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**INTERIM DEVELOPMENT REPORT
FOR
DEVELOPMENT OF A HIGH FREQUENCY
STEERABLE ANTENNA.**

**This report covers the period
1 March 1954 to 31 March 1954**

**ENGINEERING EXPERIMENT STATION
THE UNIVERSITY OF TENNESSEE
KNOXVILLE, TENNESSEE**

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Navy Department

Bureau of Ships

Electronics Divisions

Contract No. NObsr-57448

Index No. NE-091035 ST7

10 April 1954

Copy No. 10

ABSTRACT

This report covers work done on Contract No. Nobsr-57448, Index No. NE-091035 ST7, at The University of Tennessee during the month of March 1954.

The following was accomplished:

1. A vertically stacked end-fire array of rhombic antennas has been partially investigated as an additional method of obtaining vertical steering. Horizontal patterns of a simple vertically stacked array of rhombic antennas are being calculated.
2. Radiation patterns of the circular traveling wave antenna have been measured over a wide range of frequencies.
3. The vertical radiation pattern for the vertical half-rhombic antenna, over an imperfect earth, has been calculated for 10° increments.

PART I.

Purpose

This project involves the development of a high frequency steerable antenna having the following characteristics:

1. It shall be operable throughout the frequency range of 4 to 32 megacycles per second.
2. It shall be capable of four, or more, simultaneous transmissions on different frequencies, and at different azimuth and elevation angles.
3. For each transmission, it shall be capable of being directed to any azimuth angle and to any elevation angle between the horizon and 30° above the horizon.

The communication system shall provide reliable 24-hour day-to-day communication with a 20-decibel signal-to-noise ratio. The ranges to be covered are from approximately 500 nautical miles to 4000 nautical miles.

The development consists of two phases:

Phase I. Theoretical and experimental studies.

Phase II. Development of design criteria.

General Factual Data

Personnel:

F. V. Schultz	Project Director	98	Man-hours
W. E. Lear	Associate Professor	40	Man-hours
W. O. Leffell	Assistant Professor	4	Man-hours
W. J. Bergman	Junior Engineer	184	Man-hours
H. P. Neff	Junior Engineer	184	Man-hours
Lillian W. Conner	Secretary	45-1/2	Man-hours
L. Phillips	Technician	24	Man-hours
F. Collins	Draftsman	9-1/2	Man-hours
K. Bell	Student Computer	10-1/2	Man-hours
G. Craig	Student Computer	6-1/2	Man-hours
D. Guhne	Student Computer	3	Man-hours
H. Knox	Student Computer	109	Man-hours
G. Rolfe	Student Computer	85	Man-hours
J. Roote	Student Computer	23-1/2	Man-hours
D. C. Rupley	Student Computer	4	Man-hours
G. C. Watkins	Student Computer	33	Man-hours
L. Zollinger	Student Computer	76-1/2	Man-hours

References

- Bruce, E., Beck, A. C. and Lowry, L. R., "Horizontal Rhombic Antennas," Bell System Technical Journal, Vol. 14, pp. 135-138, January 1935.
- Foster, Donald, "Radiation From Rhombic Antennas," Proceedings IRE, Vol. 25, pp. 1327-1353, October 1937.
- Friis, H. T., and Feldman, C. B., "A Multiple Unit Steerable Antenna for Short-Wave Reception," Bell System Technical Journal, Vol. 16, pp. 337-419, July 1937.
- Harper, A. E., Rhombic Antenna Design, D. Van Nostrand Co., Inc., New York, 1941.
- Jahnke, Eugene and Emde, Fritz, Tables of Functions, Dover Publications, Inc., New York, 1945.
- Kraus, J. D., Antennas, McGraw-Hill Book Co., New York and London, 1950.
- McLachlan, N. W., Bessel Functions For Engineers, Clarendon Press, Oxford, 1934.
- Pickard and Burns, Inc., "Theoretical and Experimental Studies of High Phase Velocity Antennas," Contract No. NObsr-63035, Index No. NE-091035, Subtask Number 4, Phase B, December 1953.
- Relton, F. E., Applied Bessel Functions, Blackie and Son Limited, London and Glasgow, 1946.
- Terman, F. E., Radio Engineers Handbook, McGraw-Hill Book Co., New York and London, 1943.
- Watson, G. N., Theory of Bessel Functions, Cambridge University Press, Cambridge, 1922.

Detail Factual Data

1. In Interim Development Report No. 18 under Contract NObsr-57448 it was shown that an array of vertically stacked rhombics covers nearly all of the range of elevation angles required over a frequency range of four to one. Incomplete coverage is obtained only at lower elevation angles for the lower frequencies (determined from ionospheric studies). An attempt has been made to improve this array with respect to low angle radiation at the lower frequencies. An array of stacked rhombics in an end-fire array is presently being investigated as an additional means of obtaining vertical steering. (It is hoped that this array will cover all of the elevation angles required.)

Typical horizontal patterns for various elevation angles are shown in Figures 1 through 15 for the arrays of stacked rhombics investigated in Interim Development Report No. 18. These patterns are for E_{ϕ} , the perpendicularly, or horizontally polarized component of the electric field, only. At low elevation angles the E_{θ} component of the electric field is rather small and will be neglected temporarily. Horizontal beamwidths are of the order of 20° for these arrays, indicating that 9 or more of these arrays of stacked rhombics would be needed to cover 360° in azimuth if each array were made optionally unidirectional (that is, the termination end and the feed end interchangeable).

2. Radiation patterns of the circular traveling wave antenna model have been measured over a frequency range of 350-1200 Mc. The termination used for these patterns is a high-attenuation open-wire transmission line, constructed of 0.001-inch diameter nichrome wire, with a characteristic impedance designed to be 800 ohms.

The mathematical analysis of the circular traveling-wave antenna is being investigated in an attempt to simplify calculation of the theoretical patterns. The theoretical analysis produces integrals of the form

$$F_y = \int_0^{\pi} \cos \theta e^{-j (Z\theta - a \cos \theta - b \sin \theta)} d\theta$$

The first evaluation of this integral produced a group of terms containing products of Bessel functions and trigonometric functions in infinite summations, with the rapidity of convergence dependent on antenna dimensions, and for this reason, a simpler expression is being sought.

3. The vertical radiation pattern for the vertical half-rhombic antenna, over an imperfect earth, has been calculated for 10° increments. A plot of these values failed to satisfactorily locate the nodes, and additional calculations will be made at intermediate points in order to remedy this.

DEPARTMENT OF ELECTRICAL ENGINEERING - ENGINEERING EXPERIMENT STATION
 THE UNIVERSITY OF TENNESSEE
 PROJECT PERFORMANCE AND SCHEDULE
 Index No. NE-091035 ST7

Contract No. NObsr-57448 Date: 10 April 1954
 Legend: Work Performed
 Schedule of Projected Operation
 Period Covered: 1/3/54 to 31/3/54

Subject	1952					1953					1954										
	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M
1. Development of Field Test Facilities.	[Solid black bar]																				
2. Study of Propagation Problem.	[Solid black bar]																				
a. Paths lying entirely in night region.	[Solid black bar]																				
b. Paths lying entirely in day region.	[Solid black bar]																				
c. Paths lying partly in day and partly in night region.	[Solid black bar]																				
d. Auroral refraction.	[Solid black bar]																				
e. Angles-of-arrival.	[Solid black bar]																				
3. Determination of Suitable Antenna Type or Types.	[Solid black bar]																				
a. Search of literature.	[Solid black bar]																				
b. Theoretical study.	[Solid black bar]																				
4. Detailed Theoretical and Experimental investigation of Most Promising Antenna Types.	[Solid black bar]																				
5. Development of Network System Suitable for Driving Array.	[Solid black bar]																				
6. Experimental Study of Final Array.	[Solid black bar]																				
7. Preparation of Phase Report.	[Solid black bar]																				

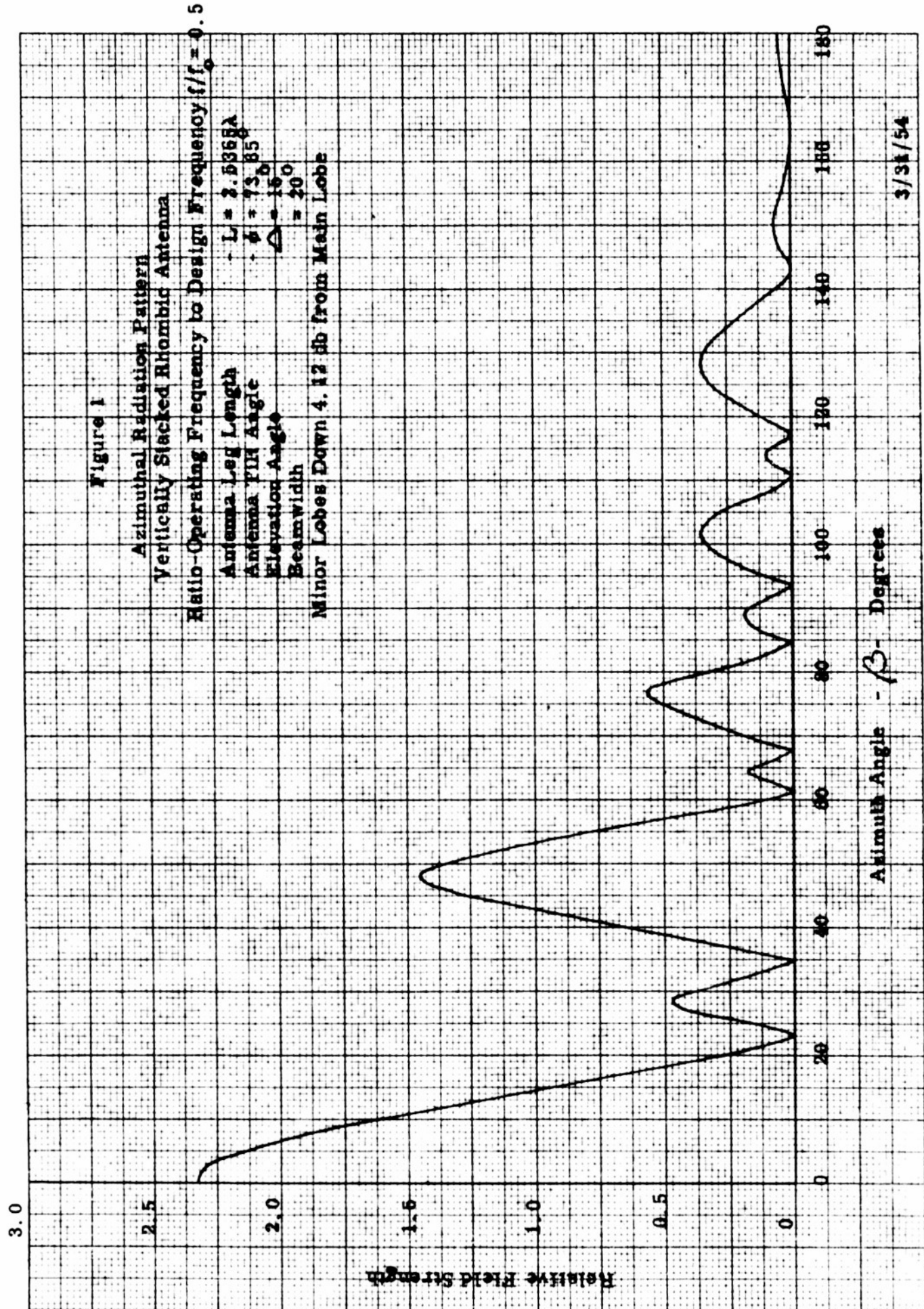
Conclusions

1. The horizontal patterns of a stacked rhombic array show average beamwidths of the order of twenty degrees.

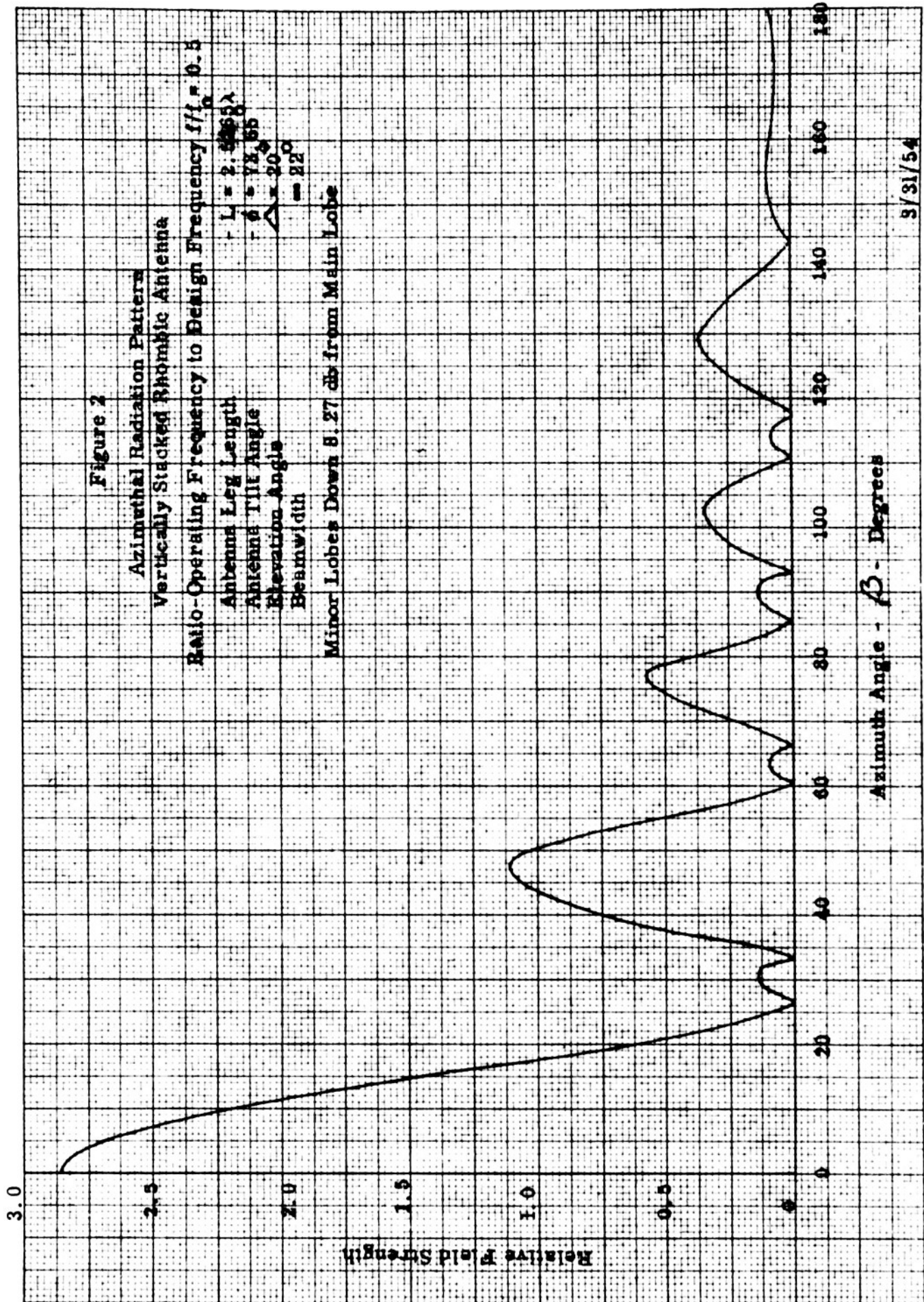
PART II

Program for Next Interval

1. An attempt will be made to improve the elevation angle and frequency coverage of the stacked rhombic array, especially at lower frequencies.
2. The investigation of the theoretical pattern of the circular traveling wave antenna will be continued.
3. Calculation of the vertical radiation pattern of the vertical half-rhombic antenna, over an imperfect earth, will be continued.



HUFFEL & ESSER CO., N. Y. NO. 300-11
 10 x 10 to the 1/2 inch 5th lines centered
 Engraving 7 x 10 in
 MADE IN U.S.A.



9/31/54

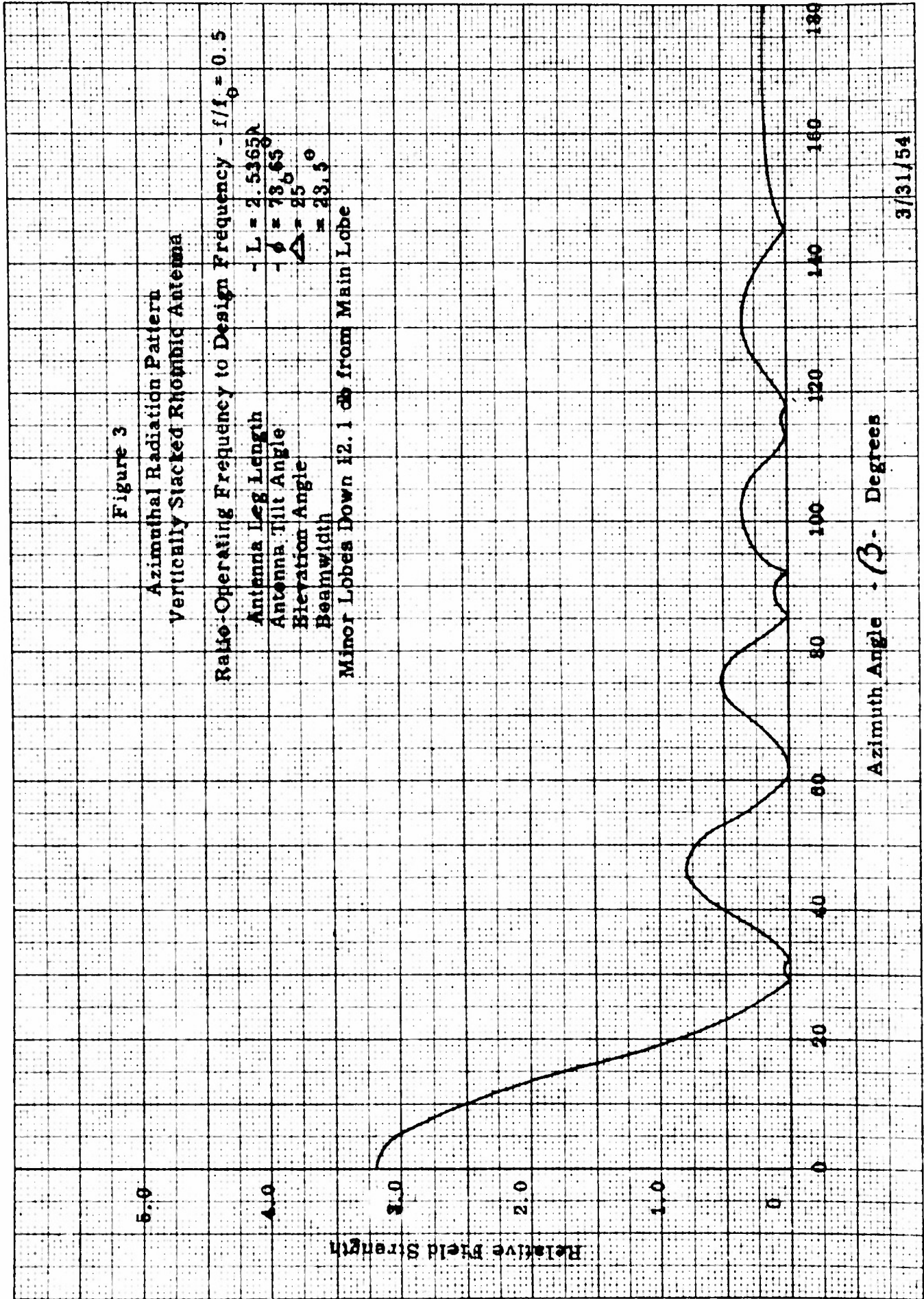


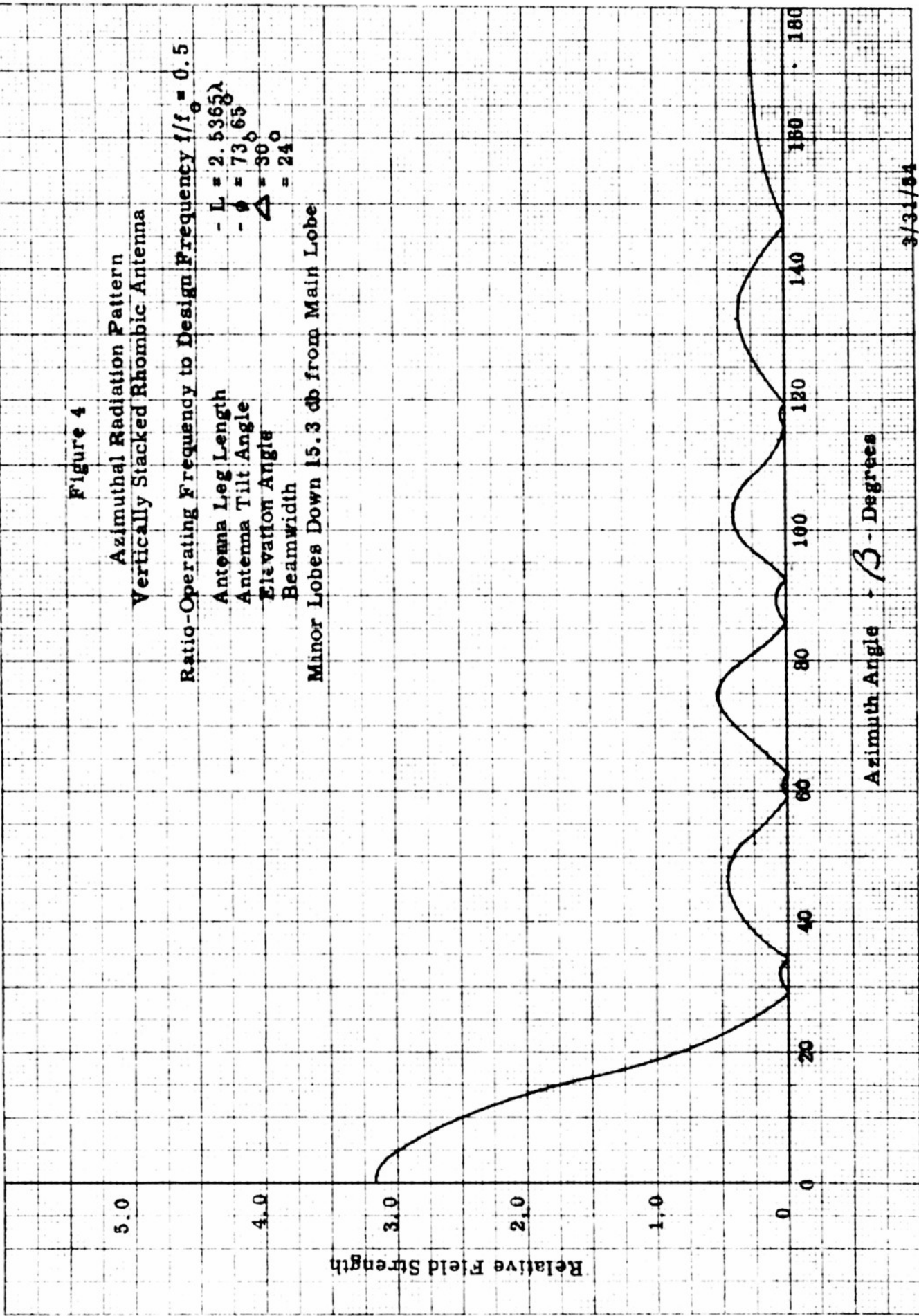
Figure 4

**Azimuthal Radiation Pattern
 Vertically Stacked Rhombic Antenna**

Ratio-Operating Frequency to Design Frequency $f/f_0 = 0.5$

- L = 2.5365λ
- φ = 73.65°
- Δ = 30°
- = 24°

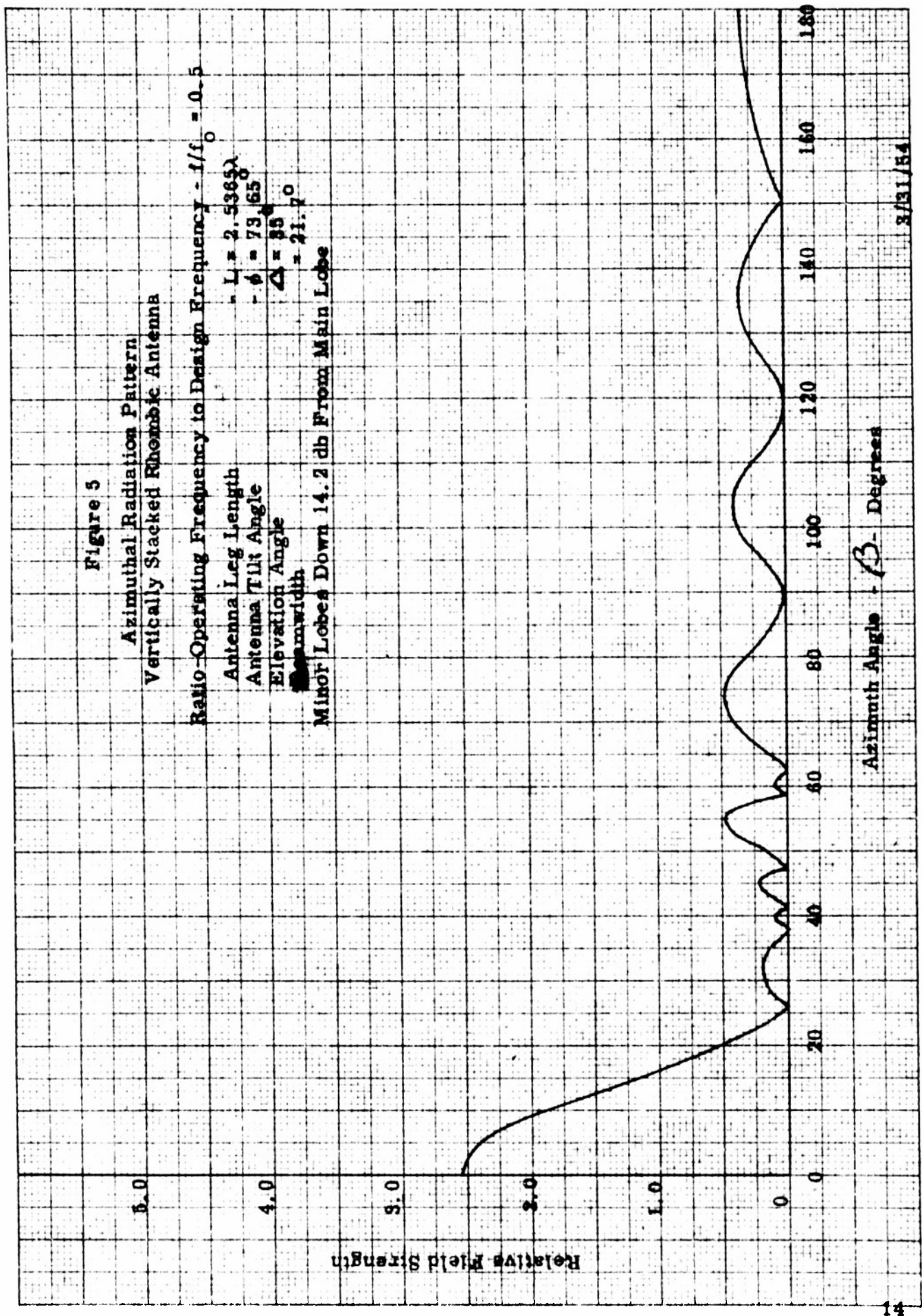
Minor Lobes Down 15.3 db from Main Lobe



3/31/54

Figure 5
Azimuthal Radiation Pattern
Vertically Stacked Rhombic Antenna

Ratio Operating Frequency to Design Frequency - $f/f_0 = 0.5$
 Antenna Leg Length - $L = 2.5365\lambda$
 Antenna Tilt Angle - $\phi = 73.65^\circ$
 Elevation Angle - $\Delta = 35^\circ$
 Beamwidth - $= 21.7^\circ$
 Minor Lobes Down 14.2 db From Main Lobe



Azimuth Angle - β - Degrees

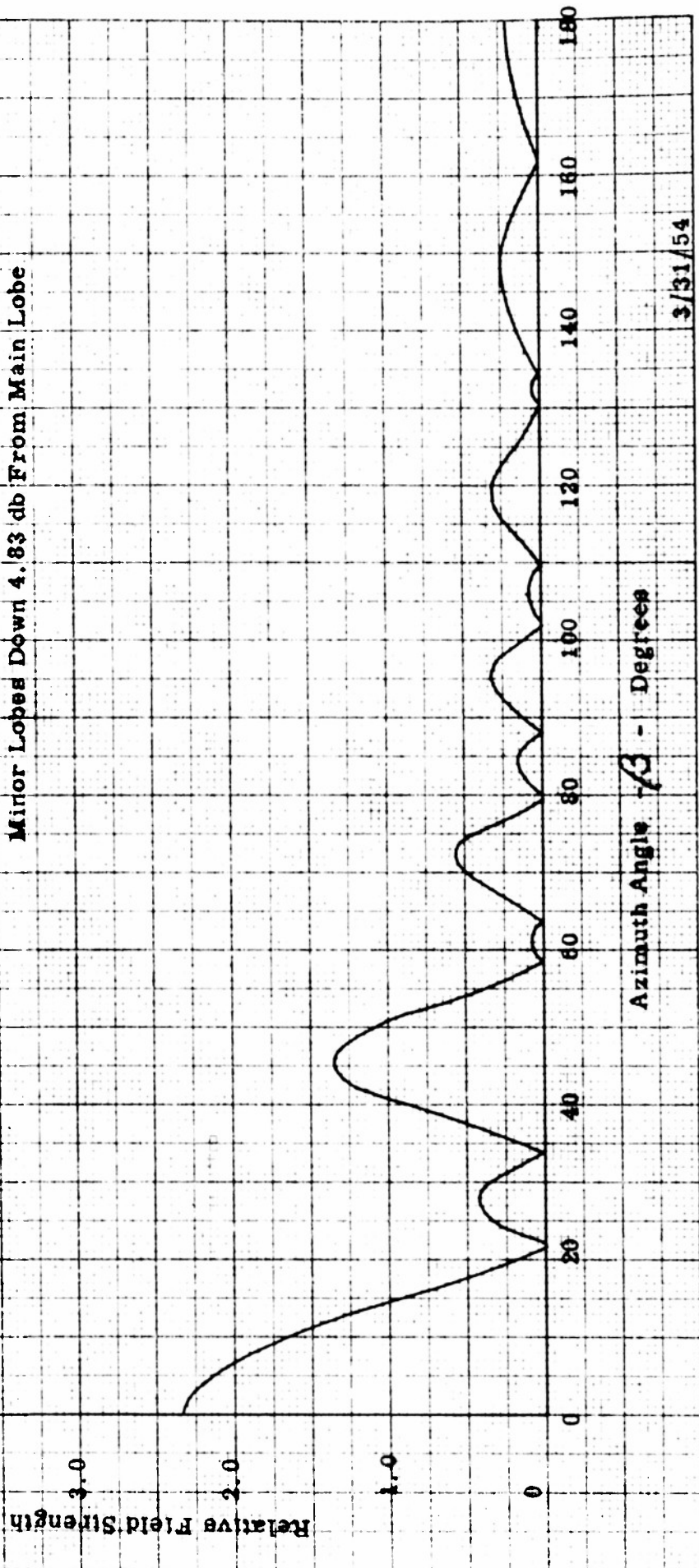
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Figure 6

**Azimuthal Radiation Pattern
 Vertically Stacked Rhombic Antennas**

Ratio-Operating Frequency to Design Frequency - $r/f = 1/2$
 Antenna Leg Length - $L_0 = 277\lambda$
 Antenna Tilt Angle - $\theta = 15^\circ$
 Elevation Angle - $\Delta = 15^\circ$
 Beamwidth - $= 19.4^\circ$

Minor Lobes Down 4.83 db From Main Lobe



Azimuth Angle β - Degrees

3/31/54

Figure 7

Azimuthal Radiation Pattern

Vertically Stacked Rhombic Antenna

Ratio-Operating Frequency to Design Frequency - $f/f_0 = 1/2$

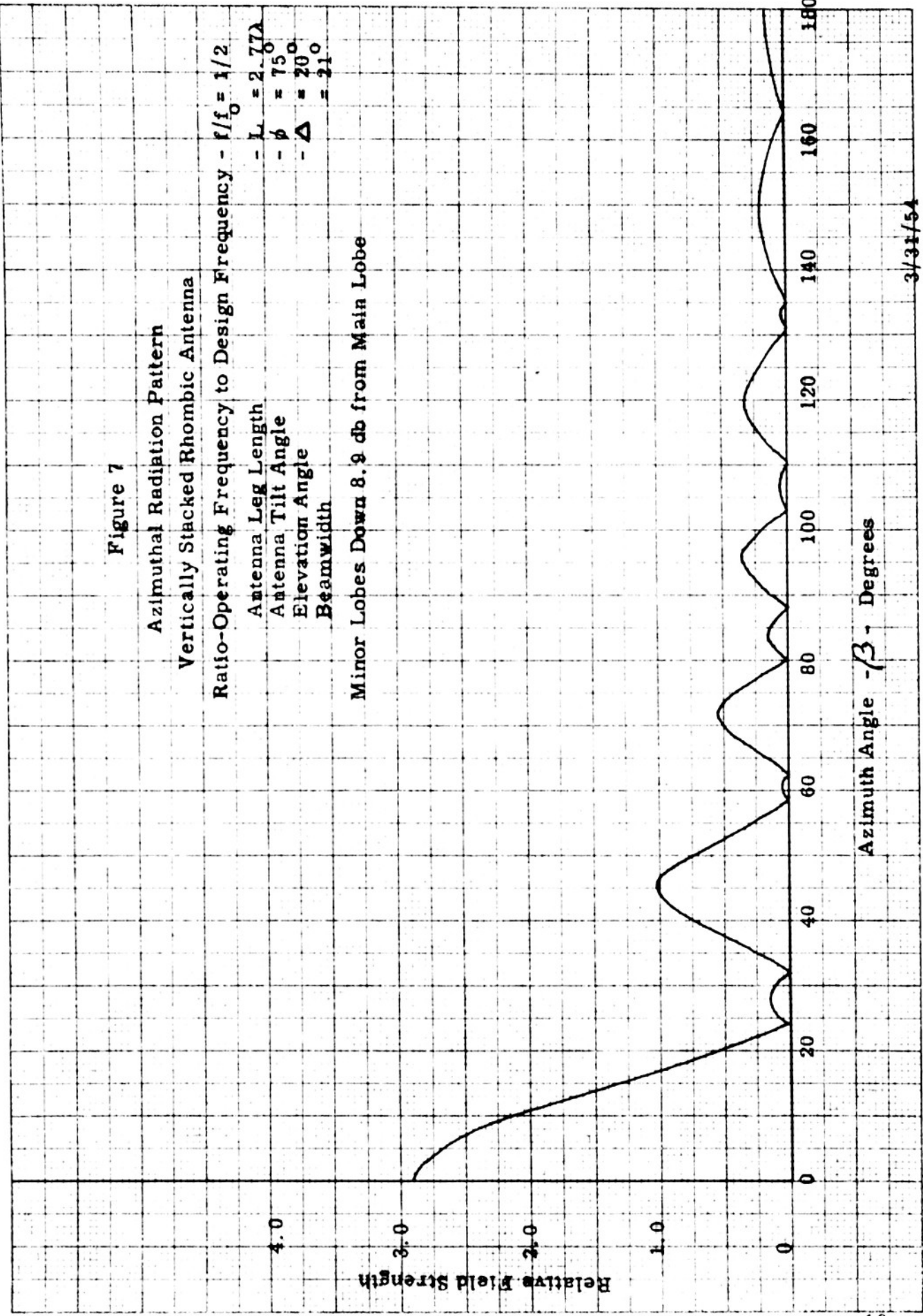
- $L = 2.77\lambda$

- $\phi = 75^\circ$

- $\Delta = 20^\circ$

- $\beta = 21^\circ$

Minor Lobes Down 8.9 db from Main Lobe



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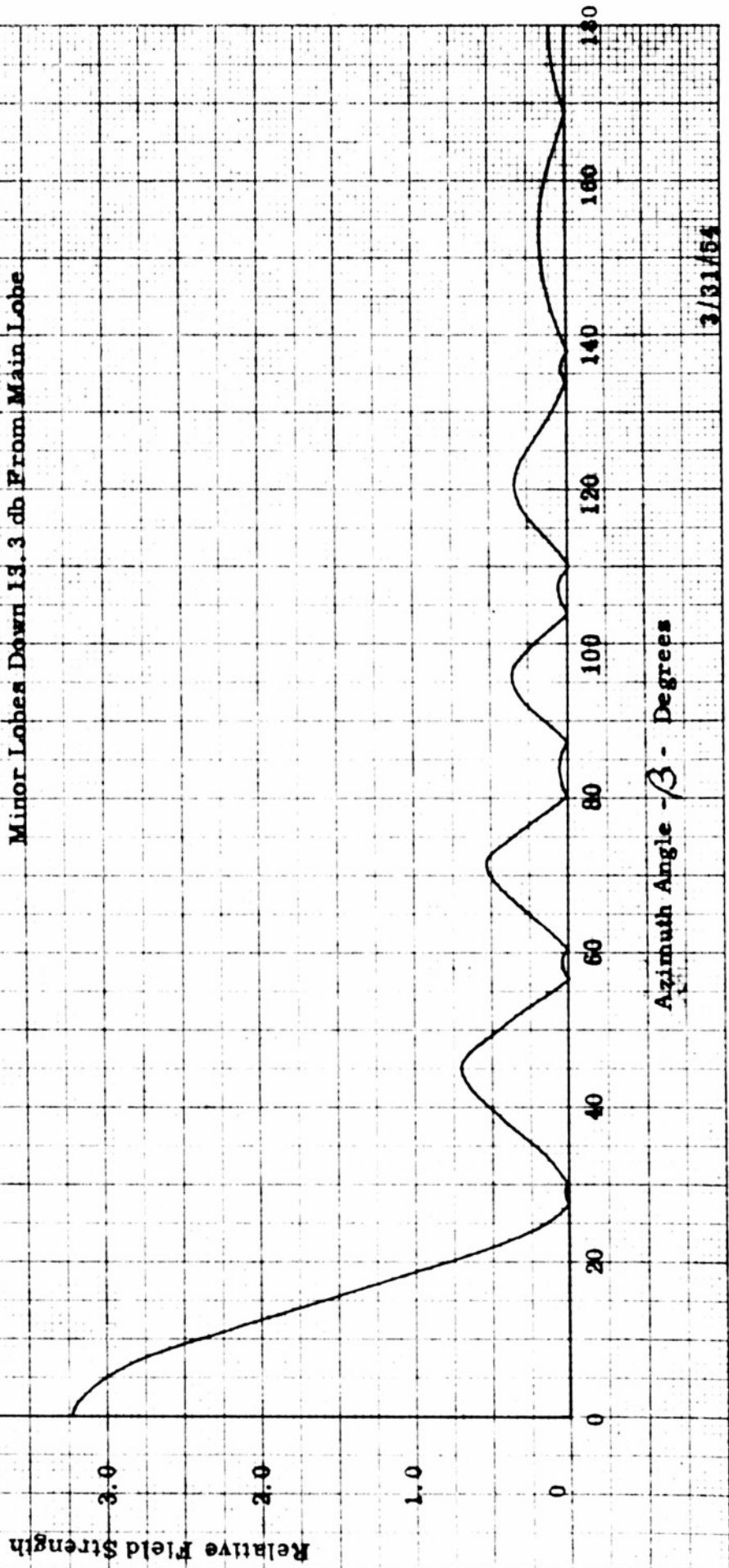
Figure 8

**Azimuthal Radiation Pattern
Vertically Stacked Rhombic Antenna**

Ratio-Operating Frequency to Design Frequency - $f/f_0 = 1/2$

- L = 2.77λ
- $\phi = 75^\circ$
- Elevation Angle = 25°
- Beamwidth = 21°

Minor Lobes Down 13.3 db From Main Lobe



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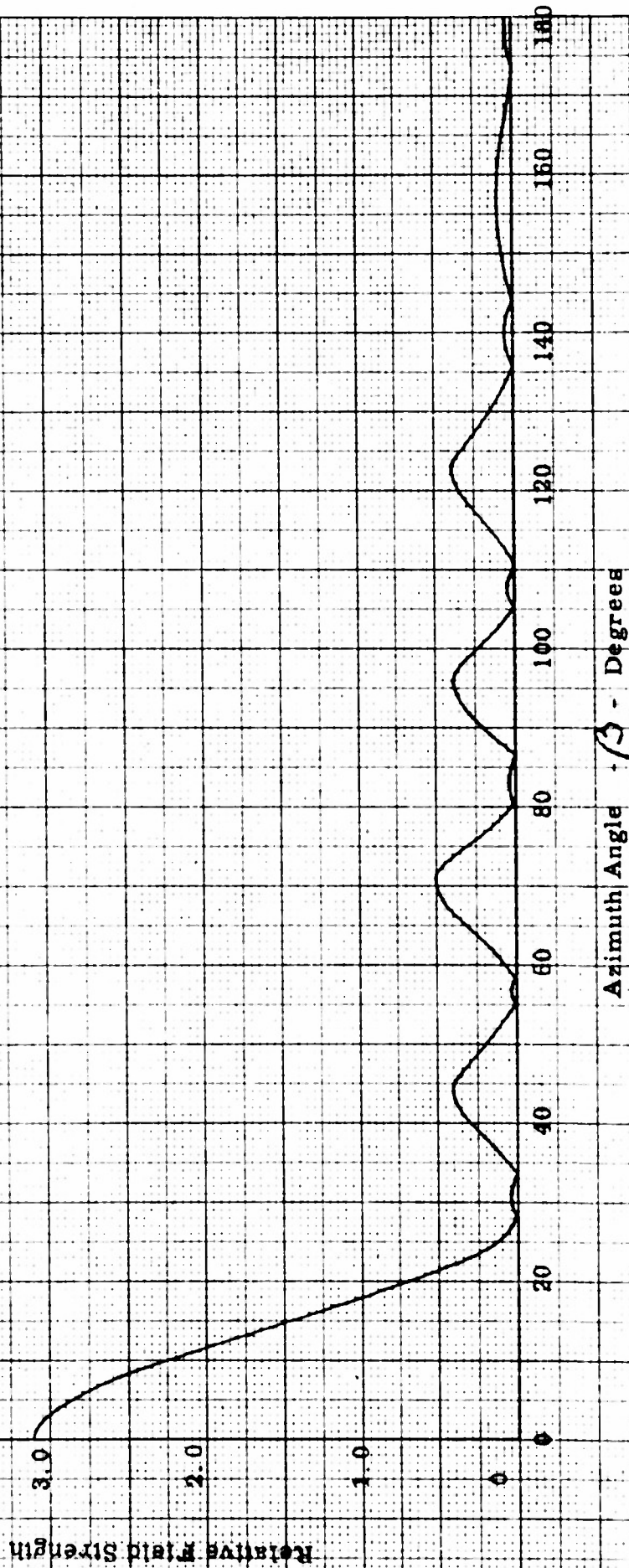
Figure 9

Azimuthal Radiation Pattern
Vertically Stacked Rhombic Antenna

Ratio-Operating Frequency to Design Frequency - $f/f_0 = 1/2$

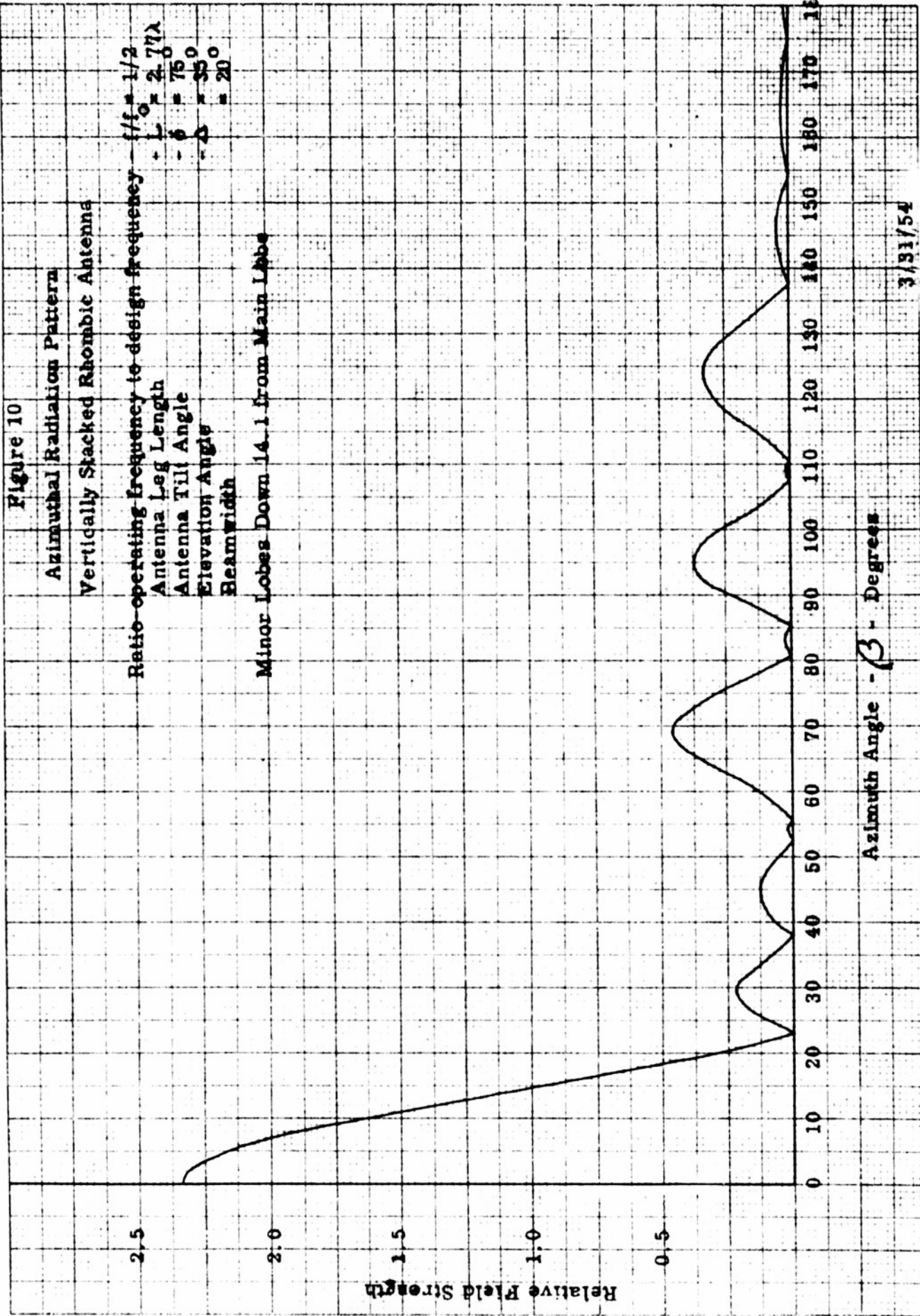
- Antenna Leg Length - $L = 2.77\lambda$
- Antenna Tilt Angle - $\phi = 75^\circ$
- Elevation Angle - $\alpha = 30^\circ$
- Beamwidth - $= 19.5^\circ$

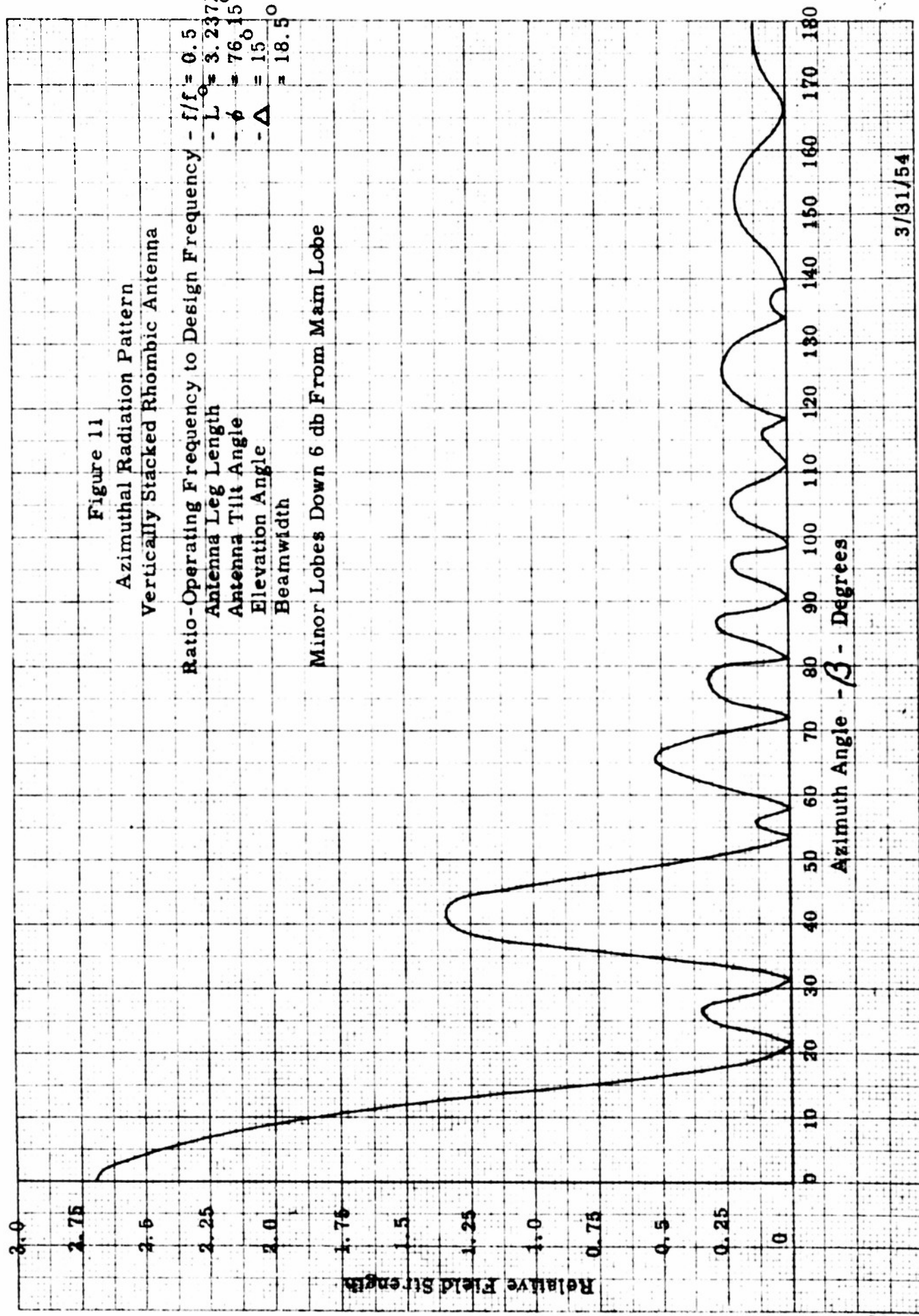
Minor Lobes Down 15.7 db from Main Lobe



Azimuth Angle - Degrees

3/31/54





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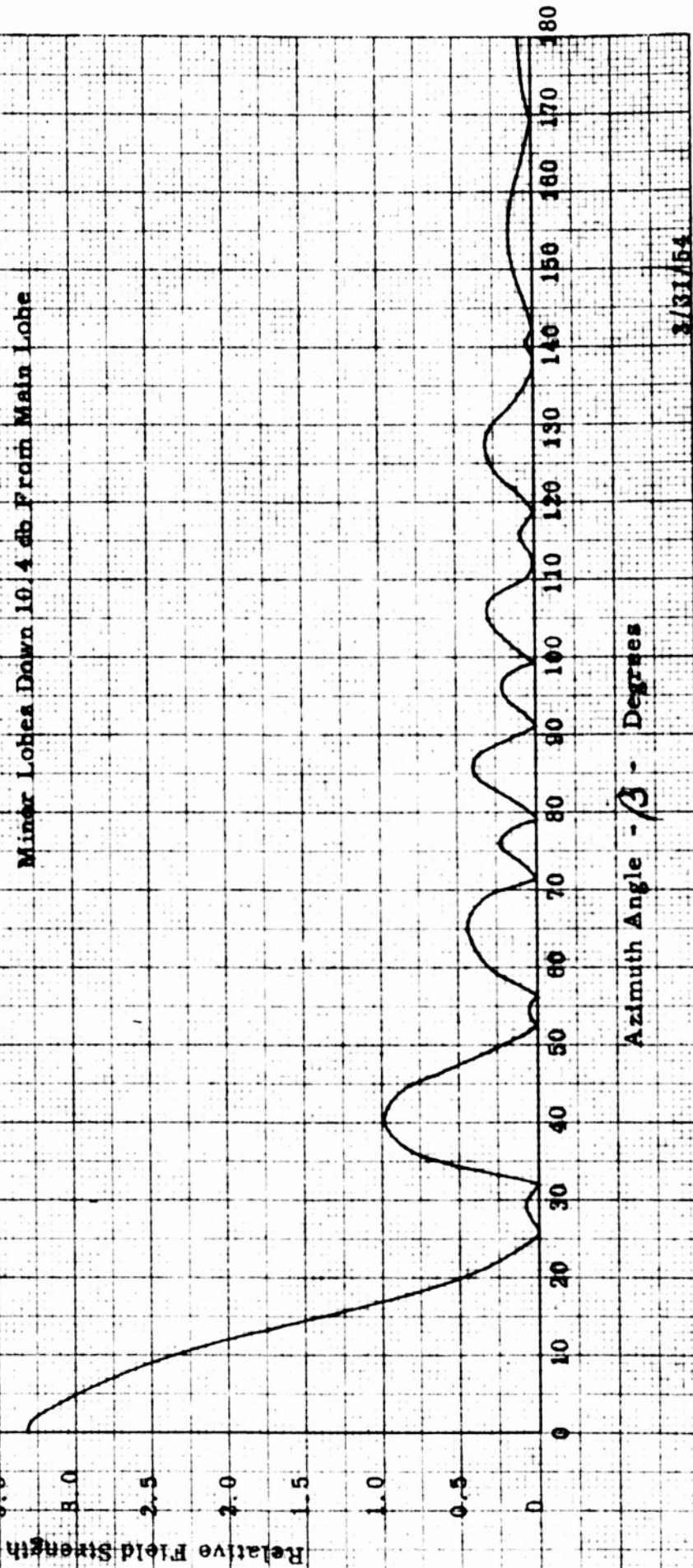
Figure 12

**Azimuthal Radiation Pattern
 Vertically Stacked Rhombic Antenna**

Ratio-Operating Frequency to Design Frequency - $f/f_0 = 0.5$

- L = 3.237λ
- $\alpha = 76.15^\circ$
- $\beta = 20^\circ$
- $\gamma = 29^\circ$

Minor Lobes Down 10.4 db From Main Lobe



Azimuth Angle - β - Degrees

3/31/54

Figure 13

Azimuthal Radiation Pattern
Vertically Stacked Rhombic Antenna

Ratio-Operating Frequency to Design Frequency $f/f_0 = 0.5$

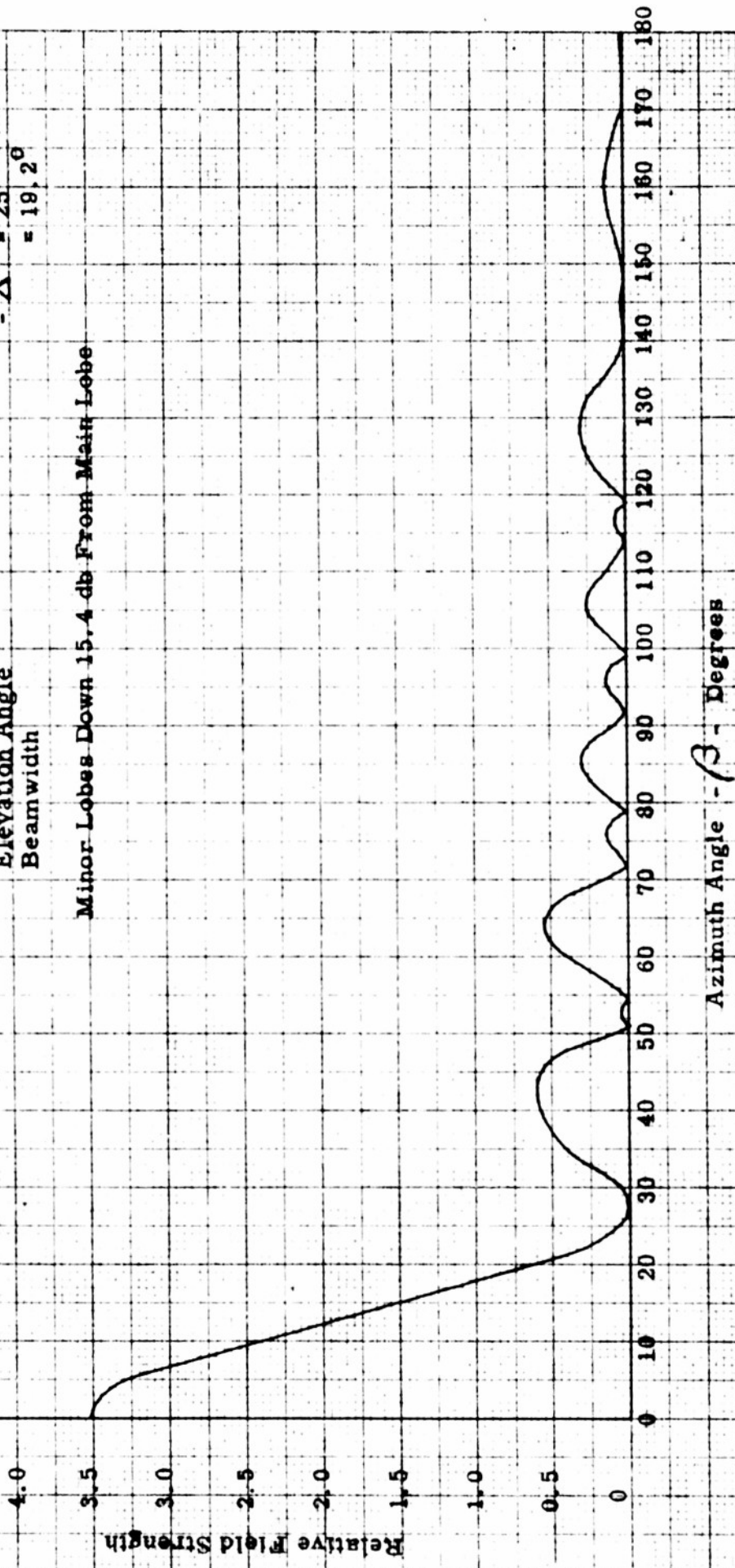
Antenna Leg Length $= 3.237\lambda$

Antenna Tilt Angle $= 76.15^\circ$

Elevation Angle $= 25^\circ$

Beamwidth $= 19.2^\circ$

Minor Lobes Down 15.4 db From Main Lobe

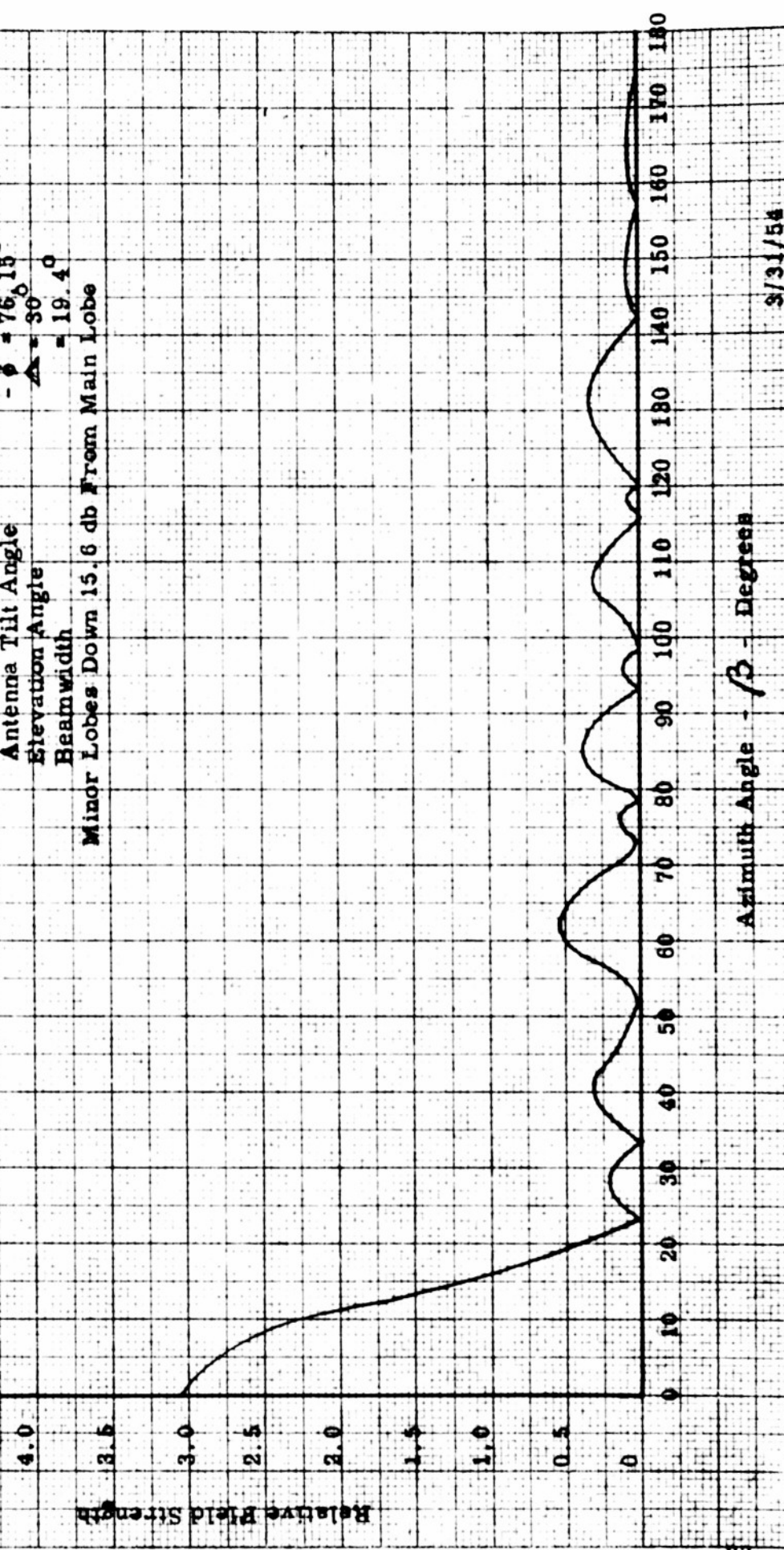


Azimuth Angle - β - Degrees

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Figure 14
Azimuthal Radiation Pattern
Vertically Stacked Rhombic Antenna

Ratio-Operating Frequency to Design Frequency $f/f_0 = 0.5$
Antenna Leg Length $- L = 3.237\lambda$
Antenna Tilt Angle $- \phi = 76.15^\circ$
Elevation Angle $\Delta = 30^\circ$
Beamwidth $= 19.4^\circ$
Minor Lobes Down 15.6 db From Main Lobe



Azimuth Angle - β - Degrees

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Figure 15

**Aximuthal Radiation Pattern
Vertically Stacked Rhombic Antenna**

Ratio-Operating Frequency to Design Frequency - $f/f_0 = 0.5$

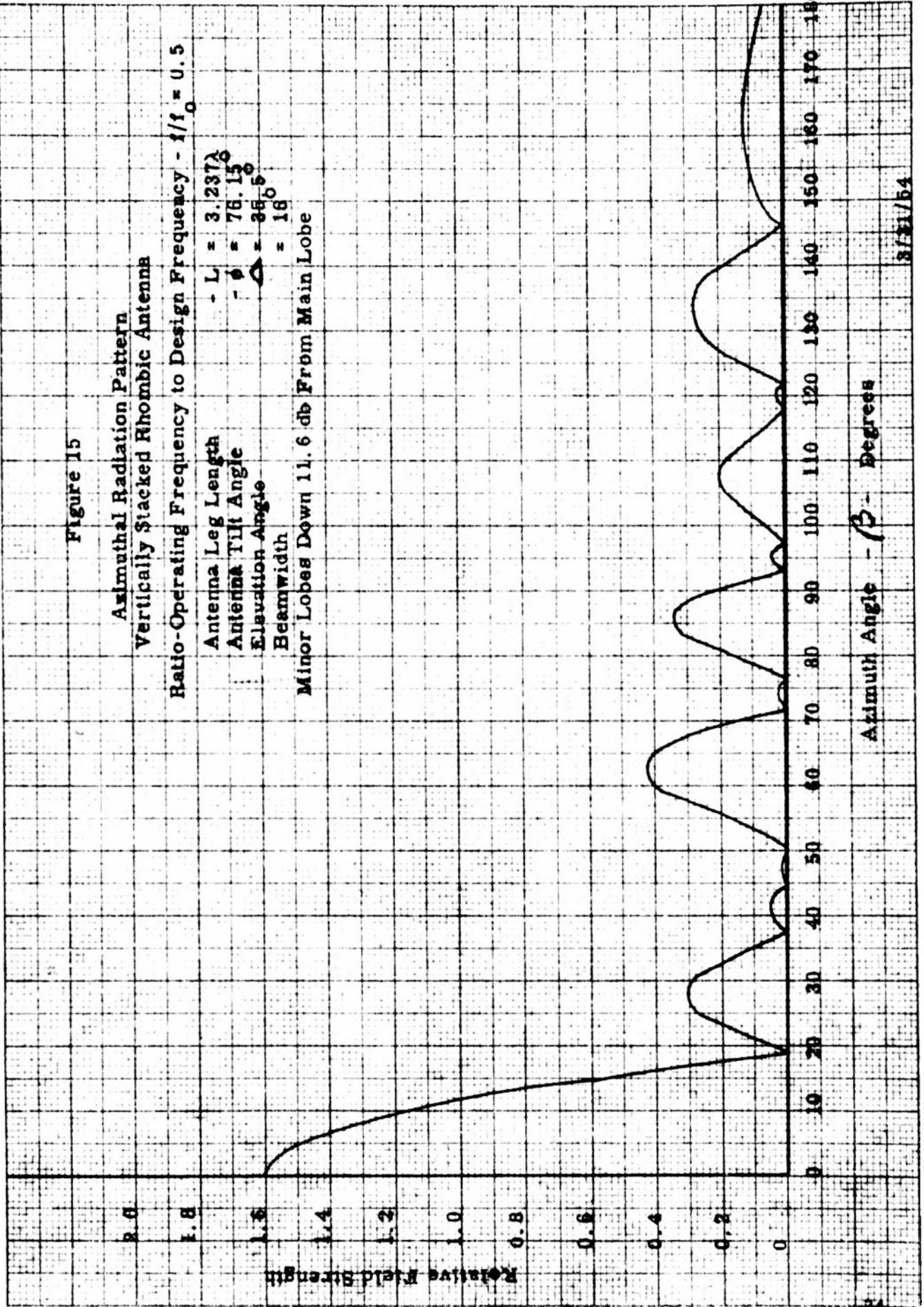
Antenna Leg Length - $L = 3.237\lambda$

Antenna Tilt Angle - $\phi = 76.15^\circ$

Elevation Angle - $\Delta = 35.5^\circ$

Beamwidth - $= 16^\circ$

Minor Lobes Down 11.6 db From Main Lobe



Azimuth Angle - β - Degrees

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