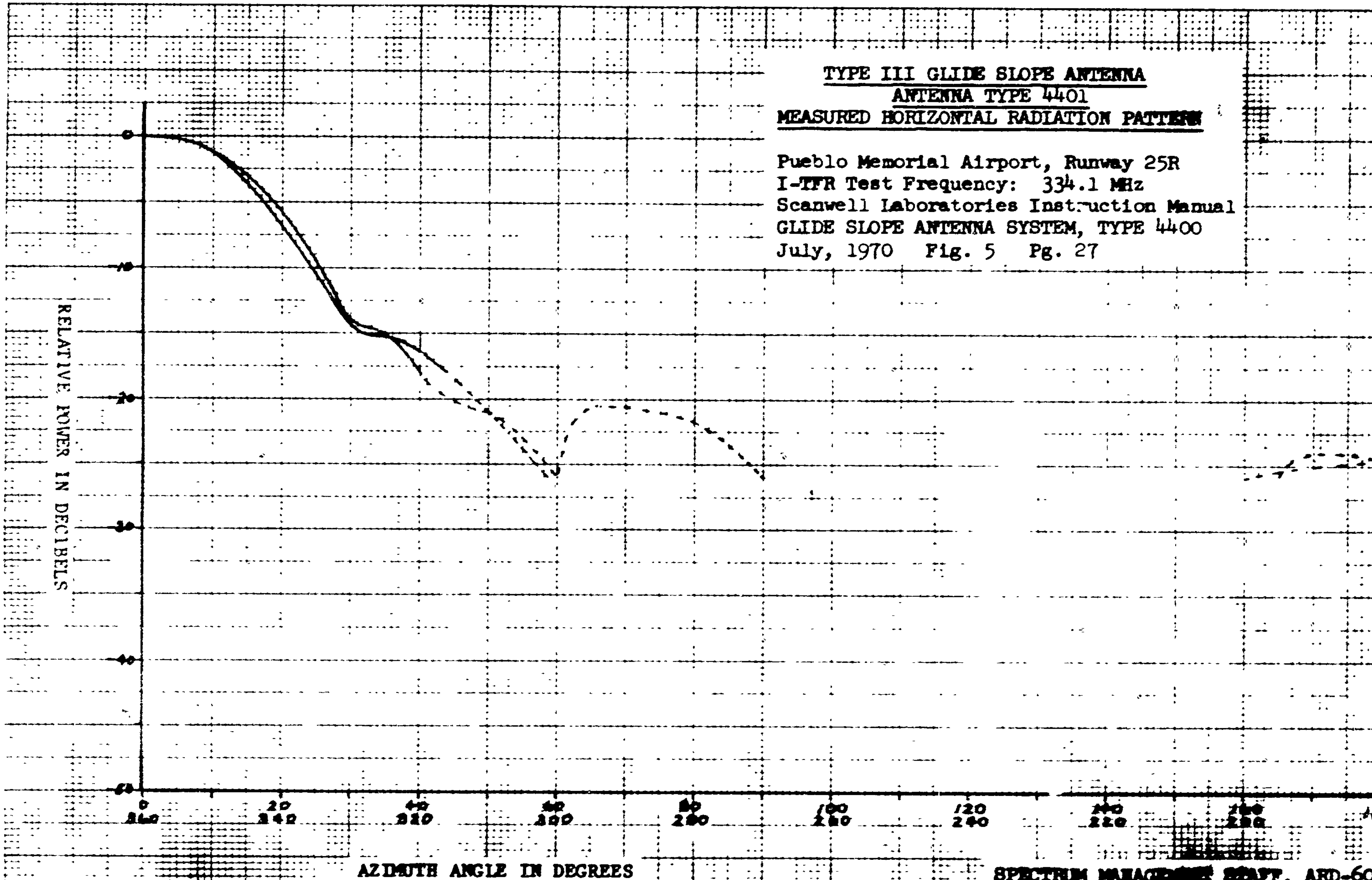

FIGURE B 2

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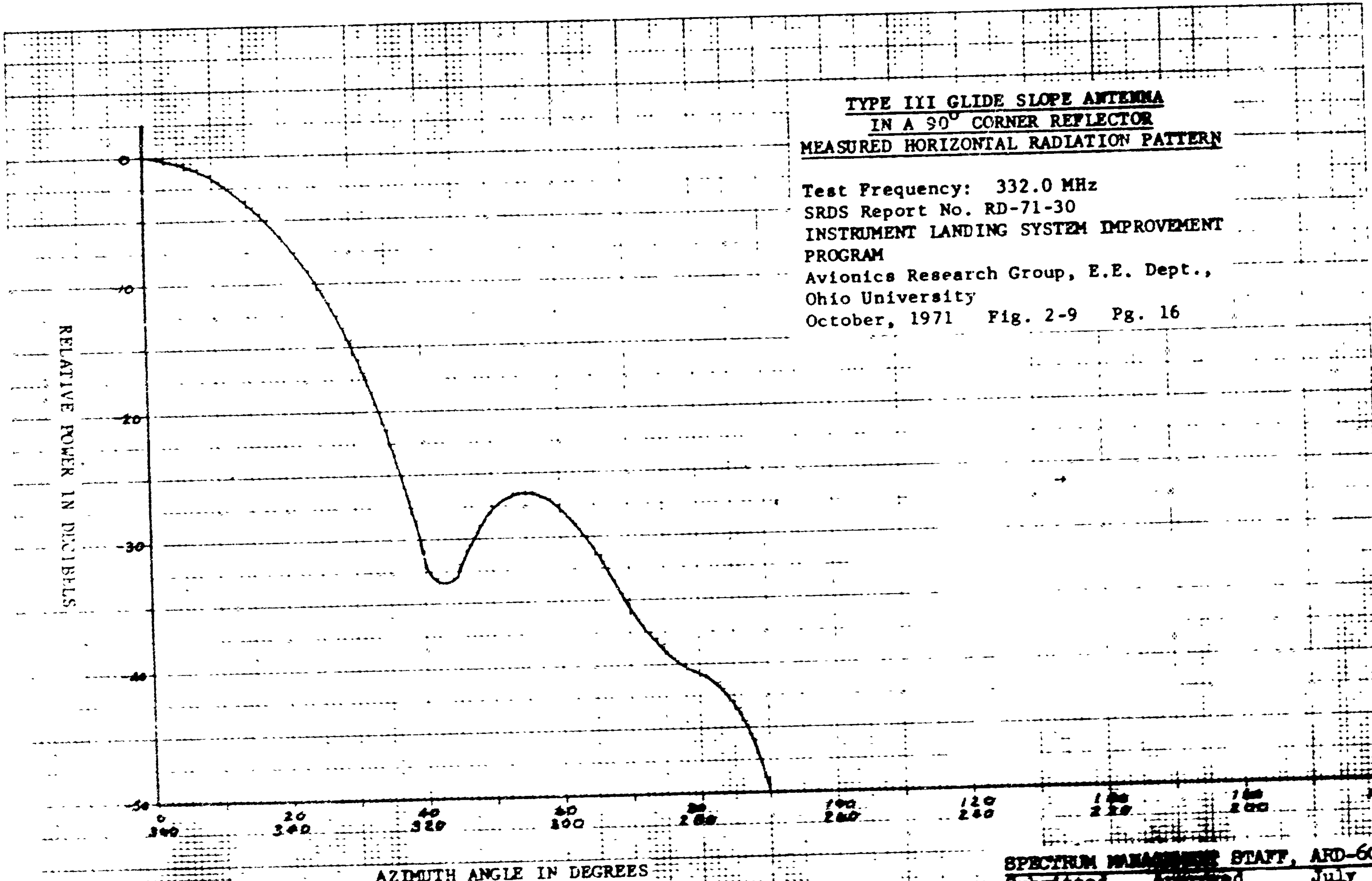

FIGURE B 3

SPECTRUM MANAGEMENT STAFF, ARD-60
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MARK LOPEZ J.L. PIERZGA 1978

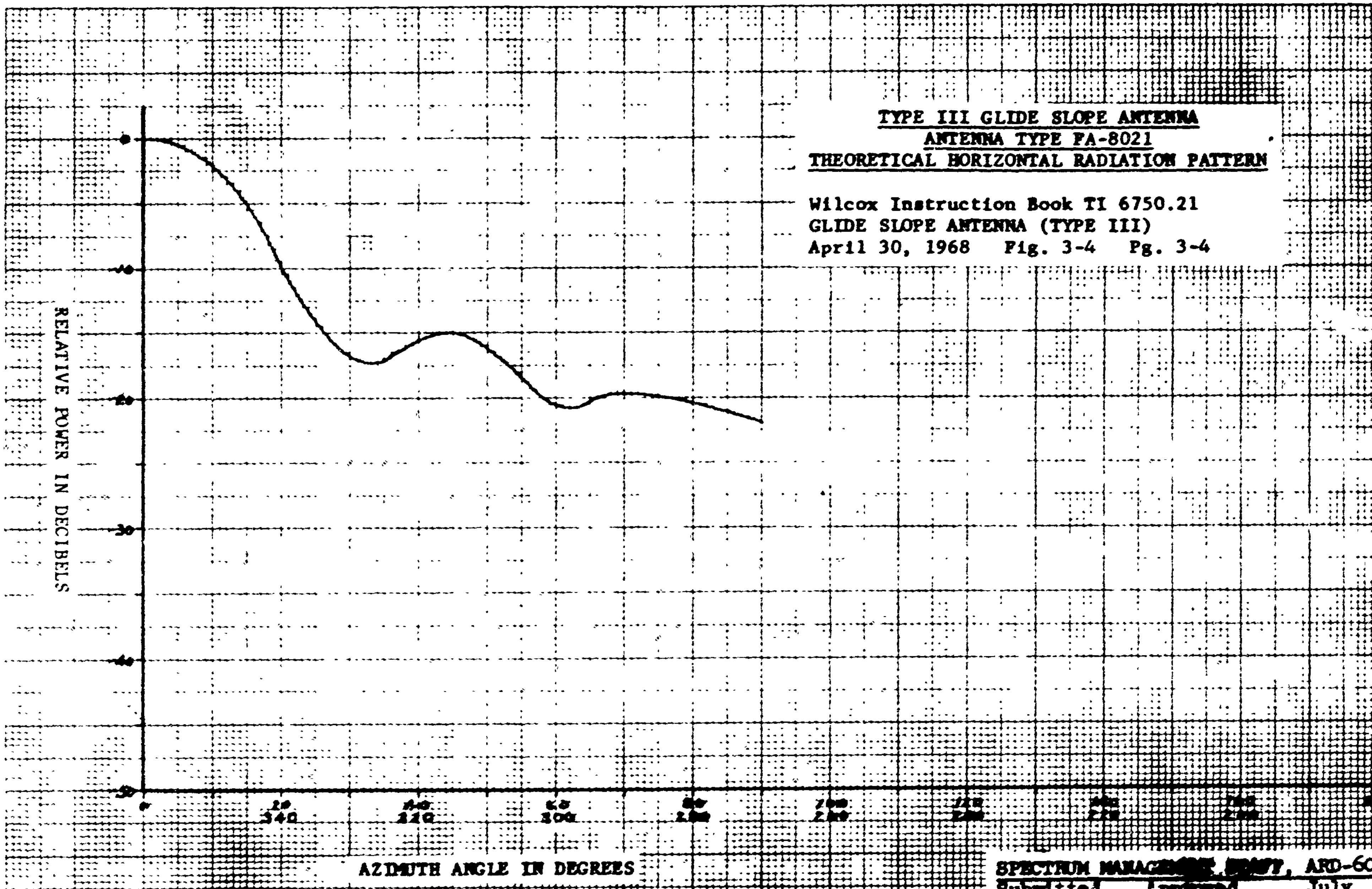

TYPE III GLIDE SLOPE ANTENNA
ANTENNA TYPE FA-8021
THEORETICAL HORIZONTAL RADIATION PATTERN
Wilcox Instruction Book TI 6750.21
GLIDE SLOPE ANTENNA (TYPE III)
April 30, 1968 Fig. 3-4 Pg. 3-4
RELATIVE POWER IN DECIBELS
0
-10
-20
-30
-40
-50
20
340
40
320
60
300
AZIMUTH ANGLE IN DEGREES
ARD-60
Submitted
July
MARK LOPEZ
1978

FIGURE B 4

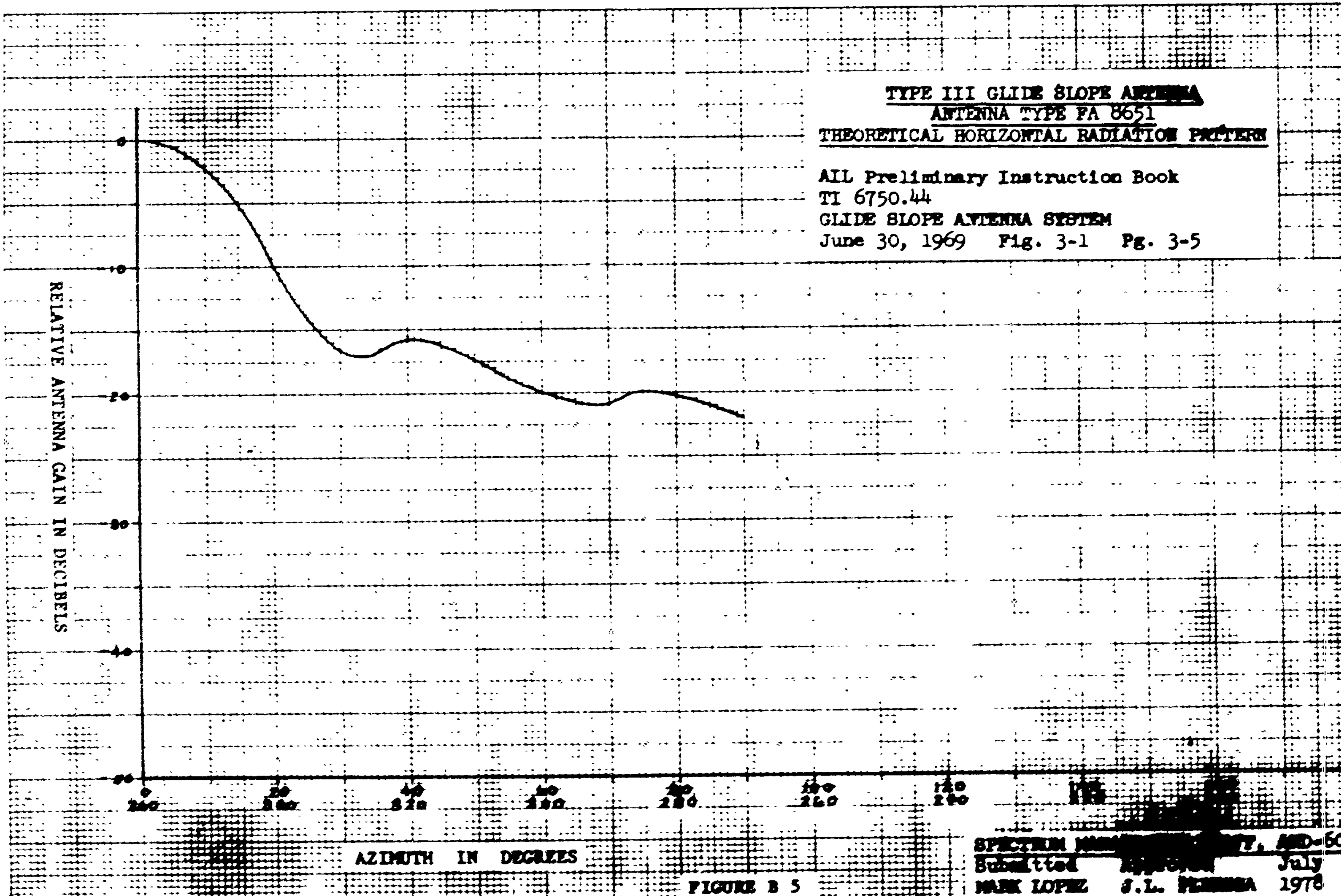


FIGURE B 5

SPECTRUM [illegible] AND-60
Submitted Approved July
MARK LOPEZ J.L. [illegible] 1976

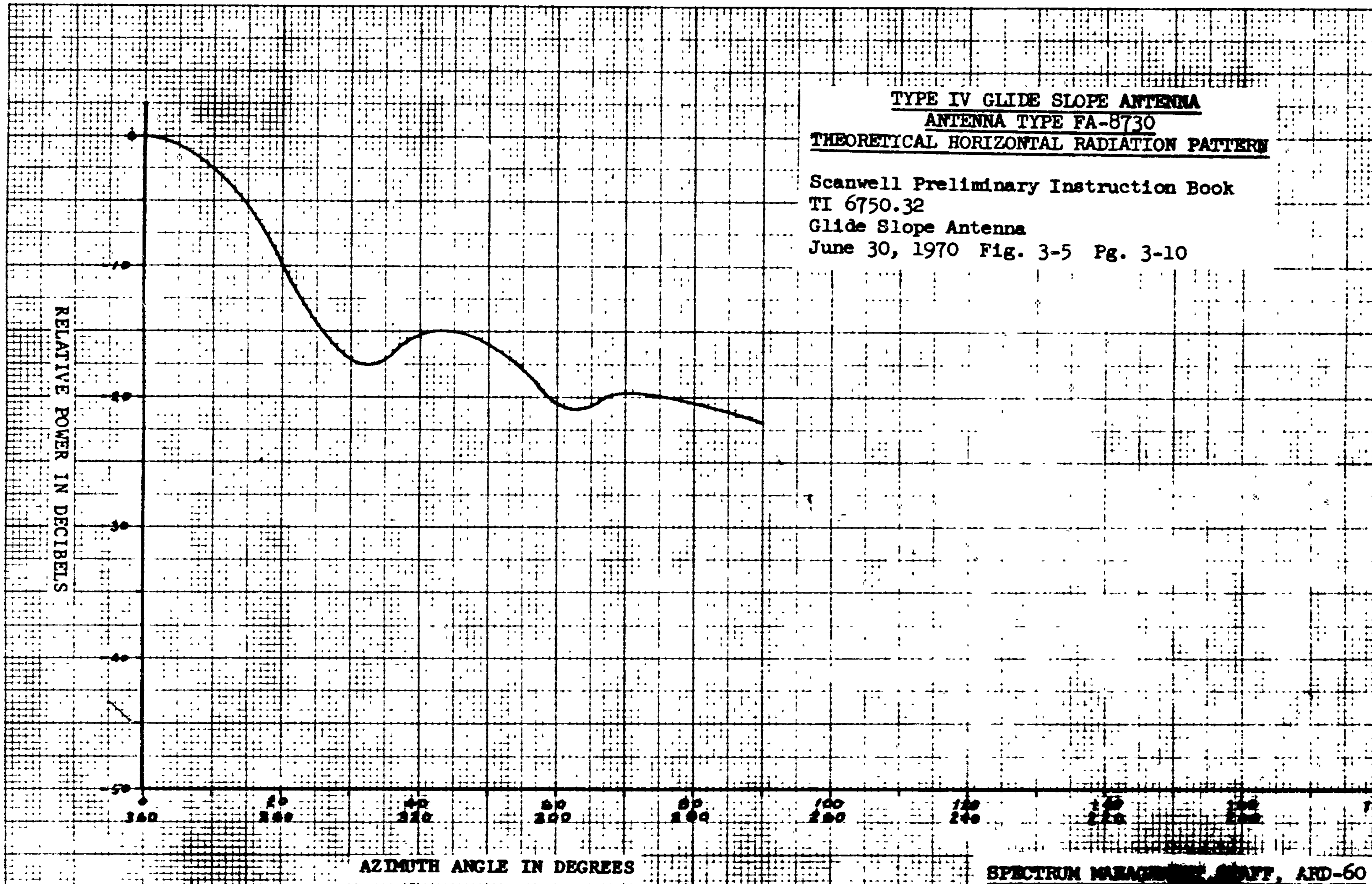


FIGURE B 6

SPECTRUM MANAGEMENT STAFF, ARD-60

Submitted	Approved	July
MARK LOPEZ	J.L. PIERZGA	1978

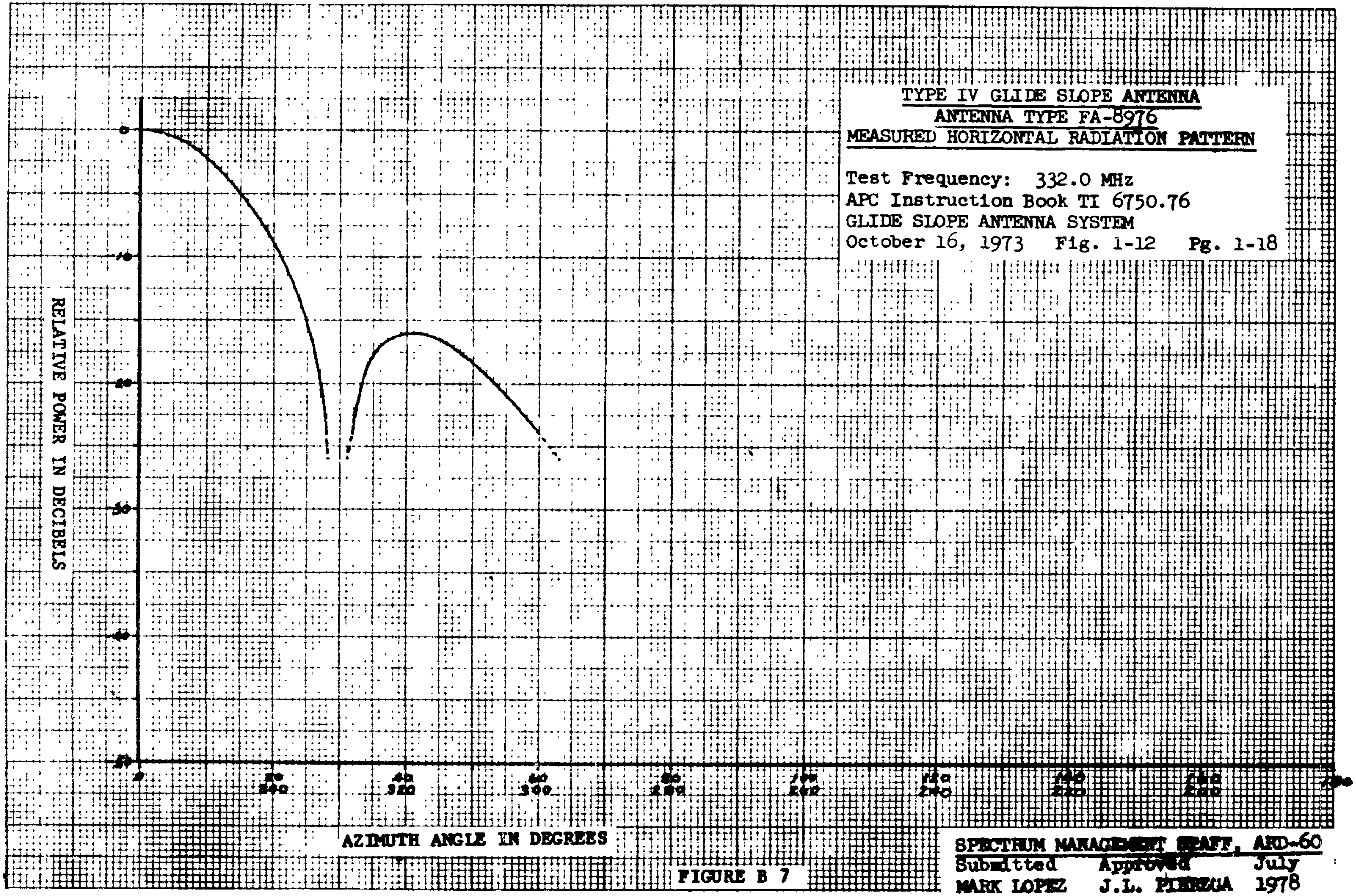
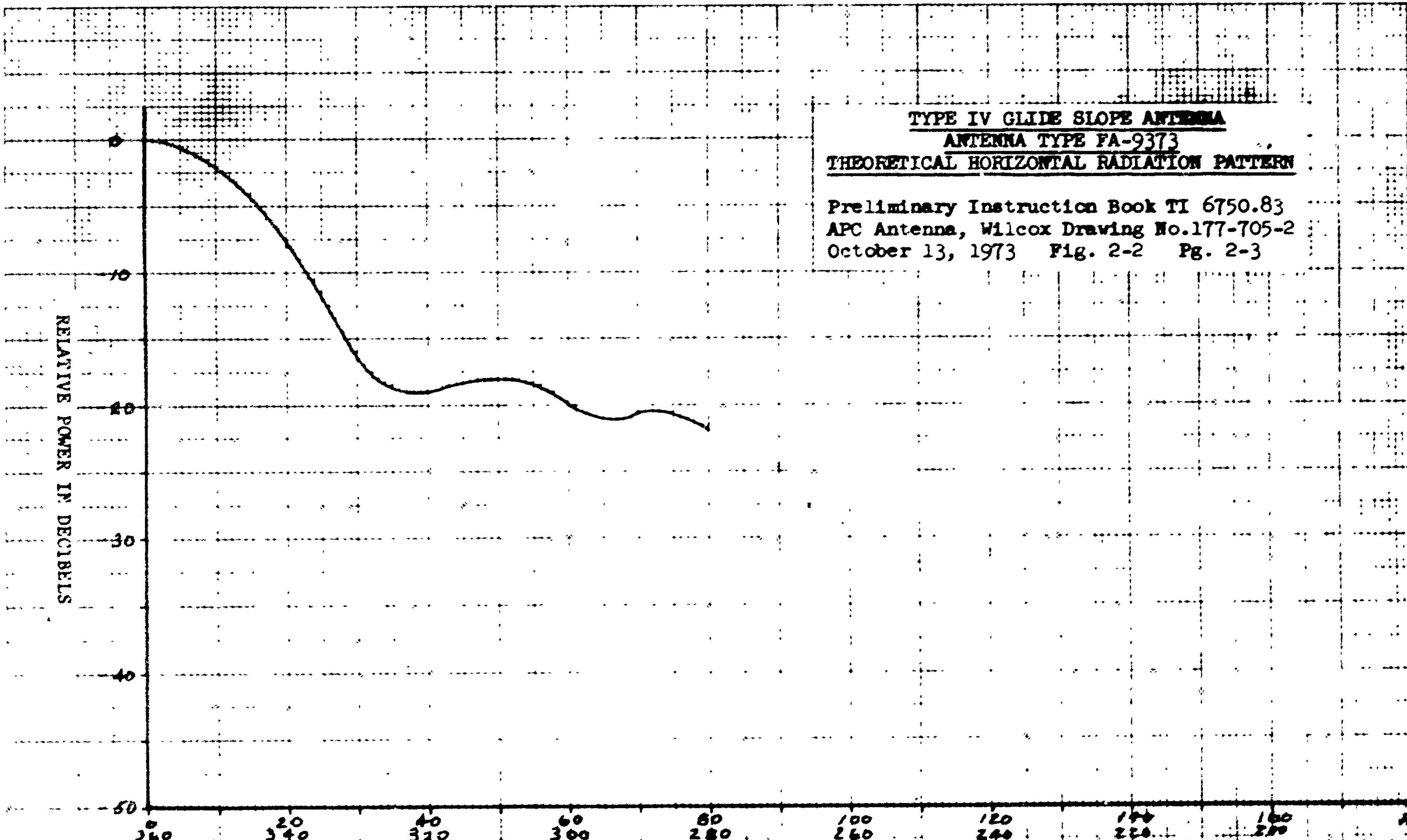

TYPE IV GLIDE SLOPE ANTENNA
ANTENNA TYPE FA-8976
MEASURED HORIZONTAL RADIATION PATTERN
Test Frequency: 332.0 MHz
APC Instruction Book TI 6750.76
GLIDE SLOPE ANTENNA SYSTEM
October 16, 1973 Fig. 1-12 Pg. 1-18
RELATIVE POWER IN DECIBELS
AZIMUTH ANGLE IN DEGREES
SPECTRUM MANAGEMENT STAFF, ARD-60
Submitted Approved July
MARK LOPEZ J.L. PIERZGA 1978

FIGURE B 7

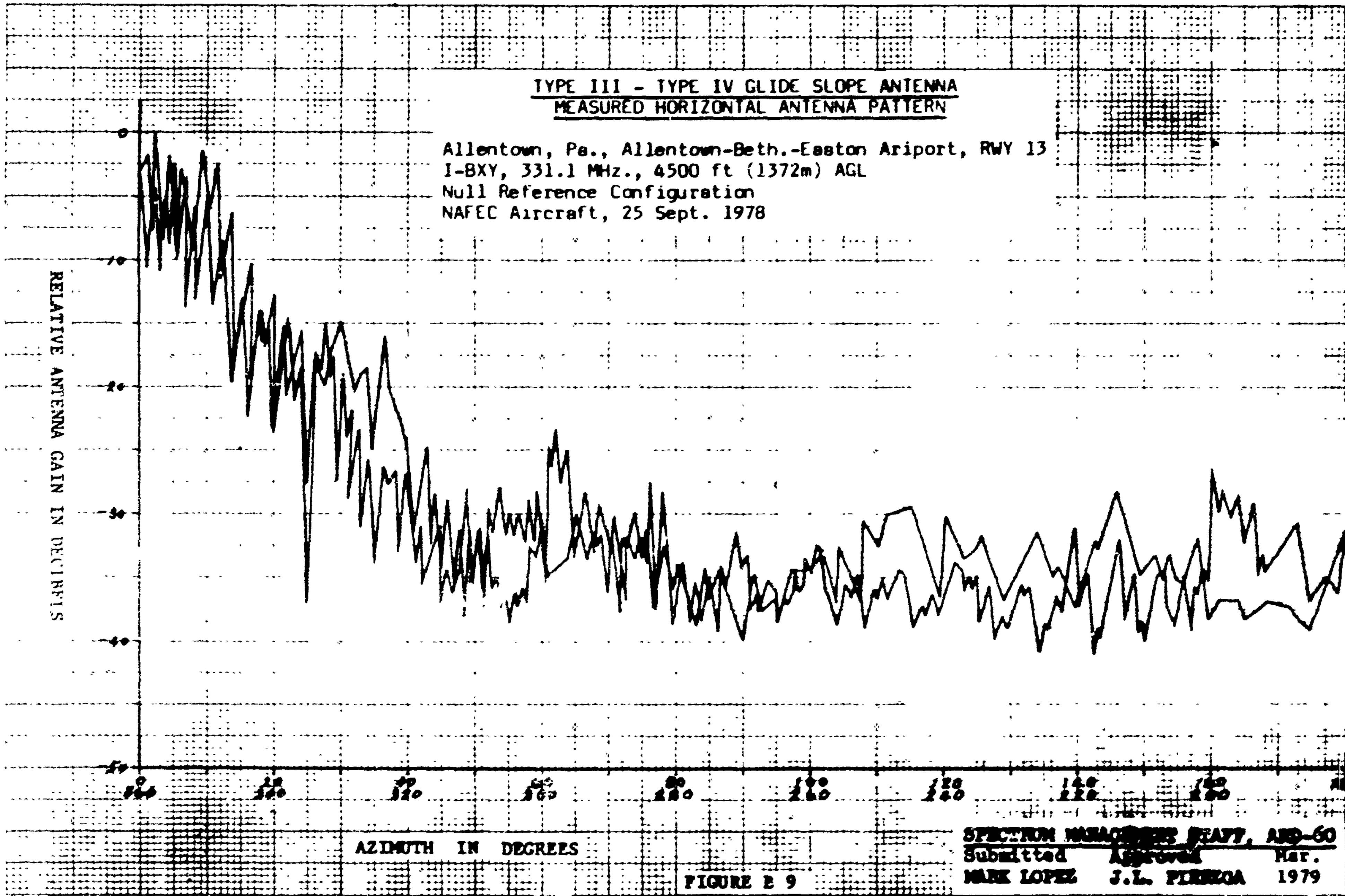


AZIMUTH ANGLE IN DEGREES

FIGURE B 8

SPECTRUM MANAGEMENT STAFF, ARD-60

Submitted	Approved	July
MARK LOPEZ	J.L. PIERZGA	1978


TYPE III - TYPE IV GLIDE SLOPE ANTENNA
MEASURED HORIZONTAL ANTENNA PATTERN
Allentown, Pa., Allentown-Beth.-Easton Ariport, RWY 13
I-BXY, 331.1 MHz., 4500 ft (1372m) AGL
Null Reference Configuration
NAFEC Aircraft, 25 Sept. 1978
RELATIVE ANTENNA GAIN IN DECIBELS
0
10
20
30
40
AZIMUTH IN DEGREES
Submitted
MARK LOPEZ
J.L.
Mar.
1979
FIGURE E 9

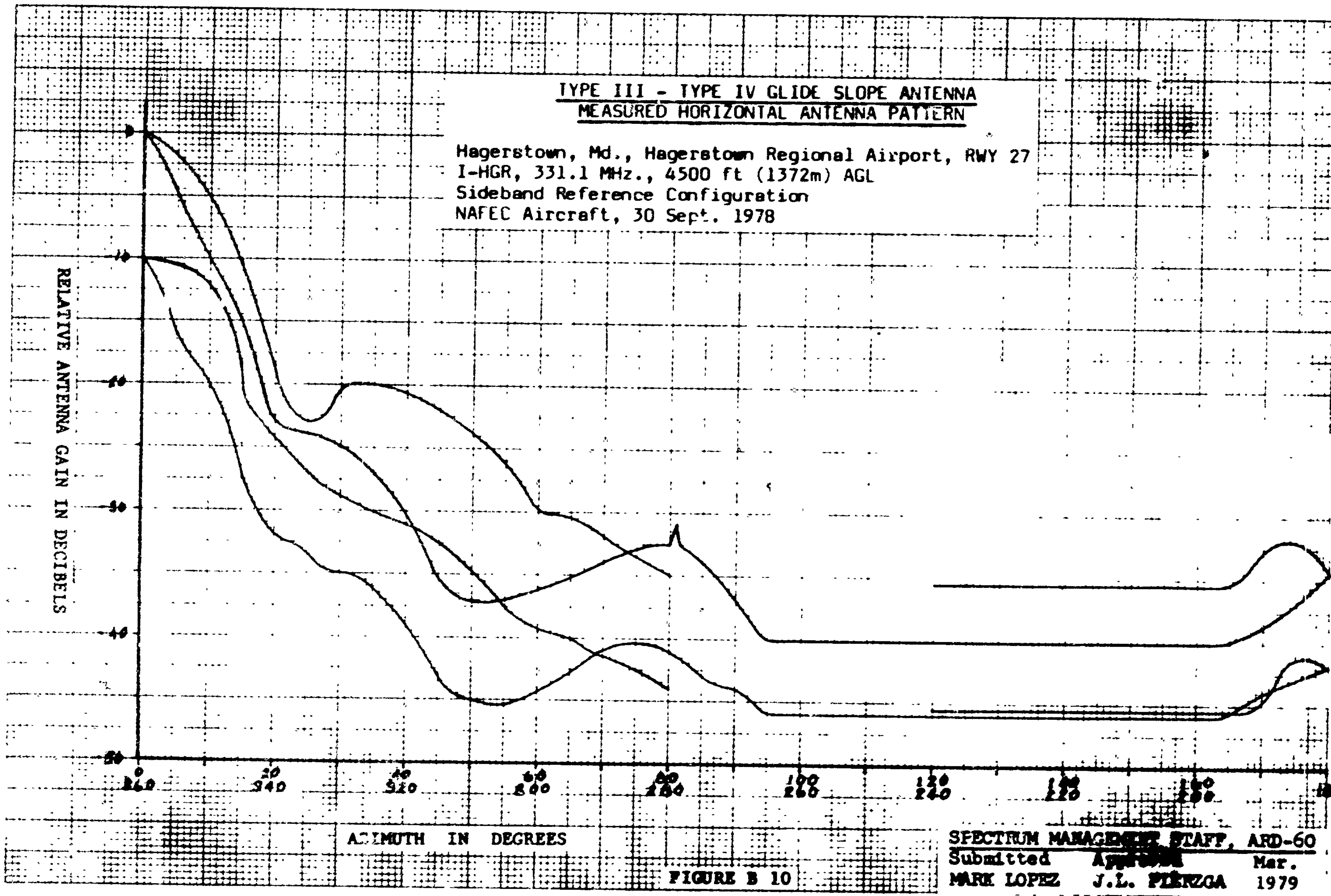
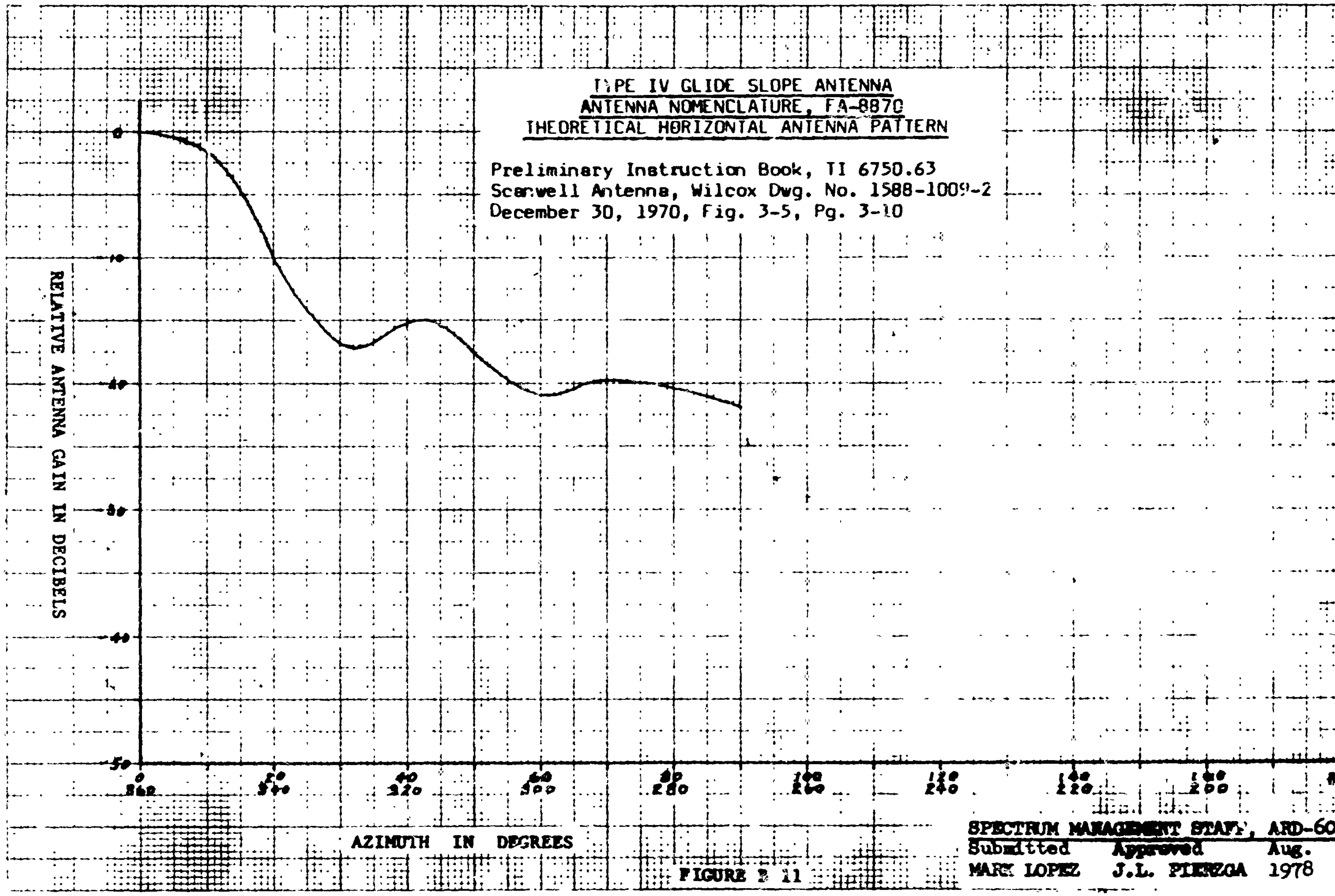

TYPE III - TYPE IV GLIDE SLOPE ANTENNA
MEASURED HORIZONTAL ANTENNA PATTERN
Hagerstown, Md., Hagerstown Regional Airport, RWY 27
I-HGR, 331.1 MHz., 4500 ft (1372m) AGL
Sideband Reference Configuration
NAFEC Aircraft, 30 Sept. 1978
RELATIVE ANTENNA GAIN IN DECIBELS
AZIMUTH IN DEGREES
SPECTRUM MANAGEMENT STAFF, ARD-60
Submitted
MARK LOPEZ
Approved
J.L. PIERZGA
Mar. 1979

FIGURE B 10


TYPE IV GLIDE SLOPE ANTENNA
ANTENNA NOMENCLATURE, FA-8870
THEORETICAL HORIZONTAL ANTENNA PATTERN
Preliminary Instruction Book, TI 6750.63
Scanwell Antenna, Wilcox Dwg. No. 1588-1009-2
December 30, 1970, Fig. 3-5, Pg. 3-10
RELATIVE ANTENNA GAIN IN DECIBELS
0
10
20
30
40
50
0 360
20 340
40 320
60 300
80 280
100 260
120 240
140 220
160 200
AZIMUTH IN DEGREES
SPECTRUM MANAGEMENT STAFF, ARD-60
Submitted Approved Aug.
MARY LOPEZ J.L. PIERZGA 1978
FIGURE B 11

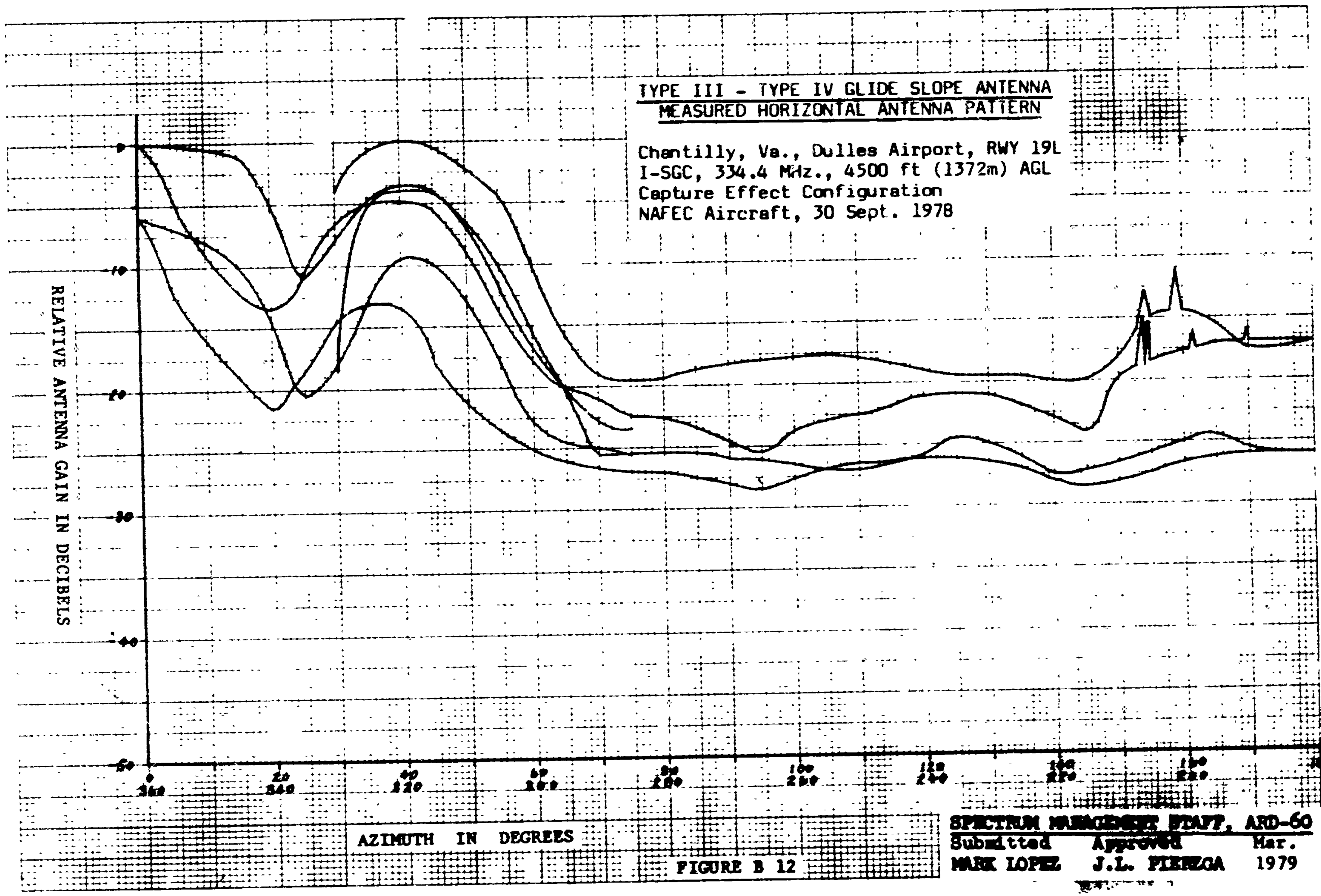

TYPE III - TYPE IV GLIDE SLOPE ANTENNA
MEASURED HORIZONTAL ANTENNA PATTERN
Chantilly, Va., Dulles Airport, RWY 19L
I-SGC, 334.4 MHz., 4500 ft (1372m) AGL
Capture Effect Configuration
NAFEC Aircraft, 30 Sept. 1978
RELATIVE ANTENNA GAIN IN DECIBELS
AZIMUTH IN DEGREES
SPECTRUM MANAGEMENT STAFF, ARD-60
Submitted Approved Mar.
MARK LOPEZ J.L. PIERZGA 1979

FIGURE B 12

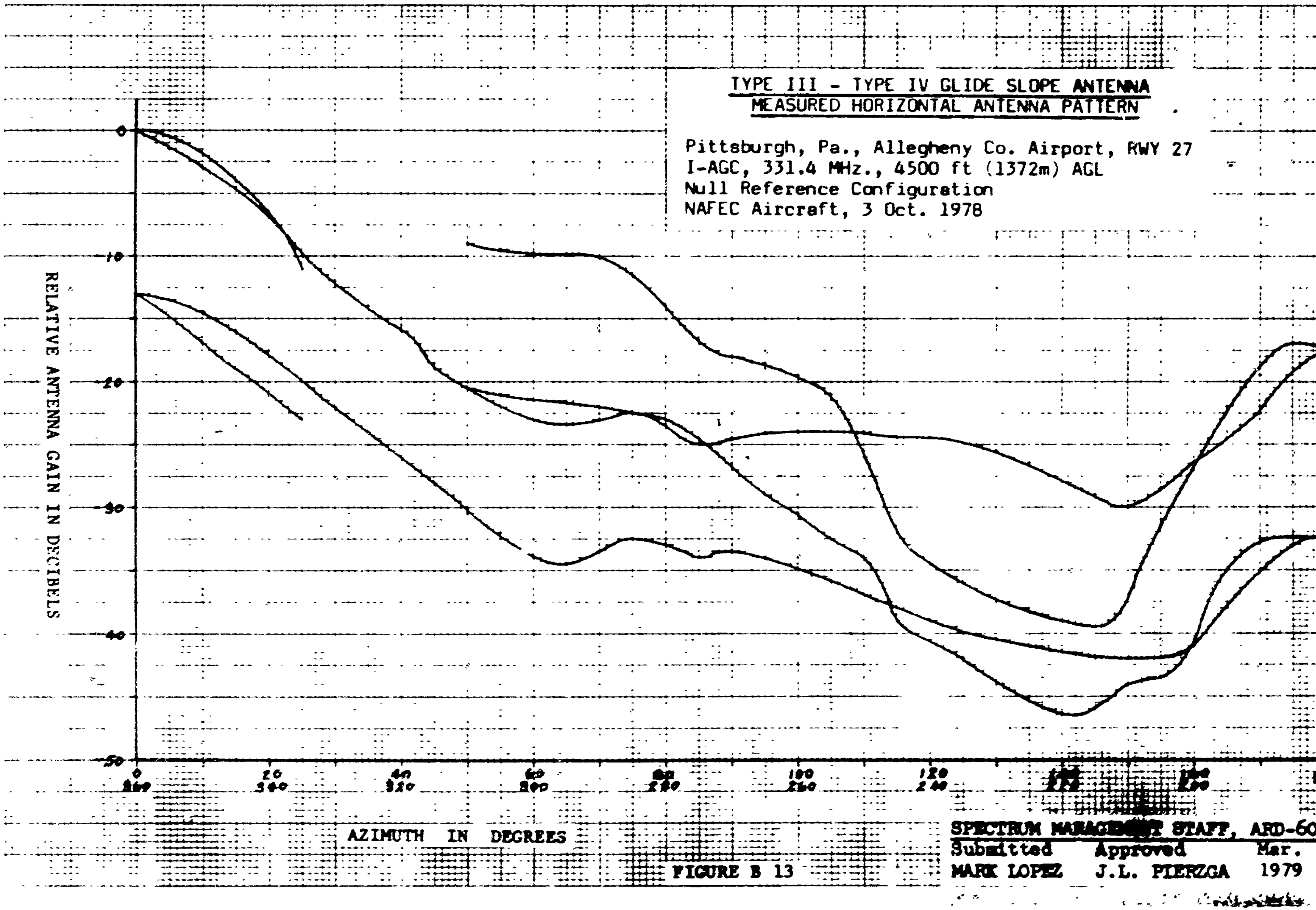
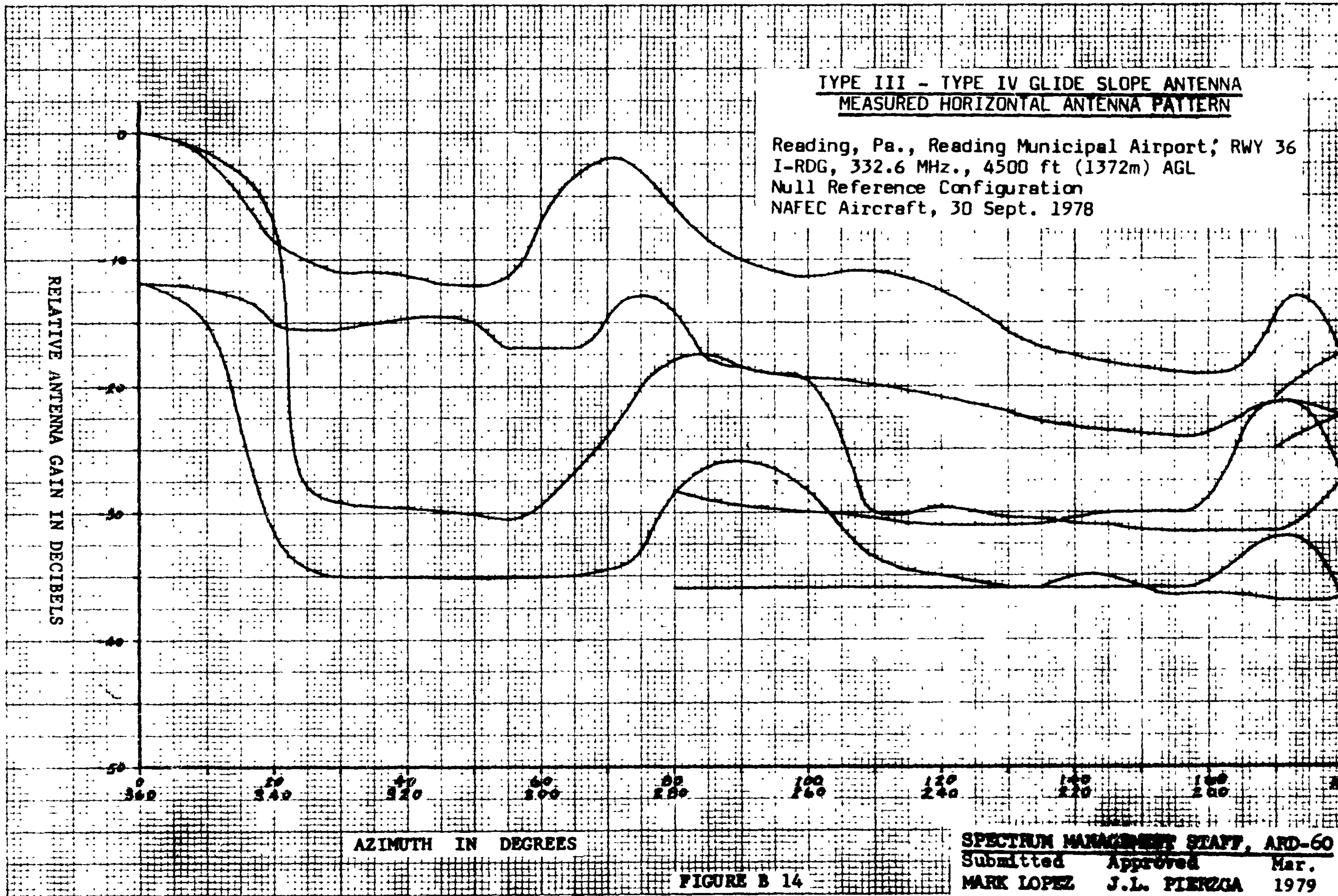

TYPE III - TYPE IV GLIDE SLOPE ANTENNA
MEASURED HORIZONTAL ANTENNA PATTERN
Pittsburgh, Pa., Allegheny Co. Airport, RWY 27
I-AGC, 331.4 MHz., 4500 ft (1372m) AGL
Null Reference Configuration
NAFEC Aircraft, 3 Oct. 1978
RELATIVE ANTENNA GAIN IN DECIBELS
0
10
20
30
40
50
AZIMUTH IN DEGREES
0
20
340
40
320
100
260
120
240
SPECTRUM MANAGEMENT STAFF, ARD-60
Submitted
MARK LOPEZ
Approved
J.L. PIERZGA
Mar.
1979

FIGURE B 13


TYPE III - TYPE IV GLIDE SLOPE ANTENNA
MEASURED HORIZONTAL ANTENNA PATTERN
Reading, Pa., Reading Municipal Airport, RWY 36
I-RDG, 332.6 MHz., 4500 ft (1372m) AGL
Null Reference Configuration
NAFEC Aircraft, 30 Sept. 1978
RELATIVE ANTENNA GAIN IN DECIBELS
0
10
20
30
40
50
0
360
20
340
40
320
60
300
80
280
100
260
120
240
140
220
160
200
AZIMUTH IN DEGREES
SPECTRUM MANAGEMENT STAFF, ARD-60
Submitted
Approved
Mar.
MARK LOPEZ
J.L. PIERZGA
1979
FIGURE B 14

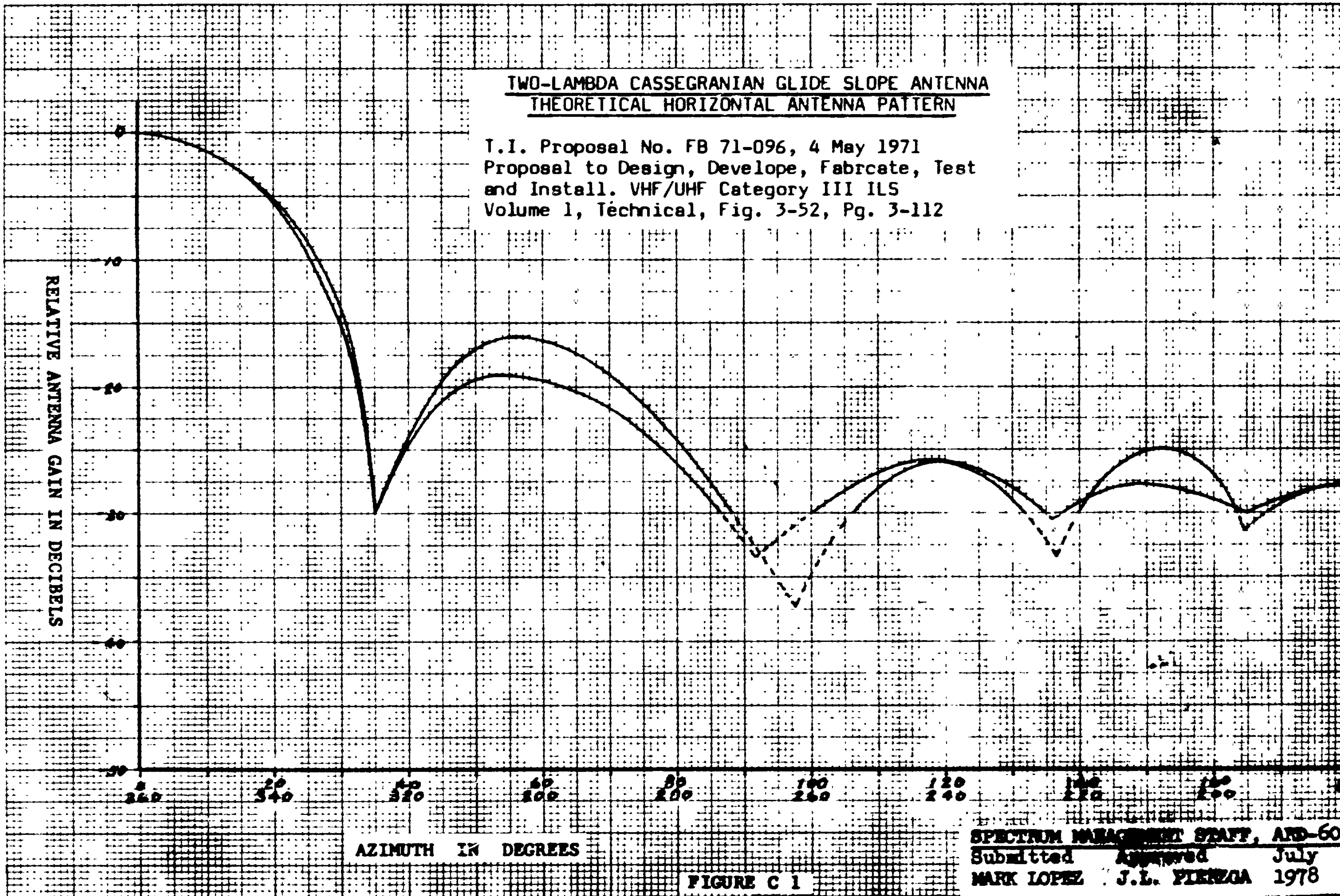
APPENDIX C

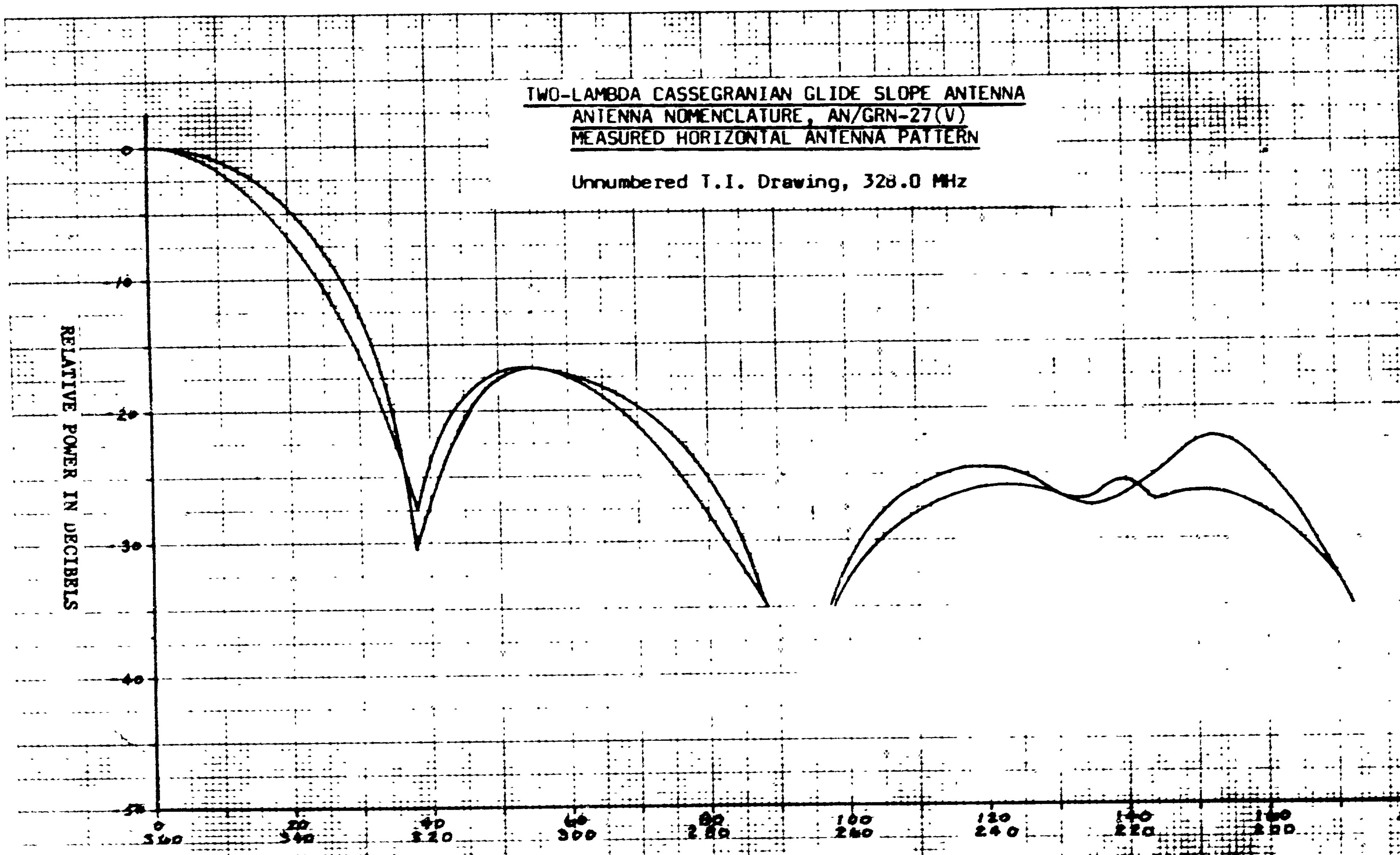
THE TWO-LAMBDA CASSEGRANIAN ANTENNA

The two-lambda cassegranian glide slope antenna is produced by Texas Instruments for use with its AN/GRN-27 (V) and Mark III glide slope systems. Each antenna consists of a single dipole with a director, reflector, secondary two-lambda by one-lambda reflecting surface, and two proximity (monitor) probes, all enclosed in a radome.

Only limited data on this system was available. The three measured patterns supplied by T.I. (Figs. C2 thru C4) agree well with the theoretical pattern (Fig. C1). In addition, they fall within the limits of FAA specification FAA-E-2429 (Fig. G5). The two patterns produced from NAFEC data (Figs. C5 and C6) don't agree very well with the theoretical pattern. In addition, they appear to have a narrower front course pattern than what is required by the specification.

The frequency assignment antenna pattern recommended for the two-lambda cassegranian glide slope antenna is based on specification FAA-E-2429 (Fig. 5) and the figures in Appendix C.


TWO-LAMBDA CASSEGRANIAN GLIDE SLOPE ANTENNA
THEORETICAL HORIZONTAL ANTENNA PATTERN
T.I. Proposal No. FB 71-096, 4 May 1971
Proposal to Design, Develope, Fabrcate, Test
and Install. VHF/UHF Category III ILS
Volume 1, Technical, Fig. 3-52, Pg. 3-112
RELATIVE ANTENNA GAIN IN DECIBELS
0
10
20
30
40
50
0
360
20
340
40
320
60
300
80
280
100
260
120
240
140
220
160
200
AZIMUTH IN DEGREES
SPECTRUM MANAGEMENT STAFF, ARD-60
Submitted Approved July
MARK LOPEZ J.L. PIERZGA 1978
FIGURE C 1



AZIMUTH ANGLE IN DEGREES

FIGURE C 2

SPECTRUM MANAGEMENT STAFF, ARD-60
Submitted Approved Aug.
MARK LOPEZ J.L. PIERZGA 1978

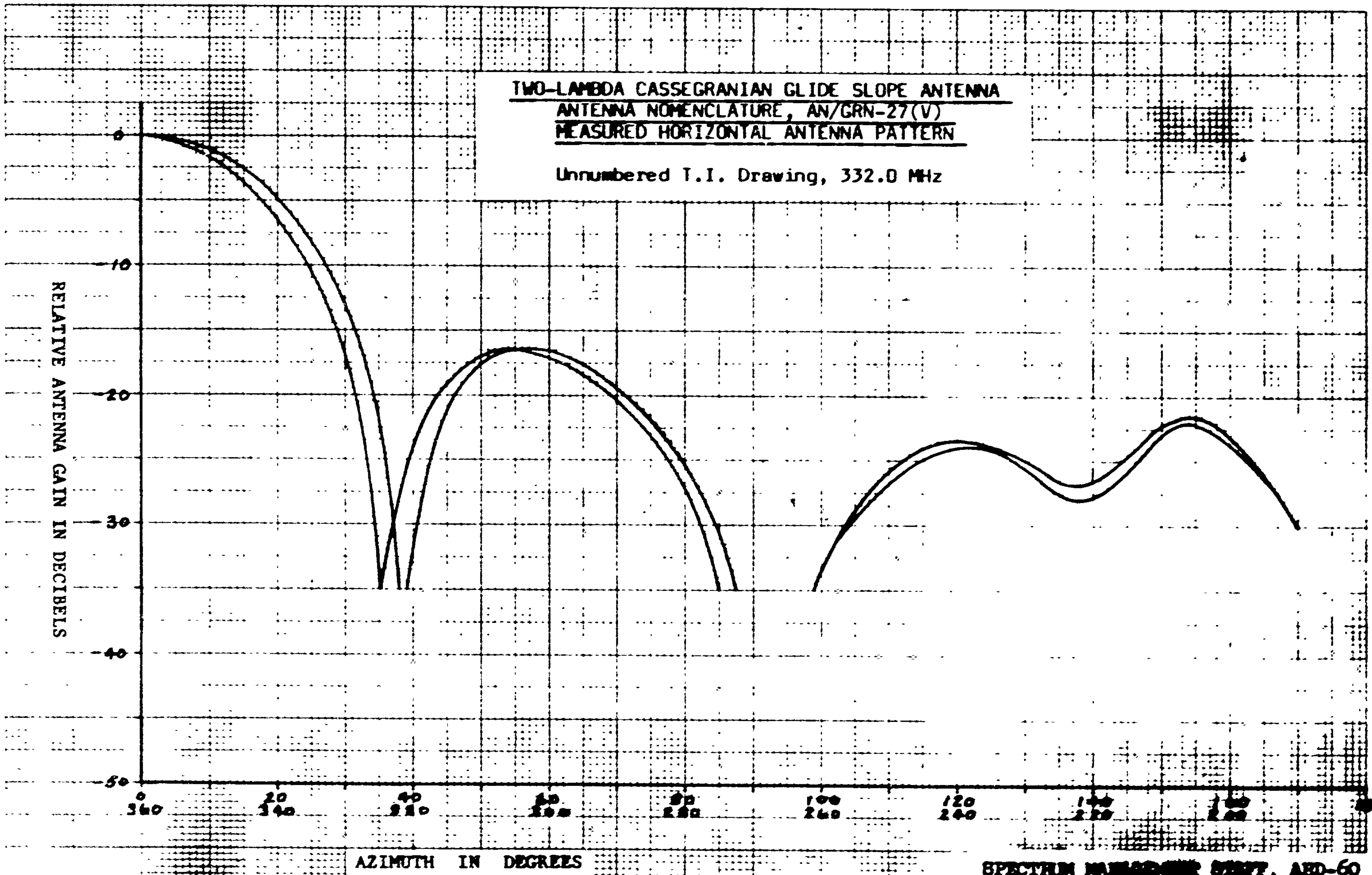


FIGURE C 3

SPECTRUM , AED-60
Submitted Aug.
MARK LOPEZ J.L. PIERZGA 1978

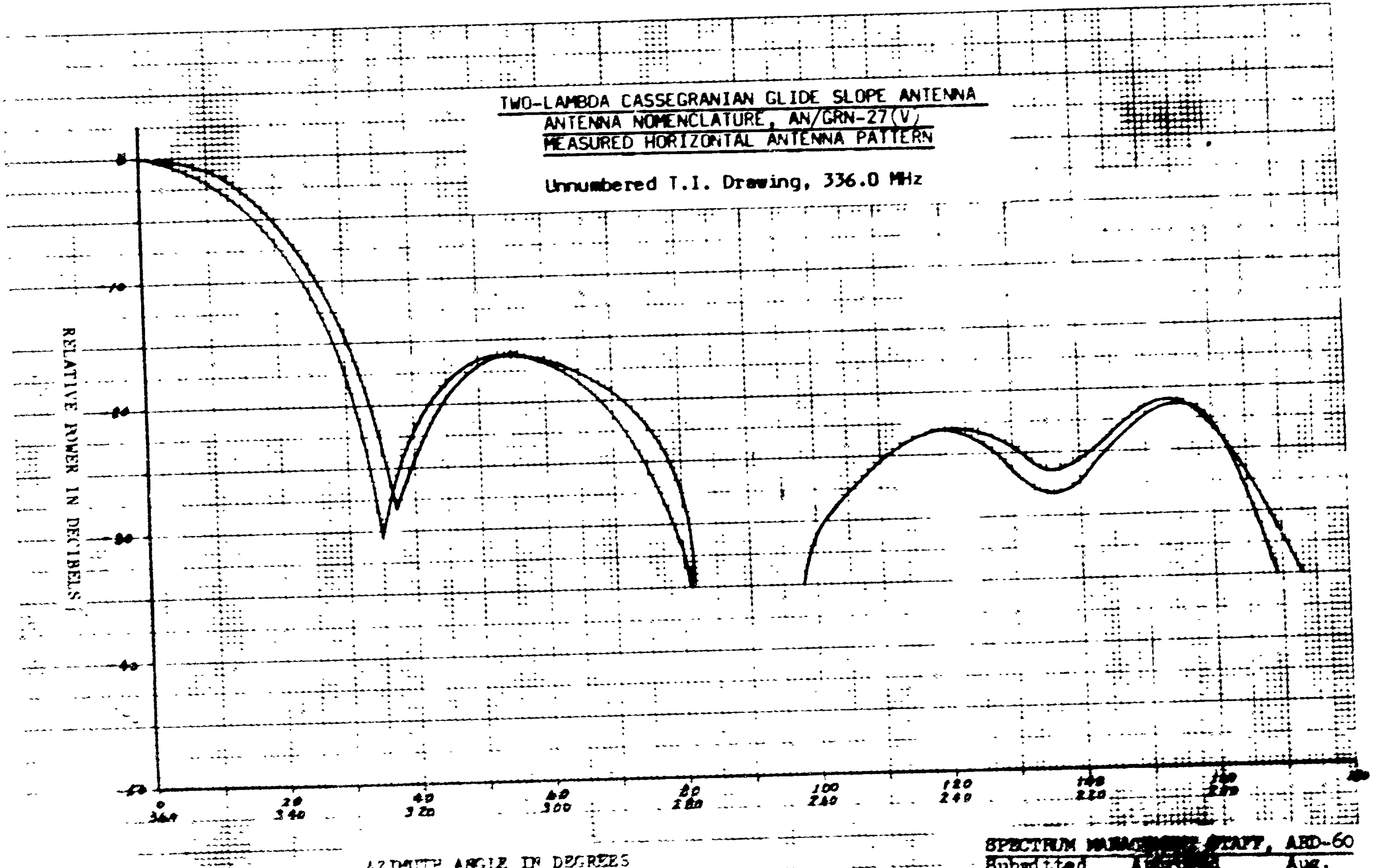


FIGURE C 4

SPECTRUM MANAGEMENT STAFF, AED-60
Submitted Approved Aug.
MARK LOPEZ J.L. PIERZGA 1978

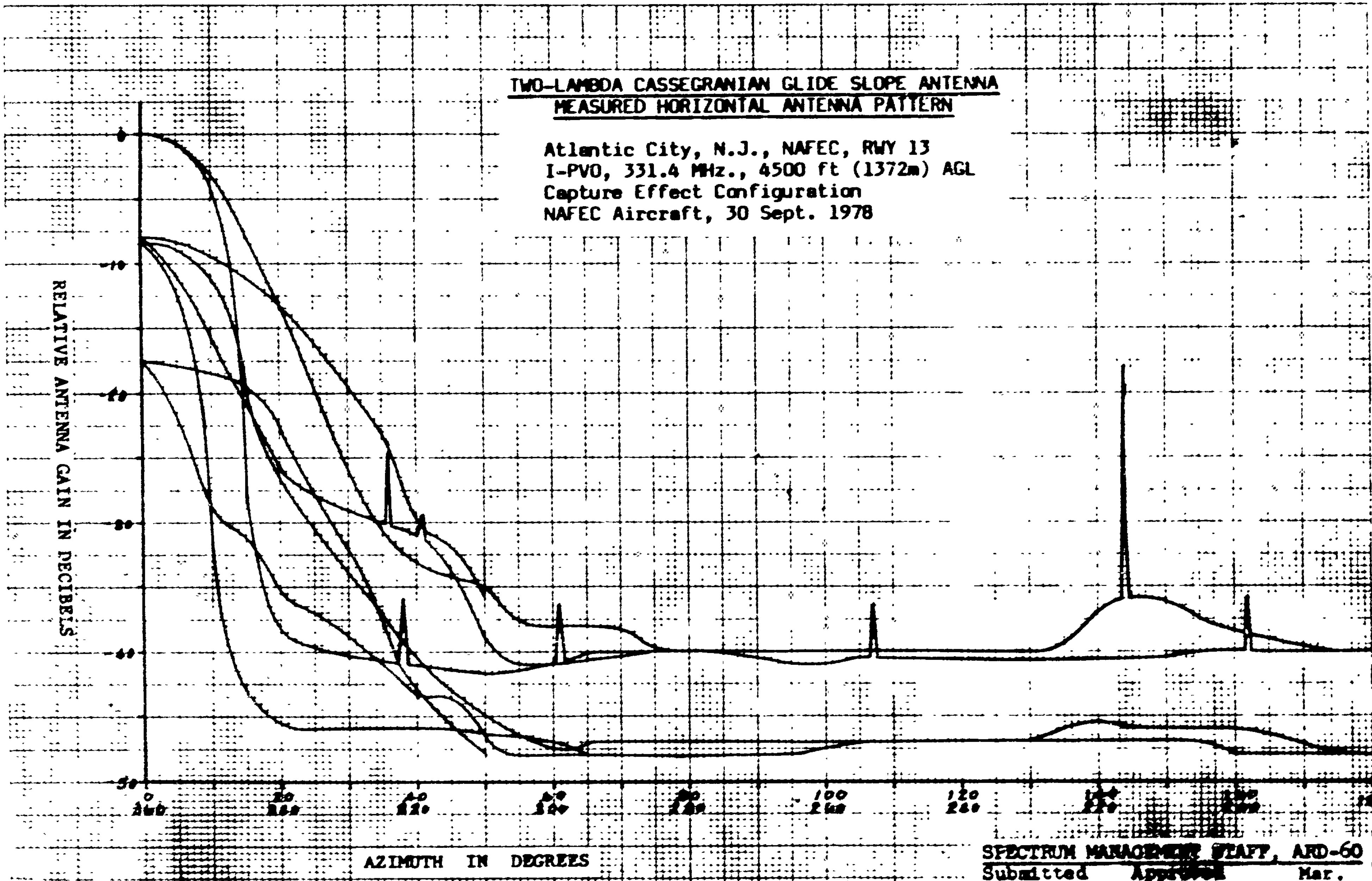

TWO-LAMBDA CASSEGRANIAN GLIDE SLOPE ANTENNA
MEASURED HORIZONTAL ANTENNA PATTERN
Atlantic City, N.J., NAFEC, RWY 13
I-PVO, 331.4 MHz., 4500 ft (1372m) AGL
Capture Effect Configuration
NAFEC Aircraft, 30 Sept. 1978
RELATIVE ANTENNA GAIN IN DECIBELS
AZIMUTH IN DEGREES
0
20
40
60
80
100
120
140
160
SPECTRUM MANAGEMENT STAFF, ARD-60
Submitted
Mar.
MARK LOPEZ
J.L. PIERZGA
1979

FIGURE C 5

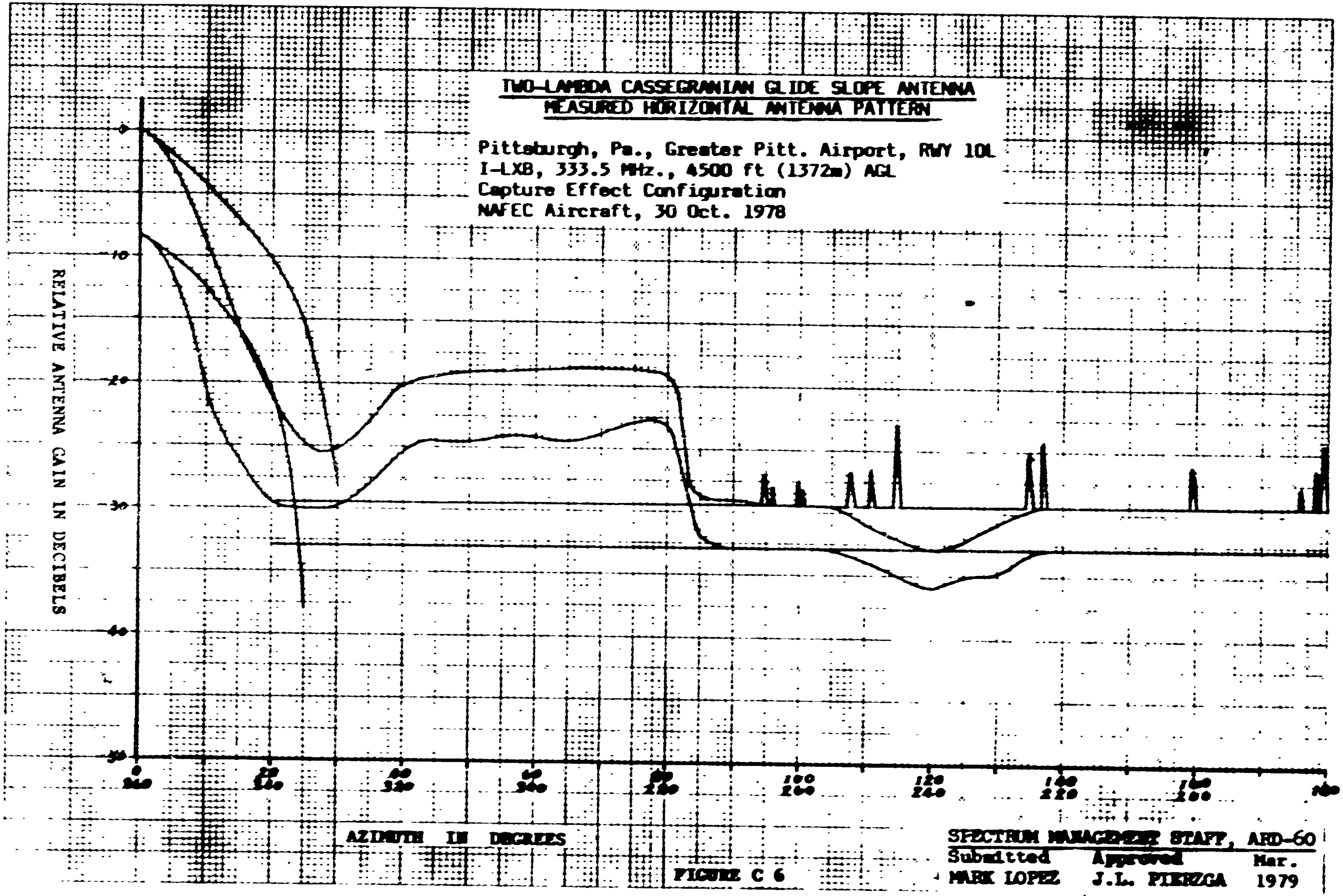

TWO-LAMBDA CASSEGRANIAN GLIDE SLOPE ANTENNA
MEASURED HORIZONTAL ANTENNA PATTERN
Pittsburgh, Pa., Greater Pitt. Airport, RWY 10L
I-LXB, 333.5 MHz., 4500 ft (1372m) AGL
Capture Effect Configuration
NAFEC Aircraft, 30 Oct. 1978
RELATIVE ANTENNA GAIN IN DECIBELS
0
10
20
30
40
AZIMUTH IN DEGREES
SPECTRUM MANAGEMENT STAFF, ARD-60
Submitted
MARK LOPEZ
Approved
J.L. PIERZGA
Mar.
1979

FIGURE C 6

APPENDIX D

THE STAN-38 ANTENNA

The Stan-38 glide slope is a part of the British ILS system located at Dulles Airport. This is the only system of its kind presently commissioned in the U.S. Additional installations in this country are unlikely.

This system uses an image - type antenna designed for use in the conventional null reference, sideband reference, and capture effect systems. The antenna is unique in that each aerial contains six dipoles (U.S. manufactured arrays house a maximum of three).

Only limited information was available on the Stan-38. The one antenna pattern obtained (Fig. D1) was taken from the British instruction manual. The frequency assignment pattern is based on this pattern, the theoretical 3dB points, the side lobe ratio, and the front-to-back ratio.

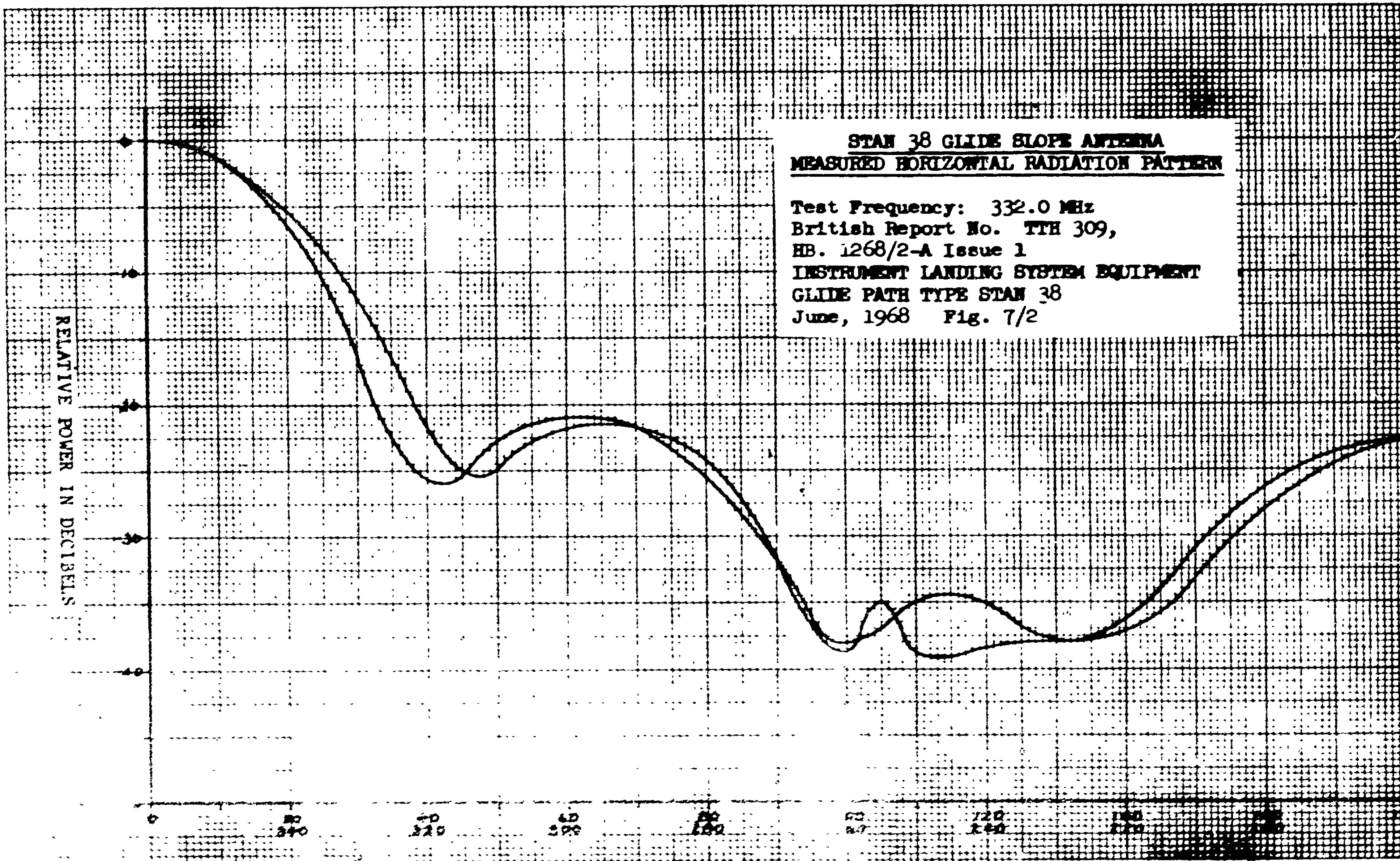


FIGURE D 1

SPECTRUM [illegible], AND-60
Submitted Approved July
MARK LOPEZ J.L. PIERZGA 1978

APPENDIX E

THE END-FIRE SLOTTED CABLE ANTENNA

This antenna system is a non-image, end-fire type glide slope currently under developement. A ground image is not required to form the glide path. Rather, the difference in path lengths from the two antennas to the aircraft produces the on-or-off course signals. This system is designed to provide glide slope service for runways where site conditions make it difficult to install the existing systems.

The only pattern available (Fig. E1) was taken from the test evaluation at Rock Springs, Wy. The frequency assignment pattern was chosen using this data and a conservative estimate of the systems off-course azimuthal pattern.

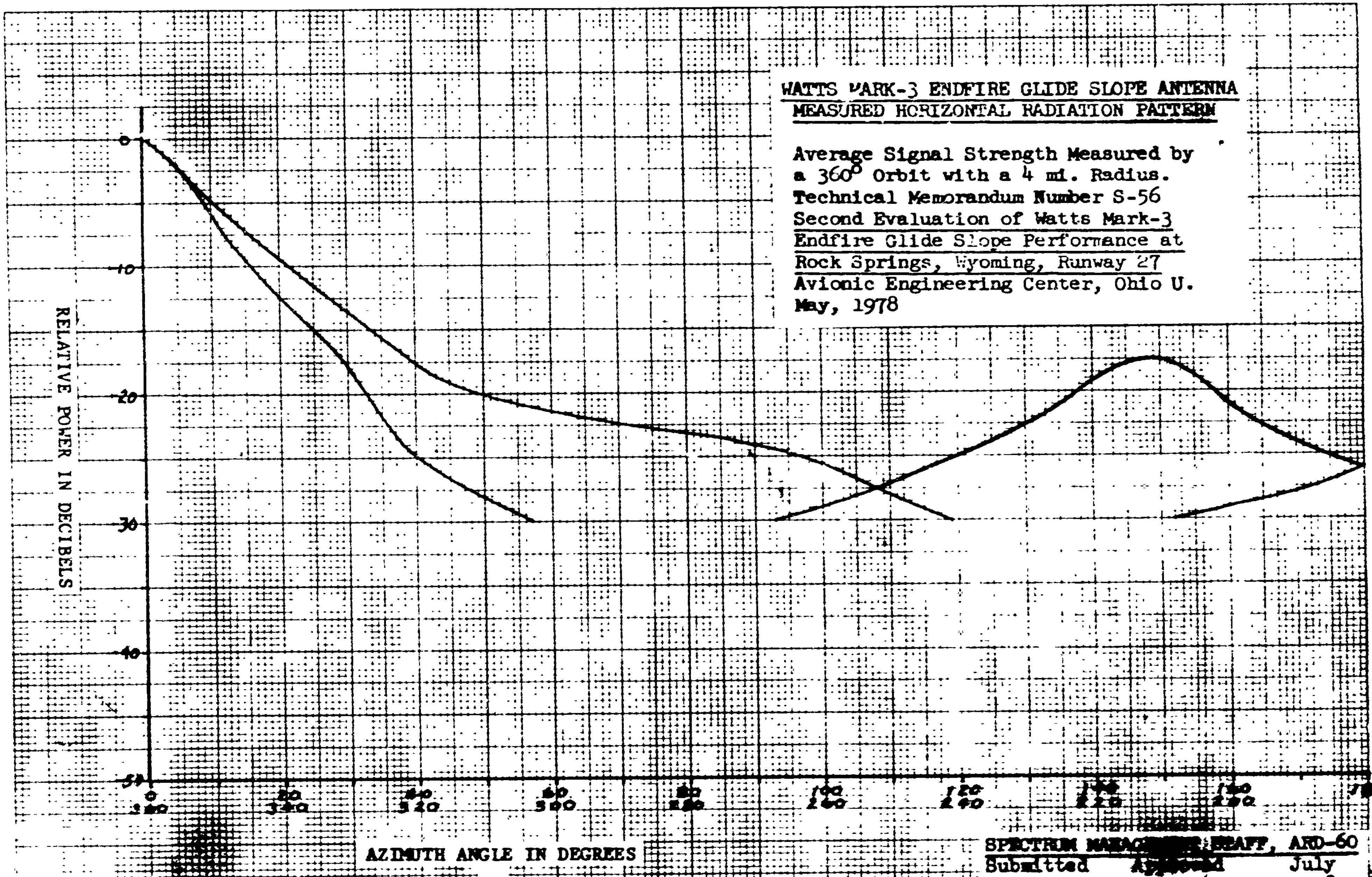


FIGURE E 1

THIS PAGE IS BEST QUALITY PRACTICABLE FROM COPY FURNISHED TO DDC

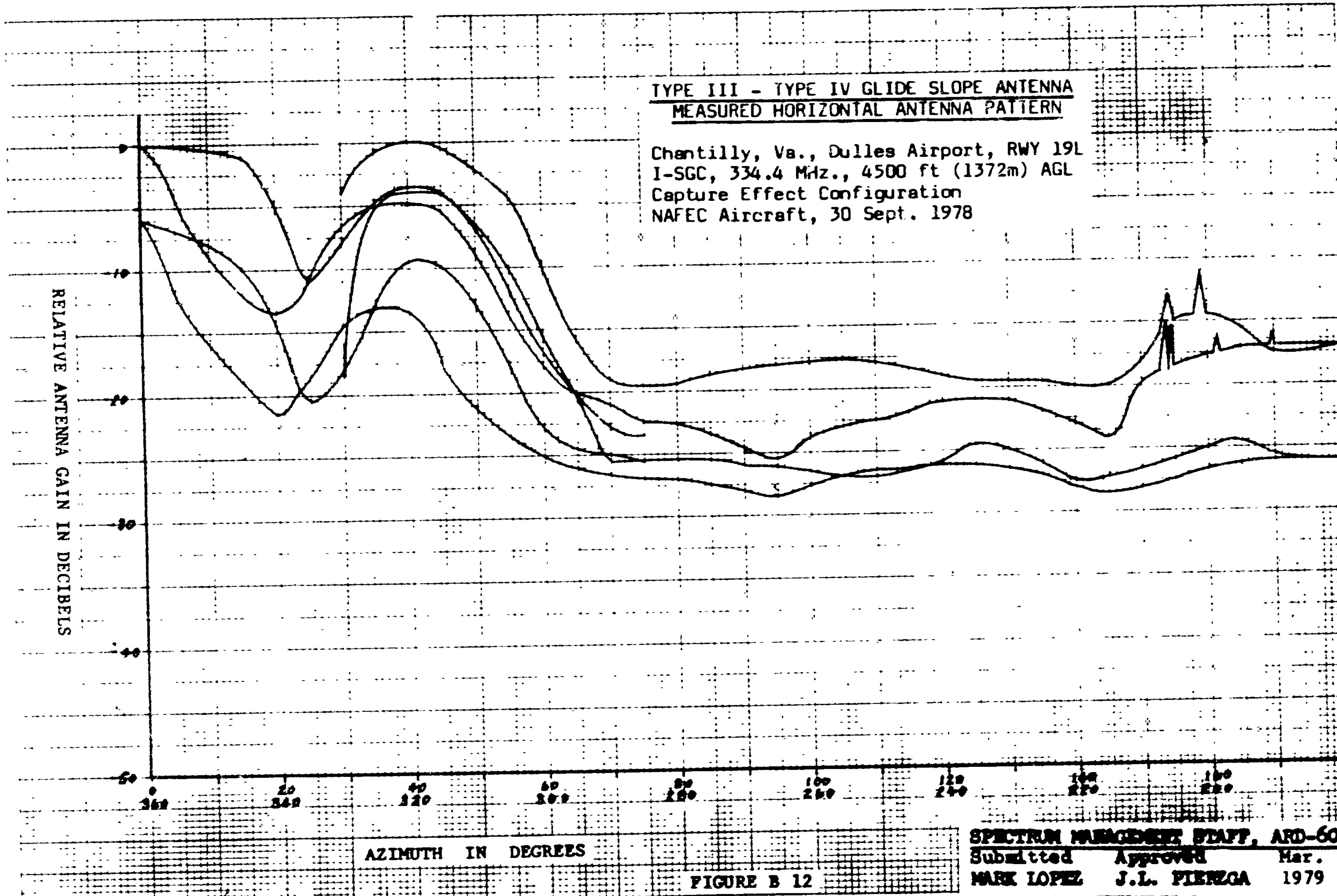


FIGURE B 12

SPECTRUM MANAGEMENT STAFF, ARD-60		
Submitted	Approved	Mar.
MARK LOPEZ	J.L. PIERZGA	1979

FIGURE F 1

SPECTRUM ... , AND-60
Submitted ... July
MARK LOPEZ J.L. ... 1978

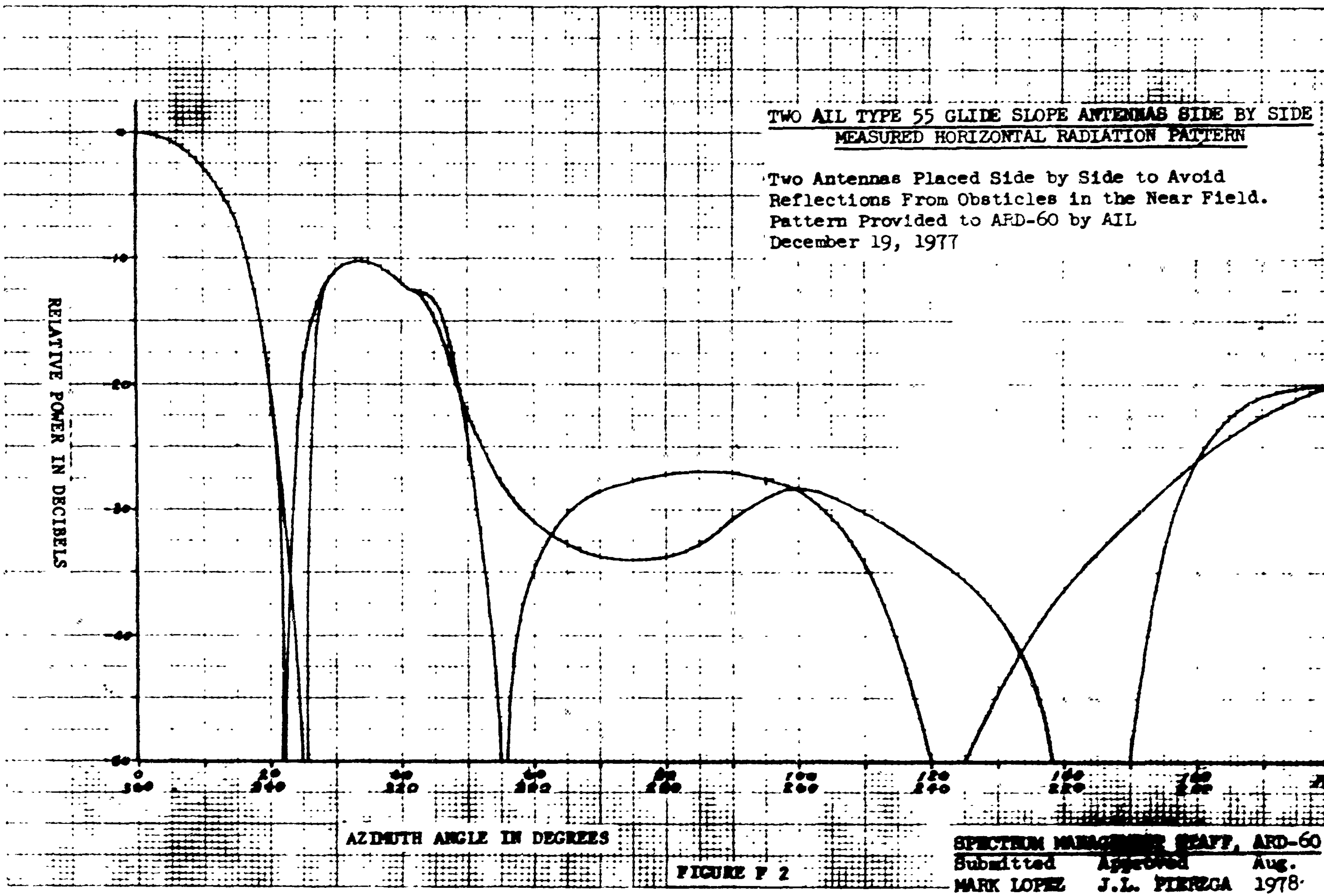

TWO AIL TYPE 55 GLIDE SLOPE ANTENNAS SIDE BY SIDE
MEASURED HORIZONTAL RADIATION PATTERN
Two Antennas Placed Side by Side to Avoid
Reflections From Obsticles in the Near Field.
Pattern Provided to ARD-60 by AIL
December 19, 1977
RELATIVE POWER IN DECIBELS
AZIMUTH ANGLE IN DEGREES
ARD-60
Submitted
Aug.
MARK LOPEZ
J.L. PIERZGA
1978

FIGURE F 2

APPENDIX G

FAA SPECIFICATIONS

In our search for glide slope antenna specifications, the following documents were found to be applicable:

FAA-E-2245. This document was originally published March 11, 1966. Three amendments, the most recent dating March 24, 1969, have been authorized. Seven types of antennas are described in this specification.

Type I - This antenna contains a single dipole mounted on an elliptical ground plane and completely enclosed in a radome. Its horizontal free space radiation pattern is shown in Figure G1.

Type II - Type II antennas are the same as Type I, except they are equipped with a heater system. Its antenna pattern is the same as the Type I.

Type III - This is an array of three Type I antennas grouped to provide azimuthal directivity. The curve in Figure G2 provides the horizontal free space pattern for the Type III and the Type IV antennas.

Type IV- This antenna is the same as a Type III antenna, except for the addition of heaters (Type II antenna elements). Its pattern is the same as the Type III.

Type V - This is an array of two dipoles mounted one quarter-wavelength from a vertical ground plane. The horizontal free space radiation patterns given in Figure G3.

Type VI - This is a single dipole identical to those comprising the Type V antenna, but utilizes a smaller ground plane. The nominal antenna pattern is to be defined by the contractor at the time that the initial equipment is submitted.

Type VII - This antenna consists of an array of two colinear dipoles mounted one quarter-wavelength from a parabolic ground plane. Figure G4 provides the horizontal free space pattern requirements.

This specification (FAA-E-2245) covers most glide slope antennas in use today. Type III and Type IV antennas are the most abundant.

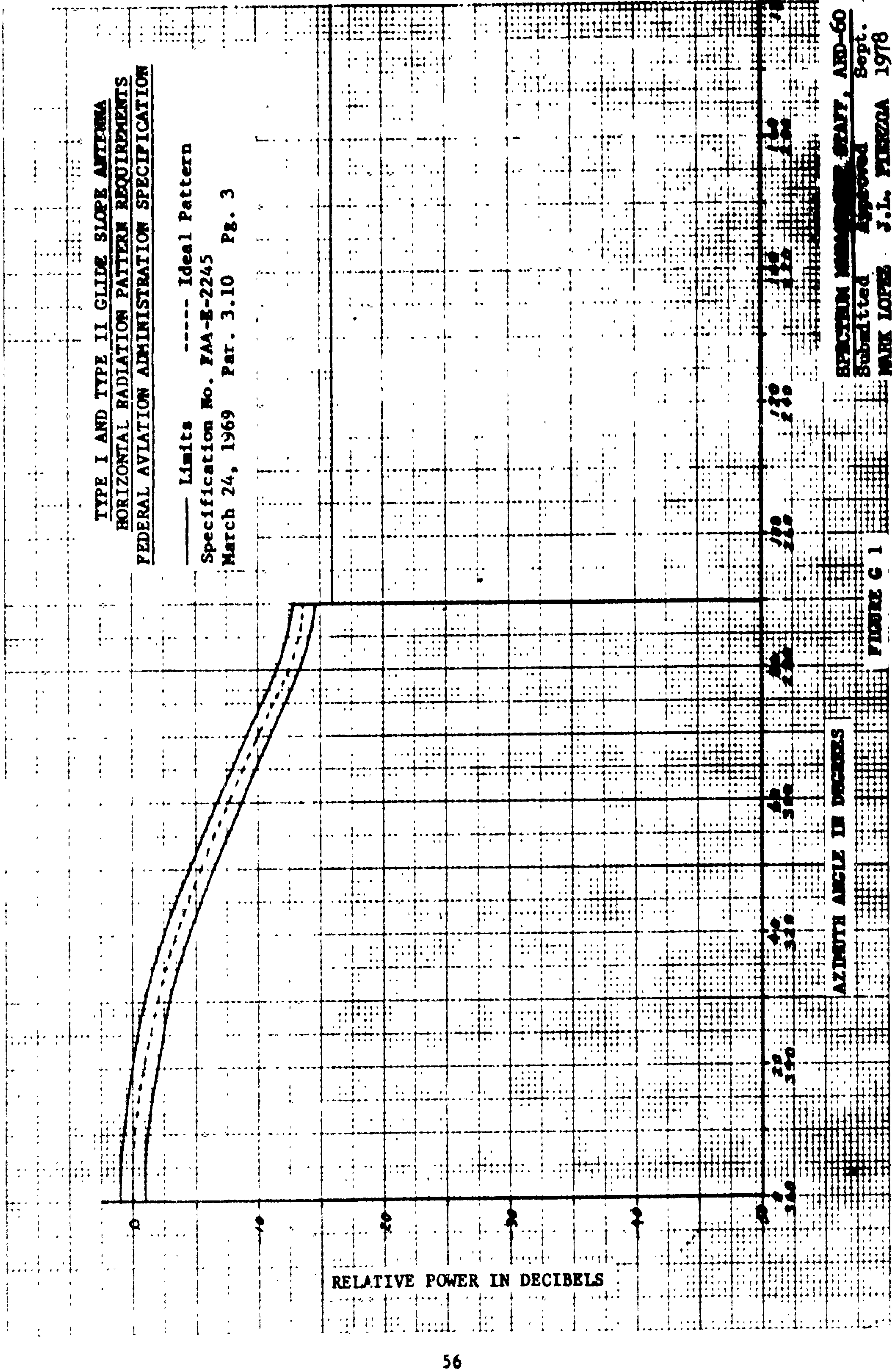
FAA-E-2429. This specification, dated January 2, 1970, is used in purchasing new image-type glide slope antenna systems. Both class 1 (null reference) and class 2 (capture effect) systems are covered. The sideband reference system is a modified version of the null reference system (Section 1.1, FAA-E-2557, April 2, 1973) and must meet the same horizontal pattern requirements.

This document does not differenciate between antenna types or element numbers, but rather sets general antenna array requirements. The antenna array is defined as "single or multiple horizontally polarized elements..." Thus, whether the antennas are in the null reference, sideband reference, or capture effect configuration, the same horizontal radiation pattern will be required by the specification.

The lower limit of this specification was modified in the contract specification FA74WA-3364. Measured data indicates that this requirement is difficult to meet, even for the antennas built under this contract (Figs.

B9 and B10).

The end-fire slotted cable and the waveguide glide slope antennas are still under development. Consequently, there are no current FAA specifications which apply to these non-image type antenna systems.


TYPE I AND TYPE II GLIDE SLOPE ANTENNA
HORIZONTAL RADIATION PATTERN REQUIREMENTS
FEDERAL AVIATION ADMINISTRATION SPECIFICATION
——— Limits ----- Ideal Pattern
Specification No. FAA-E-2245
March 24, 1969 Par. 3.10 Pg. 3
RELATIVE POWER IN DECIBELS
0
10
20
30
40
AZIMUTH ANGLE IN DEGREES
20
340
40
320
60
300
100
260
120
240
SPECTRUM [redacted] STAFF, ARD-60
Submitted Approved Sept.
MARK LOPEZ J.L. PIERZGA 1978
FIGURE C 1

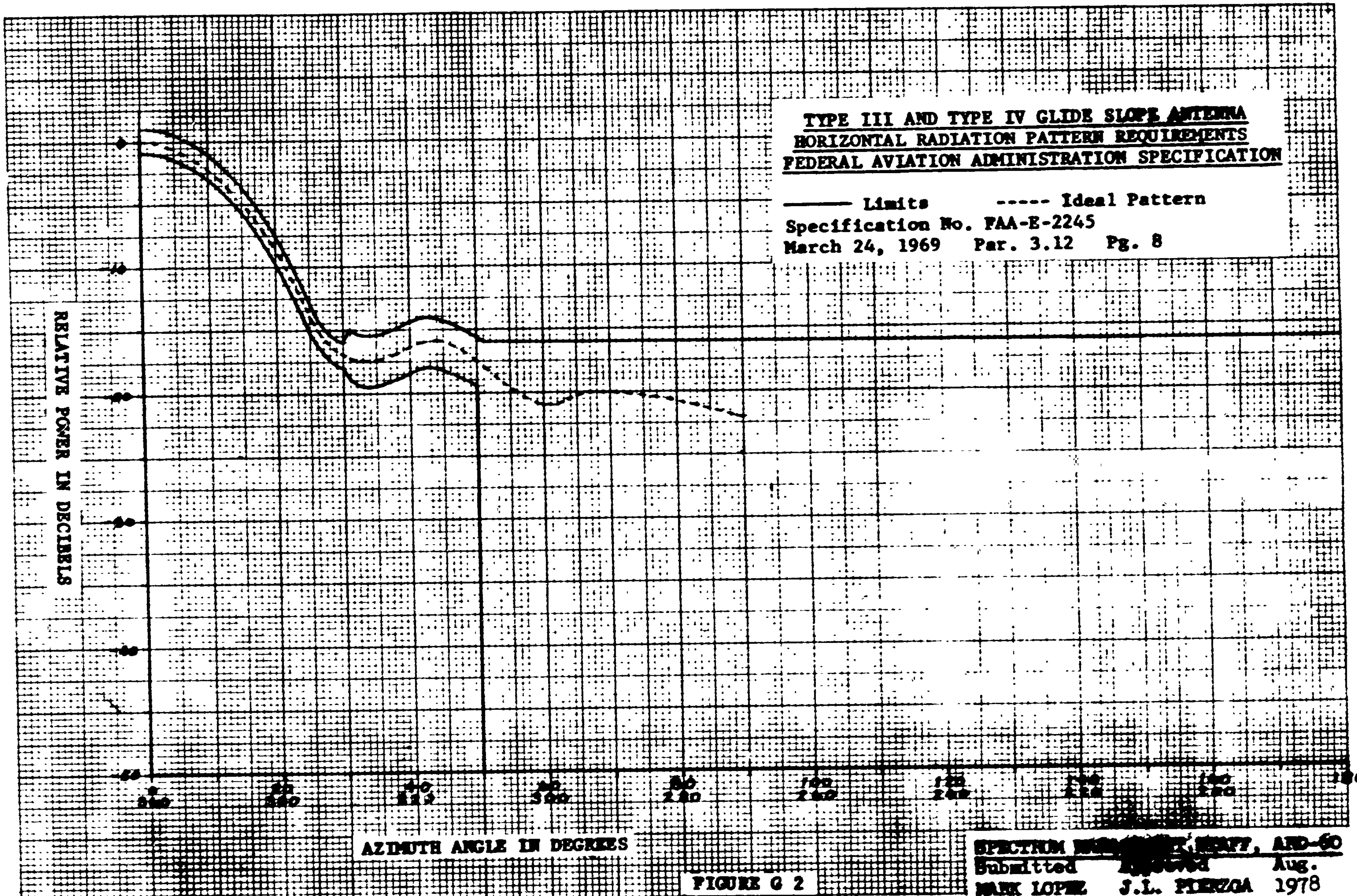
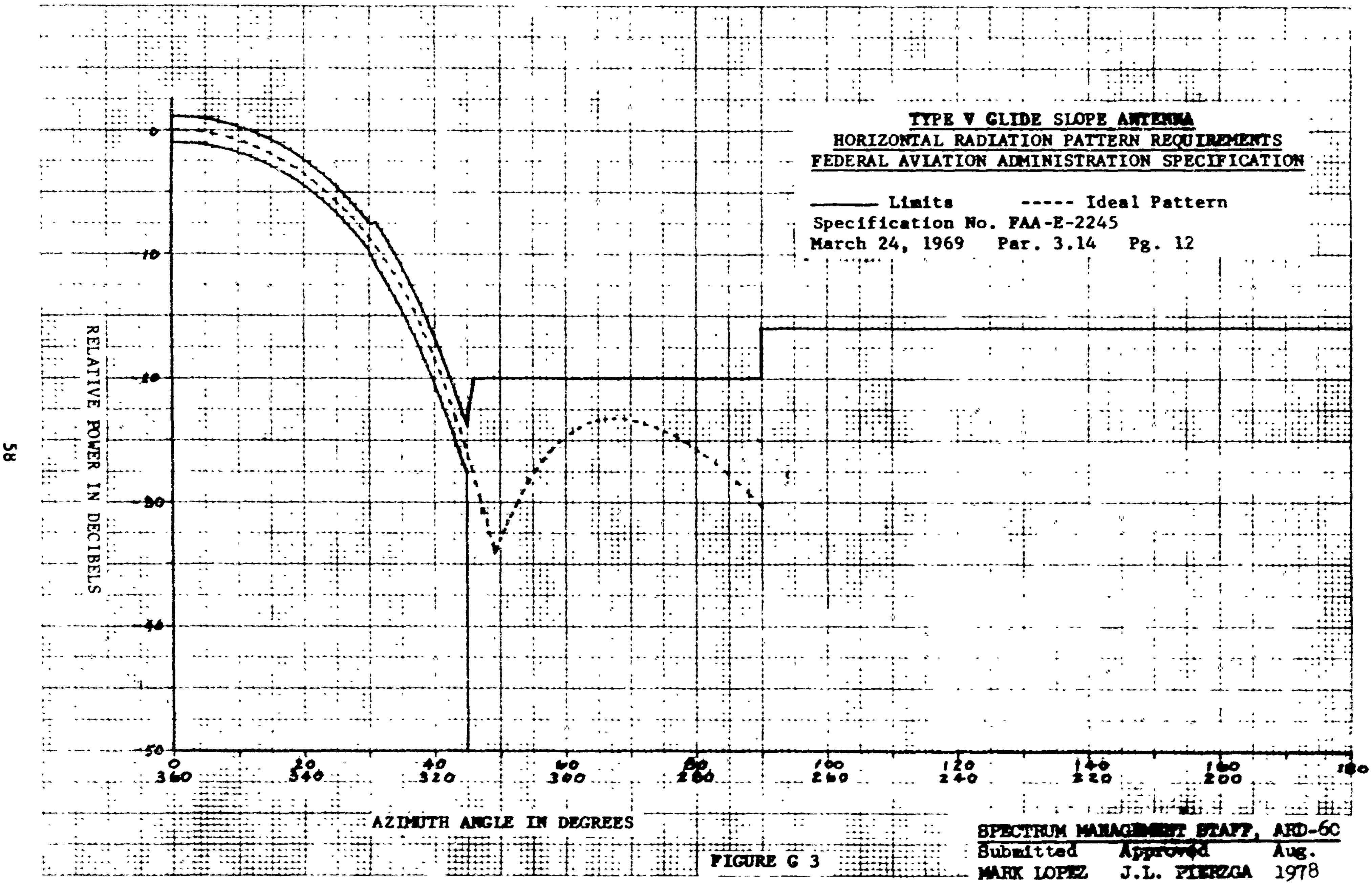

TYPE III AND TYPE IV GLIDE SLOPE ANTENNA
HORIZONTAL RADIATION PATTERN REQUIREMENTS
FEDERAL AVIATION ADMINISTRATION SPECIFICATION
——— Limits
----- Ideal Pattern
Specification No. FAA-E-2245
March 24, 1969 Par. 3.12 Pg. 8
RELATIVE POWER IN DECIBELS
AZIMUTH ANGLE IN DEGREES
Submitted
Aug.
MARK LOPEZ
J.L. PIERZGA
1978

FIGURE G 2



TYPE V GLIDE SLOPE ANTENNA
HORIZONTAL RADIATION PATTERN REQUIREMENTS
FEDERAL AVIATION ADMINISTRATION SPECIFICATION
——— Limits ----- Ideal Pattern
Specification No. FAA-E-2245
March 24, 1969 Par. 3.14 Pg. 12
RELATIVE POWER IN DECIBELS
0
10
20
30
40
50
0
360
20
340
40
320
60
300
80
280
100
260
120
240
140
220
160
200
180
AZIMUTH ANGLE IN DEGREES
SPECTRUM MANAGEMENT STAFF, ARD-6C
Submitted Approved Aug.
MARK LOPEZ J.L. PIERZGA 1978

FIGURE G 3

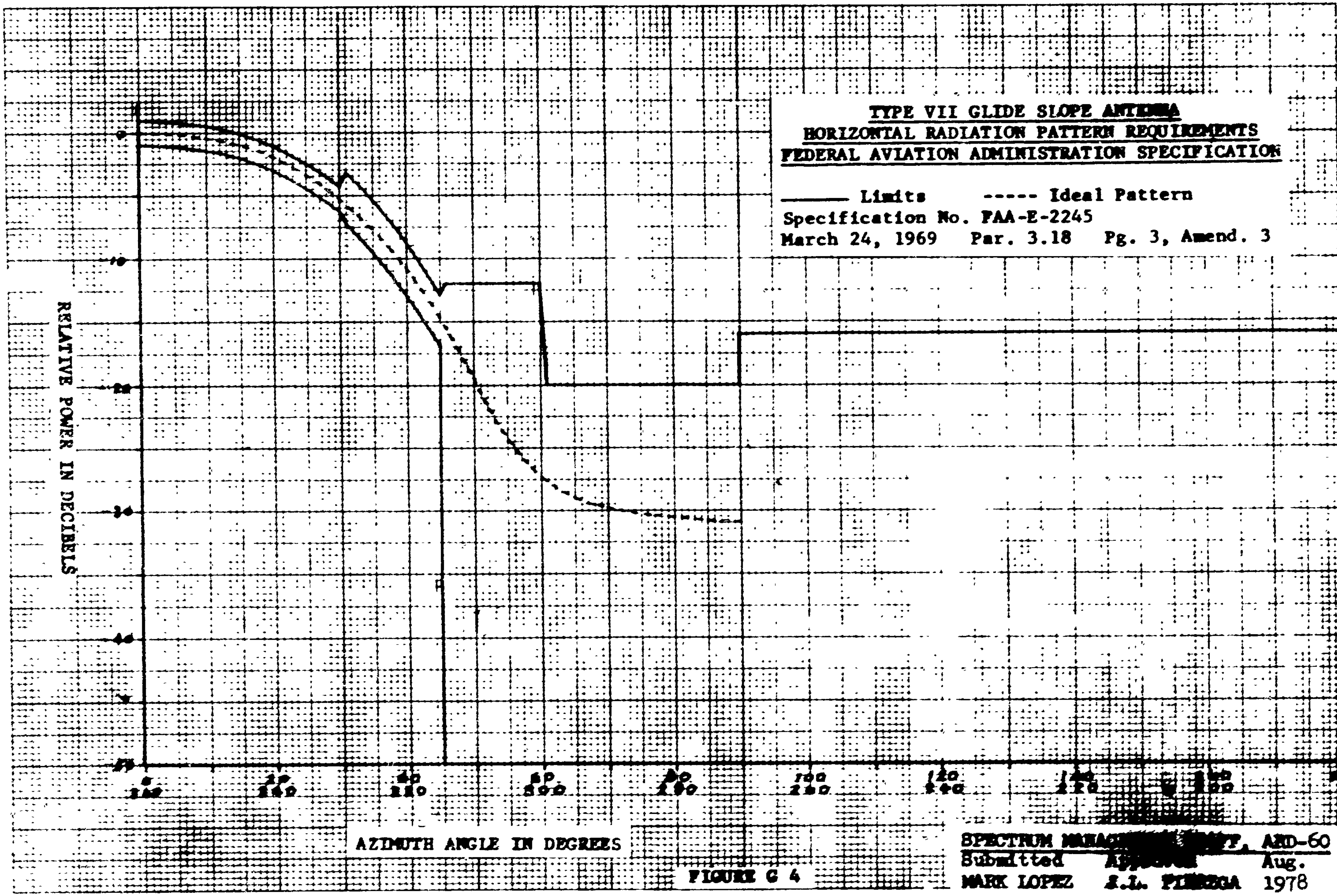
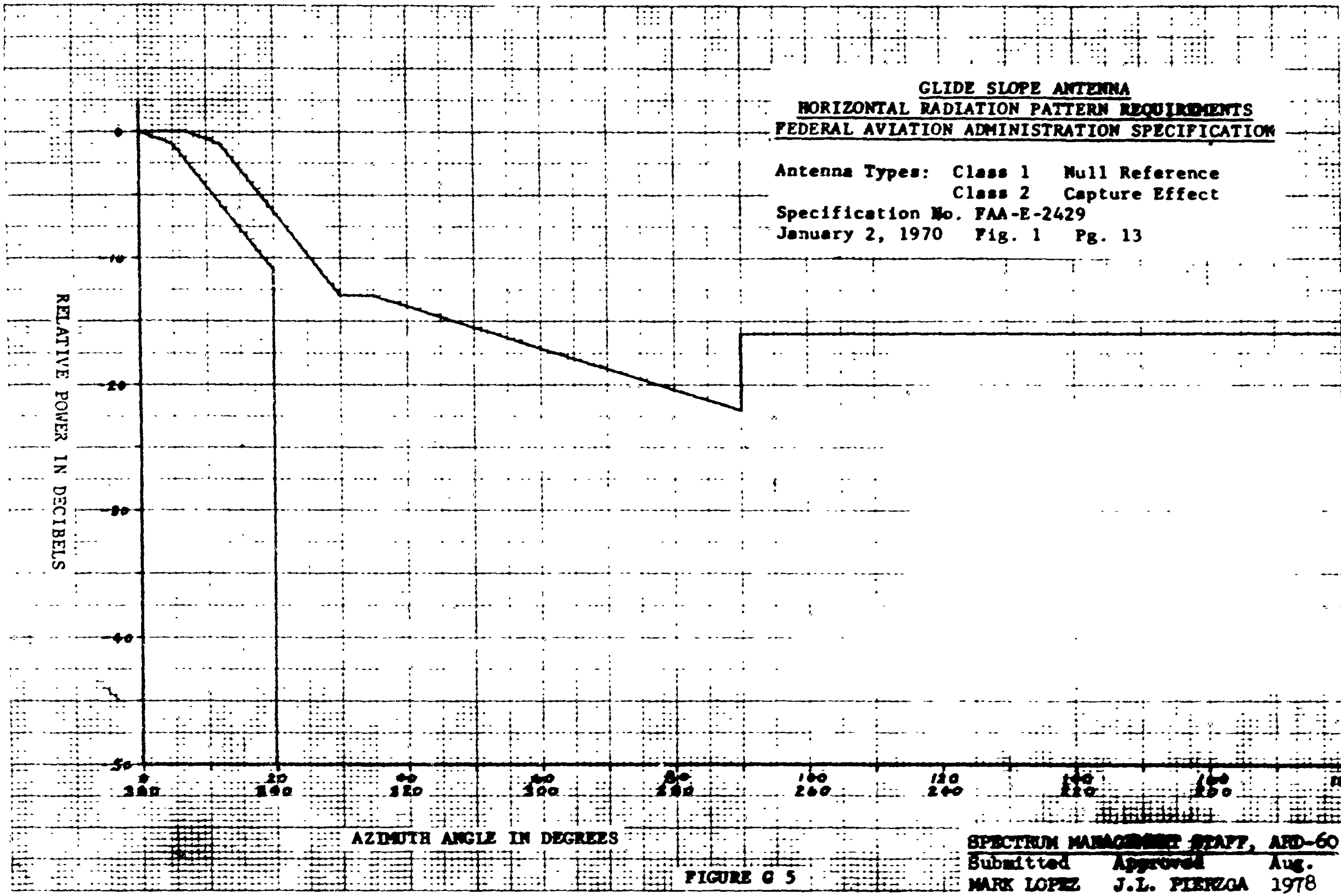

TYPE VII GLIDE SLOPE ANTENNA
HORIZONTAL RADIATION PATTERN REQUIREMENTS
FEDERAL AVIATION ADMINISTRATION SPECIFICATION
Limits
----- Ideal Pattern
Specification No. FAA-E-2245
March 24, 1969 Par. 3.18 Pg. 3, Amend. 3
RELATIVE POWER IN DECIBELS
AZIMUTH ANGLE IN DEGREES
SPECTRUM MANAG... AMD-60
Submitted
Aug.
MARK LOPEZ
1978

FIGURE G 4


GLIDE SLOPE ANTENNA
HORIZONTAL RADIATION PATTERN REQUIREMENTS
FEDERAL AVIATION ADMINISTRATION SPECIFICATION
Antenna Types: Class 1 Null Reference
Class 2 Capture Effect
Specification No. FAA-E-2429
January 2, 1970 Fig. 1 Pg. 13
RELATIVE POWER IN DECIBELS
0
10
20
30
40
50
0
360
20
340
40
320
60
300
80
280
100
260
120
240
140
220
160
200
180
AZIMUTH ANGLE IN DEGREES
SPECTRUM MANAGEMENT STAFF, ARD-60
Submitted Approved Aug.
MARK LOPEZ J.L. PIERZGA 1978
FIGURE C 5

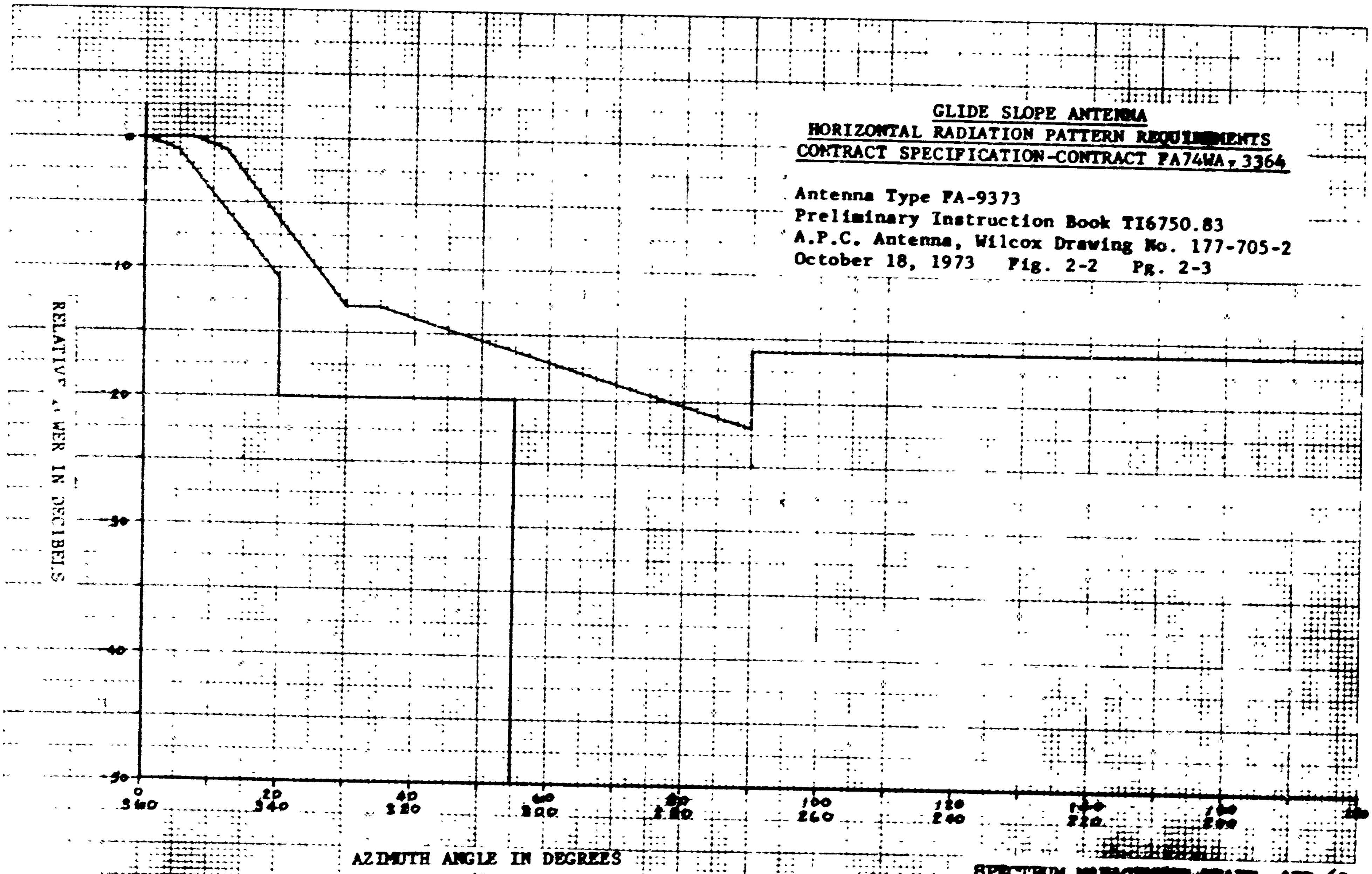


FIGURE G 6

SPECTRUM MANAGEMENT STAFF, ARD-60
Submitted Approved Aug.
MARK LOPEZ J.L. PIERZGA 1978

APPENDIX H

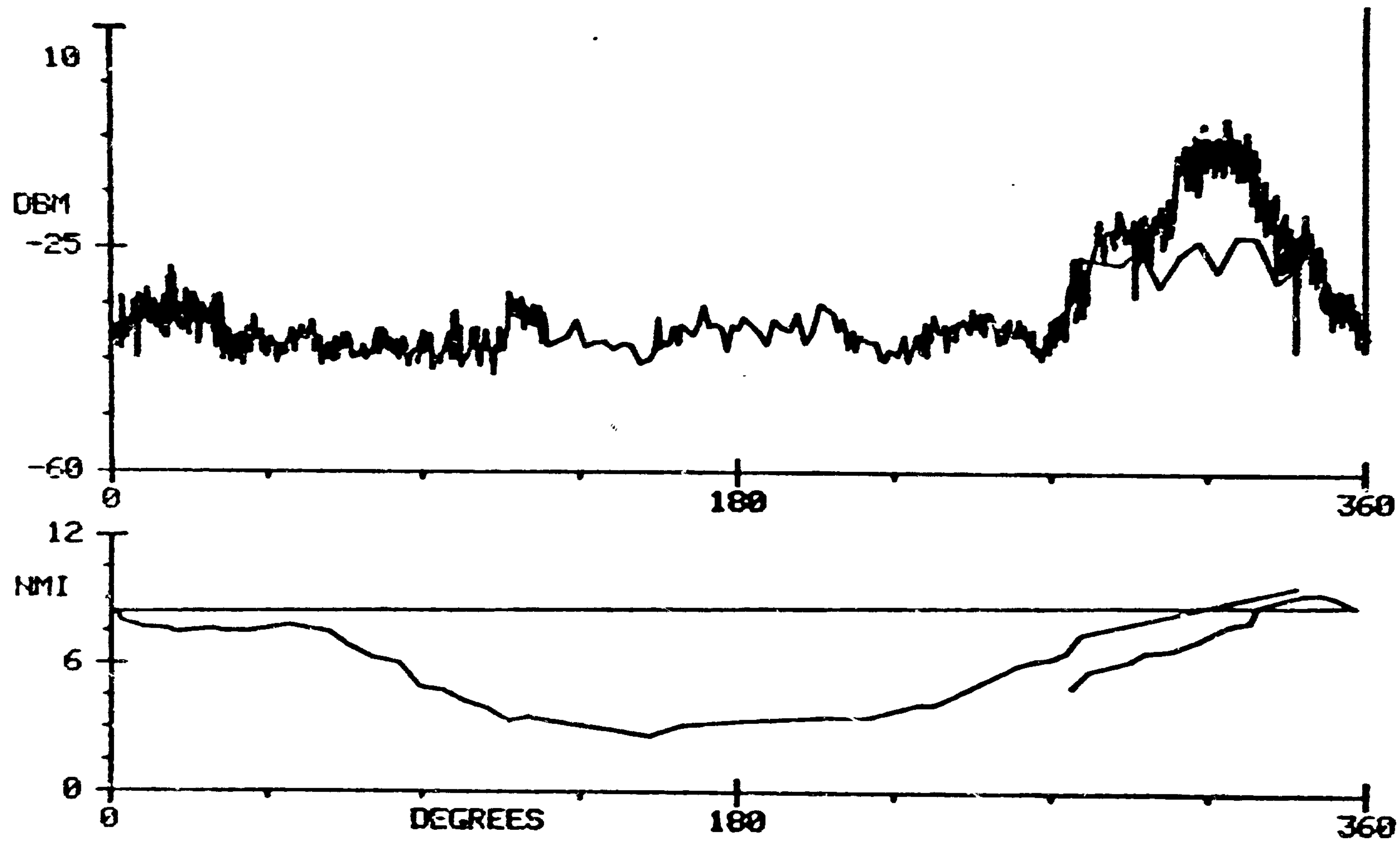
DATA OBTAINED FROM NAFEC

This section contains copies of the raw data collected by NAFEC. The following list shows the type of antenna elements are used in each antenna.

LOCATION	FIGURE NO.	SYSTEM TYPE	ELEMENT TYPE
Allentown, Pa.	B9	NR	III or IV
Allegheny Co., Pa.	B14	NR	III or IV
Reading, Pa.	B15	NR	III or IV
Hagerstown, Md.	B10	SBR	III or IV
Dulles, Va.	B12	CE	III or IV
Trenton, N.J.	A4	SBR	I or II
Atlantic City, N.J.	C5	CE	Two-Lambda
Gr. Pittsburgh, Pa.	C6	CE	Two-Lambda

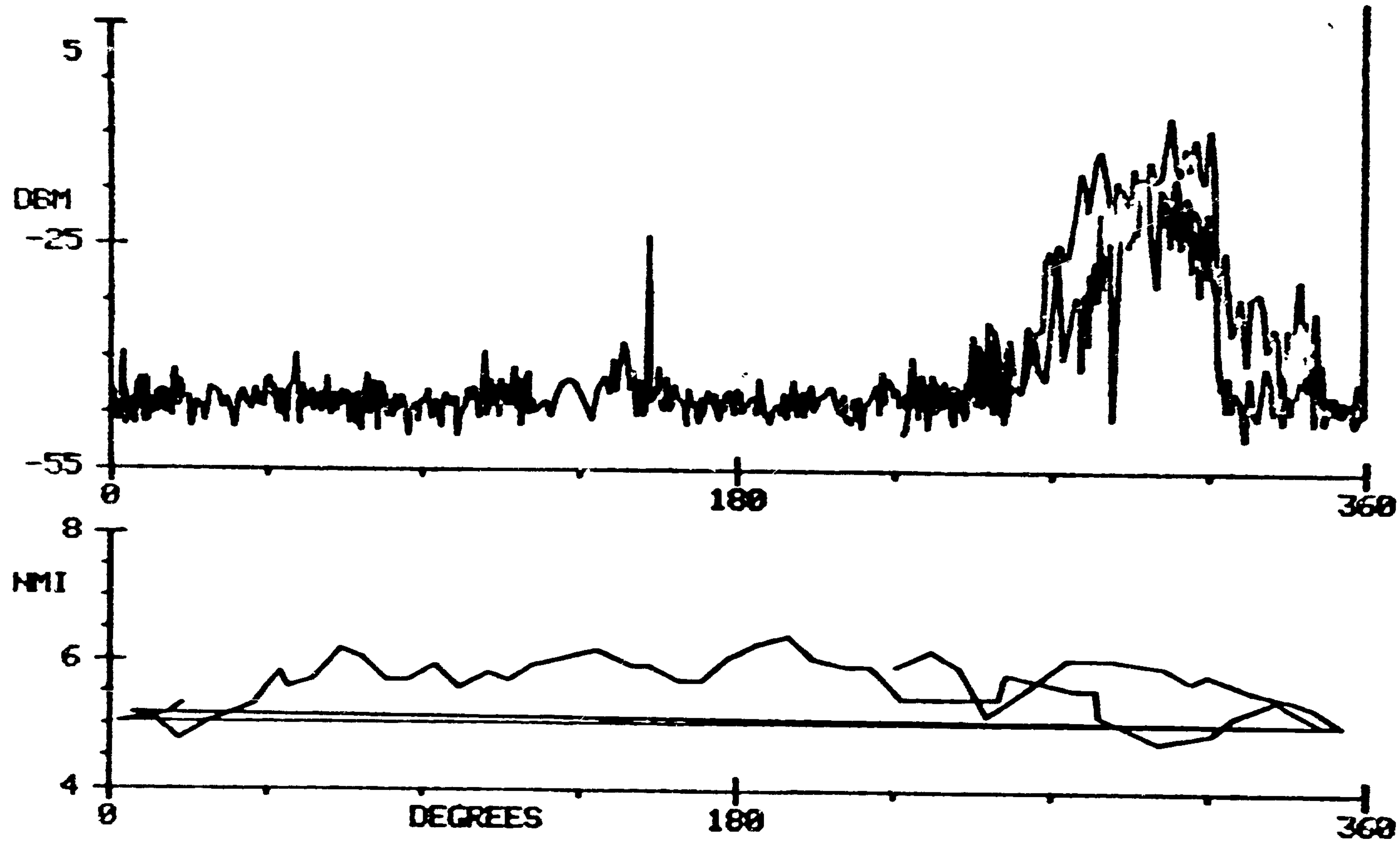
Data from the Allentown glide slope is the only antenna pattern replotted in detail. In order to save time, the remaining antenna patterns were replotted using lines to outline the maximum and minimum limits of the data. Should detailed information be desired on a particular antenna pattern, it is available in this appendix.

The data taken at Johnstown, Pa. has not been replotted. This glide slope system was shut down just prior to when the test orbit was flown. The data is no more than the ambient noise level.



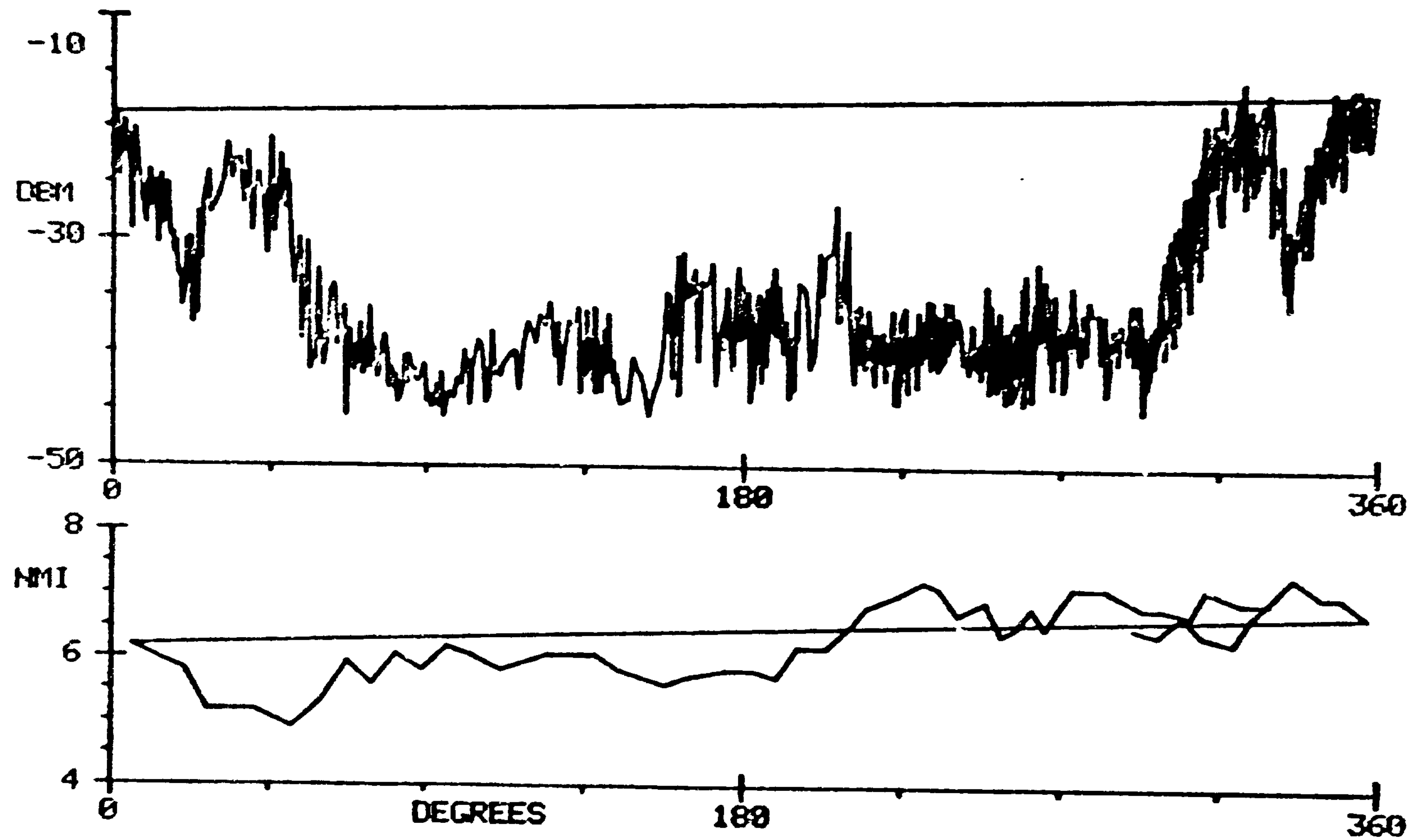
GLIDE SLOPE AT ALLENTOWN, PA.
FREQUENCY 3.31100E+08 MHZ
SPECTRUM ANALYZER HZ/DIV= 50000 HZ GAIN=10DB/DIV
FLIGHT NO. 10 ALTITUDE=4500 FEET
MAX PTS. IN PLOT= 590 START OF 340, END OF 276 DEGREES

FIGURE H 1



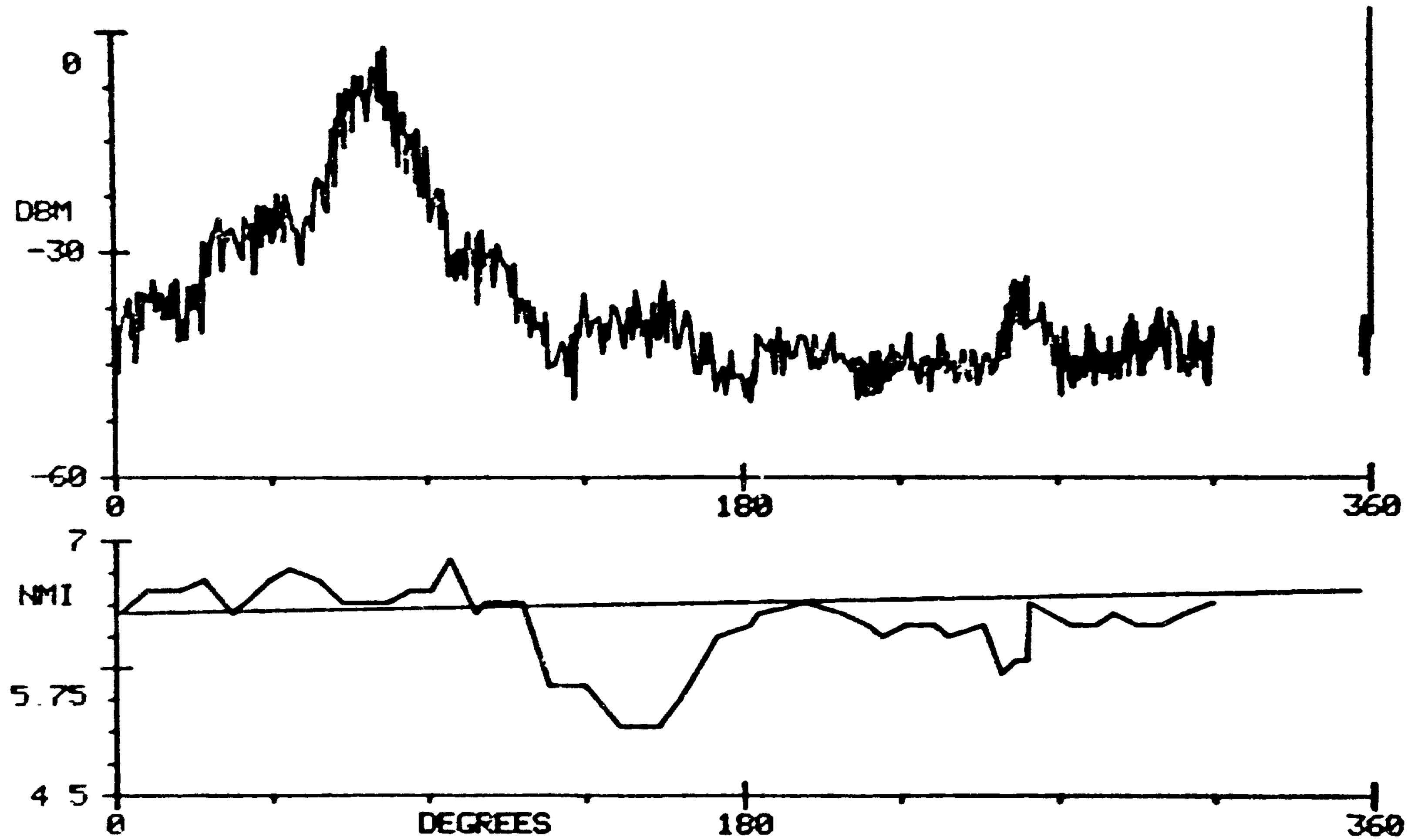
GLIDE SLOPE AT ATLANTIC CITY, NEW JERSEY
FREQUENCY 3.31400E+08 MHZ
SPECTRUM ANALYZER HZ/DIV= 50000 HZ GAIN=10DB/DIV
FLIGHT NO. 1 ALTITUDE=4500 FEET
MAX PTS. IN PLOT= 736 START OF 21, END OF 225 DEGREES

FIGURE H 2



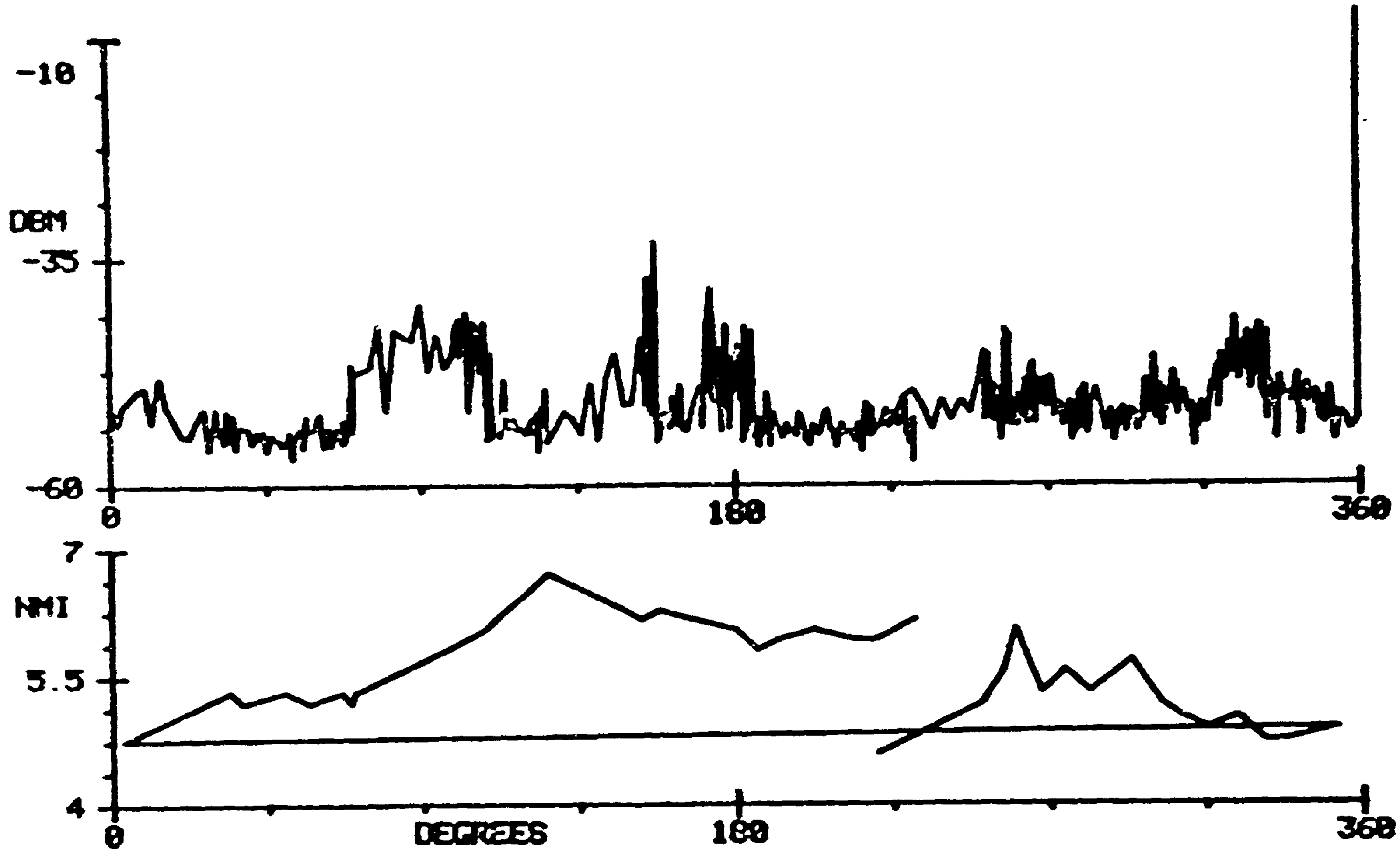
GLIDESLOPE
~~LOCALIZER~~ AT DULLES, GLIDE SLOPE, 19.
FREAQUENCY 3.34400E+08 MHZ
SPECTRUM ANALYZER HZ/DIV= 50000 HZ GAIN=1DB/DIV
FLIGHT NO. 11 ALTITUDE=4500 FEET
MAX PTS. IN PLOT= 637 START OF 329, END OF 291 DEGREES

FIGURE H 3



GLIDE SLOPE AT HAGERSTOWN ,MD.
FREQUENCY 3.31100E+08 MHZ
SPECTRUM ANALYZER HZ/DIV= 50000 HZ GAIN=10DB/DIV
FLIGHT NO. 10 ALTITUDE=4500 FEET
MAX PTS. IN PLOT= 527 START OF 314, END OF 356 DEGREES

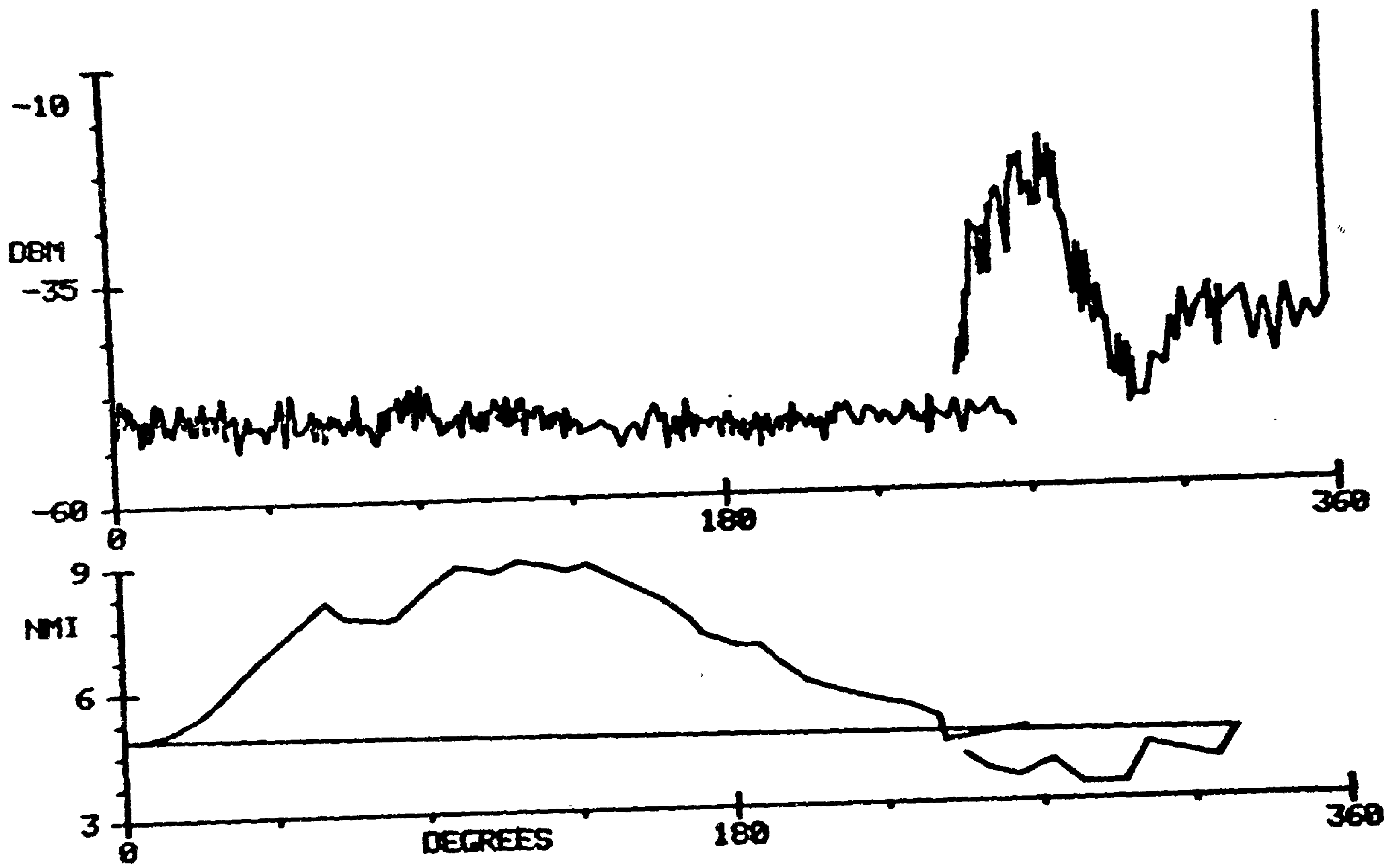
FIGURE H 4



GLIDE SLOPE AT JOHNSTOWN, PA. FREQUENCY 3.3

4400E+08 HZ
SPECTRUM ANALYZER HZ/DIV= 50000 HZ GAIN=1003/DIV
FLIGHT NO. 35 ALTITUDE=4520 FEET
MAX PTS. IN PLOT= 493 START OF 231, END OF 220 DEGREES

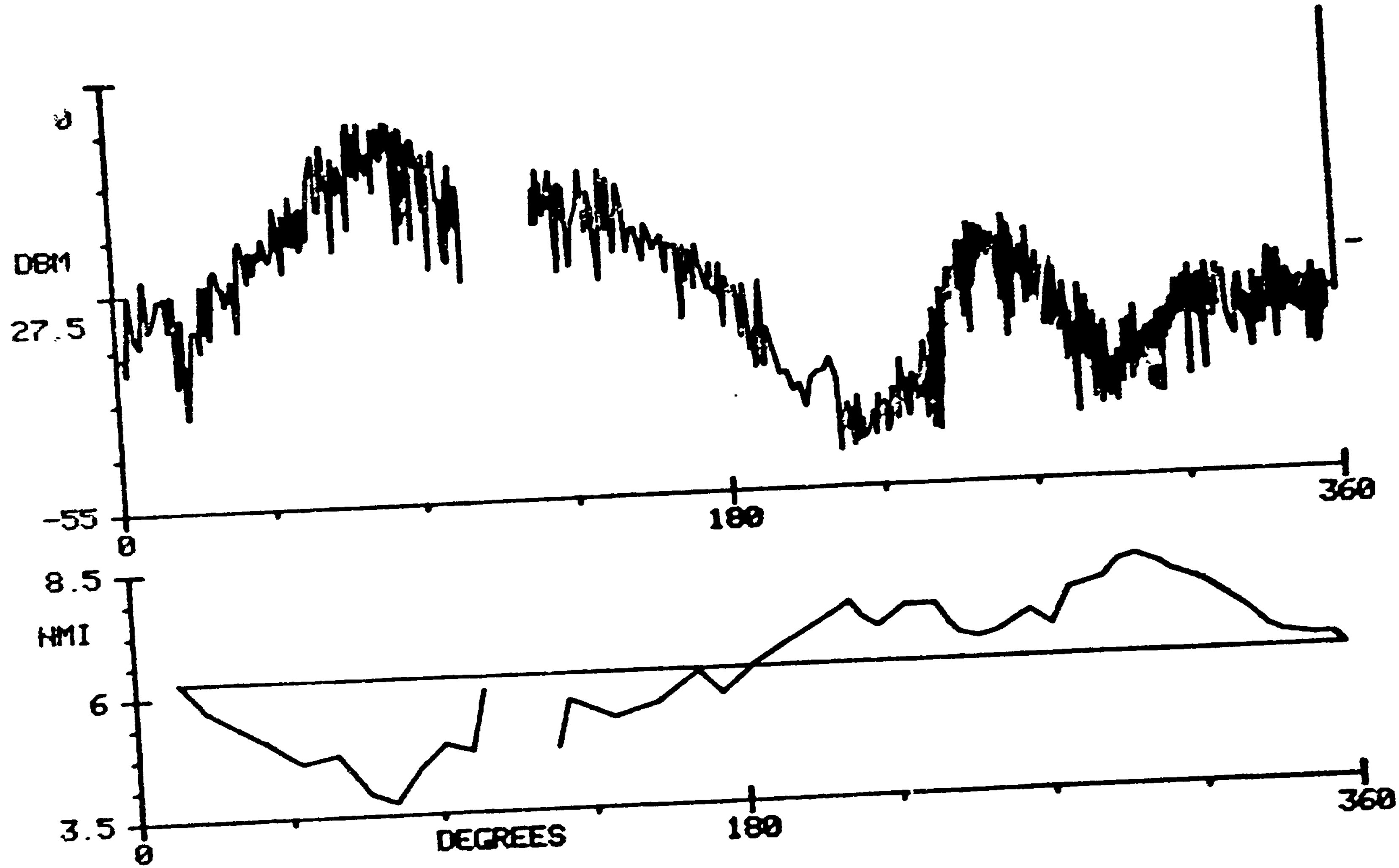
FIGURE H 5



GLIDE SLOPE AT GREATER PITTSBURG, PA. FREQUENCY 3.3

3500E+08 HZ
SPECTRUM ANALYZER HZ/DIV= 50000 HZ GAIN=10DB/DIV
FLIGHT NO. 34 ALTITUDE=4500 FEET
MAX PTS. IN PLOT= 450 START OF 265, END OF 247 DEGREES

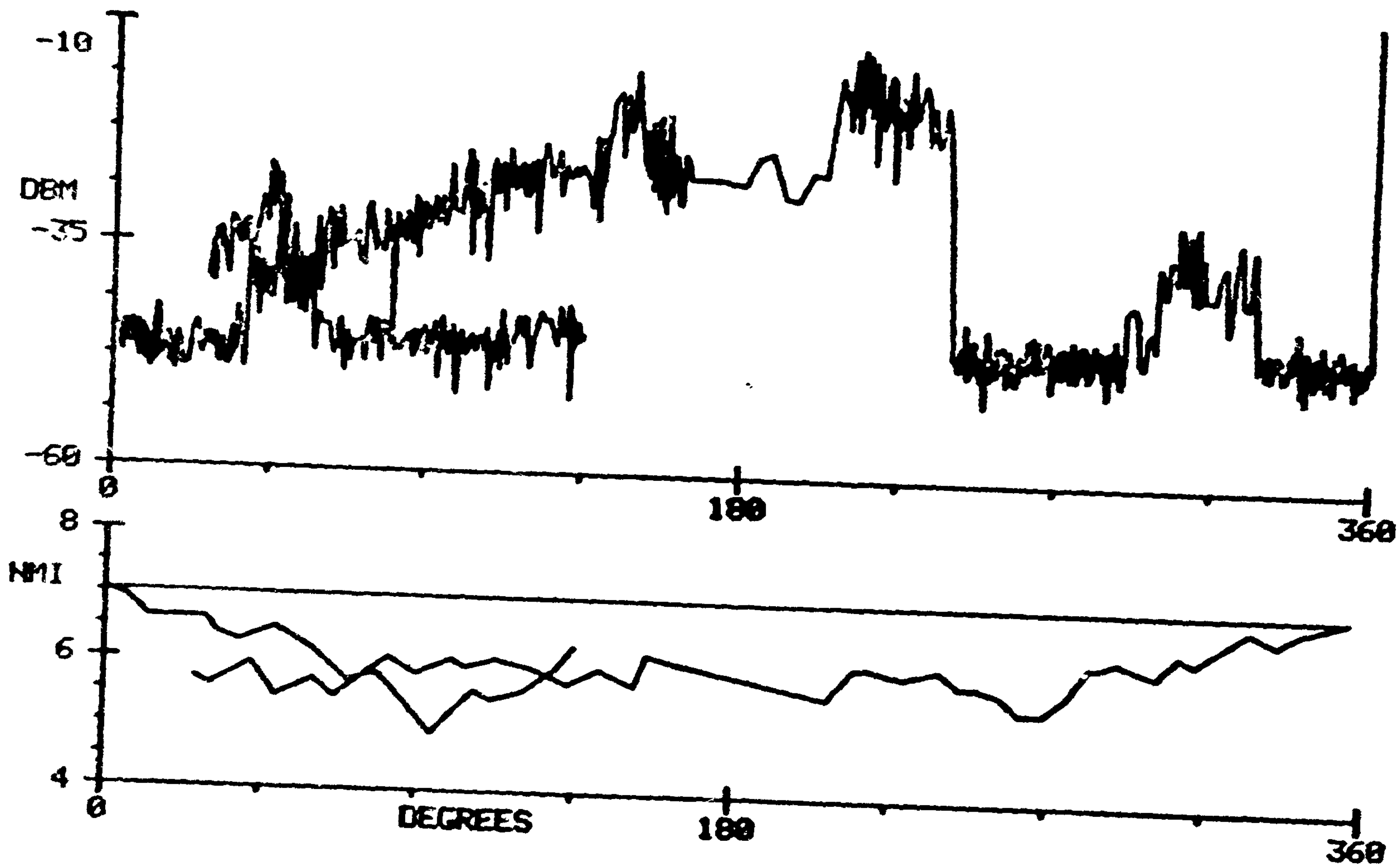
FIGURE H 6



GLIDE SLOPE AT PITTSBURG (ALLEGHENY COUNTY), PA.

FREQUENCY 3.31400E+08 HZ
SPECTRUM ANALYZER HZ/DIV= 50000 HZ GAIN=10DB/DIV
FLIGHT NO. 33 ALTITUDE=4500 FEET
MAX PTS. IN PLOT= 527 START OF 103, END OF 124 DEGREES

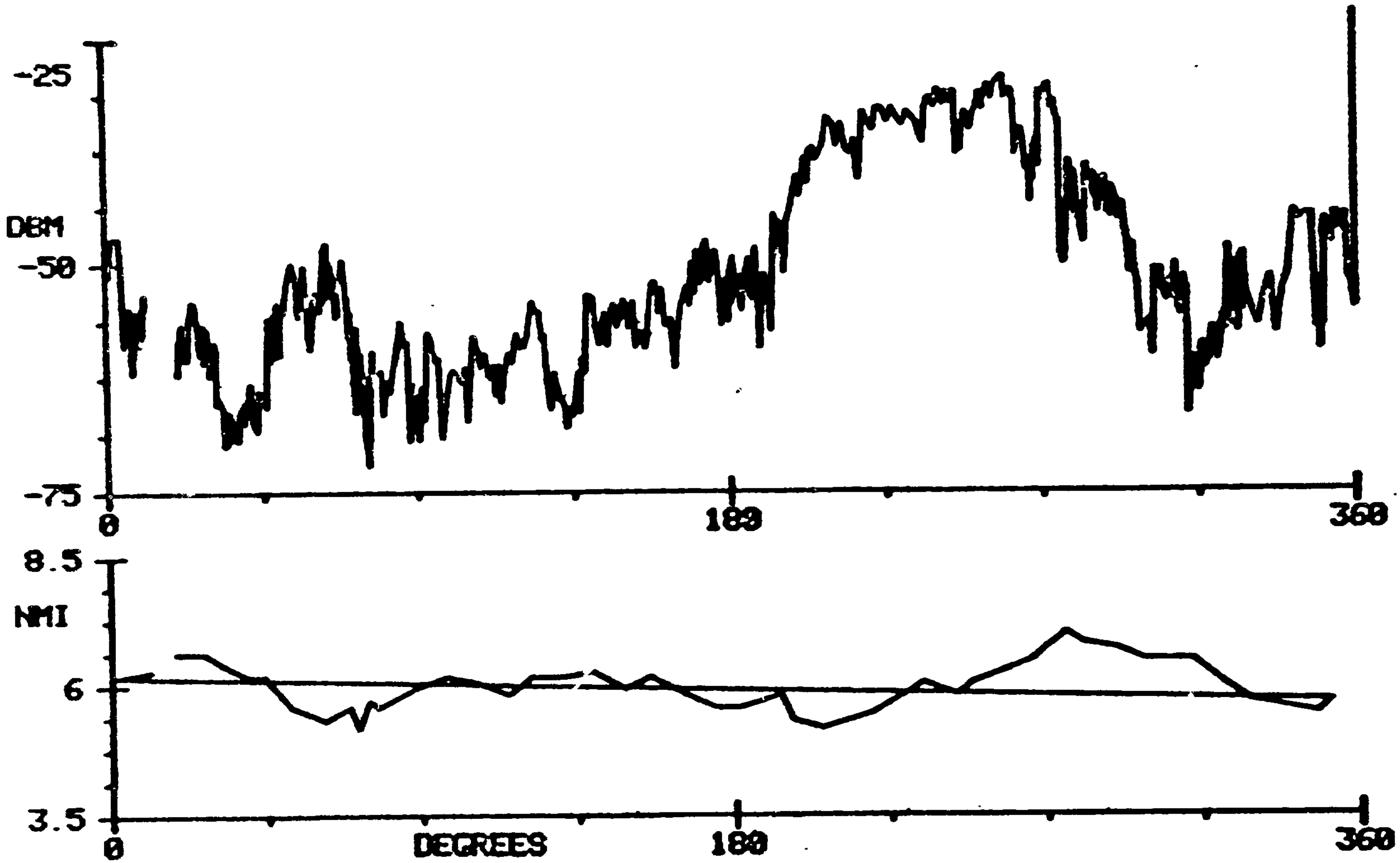
FIGURE H 7



GLIDE SLOPE AT READING, PA.

FREQUENCY 3.32600E+03 MHZ
SPECTRUM ANALYZER HZ/DIV= 50000 HZ GAIN=10DB/DIV
FLIGHT NO. 7 ALTITUDE=4500 FEET
MAX PTS. IN PLOT= 692 START OF 134, END OF 26 DEGREES

FIGURE H 8



GLIDE SLOPE AT TRENTON, N.J. FREQUENCY 3.3

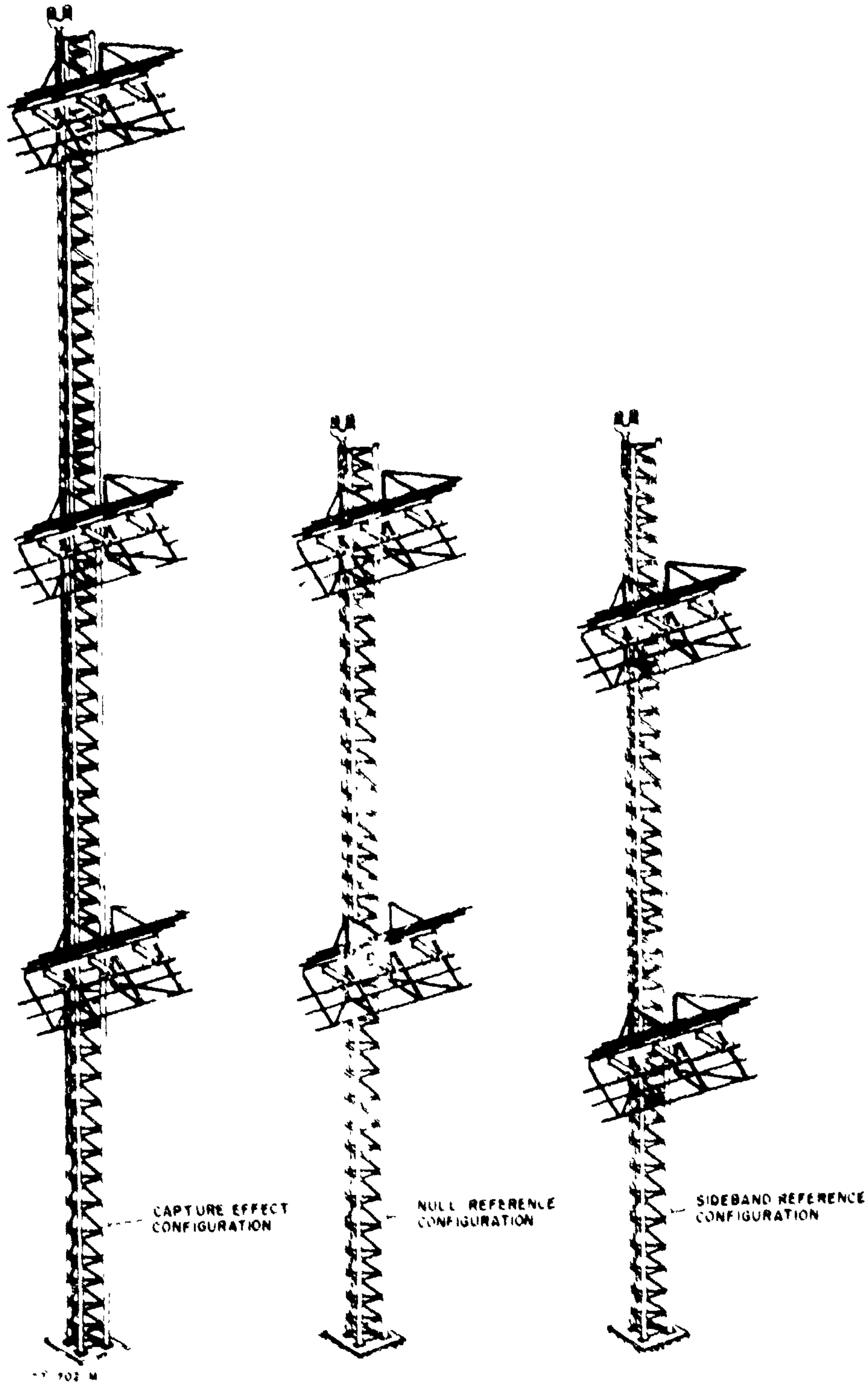
2300E+08 HZ
SPECTRUM ANALYZER HZ/DIV= 50000 HZ GAIN=1CDB/DIV
FLIGHT NO. 2 ALTITUDE=4500 FEET
MAX PTS. IN PLOT= 516 START OF 11, END OF 19 DEGREES

FIGURE H 9

APPENDIX I

PICTURES OF ILS GLIDE SLOPE ANTENNAS

Different types of glide slope antennas have different antenna patterns. Consideration of these differences may be desirable in the frequency assignment process. Consideration requires knowledge of the desired and undesired stations' antenna types. FAA sector offices provide this information to the Electromagnetic Compatibility Analysis Center (ECAC). FAA has an interagency agreement with ECAC. The FAA provides to ECAC data on telecommunication systems. ECAC does the record keeping and provides to FAA computer printouts upon request. For the frequency assignment process, the Frequency Management Officer (FMO) may choose to use the ECAC records or he may contact the FAA sector offices directly. In either case, the identification of the antenna type comes from the FAA sector maintenance office. Since this is the case, sector personnel should be capable of identifying the different antenna types. With the many different glide slope antenna types, this can be a difficult assignment. FAA type numbers are helpful but they have not been assigned to all antenna types. In many cases, visual identification is essential. Since, to our knowledge no single FAA publication shows all glide slope antenna types, this appendix has been an attempt to do that.



Conventional Glide Slope Antenna System Configurations

FIGURE I 1

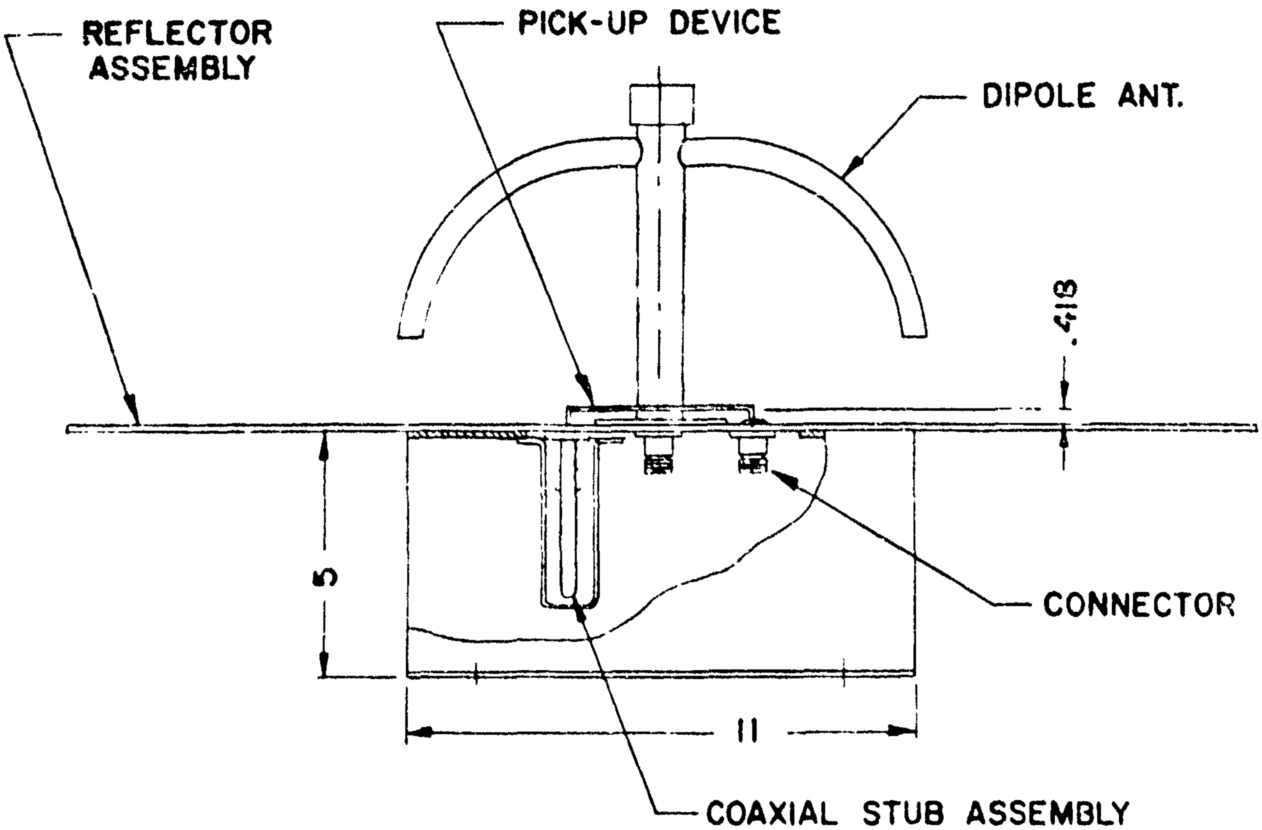


FIGURE I 2

Type I Antenna With Pick-Up Device
Antenna Type FA-8090

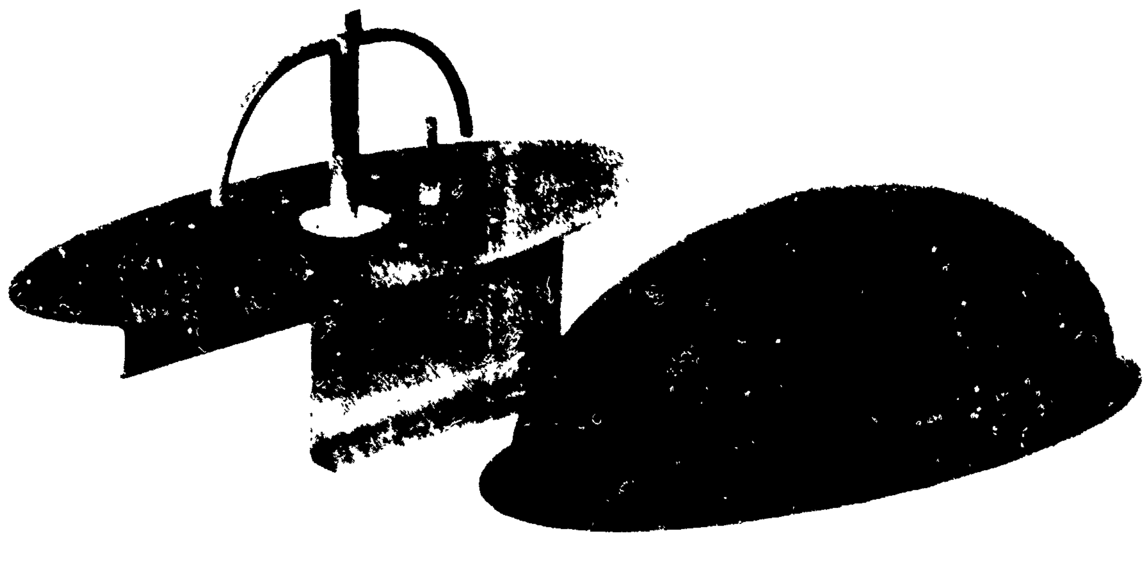
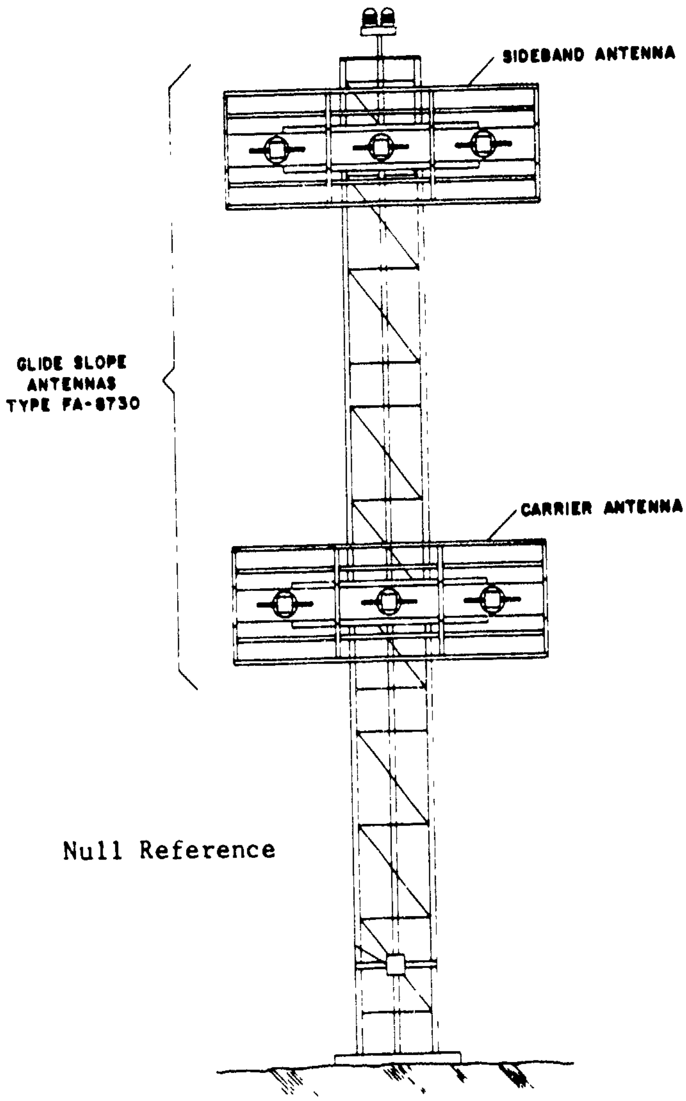
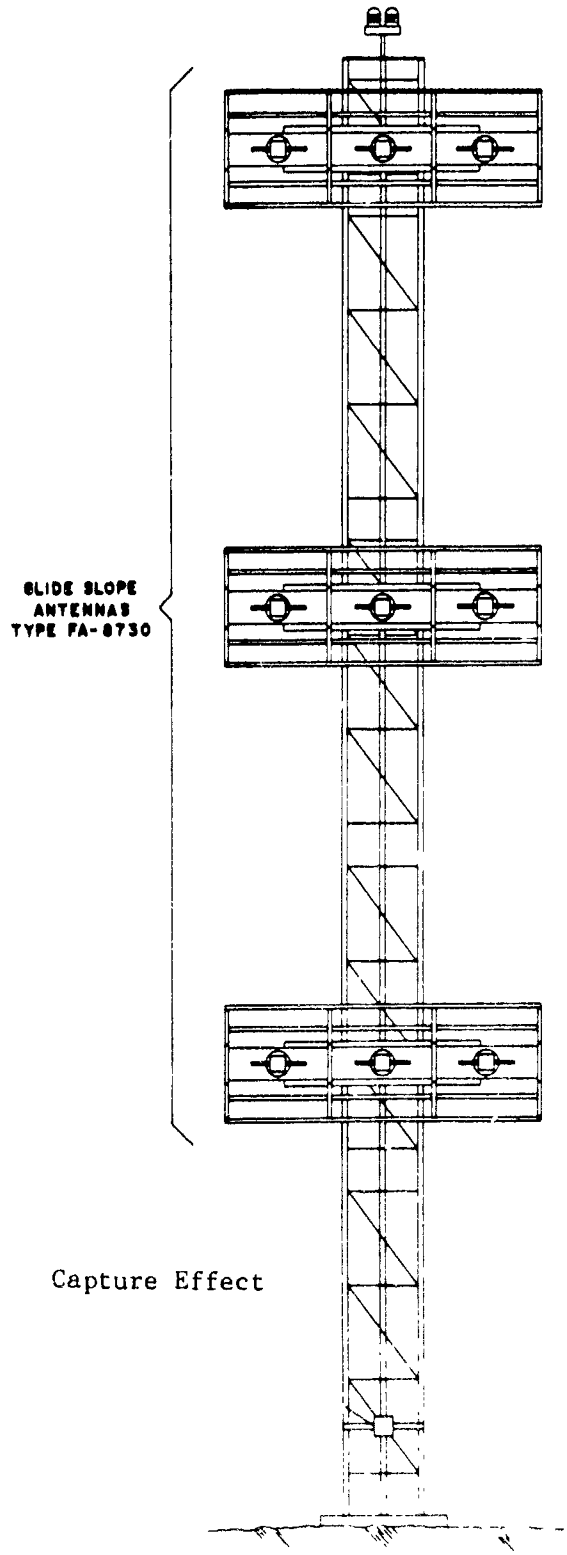


FIGURE I 3

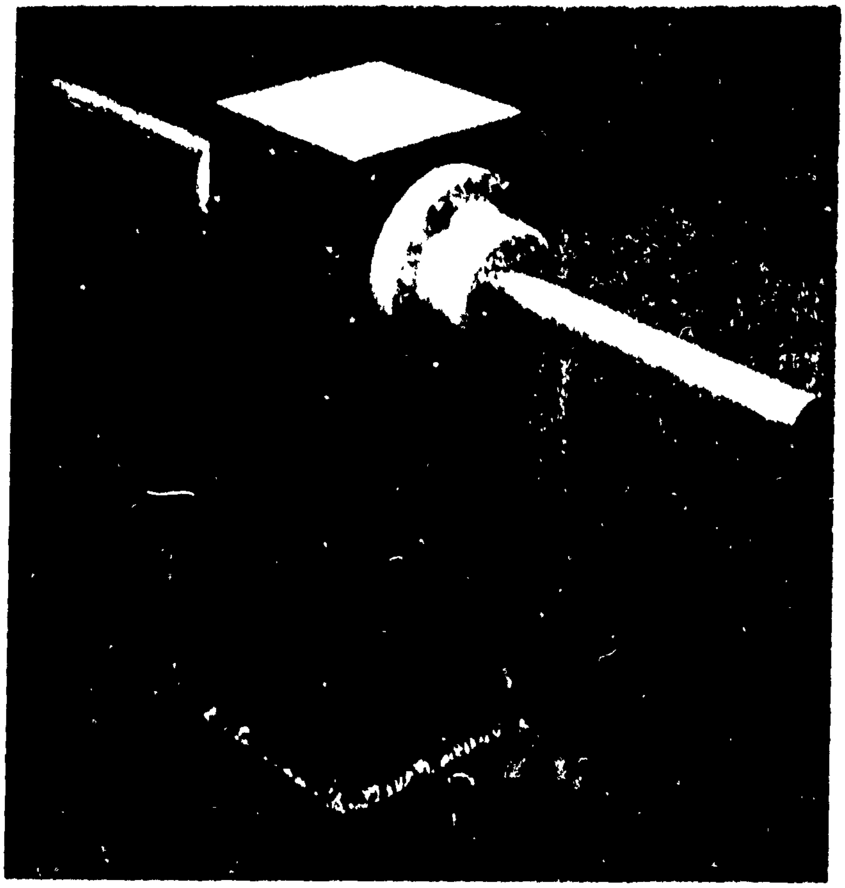
Type I Antenna With Radome Removed
Antenna Type FA-8090



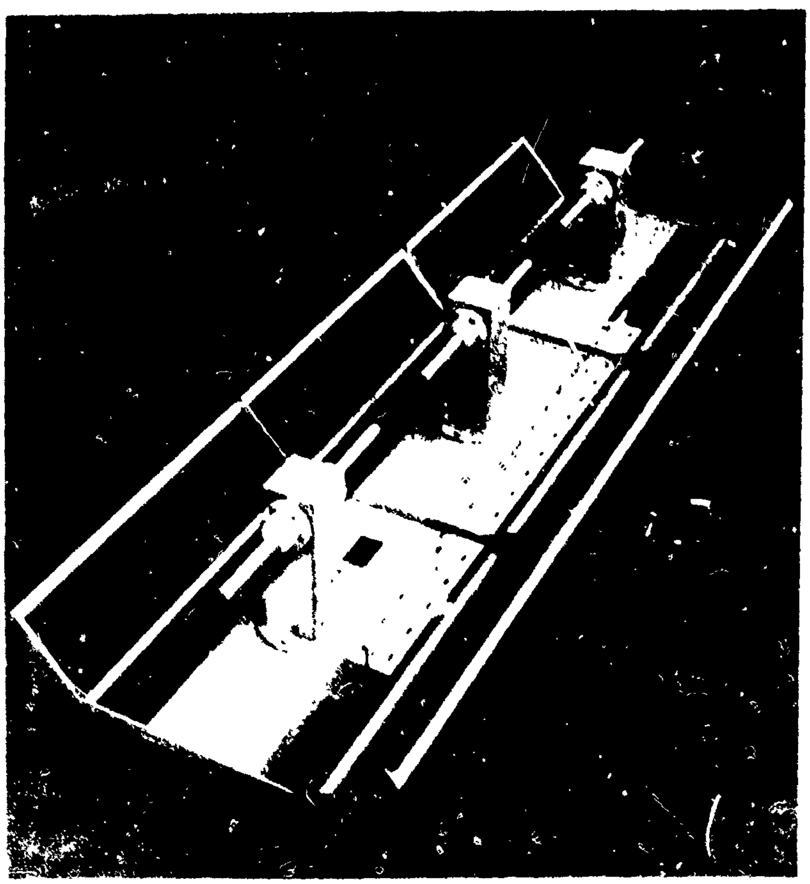


Antenna Type FA-8730 In
The Null Reference And
Capture Effect Configurations

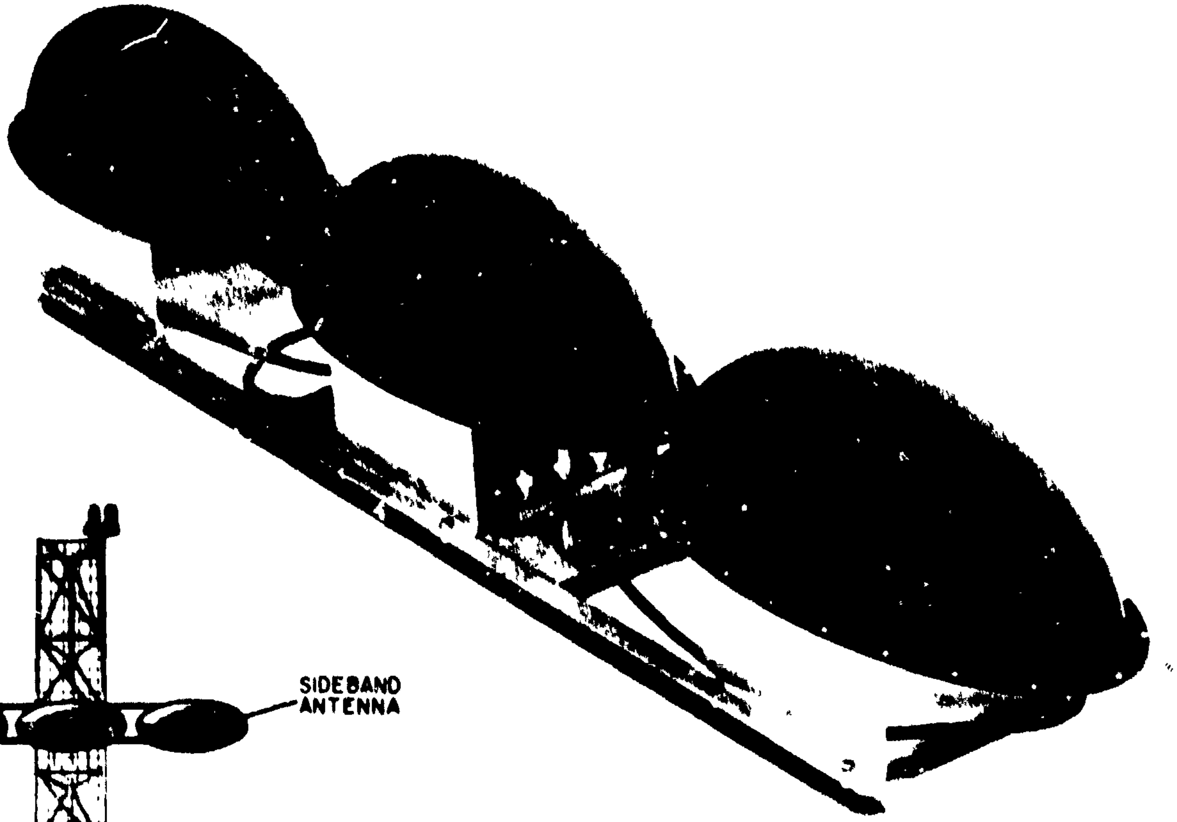
FIGURE I 4



Dipole For Antenna Type FA-8730
FIGURE I 5

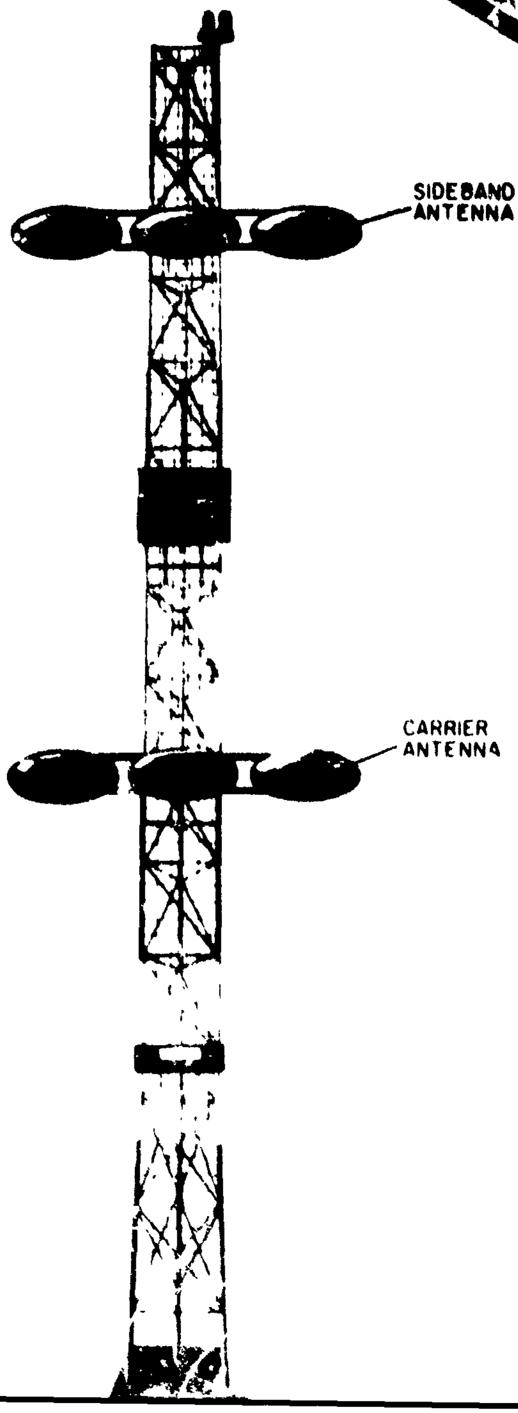


Type IV Antenna Without Radomes
Antenna Type FA-8730
FIGURE I 6



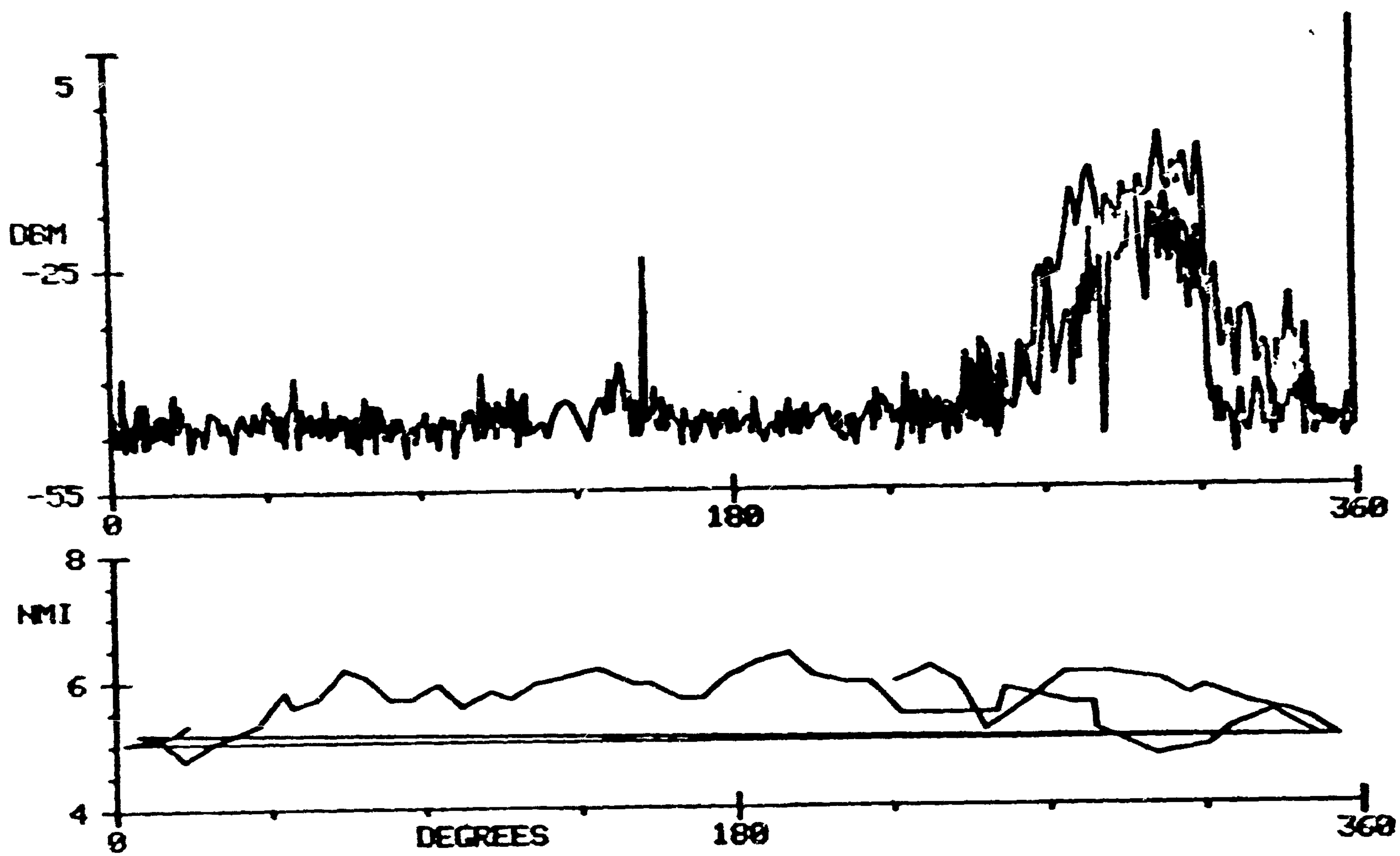
Type III Antenna With Radomes
Antenna Type FA-8021

FIGURE I 7



Type III Antenna In The Null
Reference Configuration

FIGURE I 8



GLIDE SLOPE AT ATLANTIC CITY, NEW JERSEY

FREQUENCY 3.31400E+08 MHZ
SPECTRUM ANALYZER HZ/DIV= 50000 HZ GAIN=10DB/DIV
FLIGHT NO. 1 ALTITUDE=4500 FEET
MAX PTS. IN PLOT= 736 START OF 21, END OF 225 DEGREES

FIGURE H 2

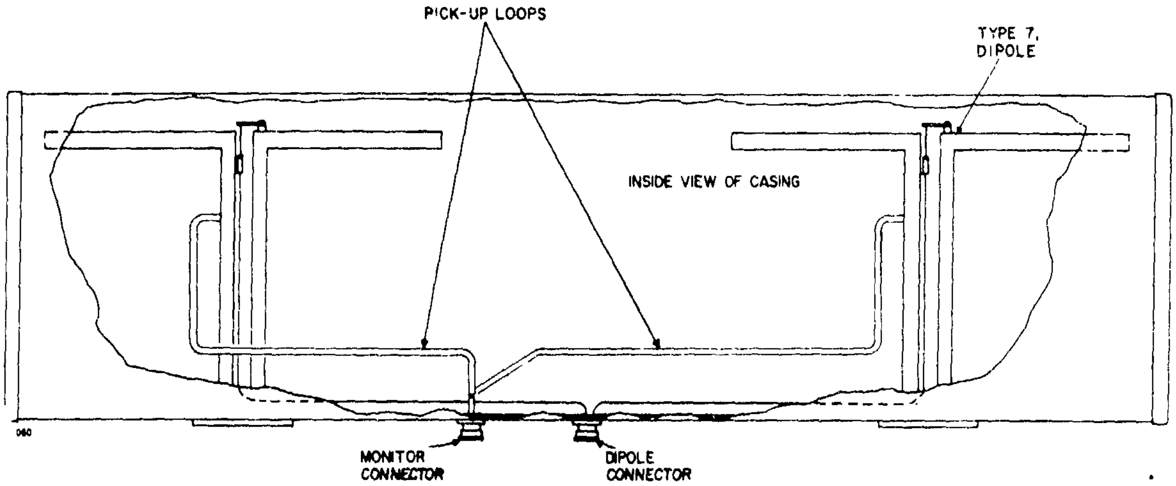


FIGURE I 10
Inside View Of The Casing For The
AIL Type 55 Glide Slope Antenna Element

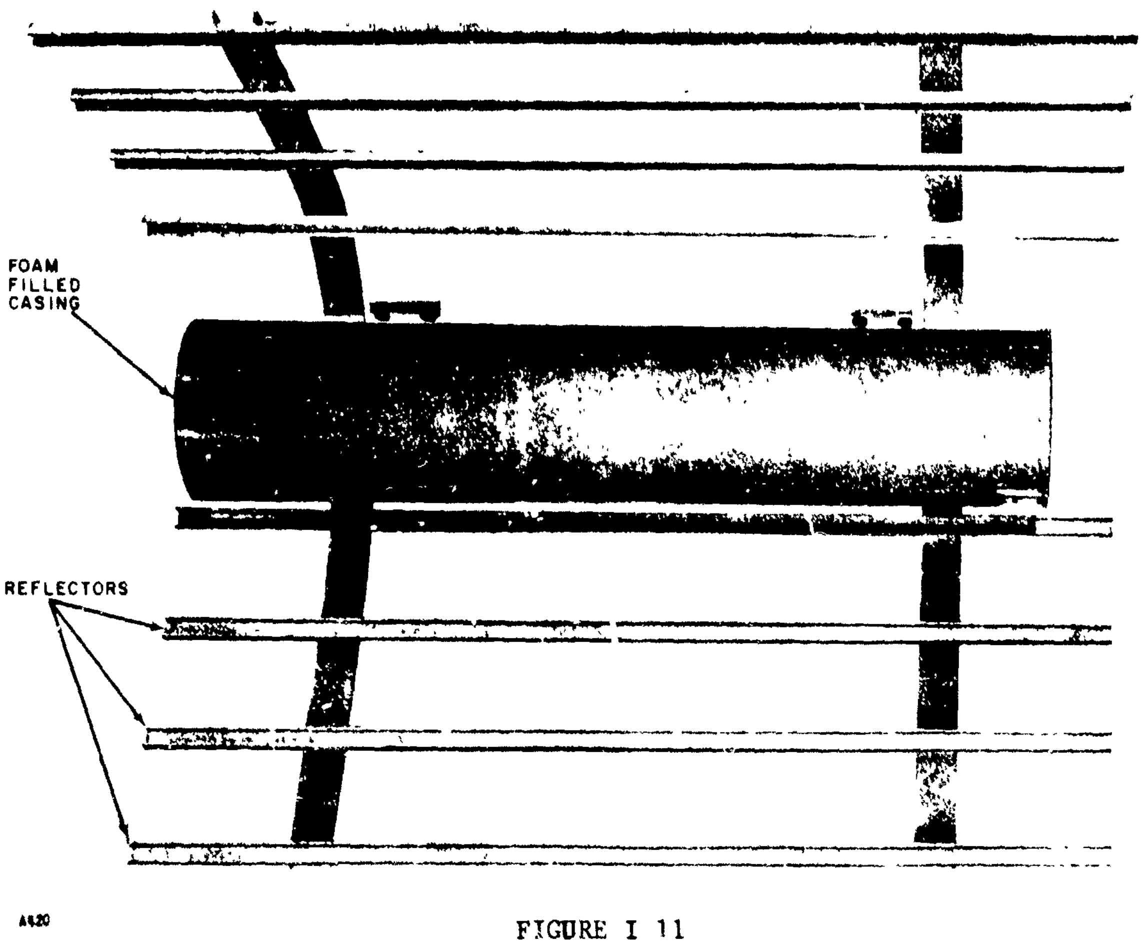
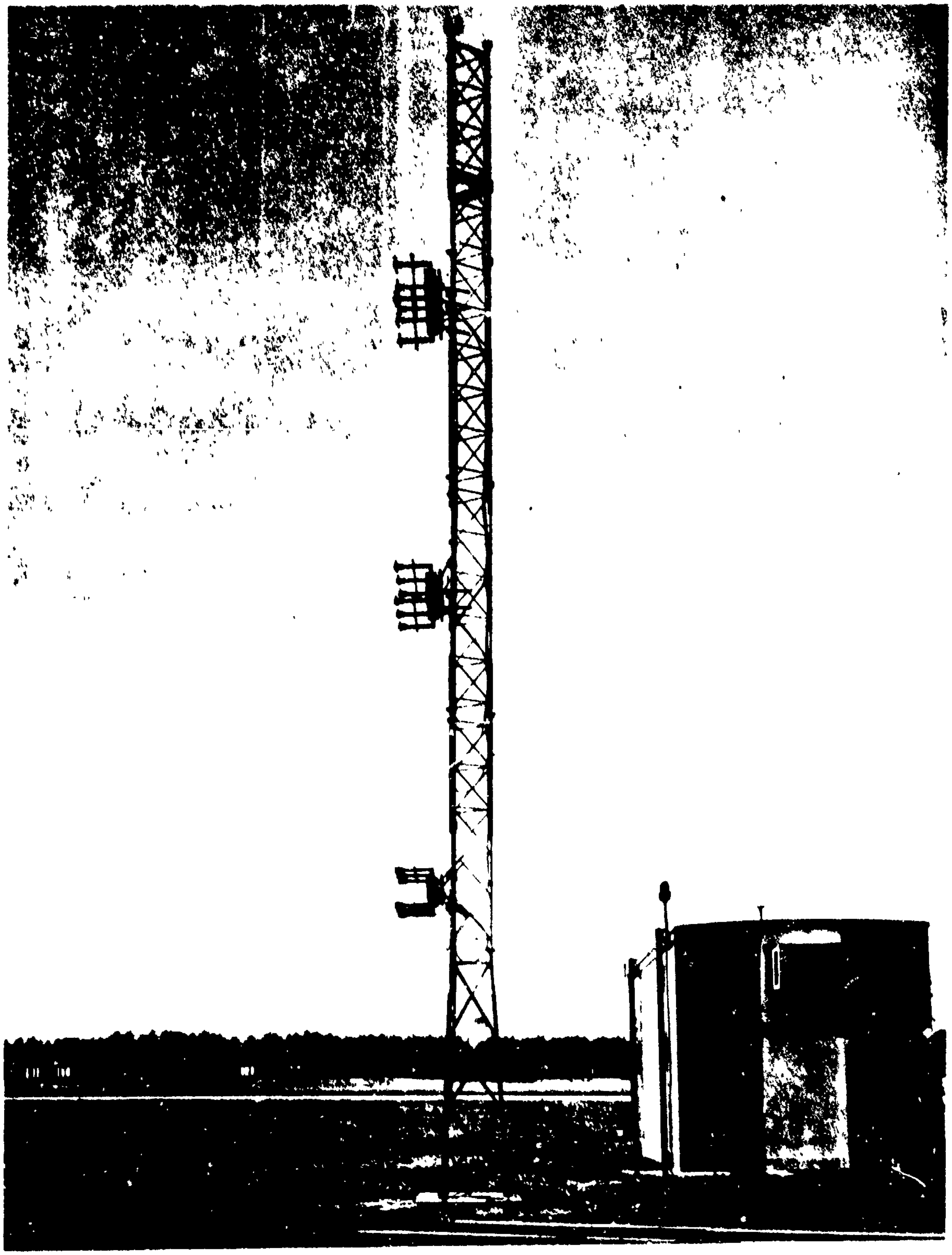


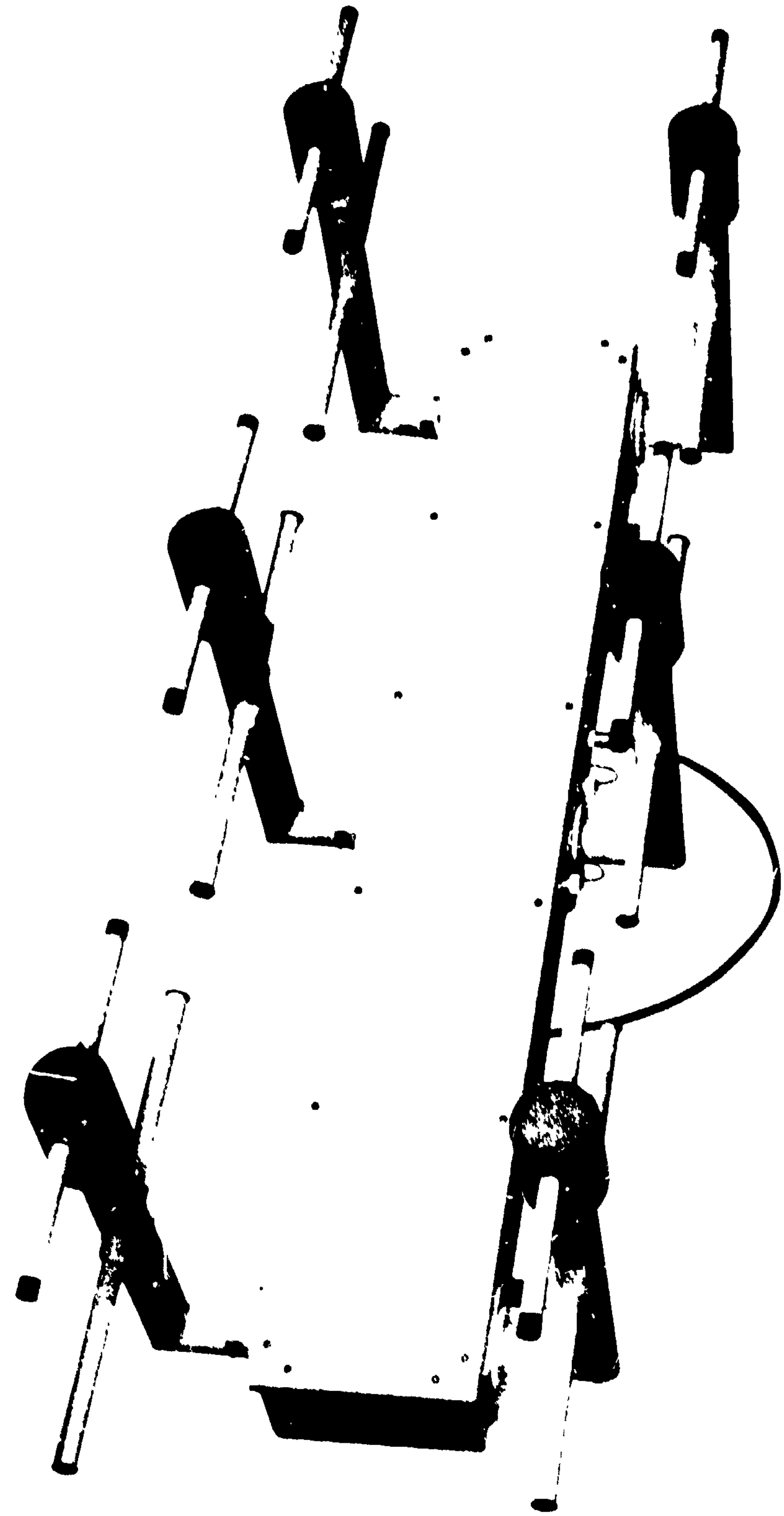
FIGURE I 11

AIL Type 55 Glide Slope Antenna Element



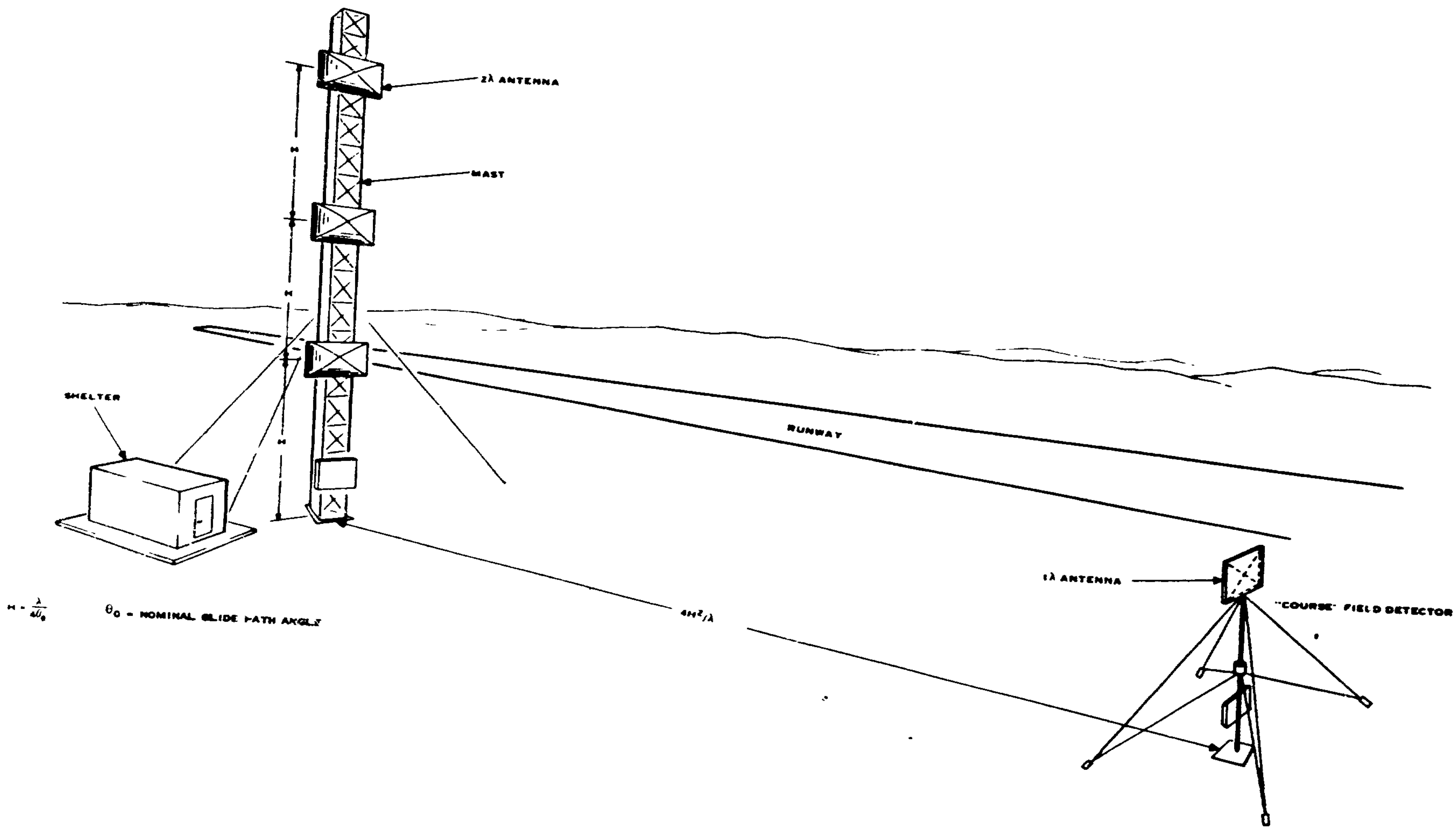
Stan 38 Glide Slope Elements In The
Capture Effect Configuration

FIGURE 1 12



Stan 37 Glide Slope Element

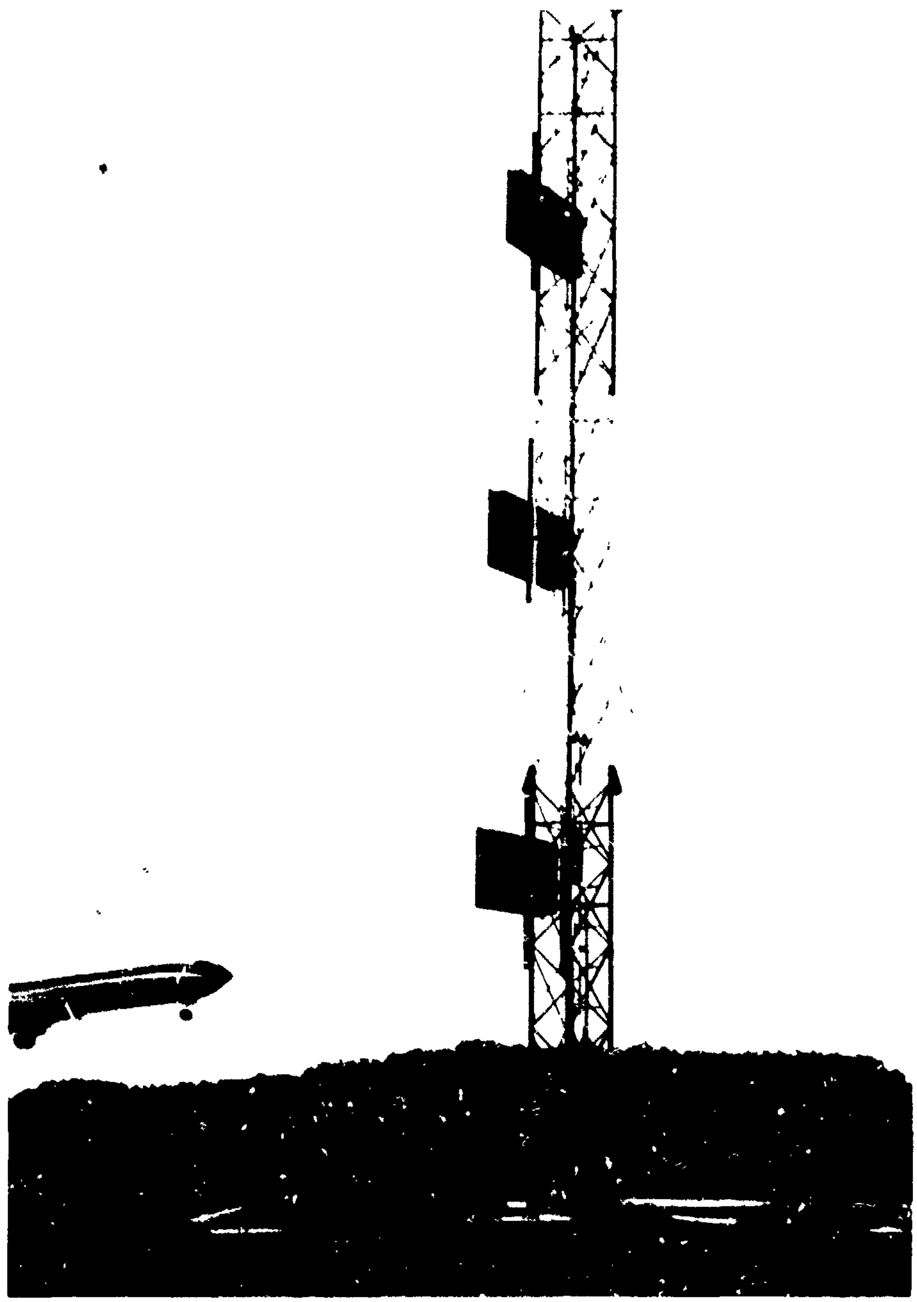
FIGURE 1 13



Two-Lambda Antenna

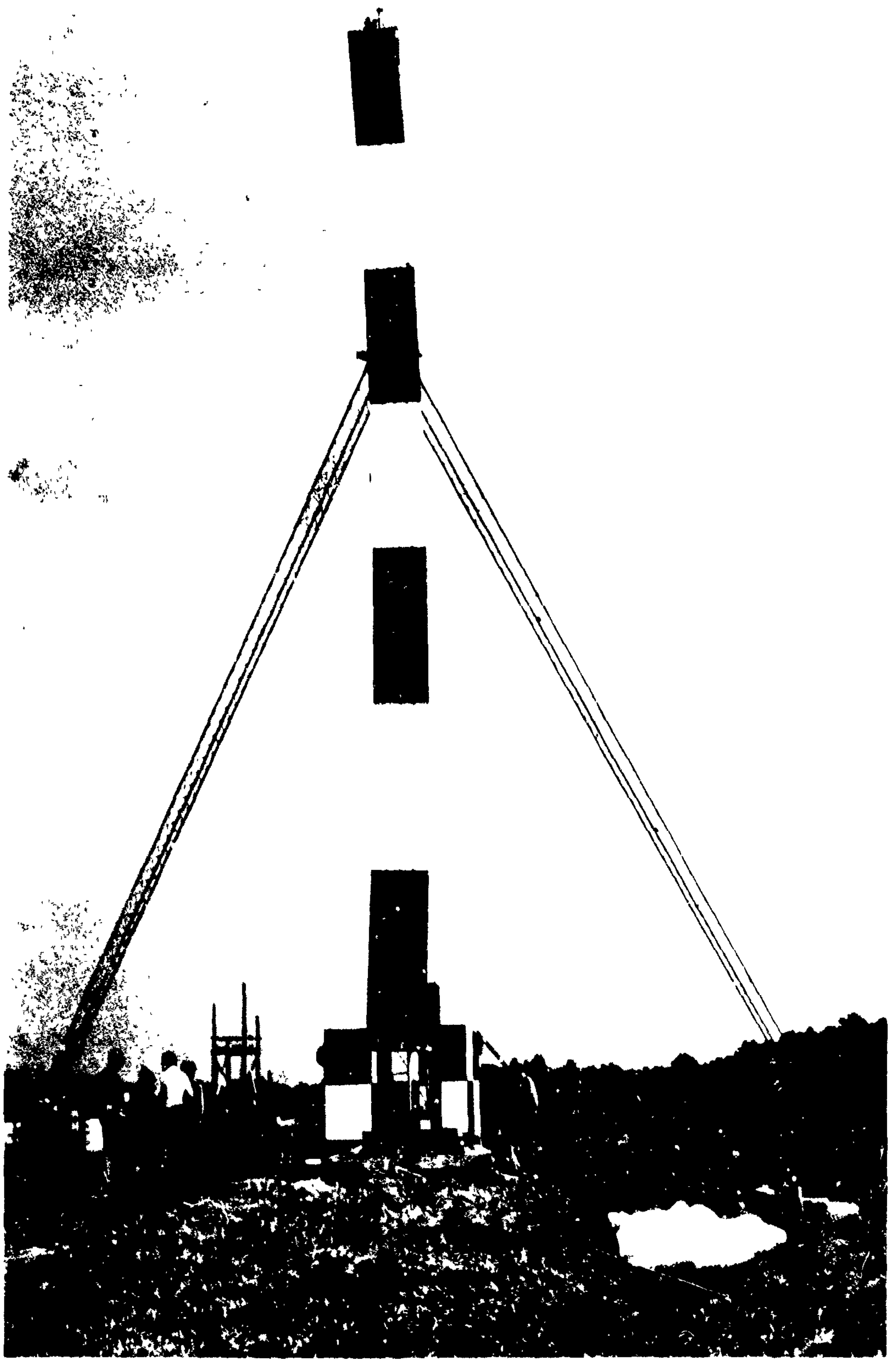
Capture Effect M-Array Glide Slope, General View

FIGURE I 14



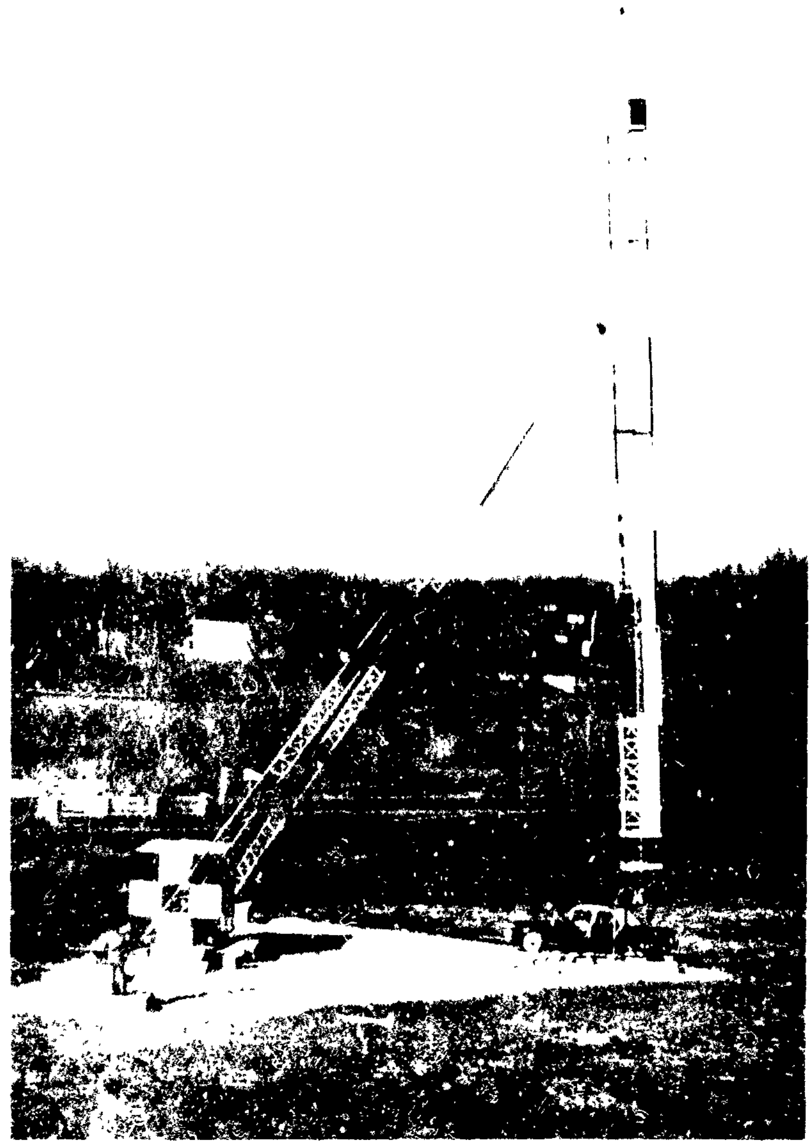
Two Lambda Cassegrainian Glide Slope Antenna
Capture Effect [illegible]

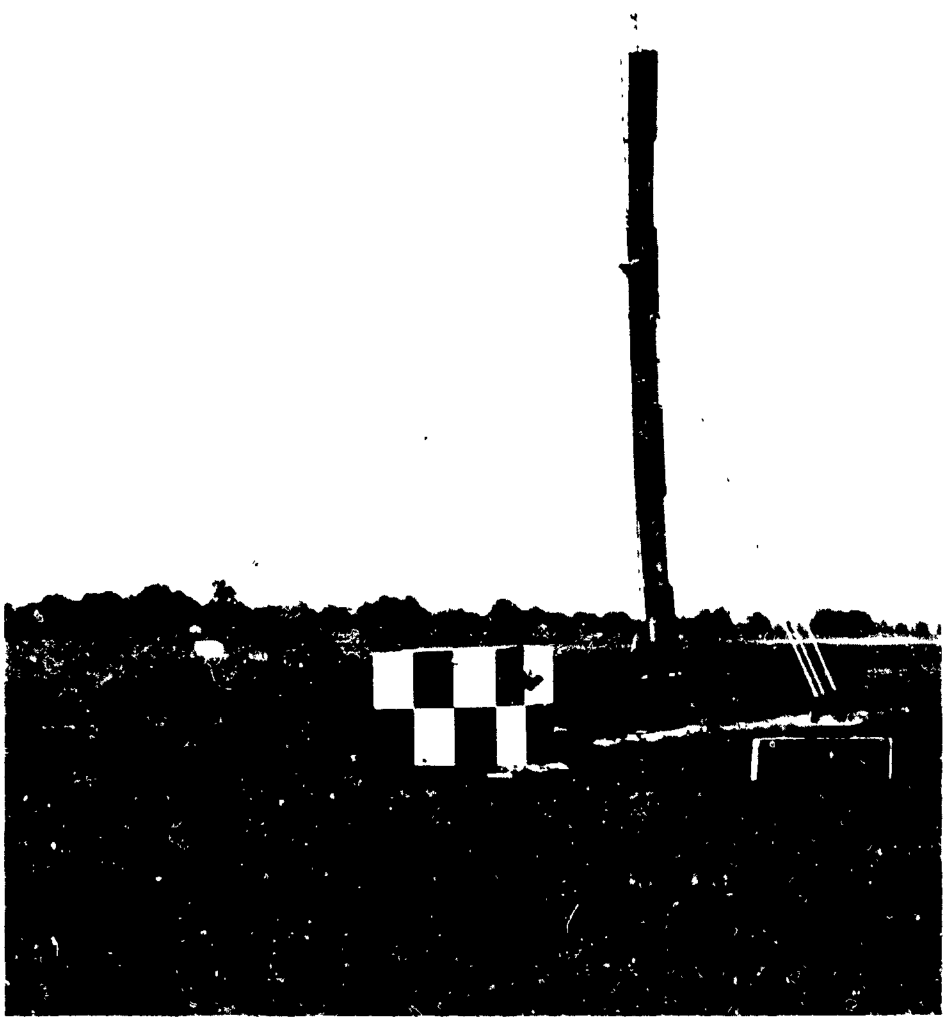
FIGURE [illegible]



Waveguide Antenna, Front View

FIGURE I-16





Reference antenna, West View

FIGURE 1-18

ENGLISH/METRIC CONVERSION FACTORS

LENGTH

From \ To	cm	m	km	in	ft	mi	nmi
cm	1	0.01	1×10^{-5}	0.3937	0.0328	6.21×10^{-6}	5.39×10^{-6}
m	100	1	0.001	39.37	3.281	0.0006	0.0005
km	100,000	1000	1	39370	3281	0.6214	0.5395
in	2.540	0.0254	2.54×10^{-5}	1	0.0833	1.58×10^{-5}	1.37×10^{-5}
ft	30.48	0.3048	3.05×10^{-4}	12	1	1.89×10^{-4}	1.64×10^{-4}
mi	160,900	1609	1.609	63360	5280	1	0.8688
nmi	185,200	1852	1.852	72930	6076	1.151	1

AREA

From \ To	cm^2	m^2	km^2	in^2	ft^2	mi^2	nmi^2
cm^2	1	0.0001	1×10^{-10}	0.1550	0.0011	3.86×10^{-11}	5.11×10^{-11}
m^2	10,000	1	1×10^{-6}	1550	10.76	3.86×10^{-7}	5.11×10^{-7}
km^2	1×10^{10}	1×10^{6}	1	1.55×10^{9}	1.08×10^{7}	0.3861	0.2914
in^2	6.452	0.0006	6.45×10^{-10}	1	0.0069	2.49×10^{-10}	1.88×10^{-10}
ft^2	929.0	0.0929	9.29×10^{-8}	144	1	3.59×10^{-8}	2.71×10^{-8}
mi^2	2.59×10^{10}	2.59×10^{6}	2.590	4.01×10^{9}	2.79×10^{7}	1	0.7548
nmi^2	3.43×10^{10}	3.43×10^{6}	3.432	5.31×10^{9}	3.70×10^{7}	1.325	1

VOLUME

From \ To	cm^3	liter	m^3	in^3	ft^3	yd^3	fl. oz	fl. pt.	fl. qt.	gal.
cm^3	1	0.001	1×10^{-6}	0.0610	3.53×10^{-5}	1.31×10^{-6}	0.0338	0.0021	0.0010	0.0002
liter	1000	1	0.001	61.02	0.0353	0.0013	33.81	2.113	1.057	0.2642
m^3	1×10^{6}	1000	1	61,000	35.31	1.308	33,800	2113	1057	264.2
in^3	16.39	0.0163	1.64×10^{-5}	1	0.0006	2.14×10^{-5}	0.5541	0.0346	2113	0.0043
ft^3	28,300	28.32	0.0283	1728	1	0.0370	957.5	59.84	[illegible]	7.481
yd^3	765,000	764.5	0.7646	46700	27	1	25900	1616	807.9	202.0
fl. oz.	29.57	0.2957	2.96×10^{-5}	1.805	0.0010	3.87×10^{-5}	1	0.0625	0.0312	0.0078
fl. pt.	473.2	0.4732	0.0005	28.88	0.0167	0.0006	16	1	0.5000	0.1250
fl. qt.	946.4	0.9463	0.0009	57.75	0.0334	0.0012	32	2	1	0.2500
gal.	3785	3.785	0.0038	231.0	0.1337	0.0050	128	8	4	1

MASS

From \ To	g	kg	oz	lb	ton
g	1	0.001	0.0353	0.0022	1.10×10^{-6}
kg	1000	1	35.27	2.205	0.0011
oz	28.35	0.0283	1	0.0625	3.12×10^{-5}
lb	453.6	0.4536	16	1	0.0005
ton	907,000	907.2	32,000	2000	1

TEMPERATURE

$°C = 5/9\ (°F - 32)$

$°F = 9/5\ (°C)$ [illegible]