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EXPERIMENTAL MEASUREMENTS OF THE SHORT BACKFIRE ANTENNA

BY

L. R. DOD

OCTOBER 1966

NASA

GODDARD SPACE FLIGHT CENTER
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ABSTRACT

Experimental radiation patterns and gain have been measured for the short backfire antenna as a function of the antenna dimensions. The antenna consists of two planar reflectors of different diameters separated by one-half wavelength forming a leaky cavity resonator with radiation normal to the smaller reflector. The antenna is fed by a dipole at the midpoint between the two reflectors and yields useful gains of 10-15 db. Typical values for the reflector diameters are 2.0 wavelengths and 0.5 wavelengths. The addition of a quarter-wave rim on the large reflector reduced back radiation from 20 db. to below 30 db. The frequency bandwidth of the antenna is presently limited by the impedance match obtainable at the antenna input.

CONTENTS

ILLUSTRATIONS

EXPERIMENTAL MEASUREMENTS OF THE SHORT BACKFIRE ANTENNA

INTRODUCTION

The short backfire antenna was first reported by Ehrenspeck in August, 1965.[1] Zucker[2] and Ehrenspeck[1] have explained the backfire antenna as a leaky cavity resonator formed by two planar reflectors of different diameters separated by 1/2 wavelength (Figure 1). The large reflector captures most of the energy radiated by the feed located at the midpoint of the cavity while the smaller reflector acts as a diffracting obstacle for the feed radiation and forms the "leaky" cavity wall. Maximum radiation from the antenna is normal to the plane of the smaller reflector. A rim on the large reflector circumference reduces back and side radiation by extending the metallic boundary of the cavity.

The purpose of this investigation was:

(1) to determine the effect of changes in antenna dimensions on antenna performance, particularly gain,

(2) and to determine the effect of the addition of a rim to the larger reflector.

Physical Description

The test model of the backfire antenna is shown in Figure 1. The physical dimensions of the antenna in terms of wavelength are shown in Figure 2. The antenna feed system consists of orthogonal sleeve dipoles fed by a dual line balun. The mechanical tolerance in construction is better than ± 1/32 inch for the antenna.

Test Site

All radiation patterns and gain measurements were conducted on a test range consisting of two antennas separated by 18 feet and elevated above ground 10 feet. The illuminating antenna was a pyramidal horn (Scientific Atlanta S. G. H. 1.12). The far field requirement based upon the horn aperture was 16 feet. The gain measurements of the short backfire were made by comparison with a second pyramidal horn (S. G. H. 1.12) with calibrated gain of 16.3 db. above isotropic at the 1500 MHz. test frequency.[3] The range was calibrated for gain measurements by using the two identical horns and measuring the insertion loss between the transmitter output and the receiving horn output. The gain of the two identical antennas is then the difference between the insertion loss and the calculated free space path loss. The separation between the horn throats was used for the path loss calculation. The average difference of 4 readings in horizontal and vertical polarization was 0.15 db. from the calibration curve of the horn. However, the accuracy of the gain measurements is limited to ± 0.5 db. by tolerances in the measuring equipment and by the small range separation.(3)

Test Results

A. Radiation Patterns - E and H plane radiation patterns were measured as the diameter of the smaller reflector was varied from 0.3-0.65 wavelengths (λ) in increments of 0.05 λ with the diameter of the large reflector fixed at 2.0 λ and λ /4 rim. All radiation patterns measured were for one linear antenna of the orthogonal pair with the other antenna terminated. The E plane patterns are shown in Figure 3 and the H plane patterns in Figure 4. The effect of changes in the size of the smaller reflector on half-power beamwidth and sidelobe level is shown in Figure 5a. Half-power beamwidth is reduced as the diameter of the smaller reflector is increased. Sidelobe level also increases with increasing reflector diameter but remains at reasonable levels for the range of diameters tested.

The radiation patterns in the E and H planes were repeated with the diameter of the larger reflector fixed at 1.5 λ and the rim height at $\lambda/4$. The E plane patterns are shown in Figure 6 and the H plane patterns in Figure 7. The effect of the smaller reflector size variations on half-power beamwidth and sidelobe level is shown in Figure 5b. Reducing the diameter of the larger reflector by 0.5 λ causes higher sidelobe levels in the E plane and larger half-power beamwidths, (c.f., Figure 5a).

Radiation patterns with the $\lambda/4$ rim removed from the larger reflector are shown in Figures 8 and 9 for the 2.0 λ diameter reflector; and Figures 10 and 11 for the 1.5 λ diameter reflector. The removal of the rim results in higher back and side radiation since the cavity shielding is reduced.

B. Gain Measurement – Gain measurements were made for the same conditions as the radiation pattern measurements. The gain values are shown in Figure 12. The maximum measured gain was 14.9 db. for the 2.0 λ diameter large reflector, $\lambda/4$ rim, and a 0.65 λ diameter small reflector. The addition of the $\lambda/4$ rim increased the gain by 1.0 db. All gain measurements were made with the antenna input stub matched to a s.w.r. of less than 1.10 to 1.

C. Frequency Bandwidth – Radiation patterns of the antenna were taken over a frequency range of 1.25-1.75 GHz. or a 33% bandwidth about the design frequency of 1.5 GHz. The E and H plane radiation patterns are shown in Figures 13 and 14 for the case of a 2.0 λ diameter reflector, $\lambda/4$ rim, and a 0.5 λ diameter small reflector. The width of the main lobe increases as the operating frequency is reduced below the design frequency. This beamwidth increase is due to the reduction in reflector diameters with frequency. The beamwidth and sidelobe level performance are good above the design frequency.

The gains at the bandwidth extremities of 1.25 and 1.75 GHz. were 8.3 and 14.5 db., respectively. Gain at the center frequency of 1.5 GHz. was 13.3 db. The higher gain at 1.75 GHz. is explained by the choice of the 0.5 λ diameter smaller reflector for low side and back lobes rather than maximum gain at 1.5 GHz. The diameters of the reflectors are larger in terms of wavelength at 1.75 GHz. and it can be seen from Figure 12 that the gain will increase with reflector size.

The input s.w.r. of the antenna is shown in Figure 15. The antenna has an impedance matching bandwidth of 6.7% for a s.w.r. of less than 3 to 1. The leaky cavity is a high Q device that requires broadband impedance matching techniques. No attempt was made to broadband the feed system of the antenna tested. The balun consists of a dual two wire line with a short circuit spaced $\lambda/4$ from the antenna terminals. It should be possible to extend the impedance bandwidth by proper choice of compensated balun and sleeve dipole parameters. The antenna was matched to less than 1.1 to 1 s.w.r. at 1.5 GHz. by adjusting the dipole sleeve lengths and dipole element lengths.

CONCLUSIONS

An approximate expression for the gain of an antenna is

$$g = \frac{27000}{\theta_e \theta_h}$$

where θ_e and θ_h are the half-power beamwidths in degrees for the two principal planes of the antenna.(4) The calculated gain is 15.4 db. based upon this approximation for the case of the 2.0 λ diameter large reflector, $\lambda/4$rim, and 0.6 λ diameter small reflector. The measured gain was 14.9 db.

The short backfire antenna is a medium gain antenna (10-15 db.) with low side and back radiation. The antenna can be cross-polarized for orthogonal linear or circular polarization. The radiation pattern and gain bandwidth are greater than 17% but the impedance matching bandwidth is limited to several percent due to the high Q of the antenna. This impedance bandwidth may be increased by broadband matching techniques. The addition of a $\lambda/4$ rim on the large reflector is necessary for low back radiation. The diameter of the smaller reflector is an effective control of the radiation characteristics of the antenna, making this a potentially useful primary feed system for paraboloidal antennas with F/D ratios in the range 0.4 to 0.6. The short backfire may also serve advantageously as an array element.

REFERENCES

1. Ehrenspeck, H. W., "The Short Backfire Antenna," Proc. IEEE, 53, 1138-1140, August, 1965.

2. Zucker, F. J., "The Backfire Antenna: A Qualitative Approach to Its Design," Proc. of the IEEE, 52, 746-747, July, 1965.

3. Slayton, William T., "Design and Calibration of Microwave Antenna Gain Standards," Naval Research Lab Report 4433, November 9, 1954.

4. "Test Procedures for Antennas," IEEE Publication No. 149, p. 21, January, 1965.

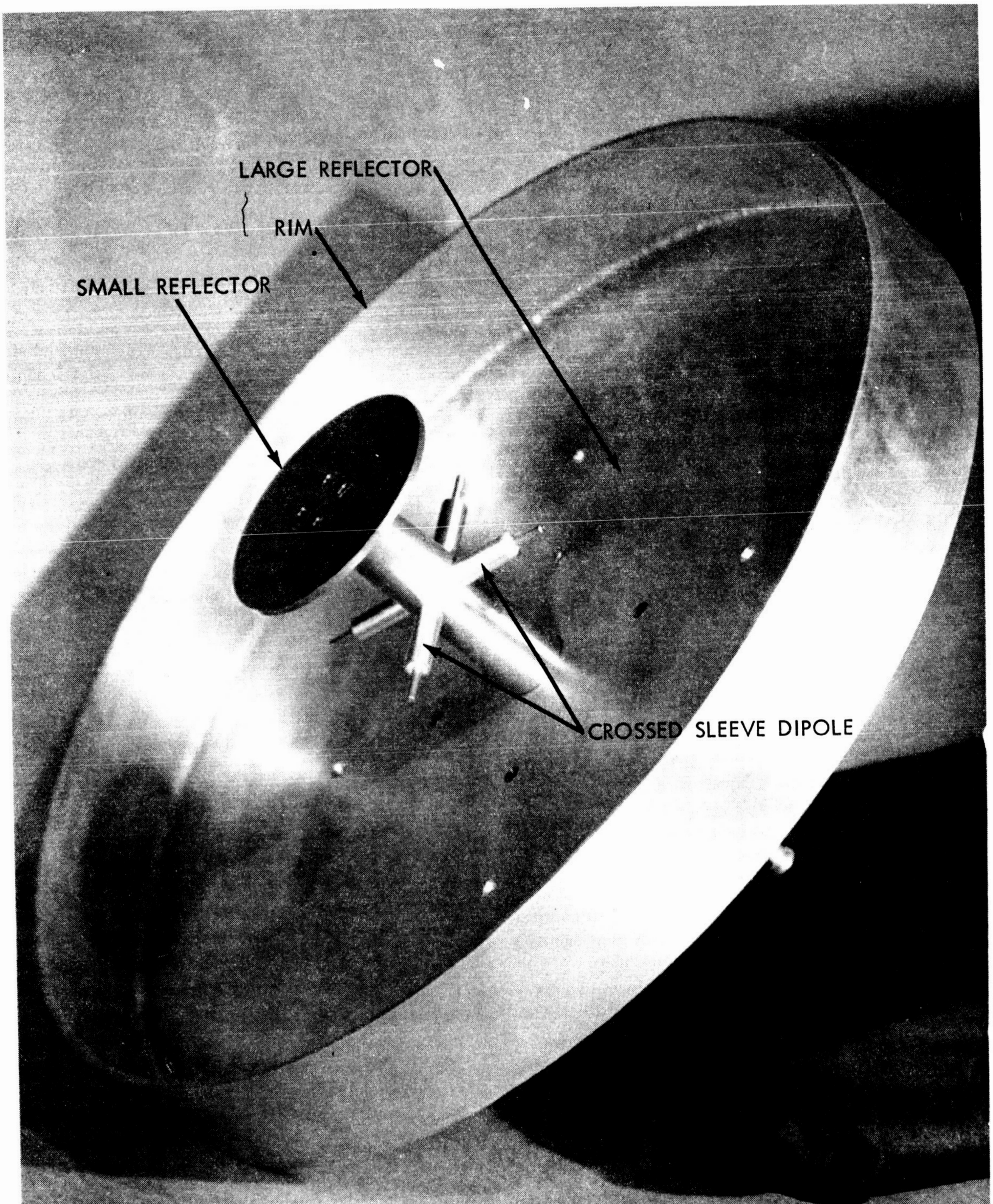


Figure 1. Photo of Backfire Antenna Model

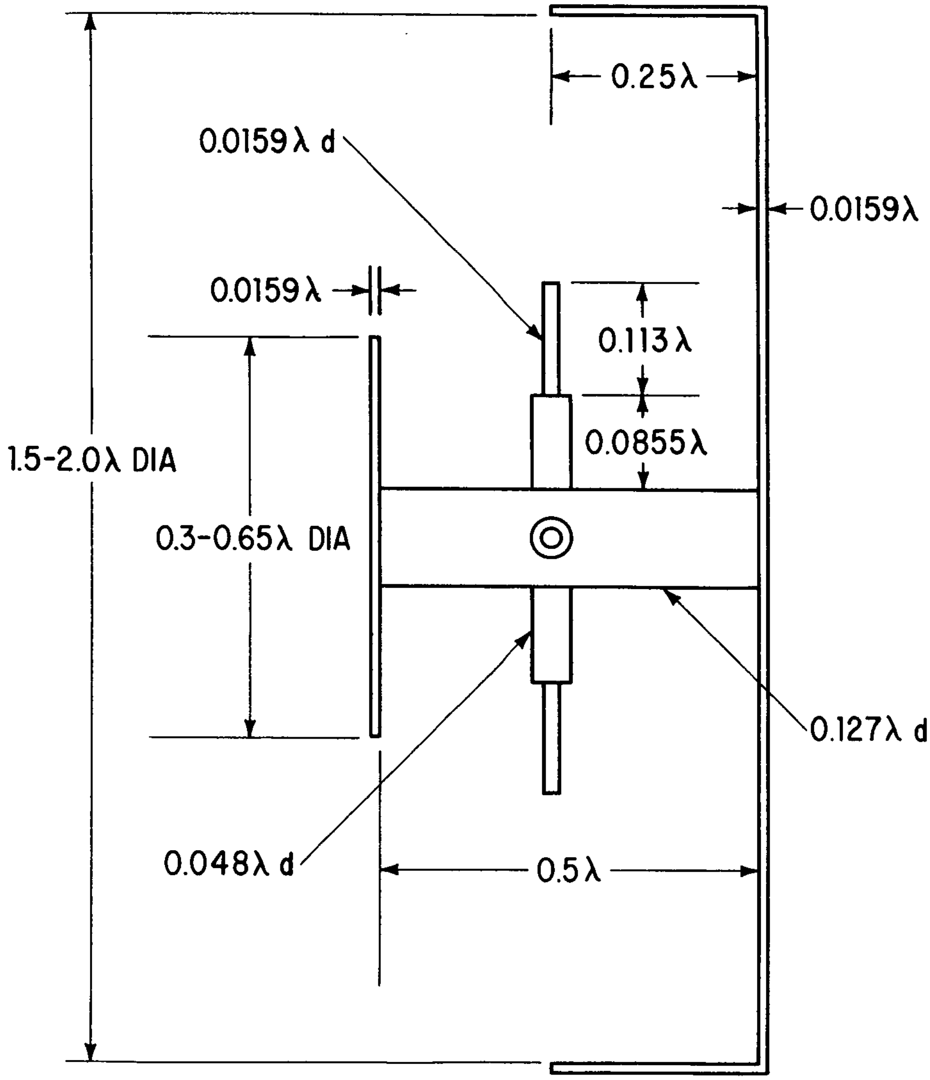
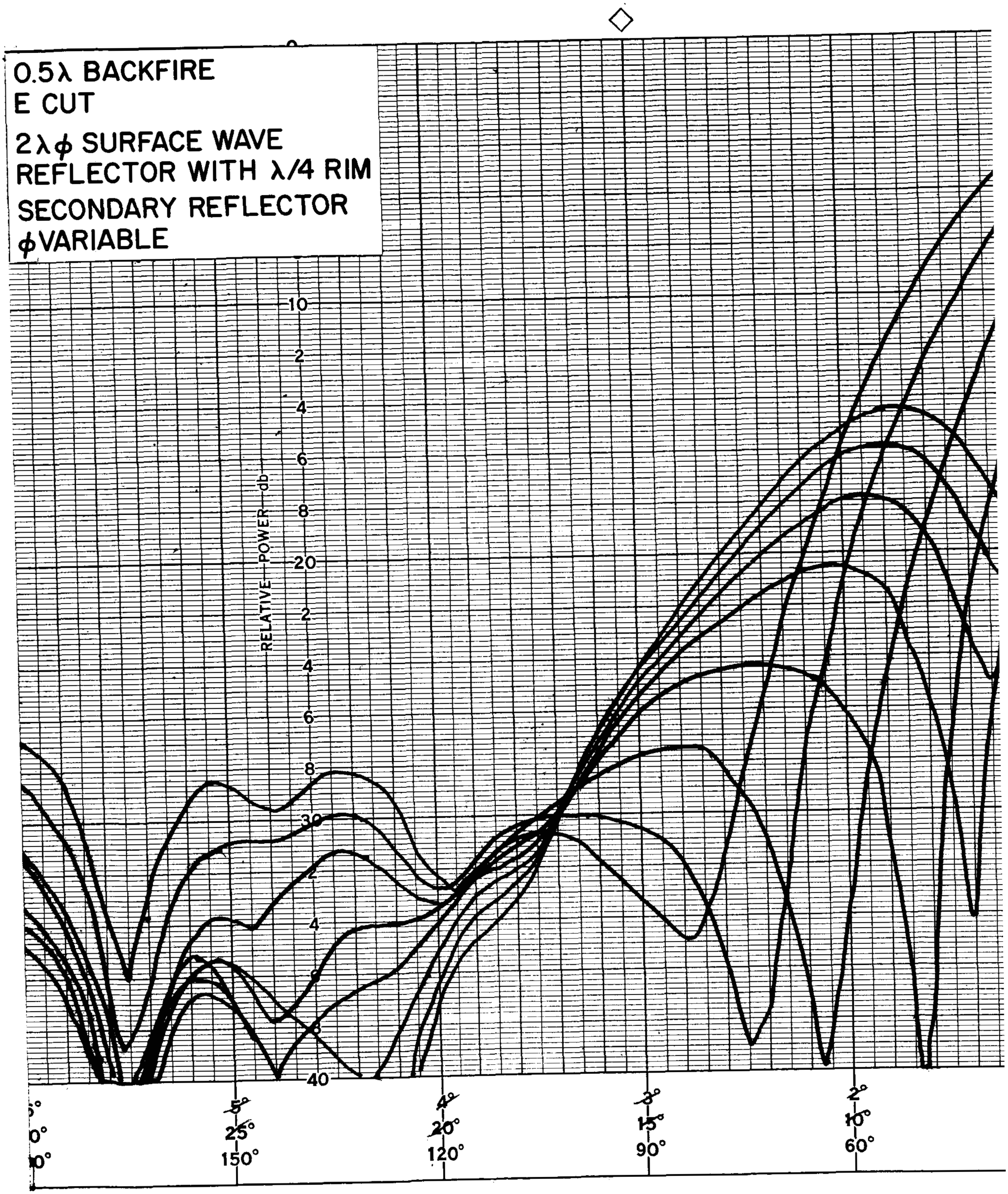
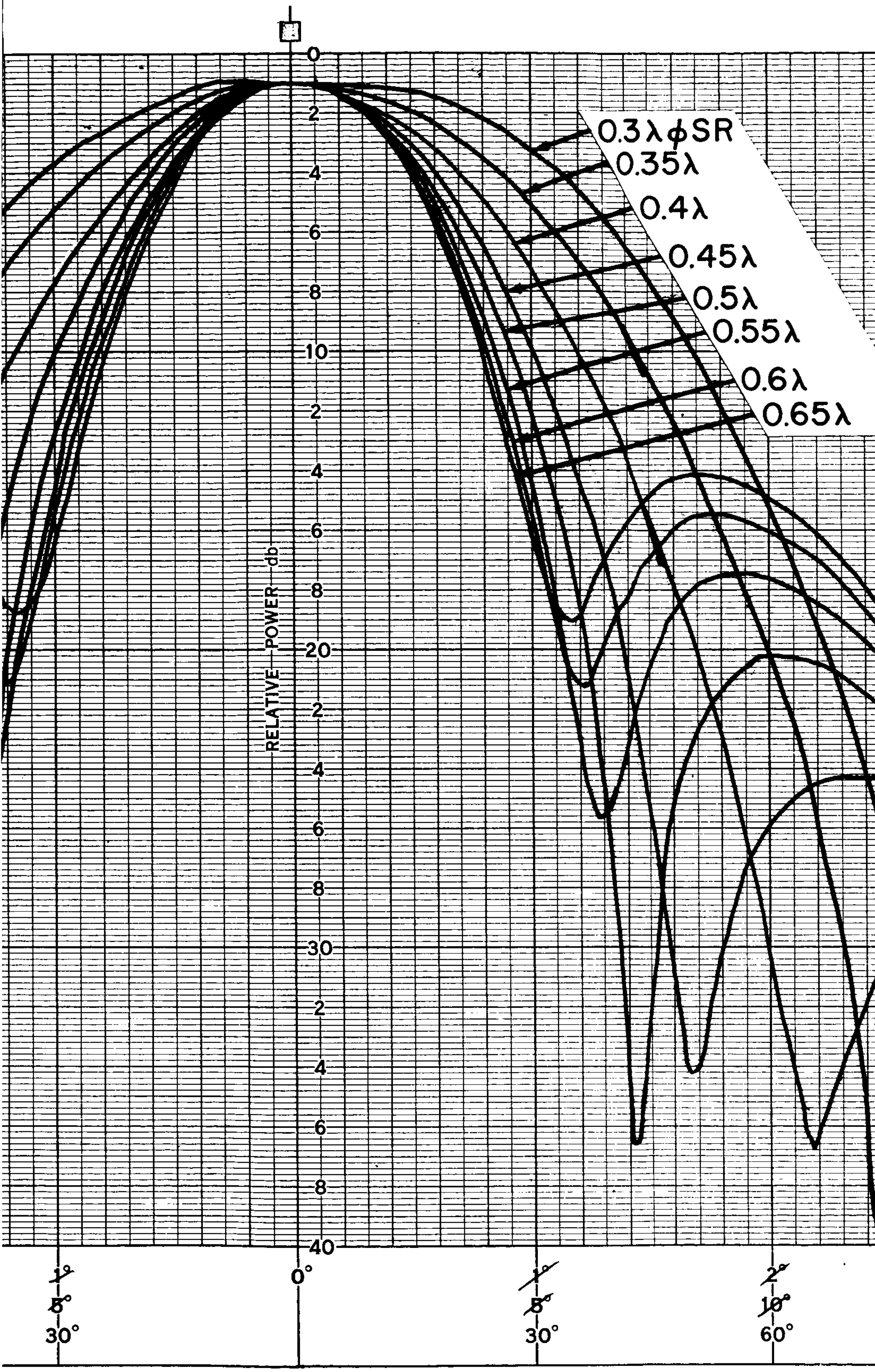


Figure 2. Dimensional Sketch of the Antenna



0.5λ BACKFIRE
E CUT
2λφ SURFACE WAVE
REFLECTOR WITH λ/4 RIM
SECONDARY REFLECTOR
φ VARIABLE
RELATIVE POWER—db
10
2
4
6
8
20
2
4
6
8
30
2
4
6
8
40
5°
25°
150°
4°
20°
120°
3°
15°
90°
2°
10°
60°


0.3λ φSR
0.35λ
0.4λ
0.45λ
0.5λ
0.55λ
0.6λ
0.65λ
RELATIVE POWER db
0
2
4
6
8
10
2
4
6
8
20
2
4
6
8
30
2
4
6
8
40
30°
0°
30°
60°

Fi

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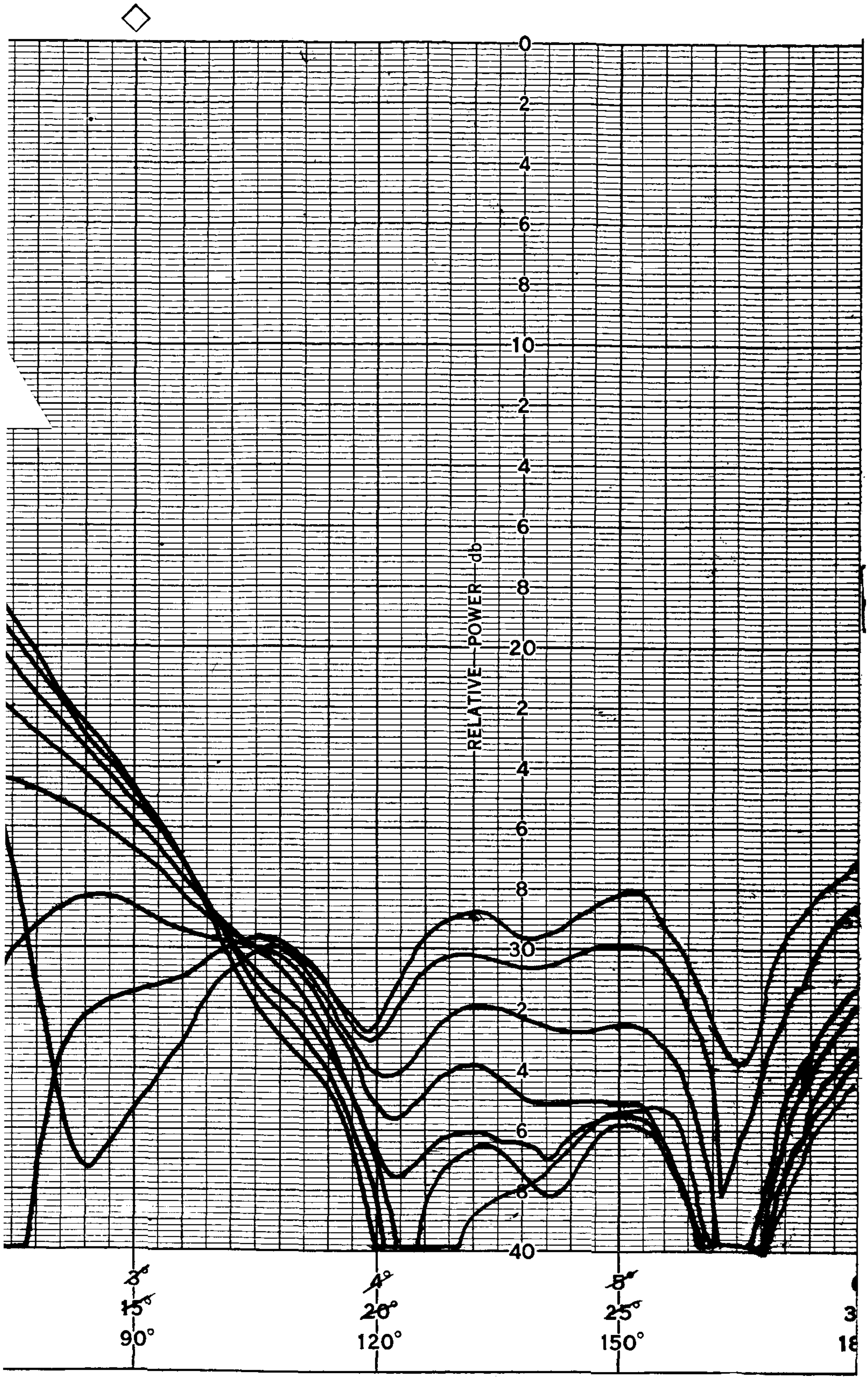
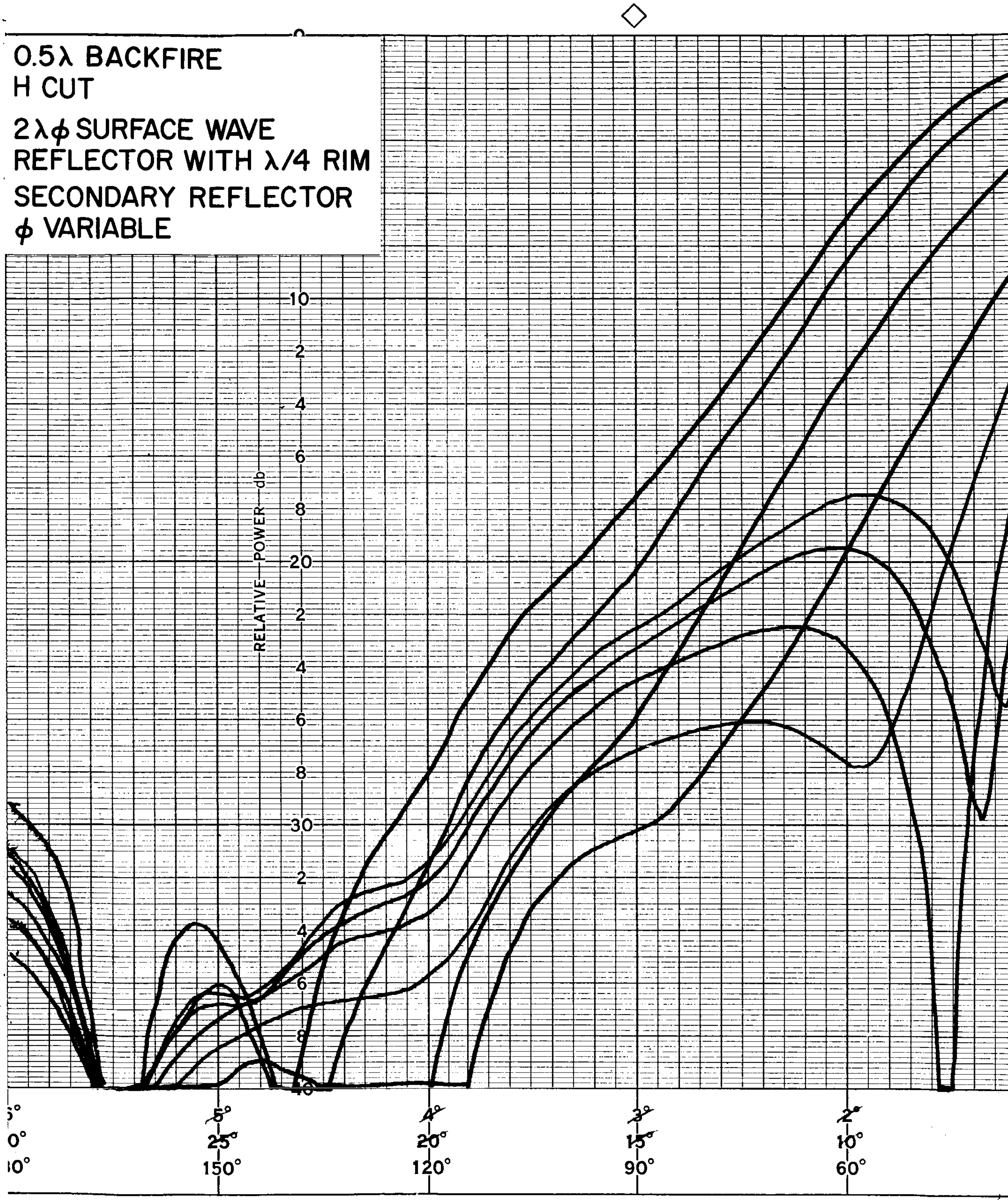
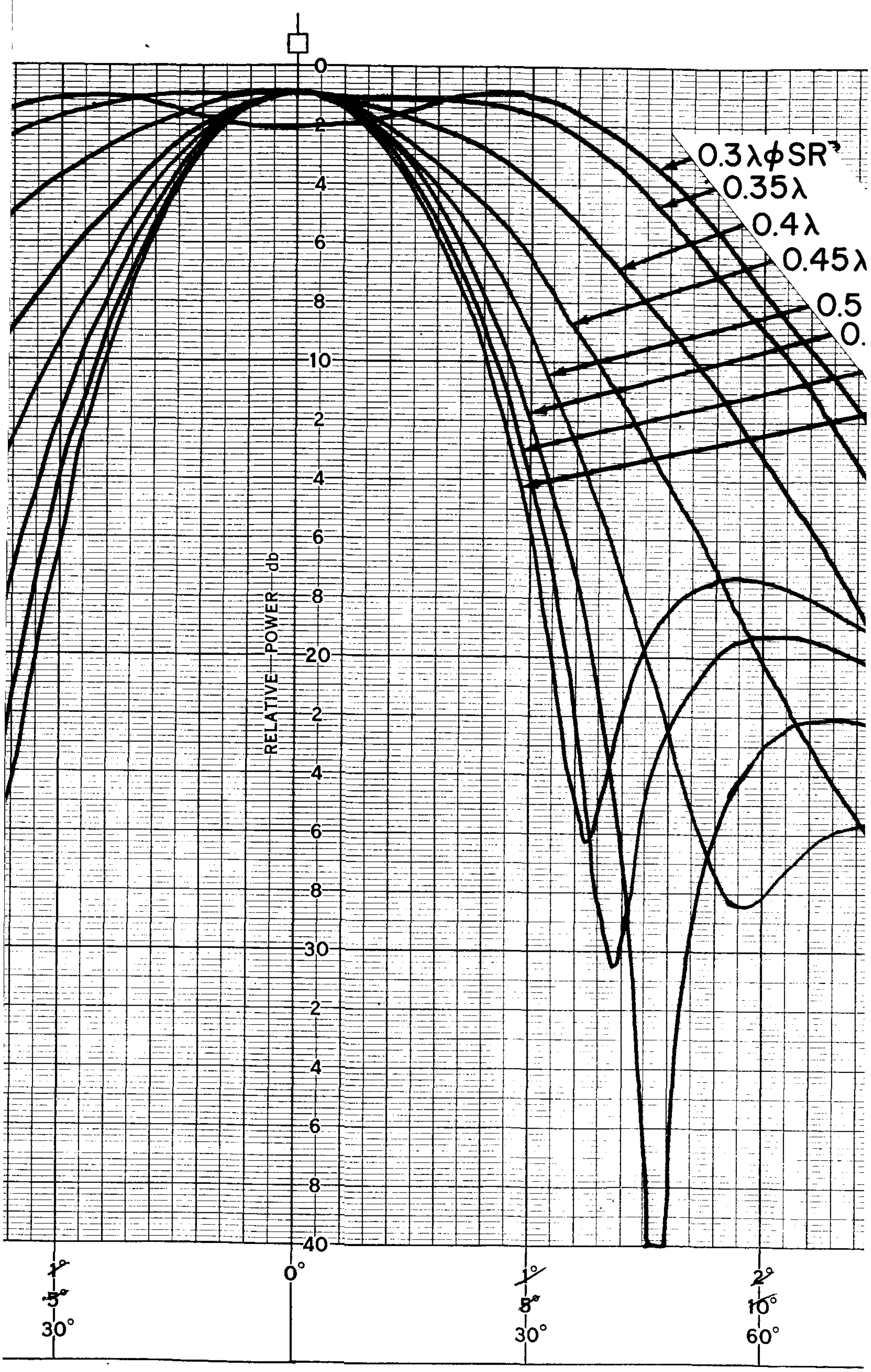


gure 3. E Plane Patterns with 2.0 λ Diameter Reflector and λ/4 Rim, Small Reflector Variable from 0.3-0.65 λ Diameter.



0.5λ BACKFIRE
H CUT
2λφ SURFACE WAVE
REFLECTOR WITH λ/4 RIM
SECONDARY REFLECTOR
φ VARIABLE
RELATIVE — POWER — db
10
20
30
40
5°
25°
150°
4°
20°
120°
3°
15°
90°
2°
10°
60°



0.3λφSR
0.35λ
0.4λ
0.45λ
0.5
0.
RELATIVE POWER db
0
2
4
6
8
10
2
4
6
8
20
2
4
6
8
30
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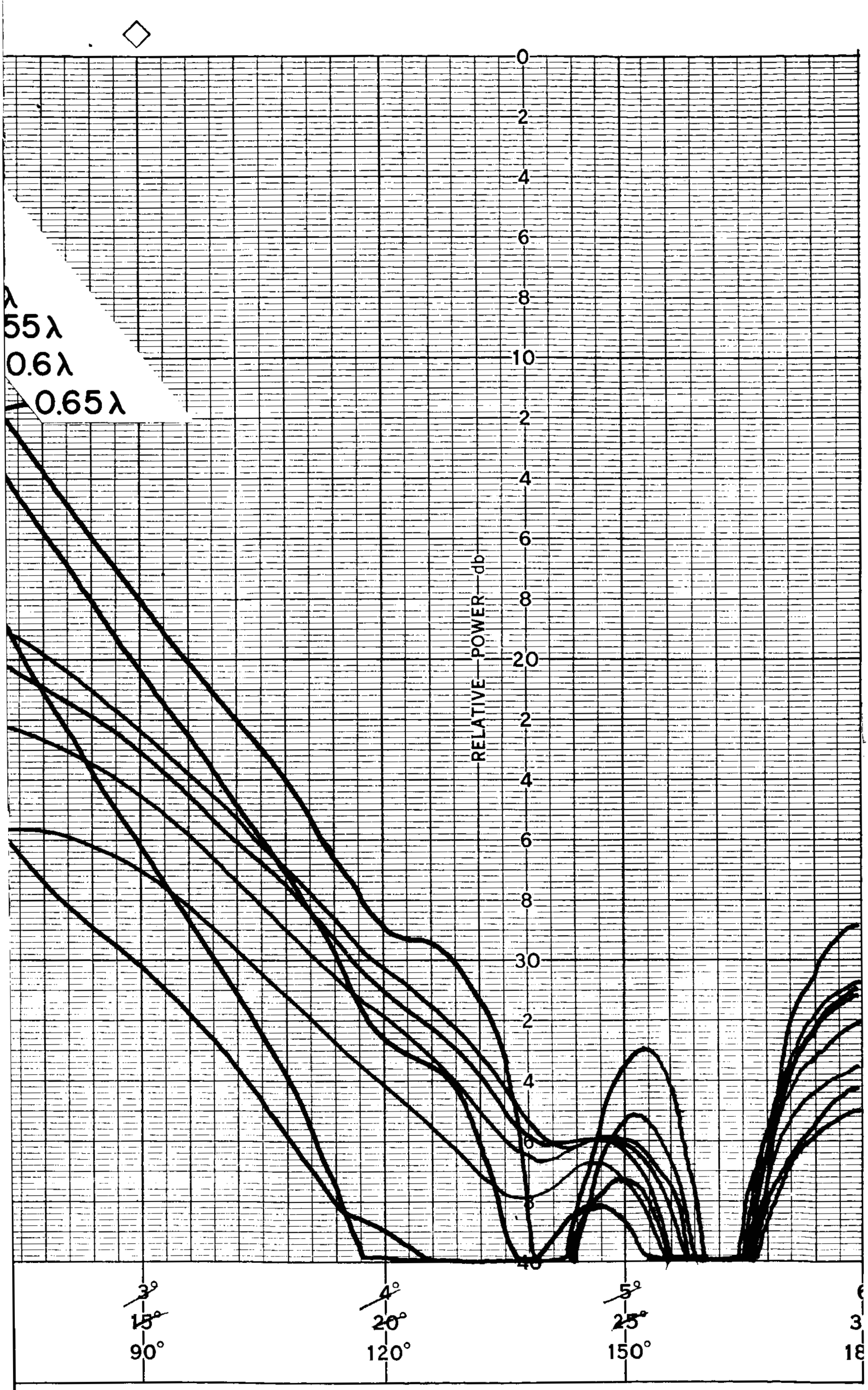
8
40
1°
5°
30°
0°
1°
5°
30°
2°
10°
60°

Figu



e 4. H Plane Patterns with 2.0 λ Diameter Reflector and λ/4 Rim, Small Reflector Variable from 0.3-0.65 λ Diameter.

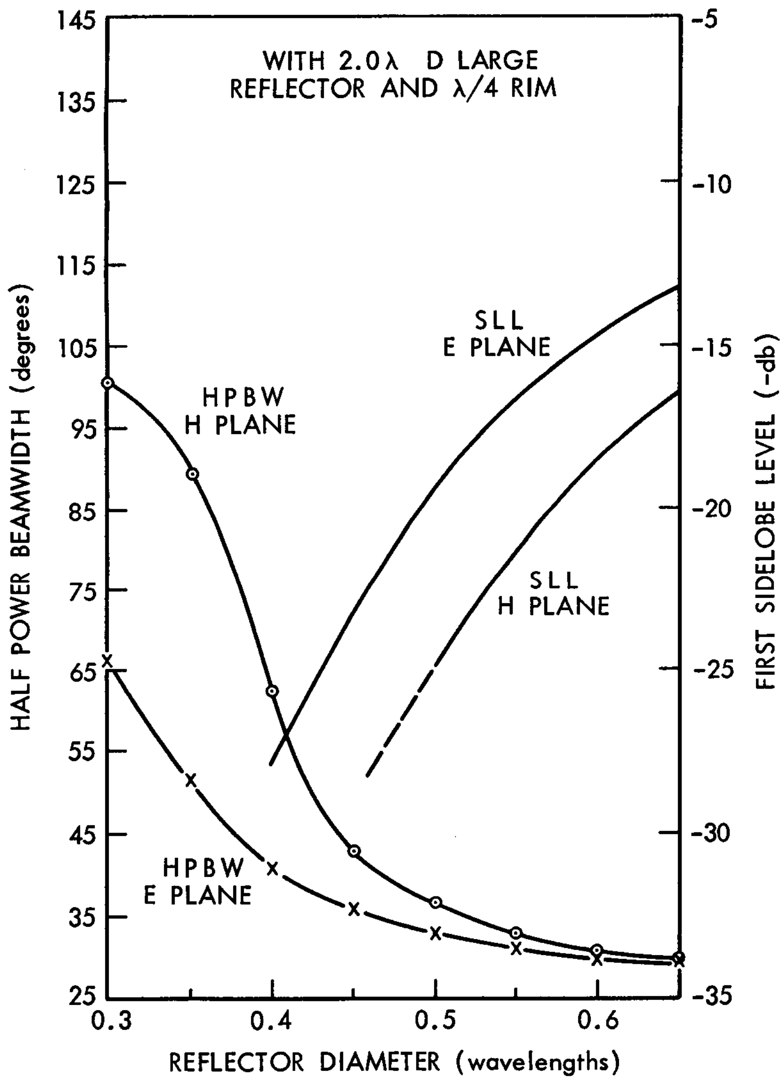


Figure 5a. Half Power Beamwidth and Sidelobe Level Versus Reflector Diameter 2.0 λDiameter Reflector with λ/4 Rim.

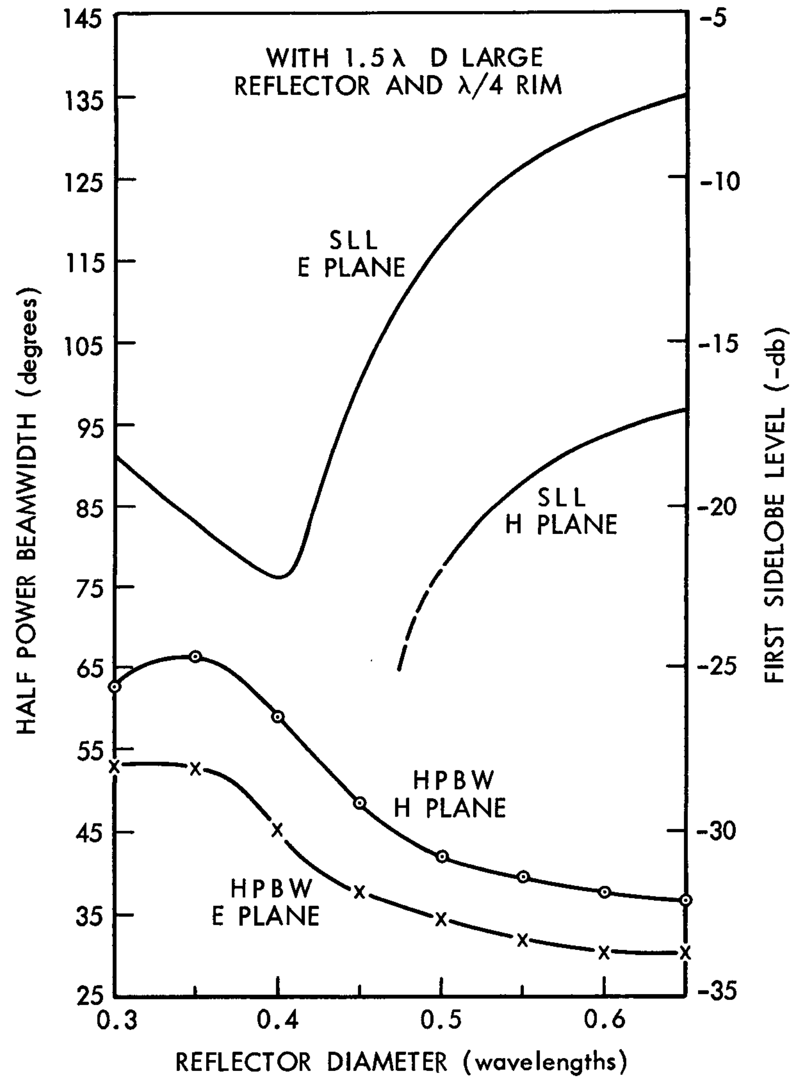
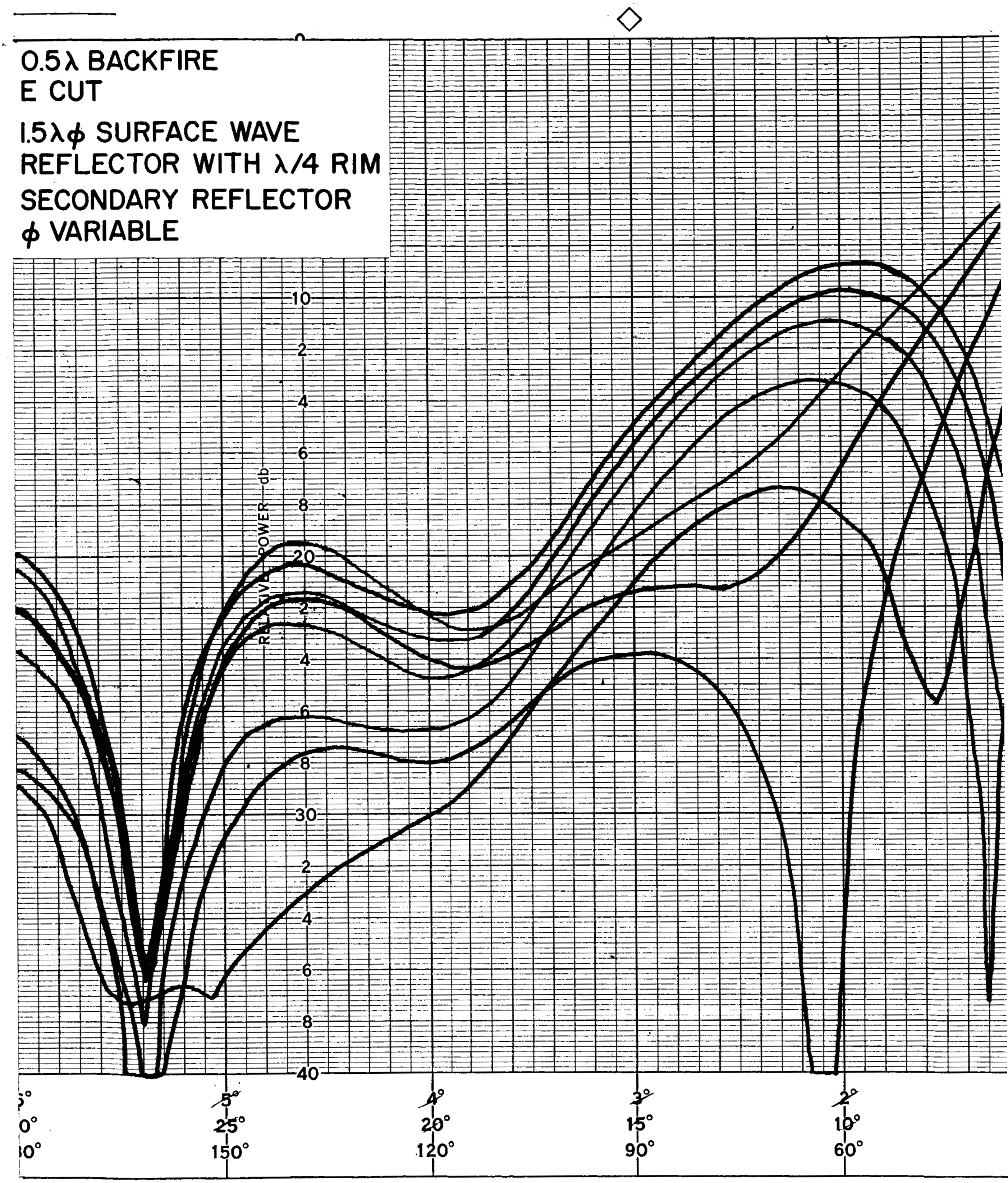
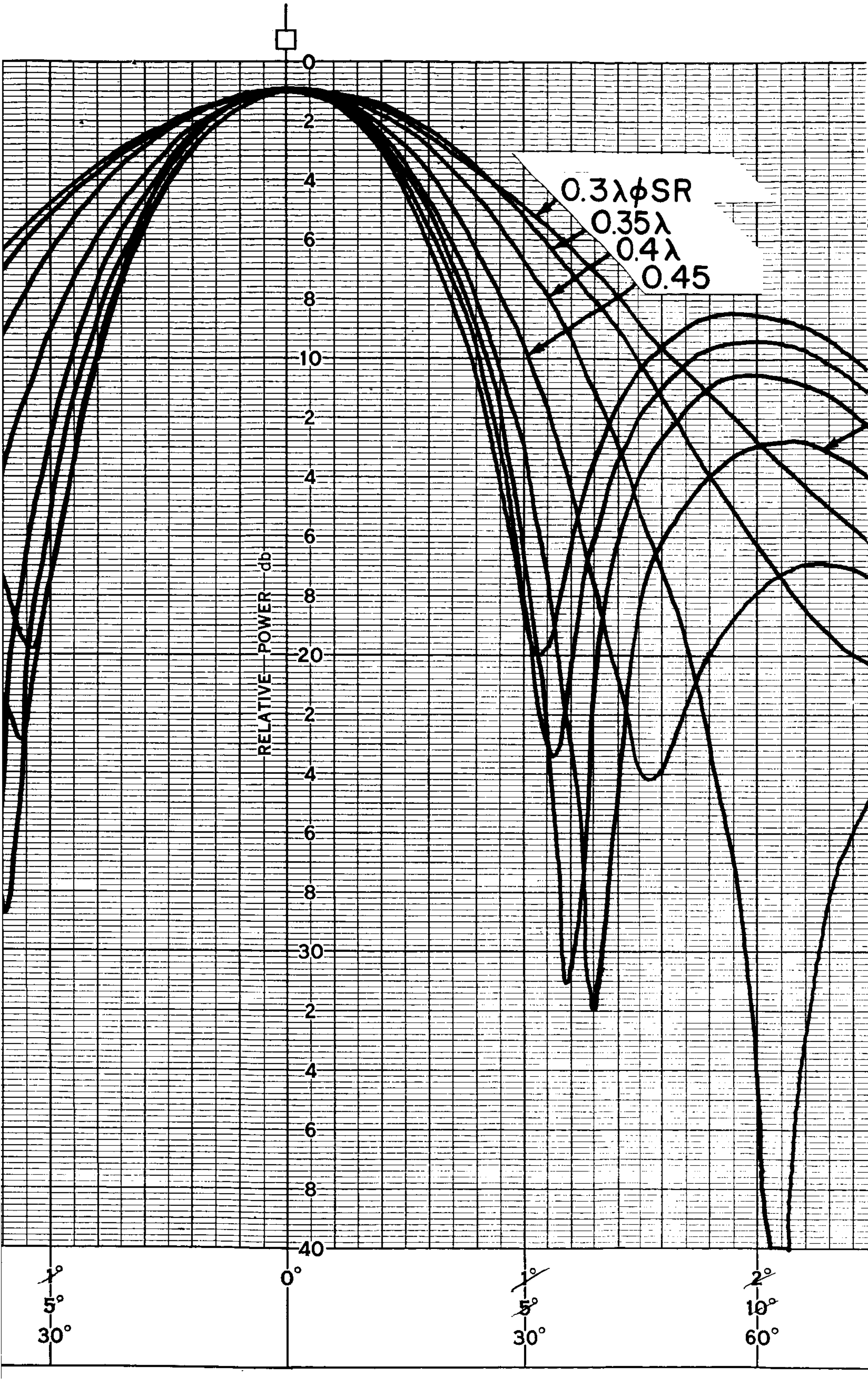


Figure 5b. Half Power Beamwidth and Sidelobe Level Versus Reflector Diameter 1.5 λDiameter Reflector with λ/4 Rim.



0.5λ BACKFIRE
E CUT
1.5λφ SURFACE WAVE
REFLECTOR WITH λ/4 RIM
SECONDARY REFLECTOR
φ VARIABLE
RELATIVE POWER—db
10
2
4
6
8
20
2
4
6
8
30
2
4
6
8
40
25°
150°
20°
120°
15°
90°
10°
60°



0.3λϕSR
0.35λ
0.4λ
0.45
RELATIVE POWER db
0
2
4
6
8
-10
2
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6
8
-20
2
4
6
8
-30
2
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6
8
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1°
5°
30°
2°
10°
60°

Figur

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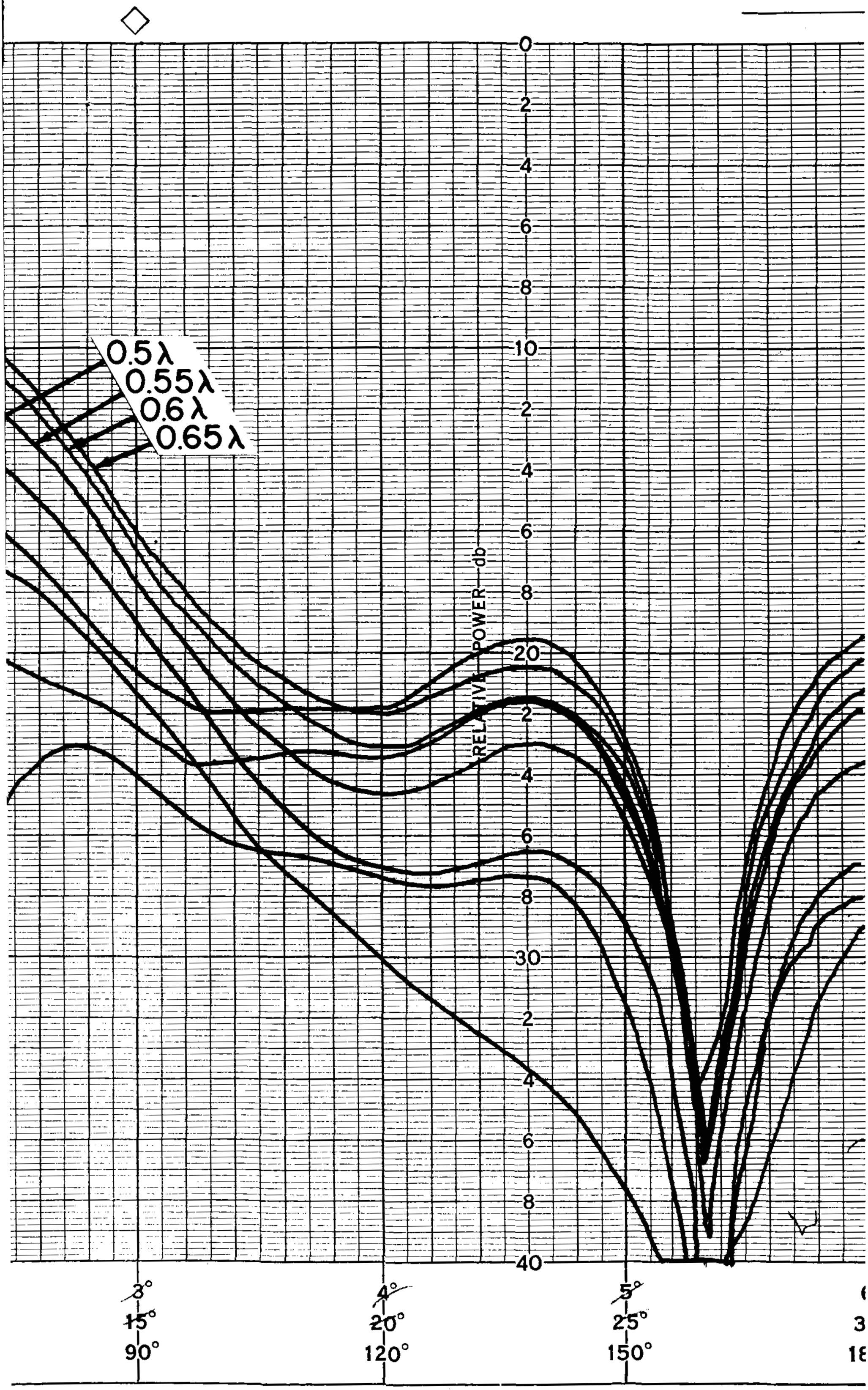
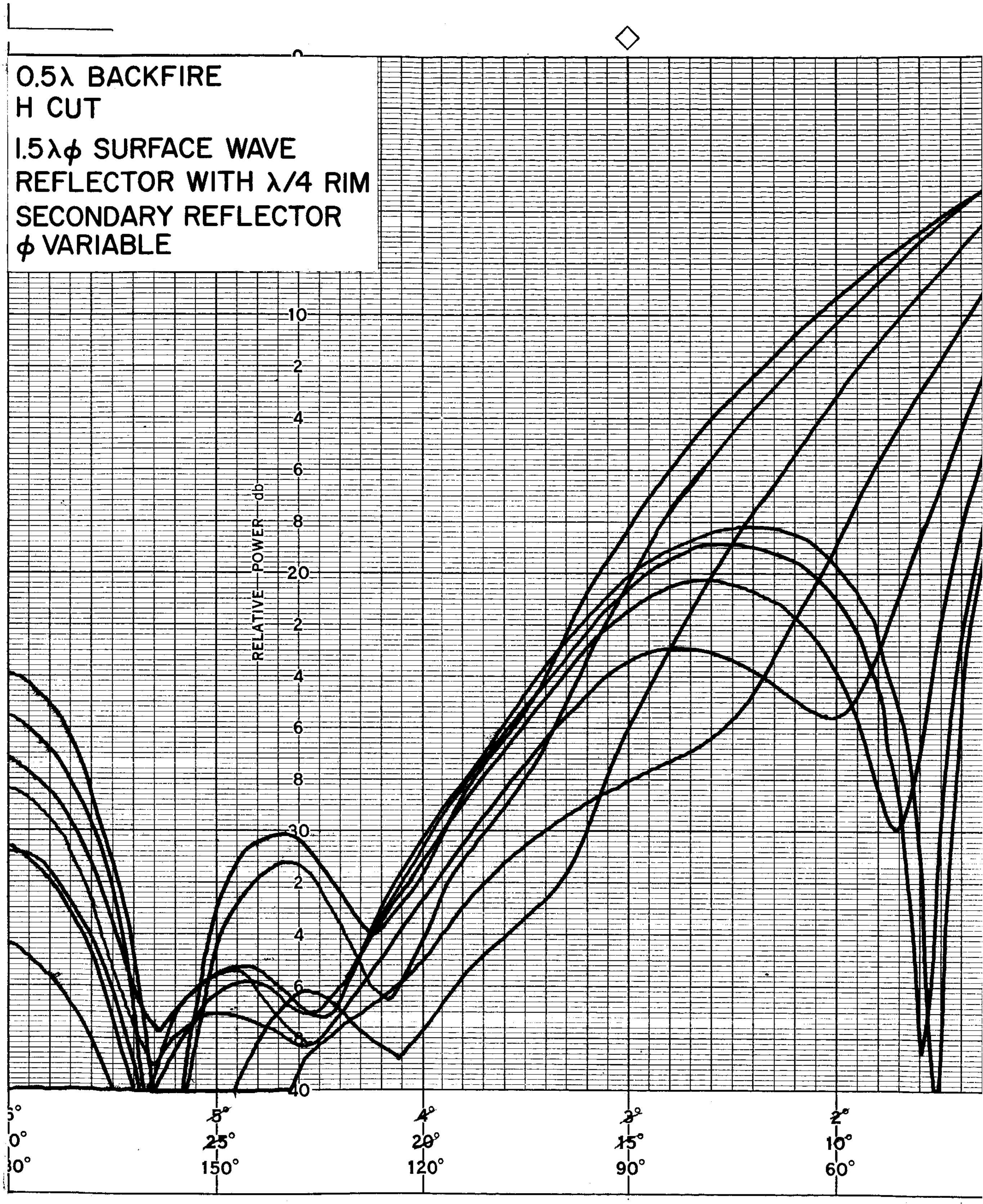


e 6. E Plane Patterns with 1.5 λ Diameter Reflector and λ/4 Rim, Small Reflector Variable from 0.3-0.65 λ Diameter


0.5λ BACKFIRE
H CUT
1.5λφ SURFACE WAVE
REFLECTOR WITH λ/4 RIM
SECONDARY REFLECTOR
φ VARIABLE
RELATIVE POWER db
10
20
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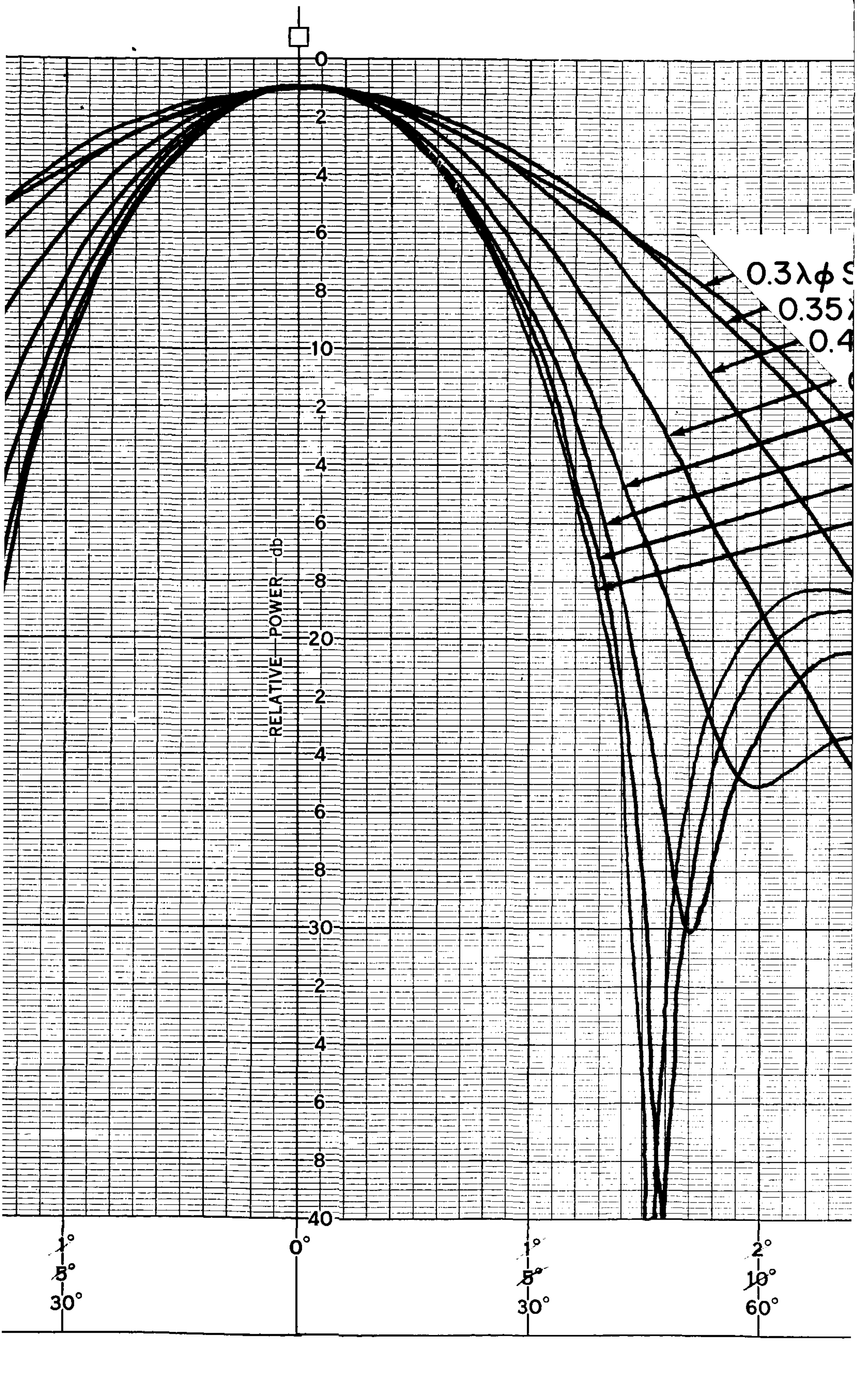
150°
120°
90°
60°



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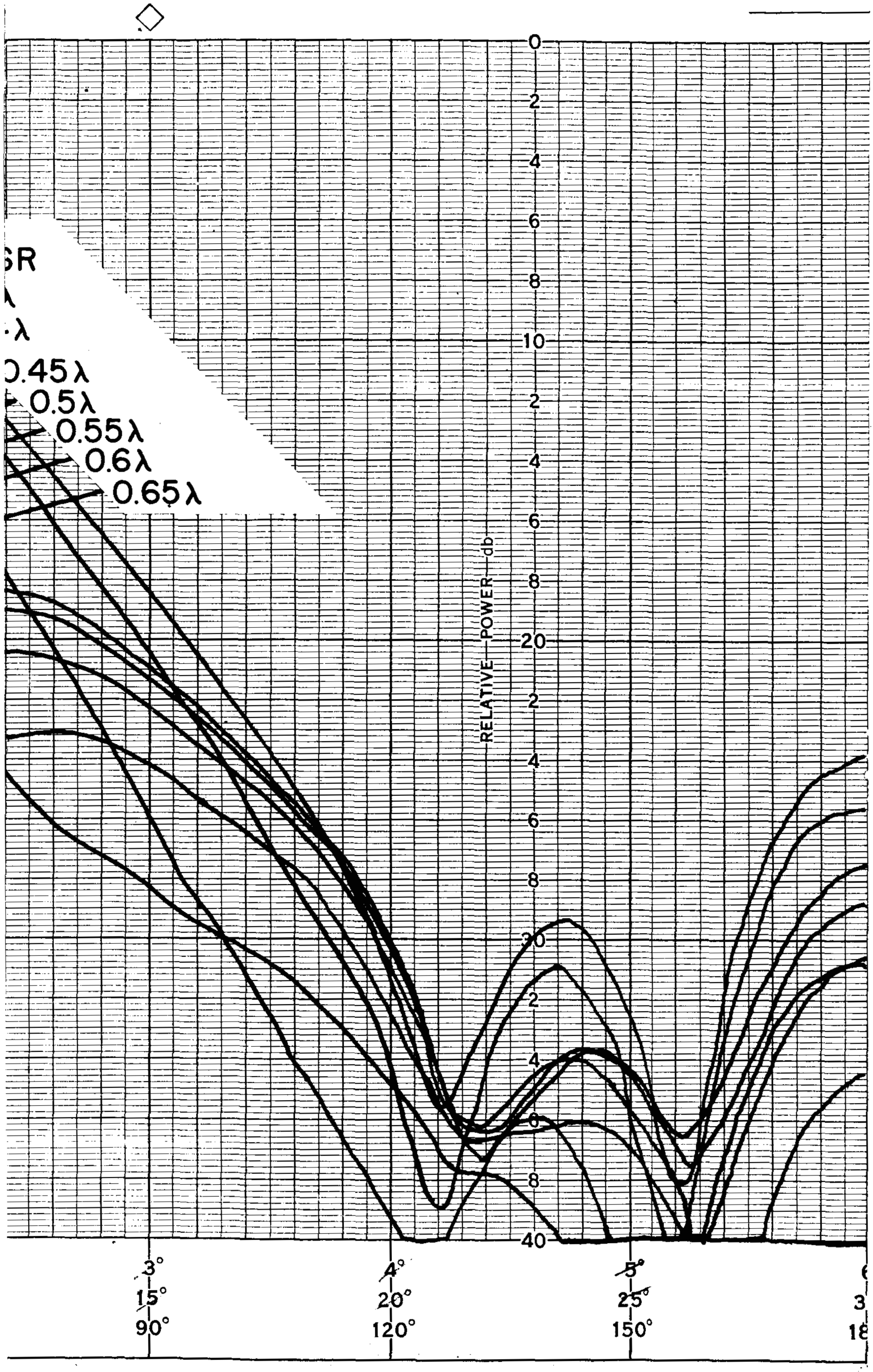
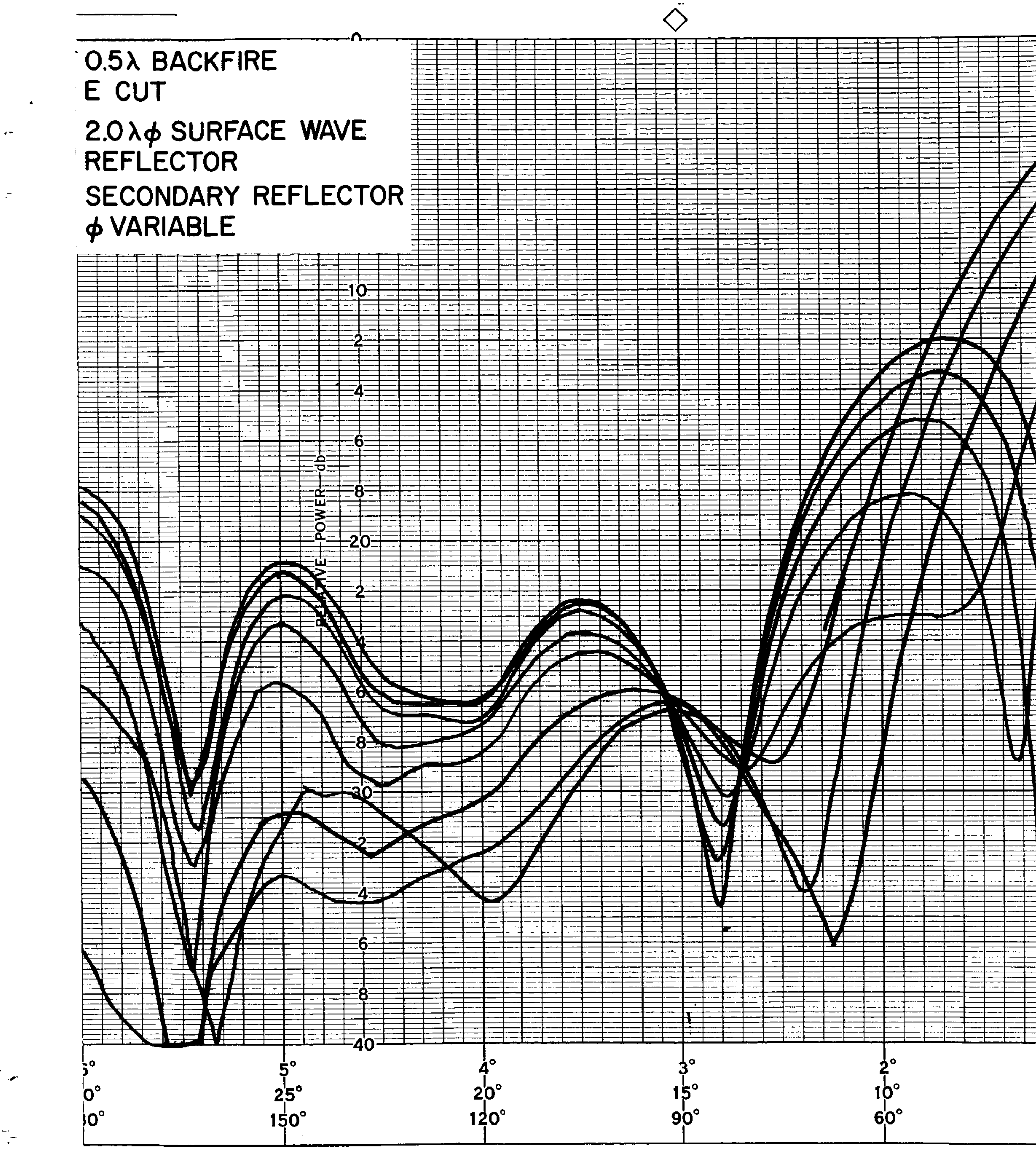


e 7. H Plane Patterns with 1.5 λ Diameter Reflector and λ/4 Rim, Small Reflector Variable from 0.3-0.65 λ Diameter


0.5λ BACKFIRE
E CUT
2.0λφ SURFACE WAVE
REFLECTOR
SECONDARY REFLECTOR
φ VARIABLE
RELATIVE POWER—db
10
2
4
6
8
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2
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6
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30
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4°
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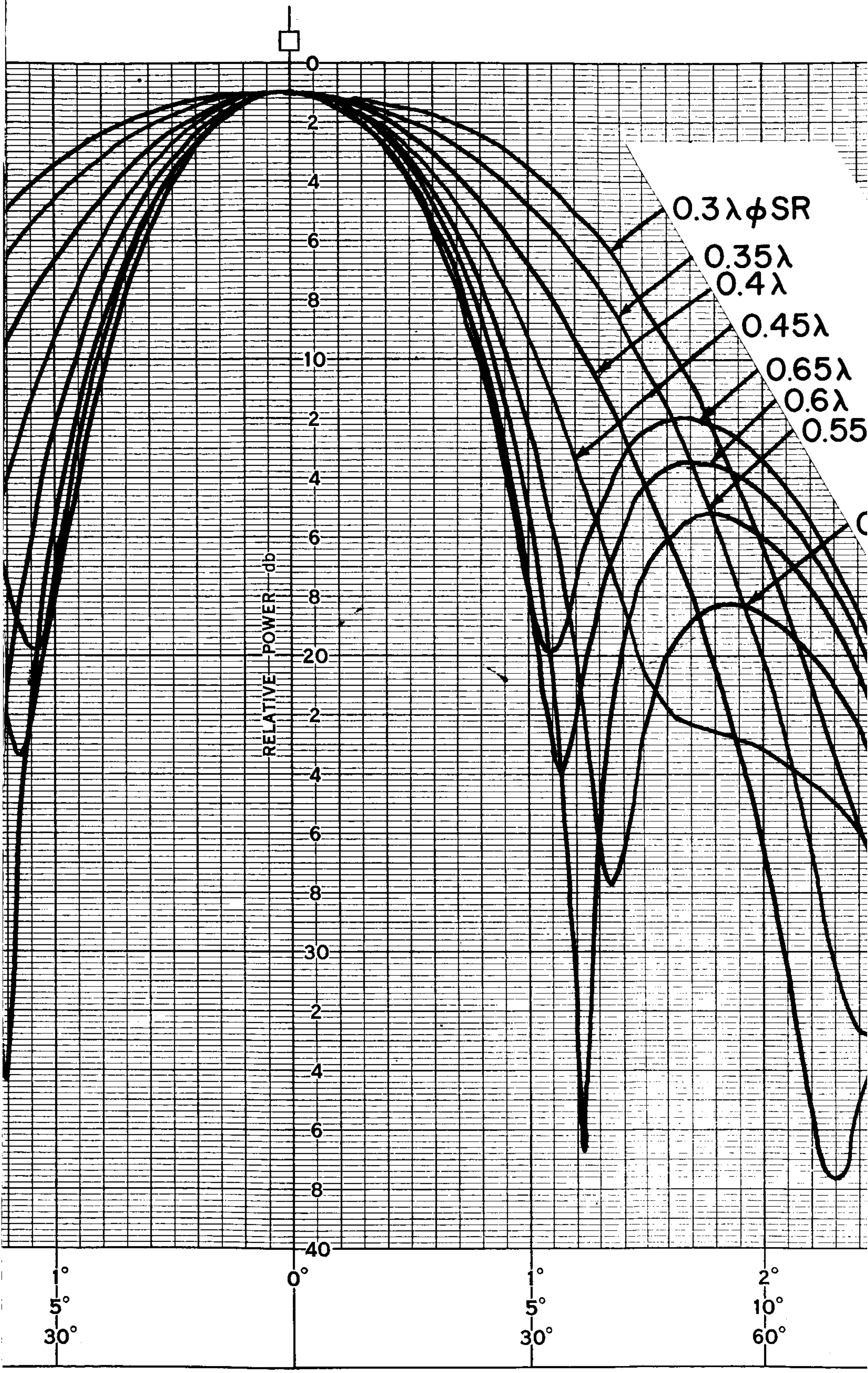
3°
15°
90°
2°
10°
60°



0.3λ ϕ SR
0.35λ
0.4λ
0.45λ
0.65λ
0.6λ
0.55
RELATIVE POWER db
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60°

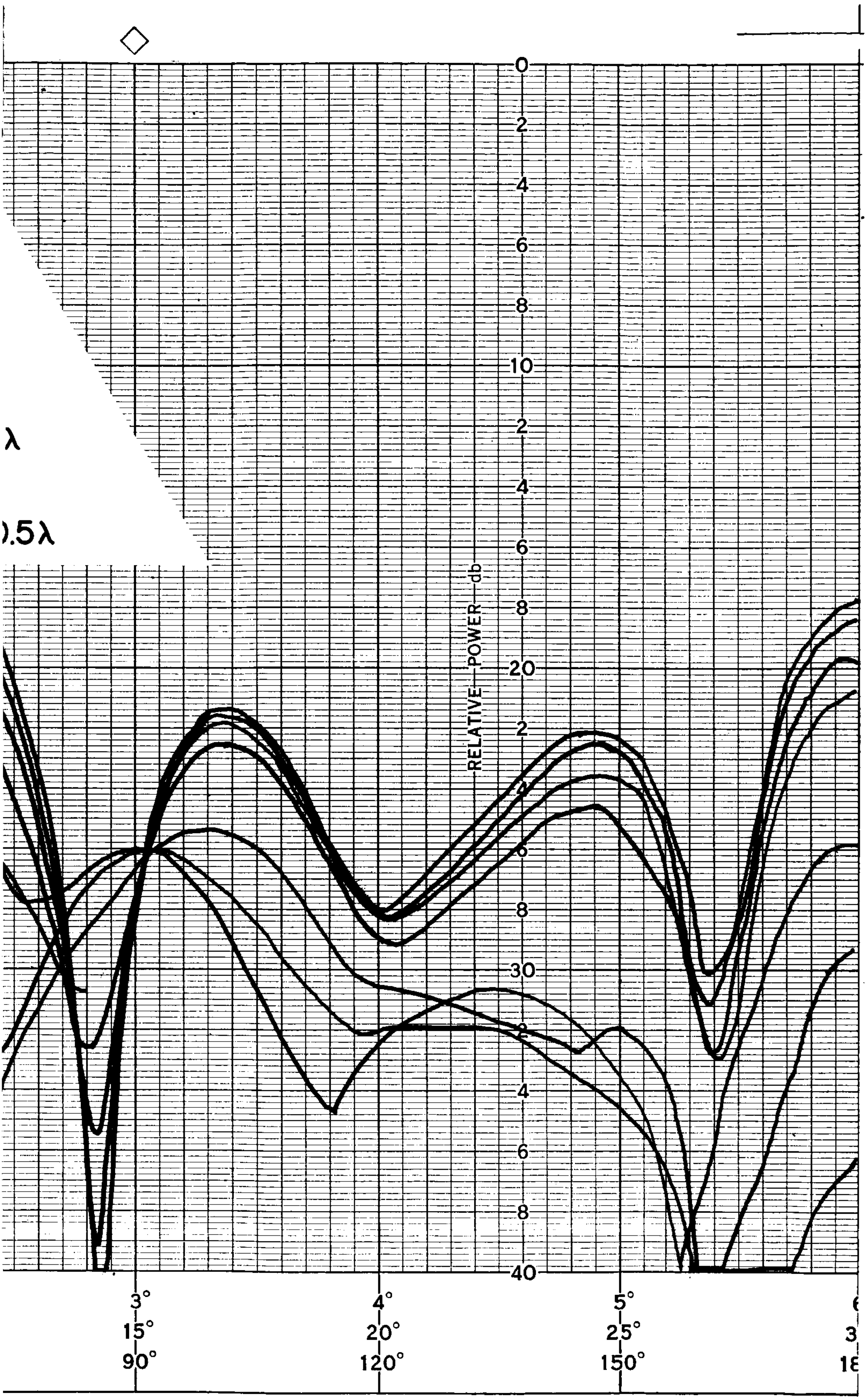
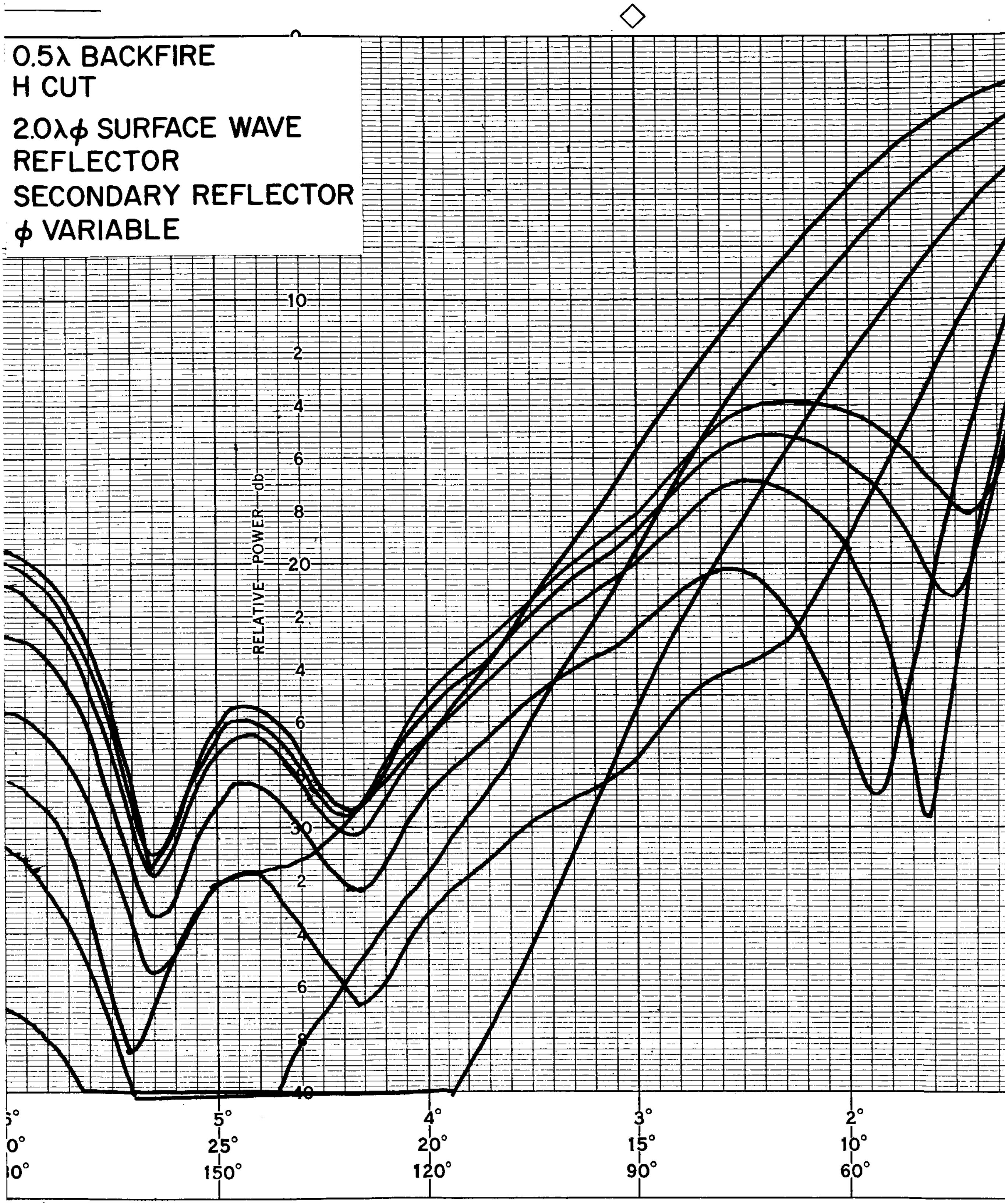
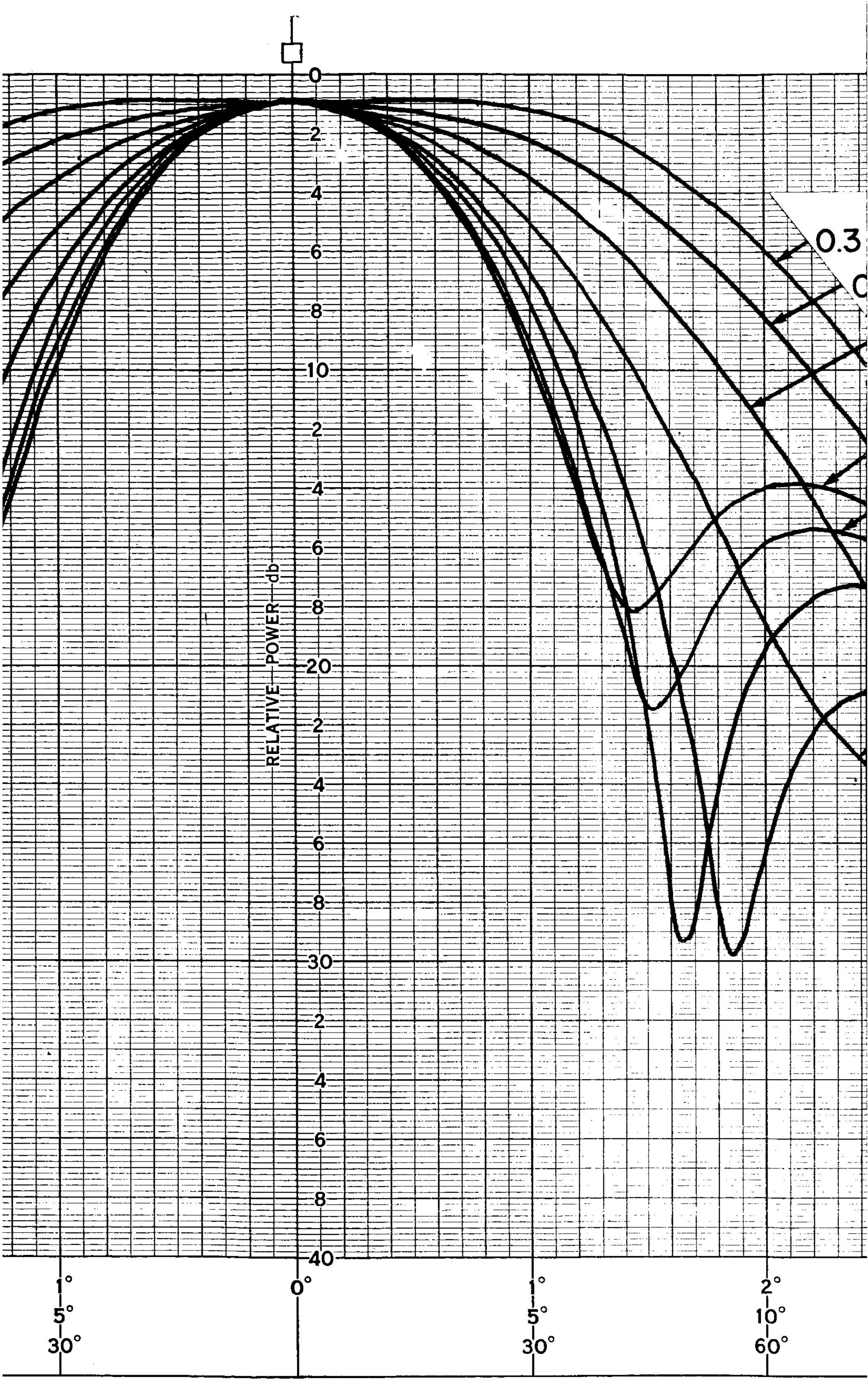


Figure 8. E Plane Patterns with 2.0 λ Diameter Reflector, λ/4 Rim Removed, Small Reflector 0.30-0.65 λ Diameter

18-2



0.5λ BACKFIRE
H CUT
2.0λφ SURFACE WAVE
REFLECTOR
SECONDARY REFLECTOR
φ VARIABLE
RELATIVE POWER—db
10
20
30
40
5°
25°
150°
4°
20°
120°
3°
15°
90°
2°
10°
60°



RELATIVE POWER—db
0
2
4
6
8
10
2
4
6
8
20
2
4
6
8
30
2
4
6
8
40
0.3
1°
5°
30°
0°
1°
5°
30°
2°
10°
60°

20-1

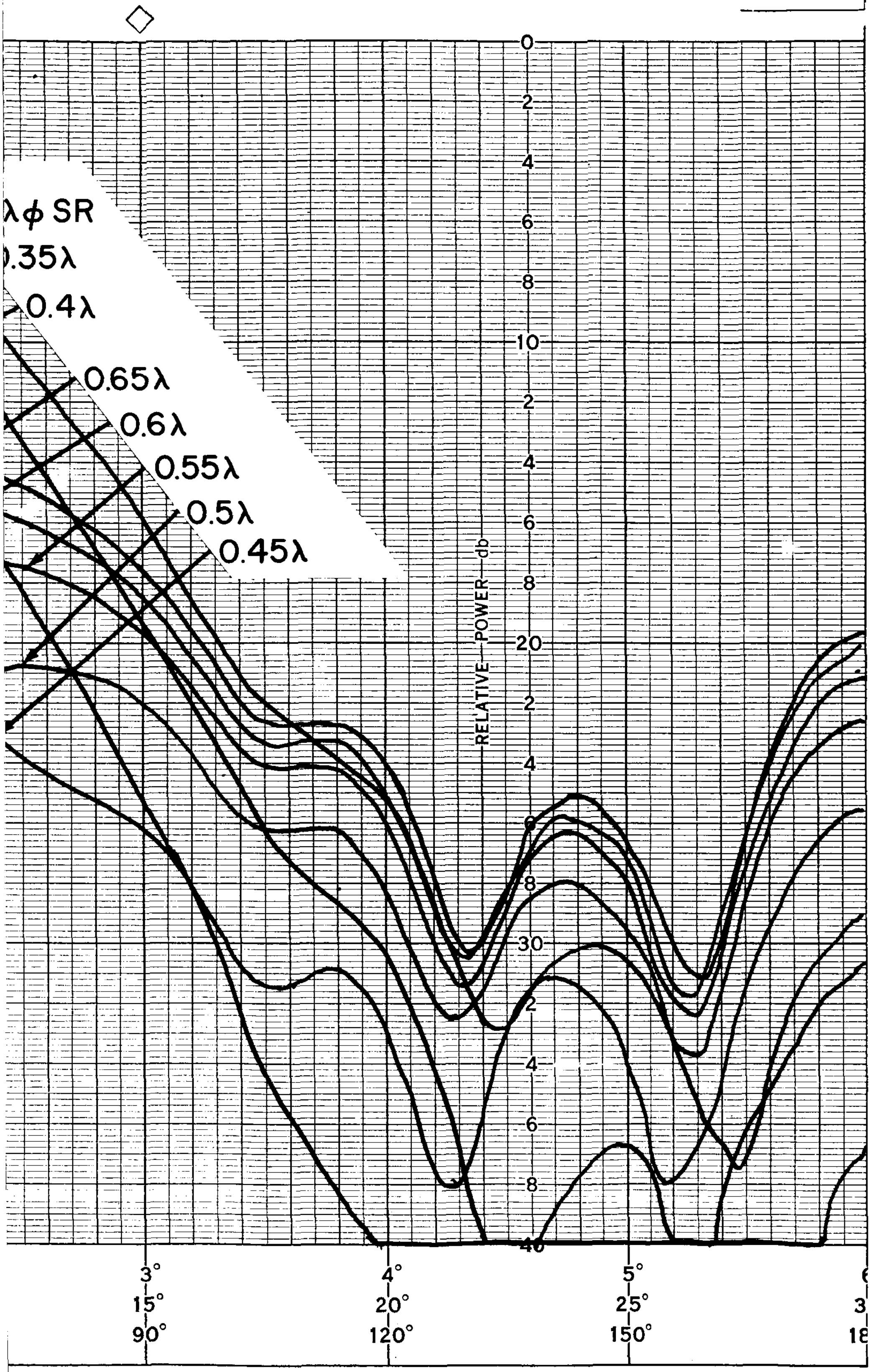
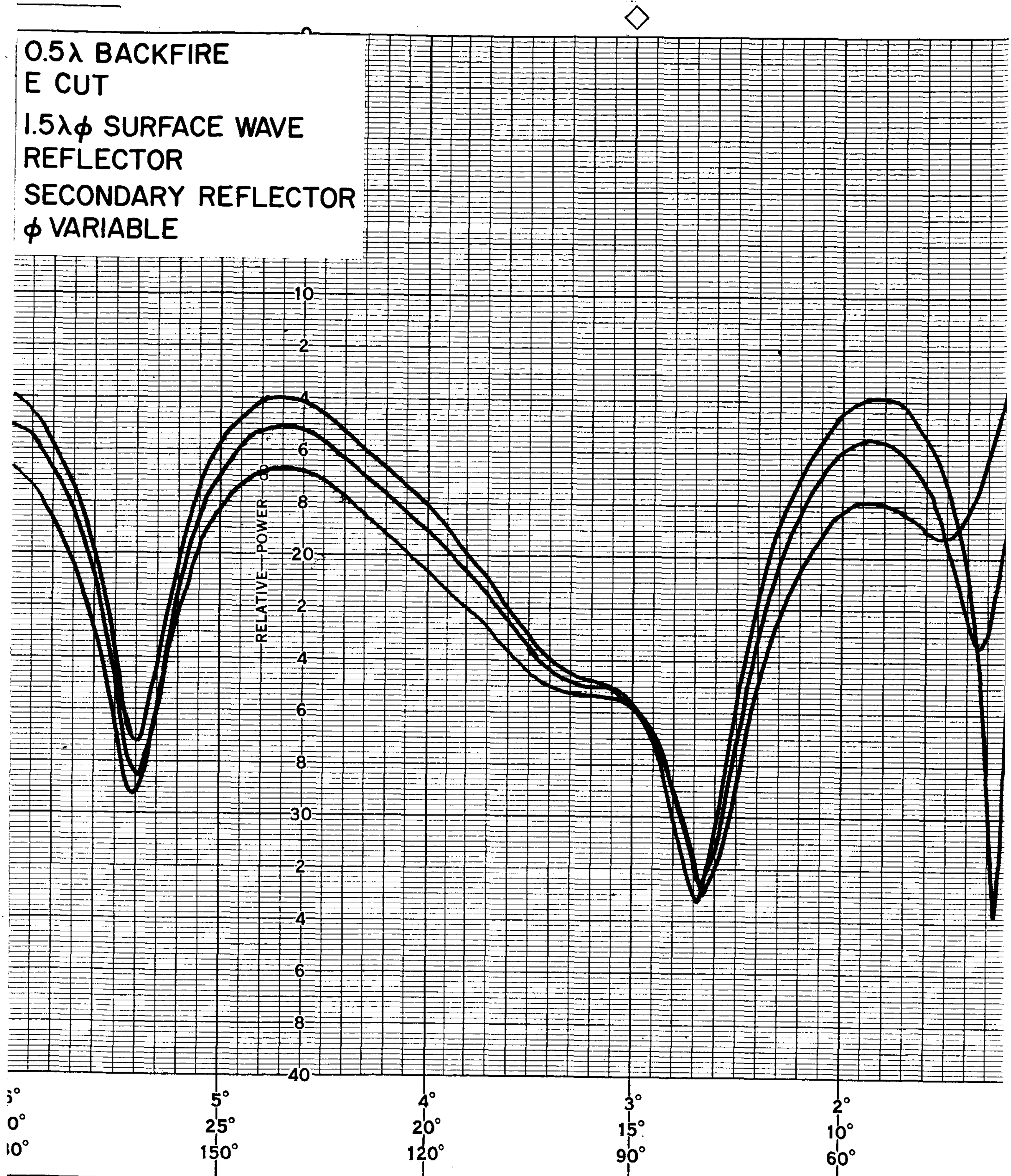


Figure 9. H Plane Patterns with 2.0 λ Diameter Reflector, λ/4 Rim Removed, Small Reflector 0.30-0.65 λ Diameter



0.5λ BACKFIRE
E CUT
1.5λϕ SURFACE WAVE
REFLECTOR
SECONDARY REFLECTOR
ϕ VARIABLE
RELATIVE POWER
10
2
4
6
8
20
2
4
6
8
30
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150°
4°
20°
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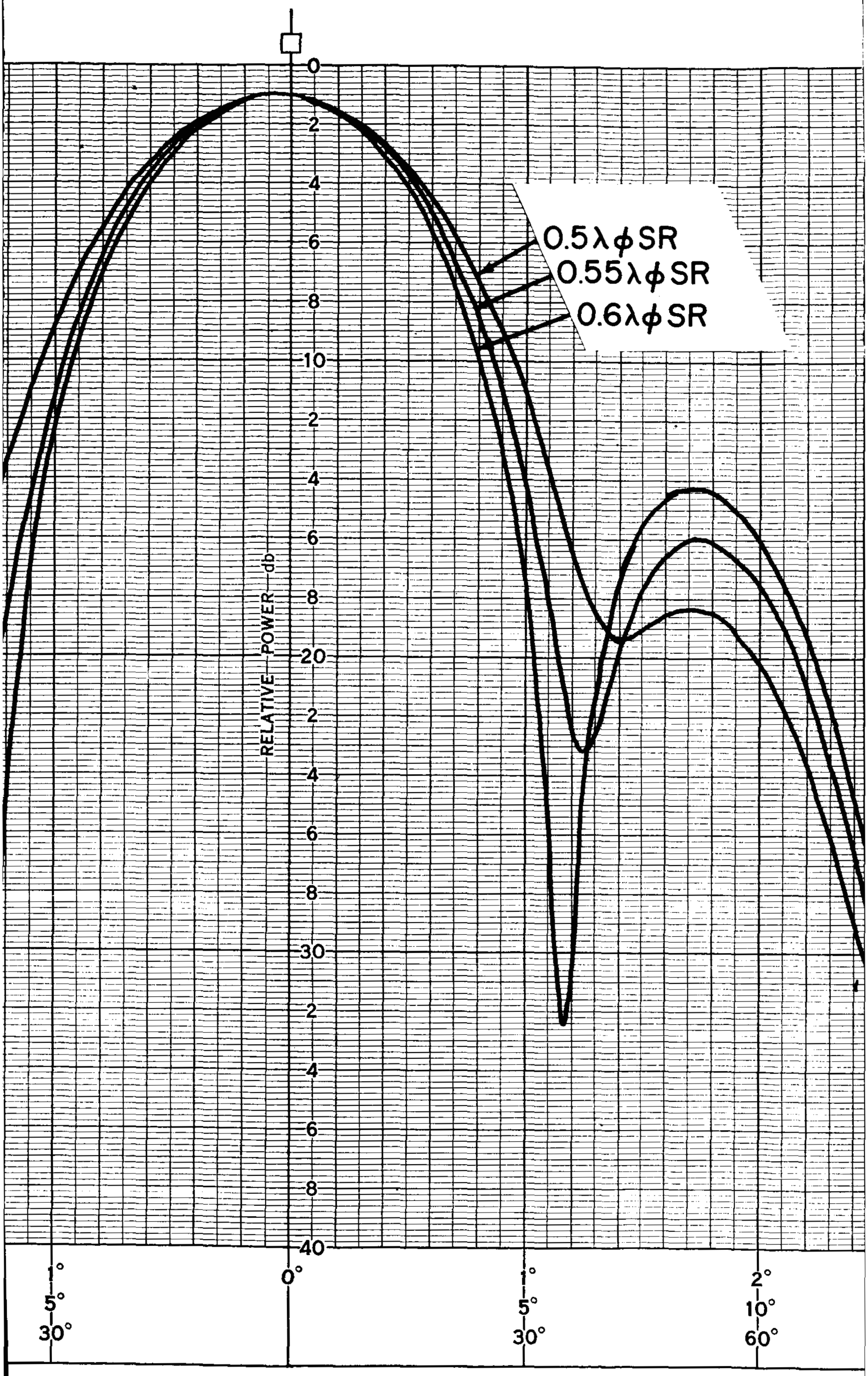
3°
15°
90°
2°
10°
60°


0.5λφSR
0.55λφSR
0.6λφSR
RELATIVE POWER db
0
2
4
6
8
10
2
4
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8
20
2
4
6
8
30
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8
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30°
2°
10°
60°

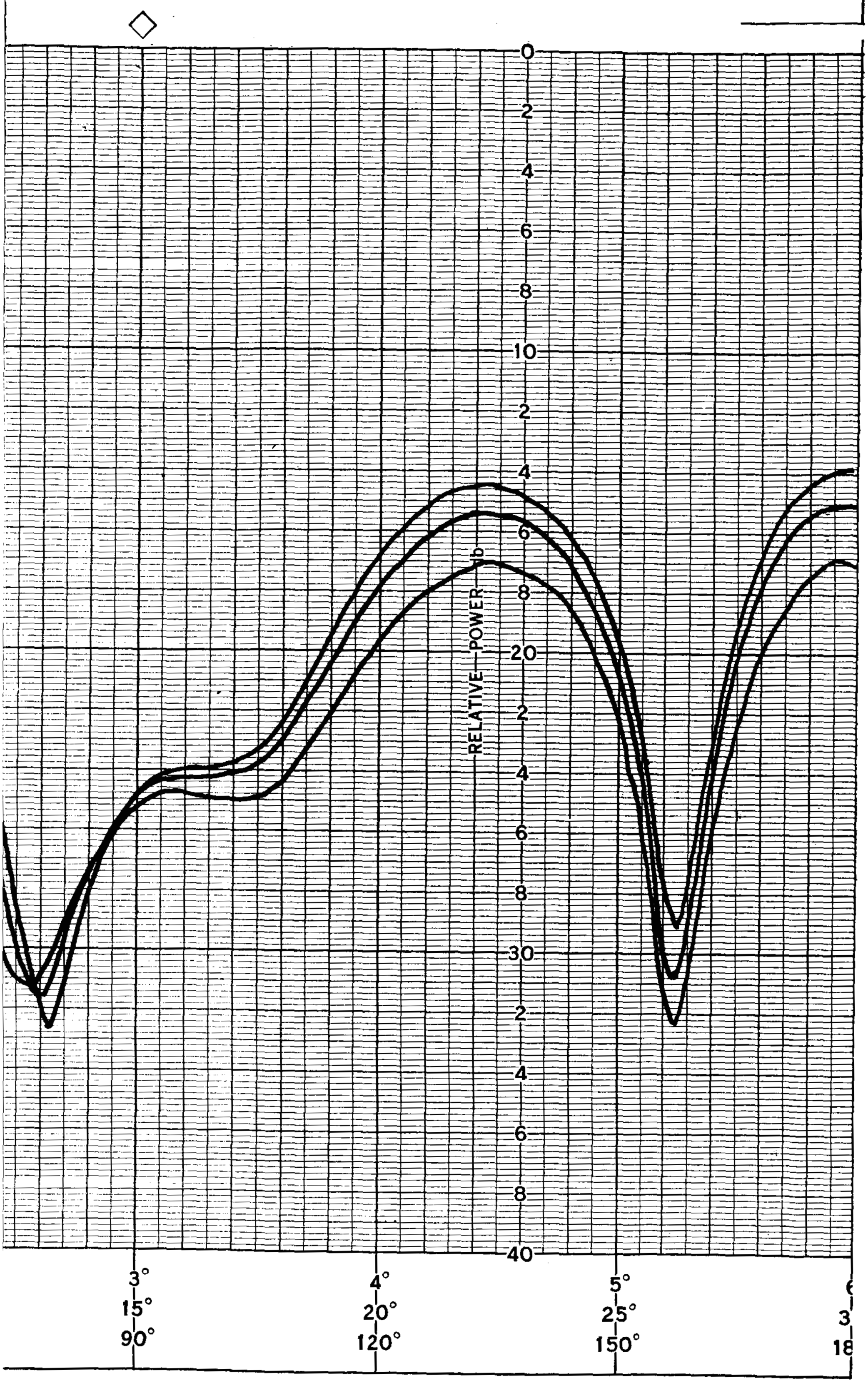
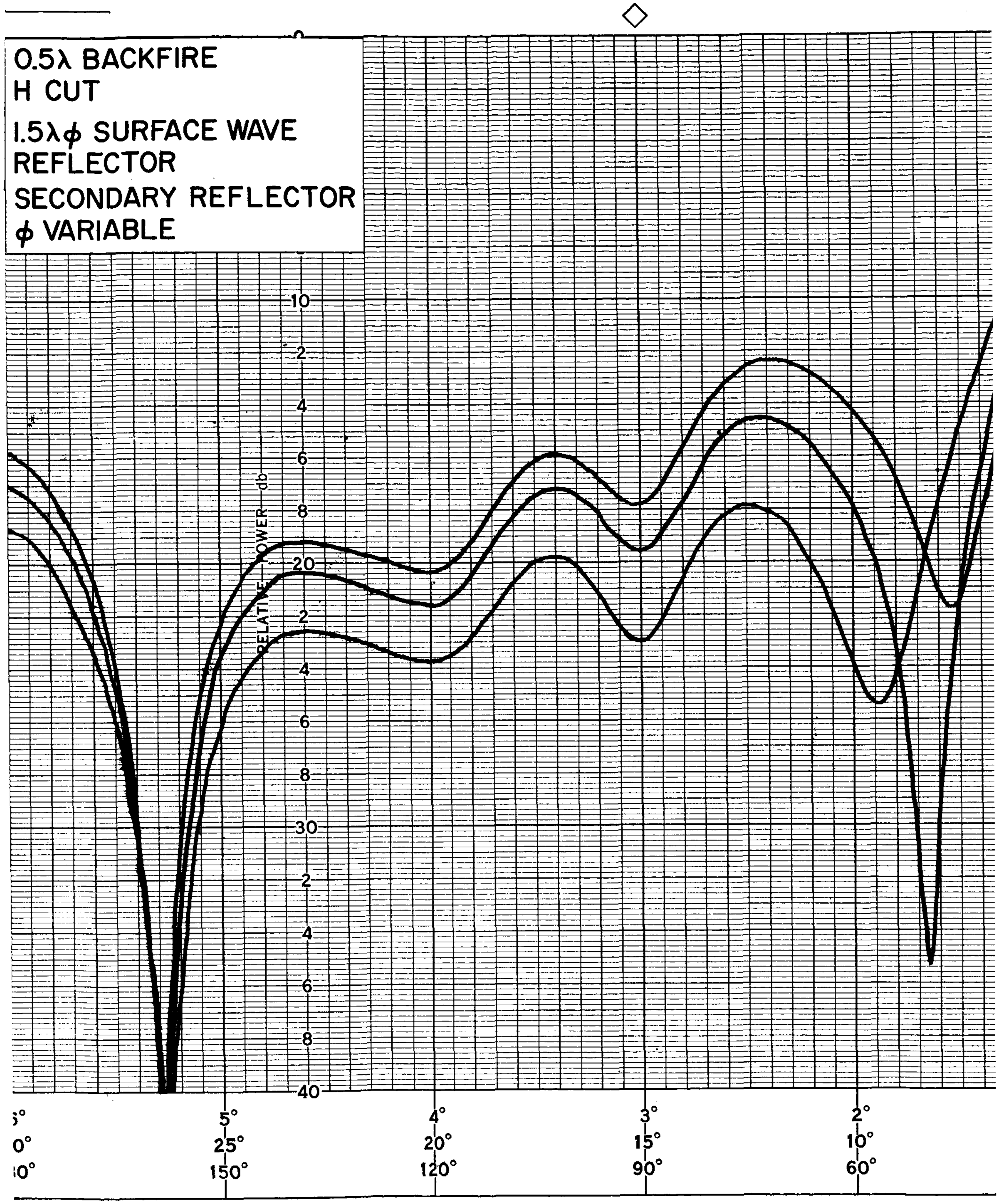


Figure 10. E Plane Patterns with 1.5 λ Diameter Reflector, λ/4 Rim Removed, Small Reflector Variation 0.50, 0.55, and 0.60 λ Diameters


0.5λ BACKFIRE
H CUT
1.5λφ SURFACE WAVE
REFLECTOR
SECONDARY REFLECTOR
φ VARIABLE
RELATIVE POWER - db
10
2
4
6
8
20
2
4
6
8
30
2
4
6
8
40
5°
25°
150°
4°
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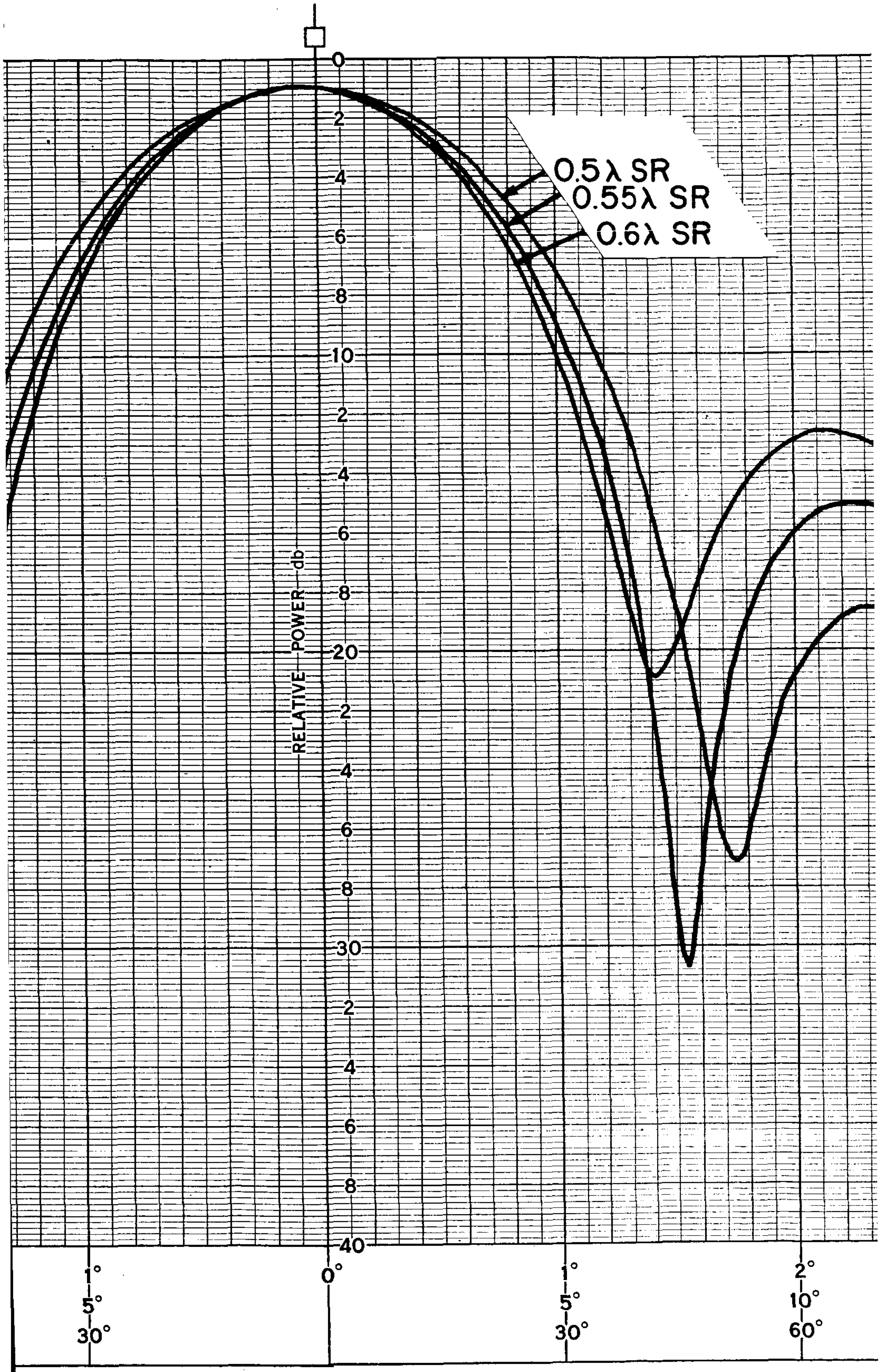
90°
2°
10°
60°


0.5λ SR
0.55λ SR
0.6λ SR
RELATIVE POWER db
0
2
4
6
8
10
20
30
40
1°
5°
30°
0°
2°
10°
60°

24-1

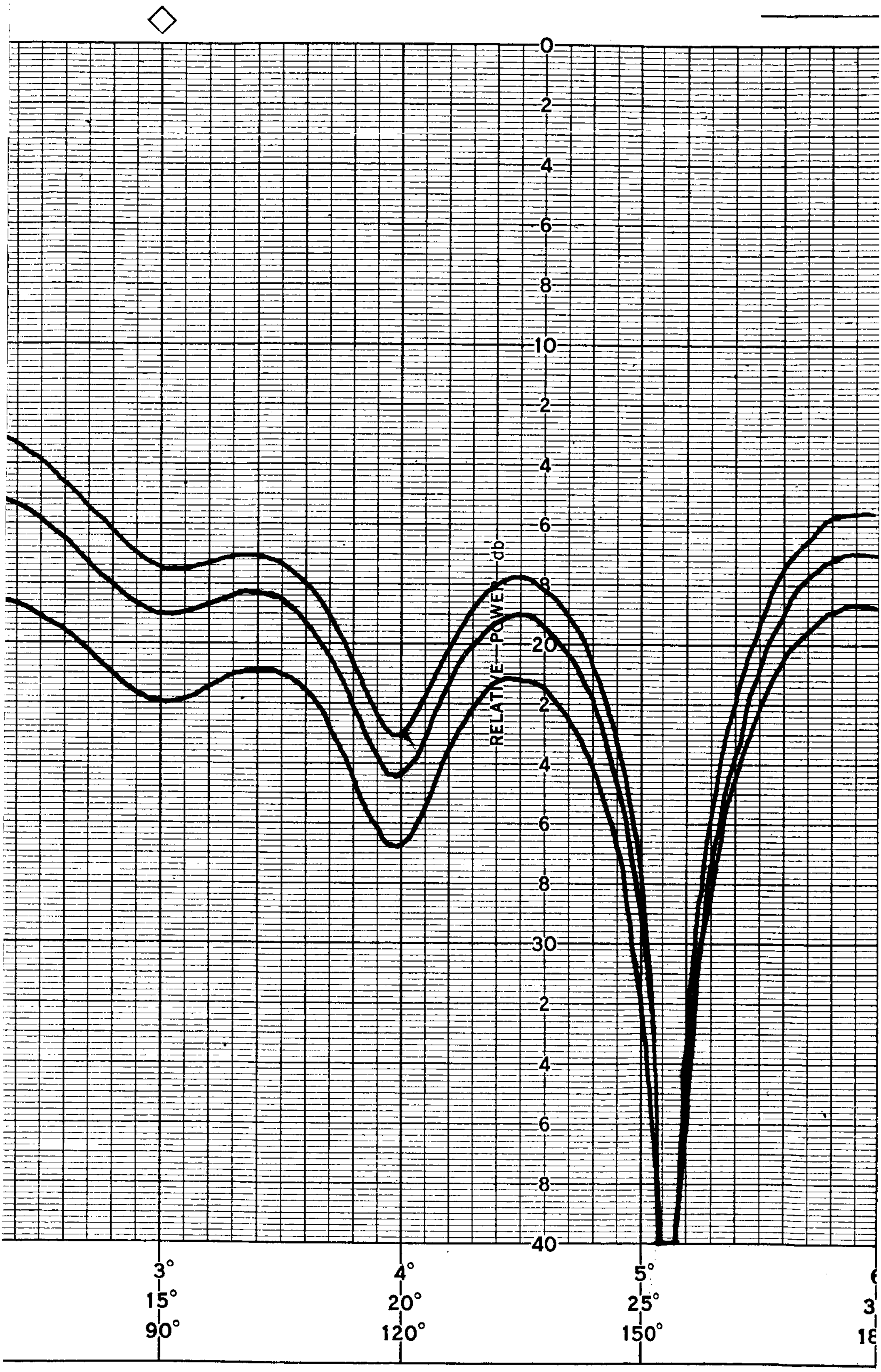


Figure 11. H Plane Patterns with 1.5 λDiameter Reflector, λ/4 Rim Removed, Small Reflector Variation 0.50, 0.55, and 0.60 λ Diameter

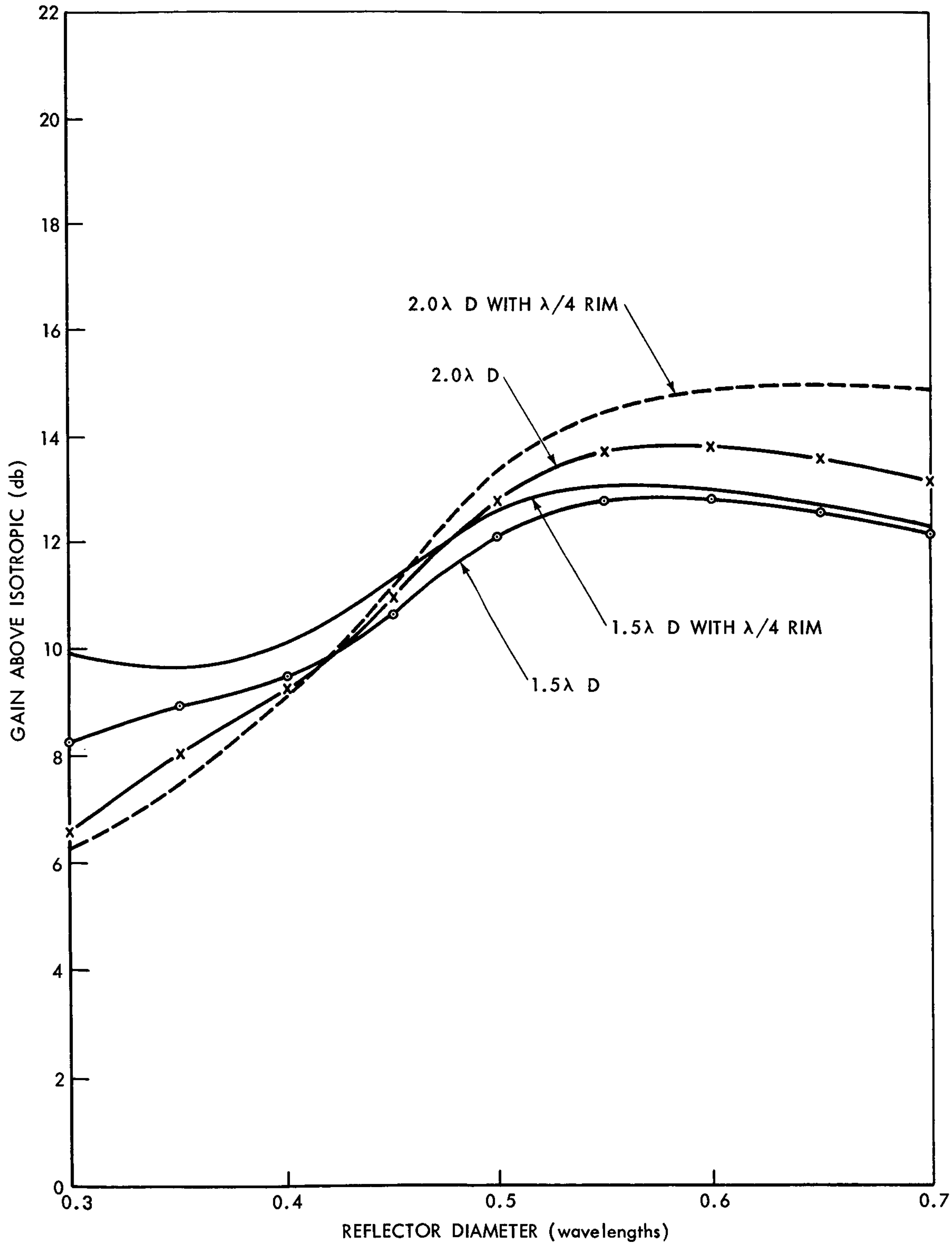
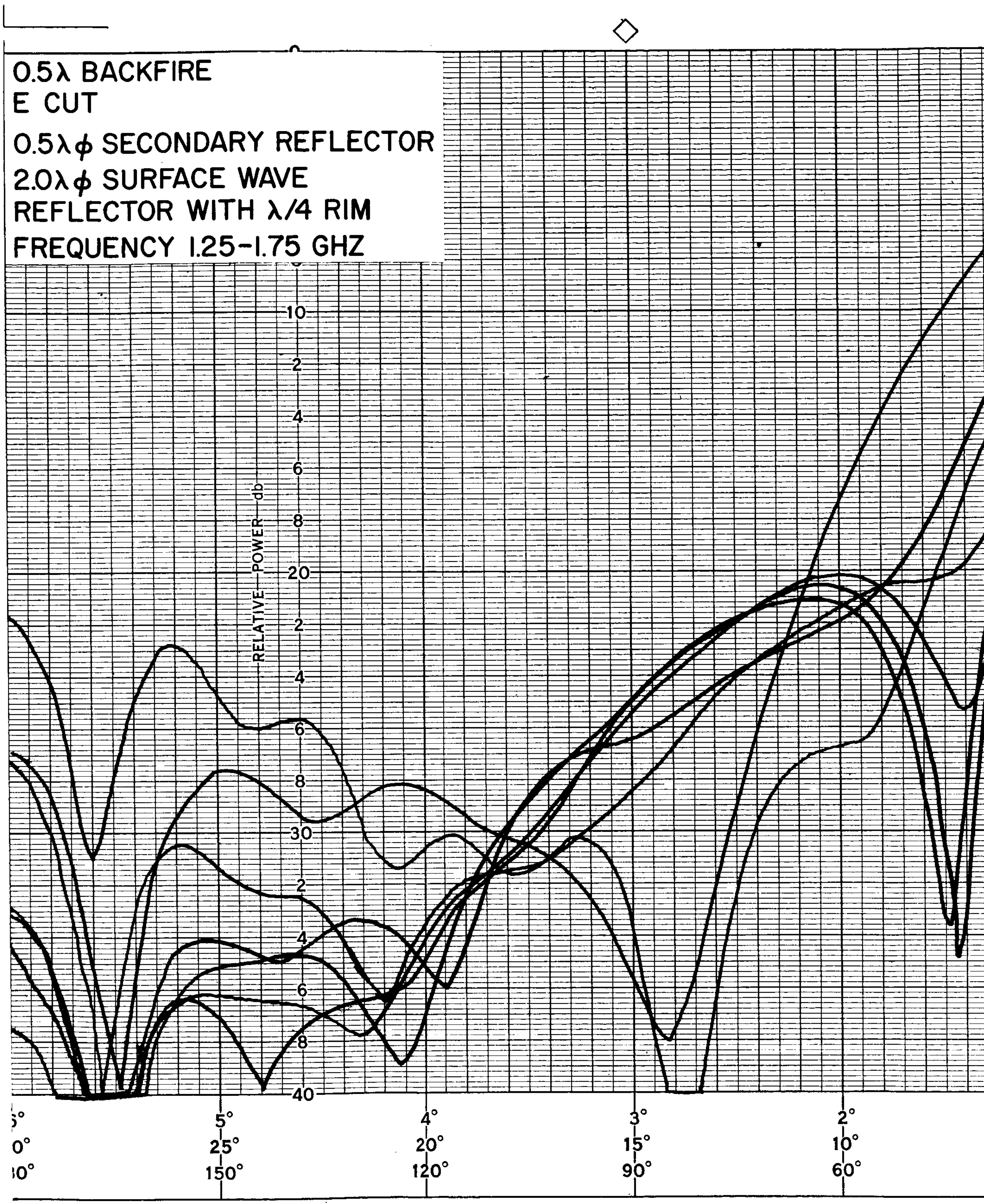
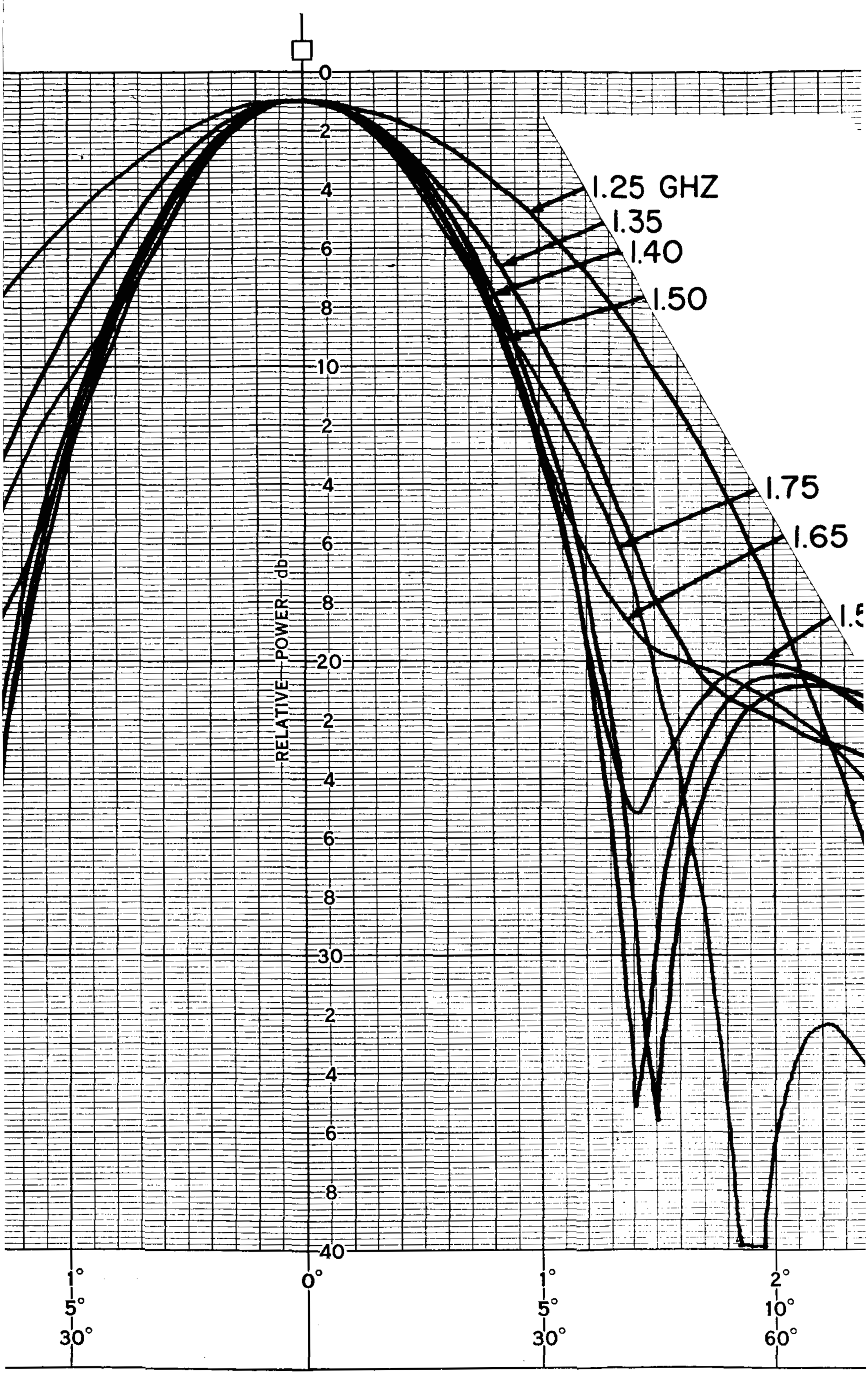


Figure 12. Gain Versus Reflector Diameter


0.5λ BACKFIRE
E CUT
0.5λφ SECONDARY REFLECTOR
2.0λφ SURFACE WAVE
REFLECTOR WITH λ/4 RIM
FREQUENCY 1.25-1.75 GHZ
RELATIVE POWER—db
10
2
4
6
8
20
2
4
6
8
30
2
4
6
8
40
5°
25°
150°
4°
20°
120°
3°
15°
90°
2°
10°
60°


1.25 GHZ
1.35
1.40
1.50
1.75
1.65
RELATIVE POWER db
0
2
4
6
8
10
20
30
40
1°
5°
30°
0°
2°
10°
60°

28-1

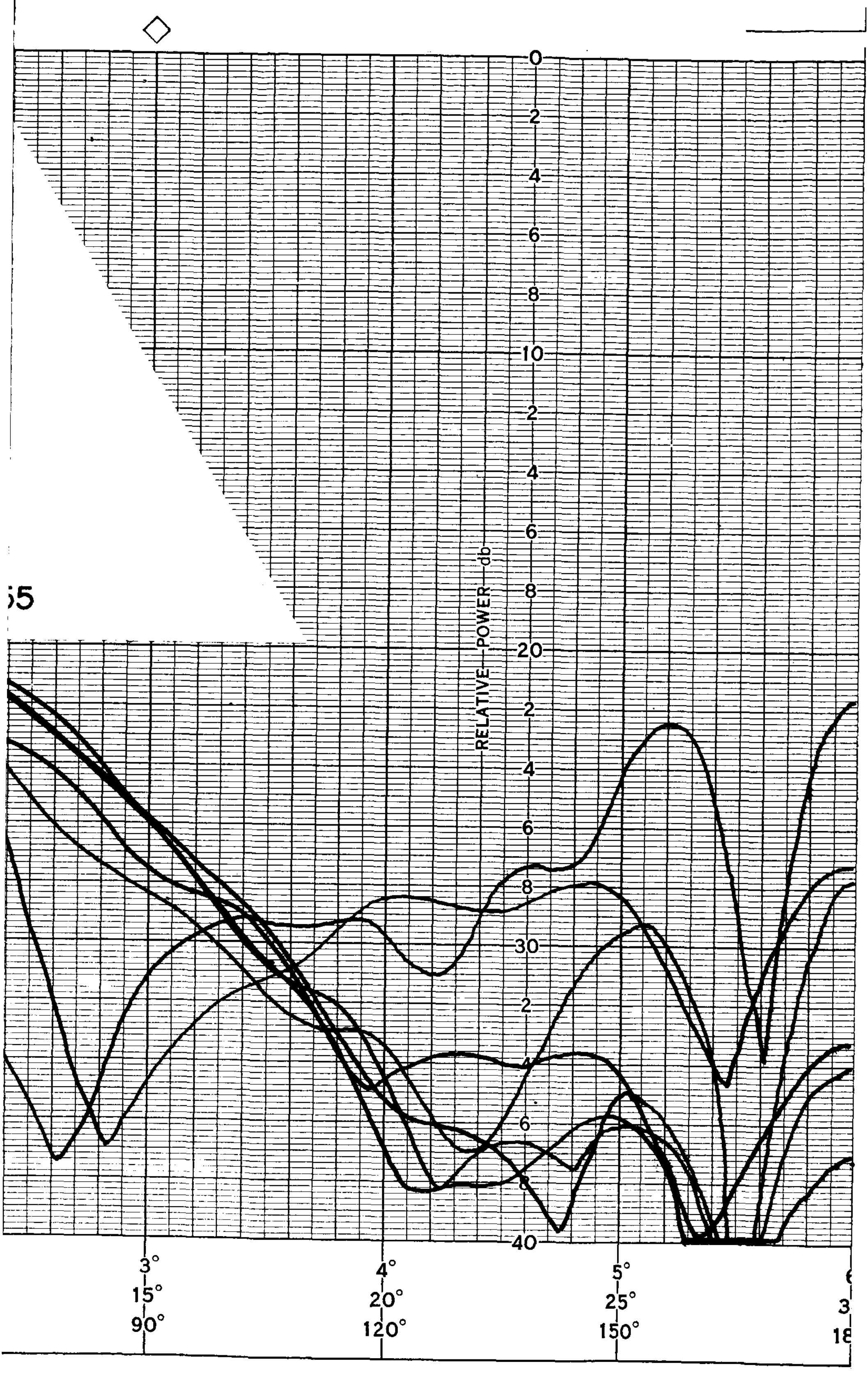
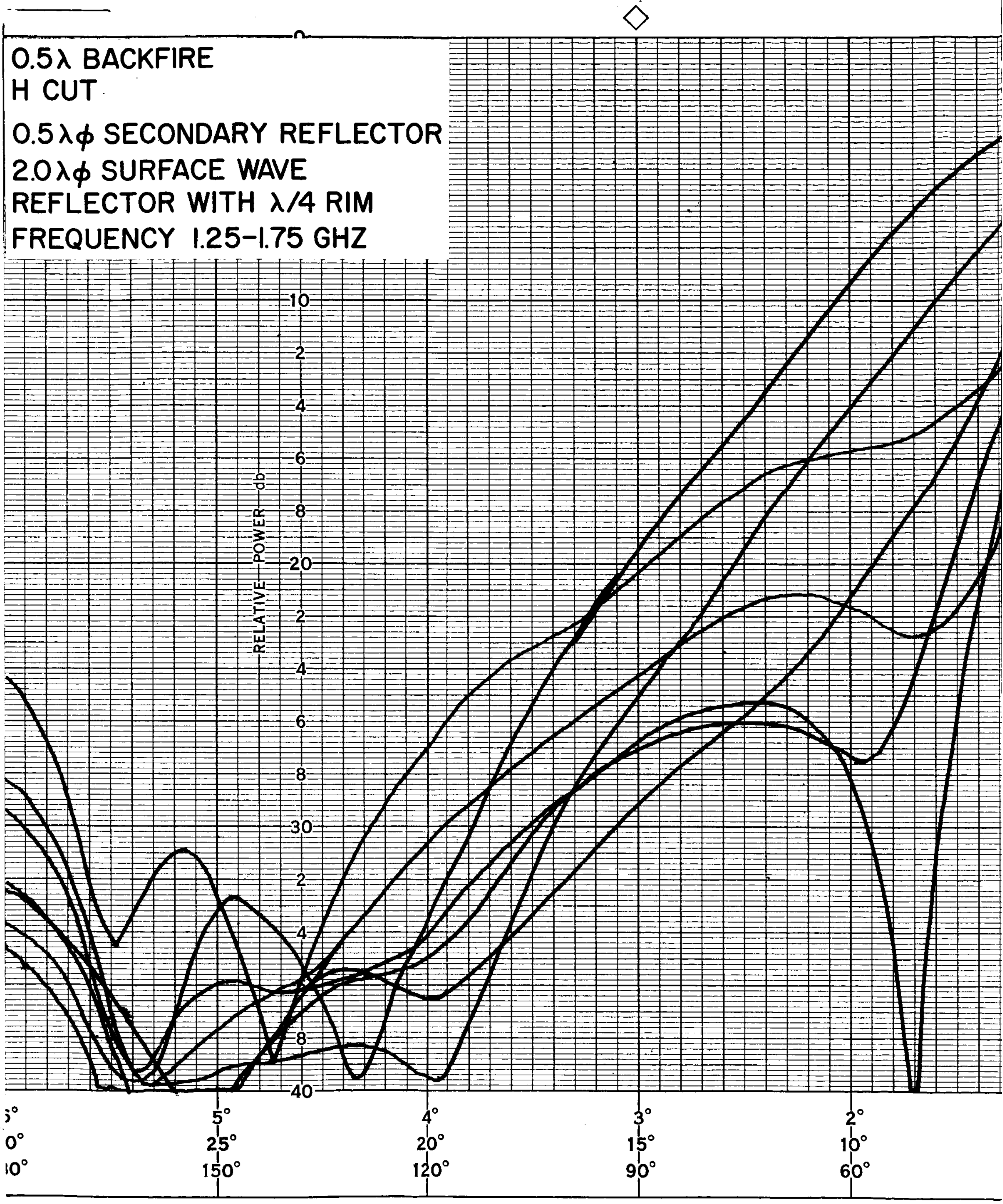
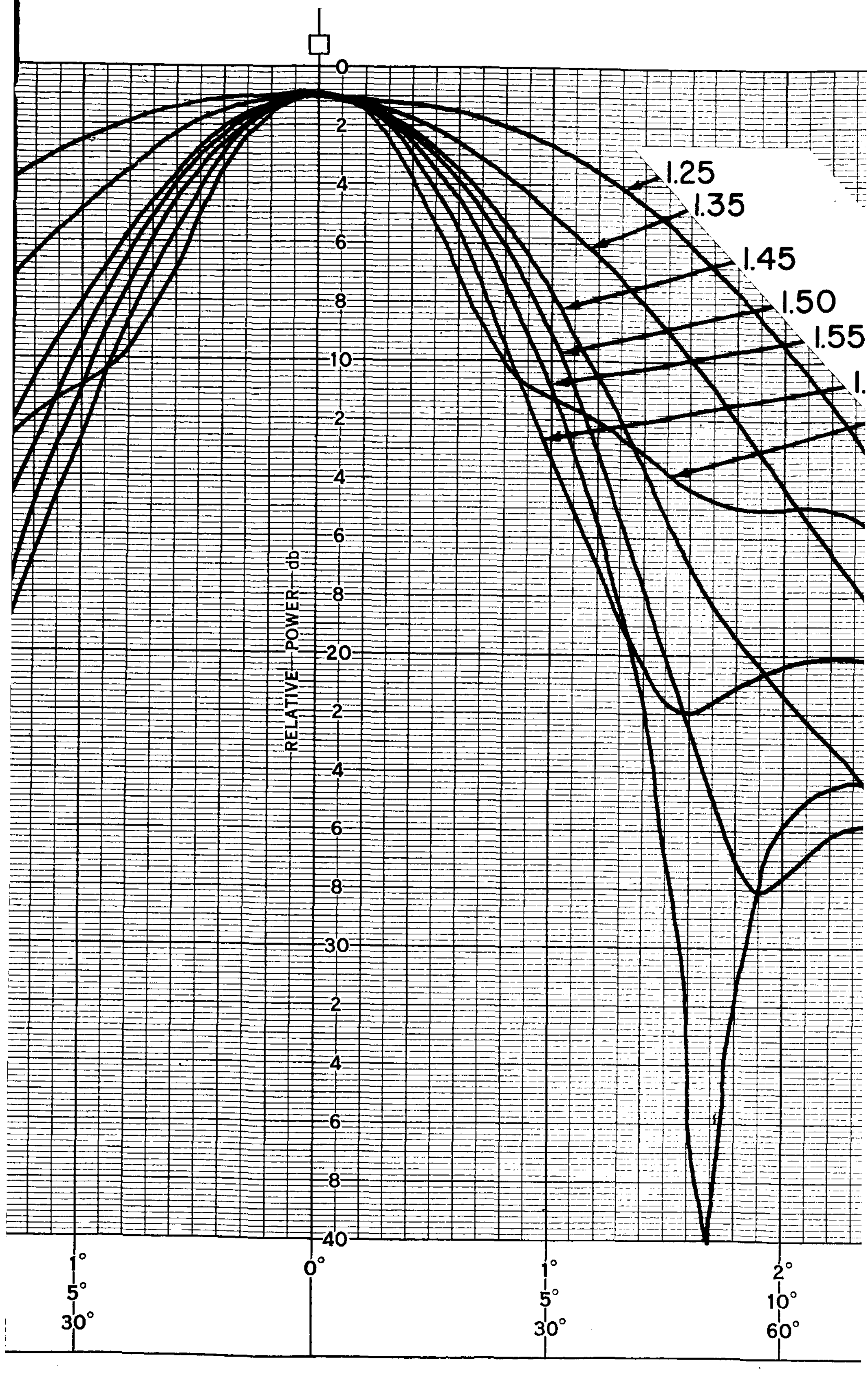


Figure 13. E Plane Radiation Patterns from 1.25-1.75 GHz. with 2.0 λ Diameter Reflector, λ/4 Rim, 0.5 λ Diameter Small Reflector

28-2


0.5λ BACKFIRE
H CUT
0.5λφ SECONDARY REFLECTOR
2.0λφ SURFACE WAVE
REFLECTOR WITH λ/4 RIM
FREQUENCY 1.25-1.75 GHZ
RELATIVE POWER db
0
10
2
4
6
8
20
2
4
6
8
30
2
4
6
8
40
5°
25°
150°
4°
20°
120°
3°
15°
90°
2°
10°
60°



1.25
1.35
1.45
1.50
1.55
RELATIVE POWER—db
0
2
4
6
8
10
2
4
6
8
20
2
4
6
8
30
2
4
6
8
40
1°
5°
30°
0°
1°
5°
30°
2°
10°
60°

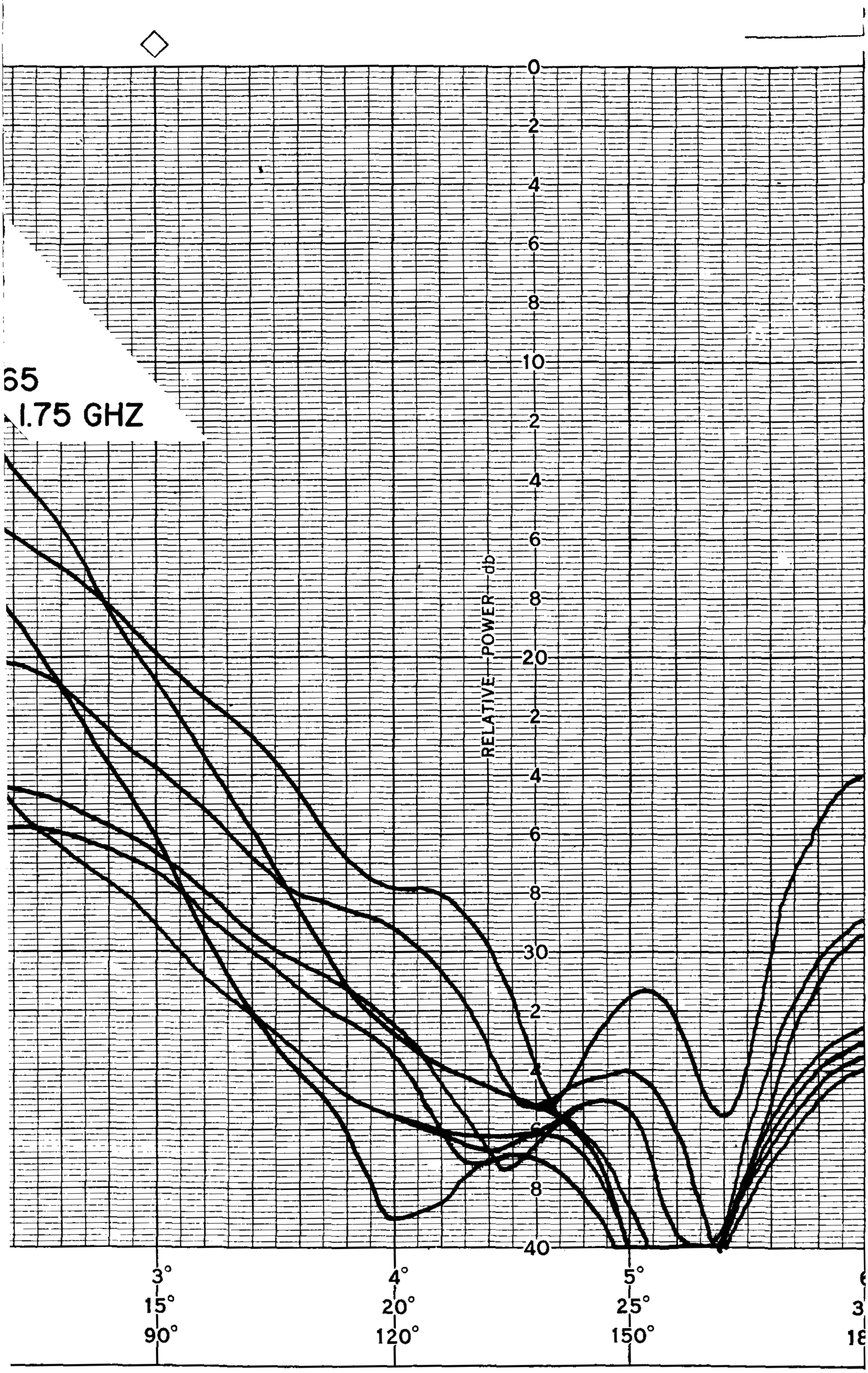


Figure 14. H Plane Radiation Patterns from 1.25-1.75 GHz. with 2.0 λ Diameter Reflector, λ/4 Rim, 0.5 λ Diameter Small Reflector

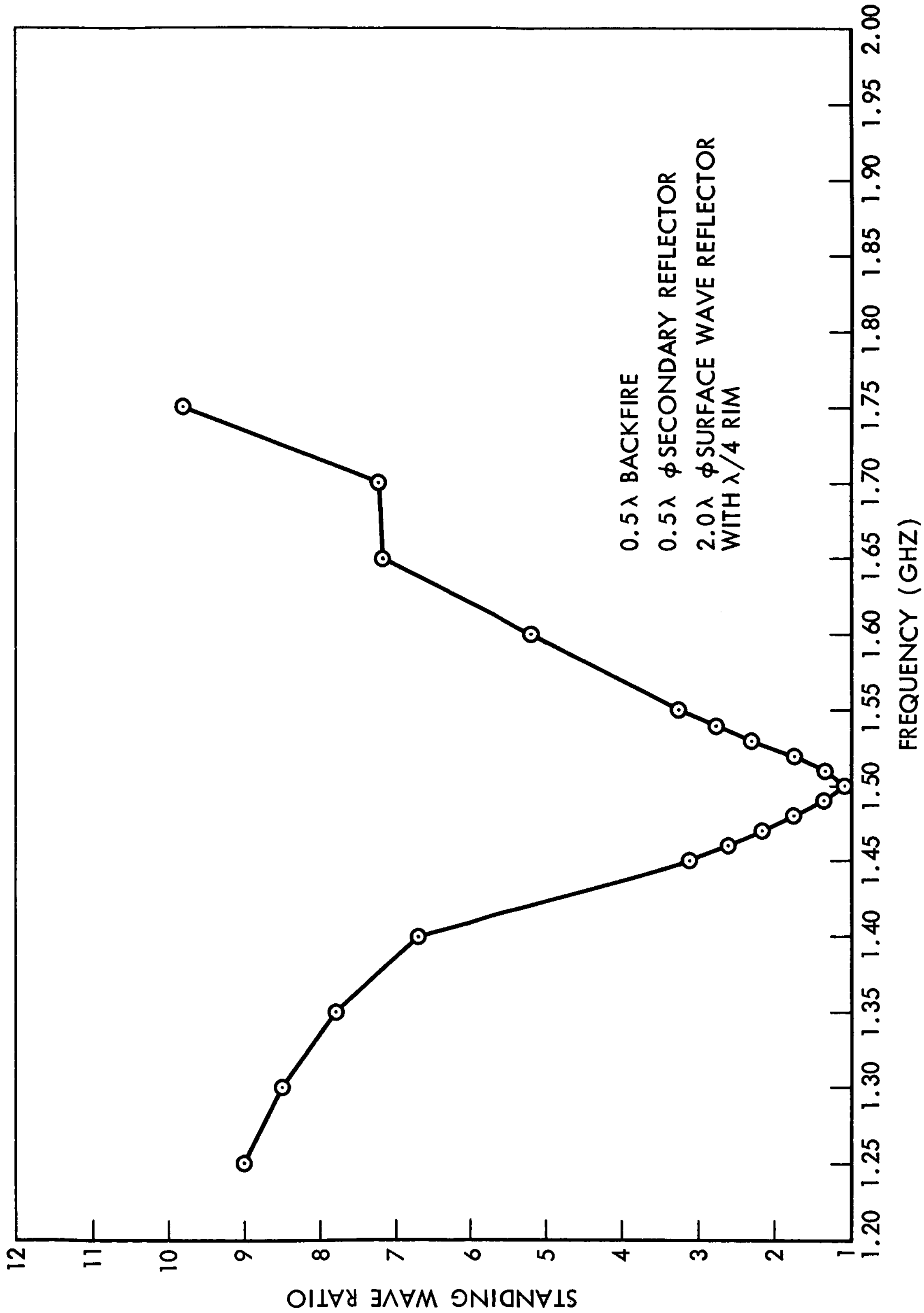


Figure 15. Antenna s.w.r. Versus Frequency