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Television Receiving Antenna System Component Measurements

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TELEVISION RECEIVING ANTENNA SYSTEM COMPONENT MEASUREMENTS

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Relative gain of fifteen television receiving antennas was measured as a function of frequency and azimuth angle. Input voltage standing-wave ratio was measured as a function of frequency to determine the scalar impedance properties of the antennas. These antennas, a sample of those available from sources likely to be utilized by TV antenna installation technicians as well as consumers, ranged in price from $1.00 to $78.00 and in length from 18 cm to 400 cm. Insertion loss of a sample of system components, balanced-to-unbalanced line transformers and VHF/UHF signal splitters, was measured, and transmission line attenuation was obtained from manufacturers' data. Antenna gain, component insertion loss, transmission line attenuation, and calculated dipole antenna constant are the significant components of a power budget equation relating power flow in the TV signal field incident upon the antenna to the signal power available at the receiver. Results for four simple types of home installations are given. The range of the power budget data for best and worst combinations of antennas, transmission lines, and other system components illustrates the range of the power available at the receiver versus frequency for a specified power flow in the signal field.

Key words: Antenna gain; power budget calculations; TV.

1. INTRODUCTION

Data compiled during this measurement effort consist primarily of antenna gain incorporating antenna mismatch loss, balun insertion loss, signal splitter insertion loss, and manufacturers' data for transmission line attenuation. These data and an antenna constant, equal to the ratio of power received at the terminals of a properly oriented half-wave dipole antenna to the power flow per unit area in the incident field, are components of a power budget equation giving the power level at the TV receiver terminals when the

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antenna is in a specified field. The antenna constant is a function of frequency and, as defined here, is simply a power ratio which is expressed in decibels (dB).

Therefore, a <u>free-space</u> power budget equation can be written as follows:

$$P_{rec}(\text{dBW}) = \text{Antenna Constant} + \text{Antenna Gain} - \text{Balun Insertion Loss} - \text{Signal Splitter Loss} - \text{Transmission Line Loss},$$

when the TV antenna is in a plane-wave field with a linearly polarized power flow of 1 W/m^2. All gains and losses are expressed in decibels, and the available power at the receiver terminals, P_{rec}, is expressed in decibels relative to 1 W. Note that P_{rec} can be determined for any power flow, P, by adding 10 $\log_{10}$ P to the antenna constant. If field strength rather than power flow is known, use the following equation to determine P:

$$P(W/m^2) = \frac{E^2}{120\ \pi} ,$$

where E is the electric field strength in volts/meter and 120 π is the intrinsic impedance of free space.

The remainder of this report discusses the component parts of this power budget equation and their significance in the overall antenna system performance.

Antenna gain data were measured relative to that of a lossless half-wave dipole antenna at 63, 79, 183, 213, 473, 641, and 803 MHz, corresponding to the center frequencies of channels 3, 5, 8, 13, 14, 42, and 69. Voltage standing-wave ratios of various system components, including the antennas, also were measured using swept-frequency techniques between 50 and 810 MHz. Manufacturers' data were obtained for transmission line attenuation and, when possible, for component specifications.

2. DEFINITIONS AND TERMINOLOGY

2.1 Voltage Standing-Wave Ratio (VSWR) and Mismatch Loss

The VSWR is a measure of the amplitude ratio of the reflected to incident waves at the terminals of an rf component in a receiving or transmitting system. This easily measured scalar quantity indicates directly the extent to which an rf component will cause reflected waves in a system resulting in less than ideal transfer of rf power through the system. This less-than-ideal transfer of power indicated by a VSWR > 1 at the terminals of an rf component is called the conjugate mismatch loss, or simply mismatch loss, when the properly terminated component is attached to a nonreflecting generator. This loss, given by

$$M_L(\mathrm{dB}) = 10 \log_{10} \left[1 - \left(\frac{\mathrm{VSWR}-1}{\mathrm{VSWR}+1} \right)^2 \right] \Bigg|_{\mathrm{VSWR\ gen} = 1}$$

is the loss due to impedance mismatch for an rf component inserted into a previously nonreflecting system.

A 75-ohm reflection bridge was used to measure 300-ohm balanced rf component VSWR by incorporating the "best" commercial 75-ohm unbalanced-to-300-ohm balanced line transformer (balun) into the test terminals of the bridge. The "best" commercial balun was the one of twelve exhibiting the lowest 75-ohm terminal VSWR over the 50 MHz to 810 MHz frequency range when terminated with a "precision" 300-ohm resistor as well as exhibiting a low insertion loss. The rf properties of the balun degrade the measurement capability of the reflection bridge, and the accuracy of the VSWR measurements is limited.

2.2 Insertion Loss

Insertion loss of an rf component when placed in a nonreflecting system is simply the attenuation of the component due to the dissipation of energy in the component. Attenuation is defined as follows:

$$A(\mathrm{dB}) = 10 \log_{10} \frac{1}{|S_{21}|^2} ,$$

where $|S_{21}|$ is the magnitude of the transmission coefficient of the rf component.

The attenuation of power splitters was measured directly by recording the loss added by the splitters with the unused terminals properly terminated when inserted between two of the "best" baluns attached to a swept-frequency generator and a receiver, respectively. Since this 300-ohm balanced test system is not reflection free, the measured data are approximate.

Attenuation of the baluns was measured indirectly by measuring $|S_{21}|^2$ at the 75-ohm terminal of the balun with the 300-ohm terminal shorted, using the 75-ohm reflection bridge. These attenuation data are accurate to within ± 0.2 dB.

2.3 System Loss

The losses in a transmission system consisting of transmission lines, baluns, and signal splitters between the antenna and TV receiver can only be approximated by adding mismatch and insertion losses when these components are interconnected. System insertion loss must be measured as a whole to give accurate loss data.

The range of complexity of TV systems, implied by measured data in this report, is shown in Figure 1.

2.4 Antenna Gain

Power gain of an antenna is that performance parameter defined by the IEEE (1969) as follows:

> "In a given direction, 4π times the ratio of the radiation intensity in that direction to the net power accepted by the antenna from the connected transmitter.
>
> Note 1. When the direction is not stated, the power gain is usually taken to be the power gain in the direction of its maximum value.
>
> Note 2. Power gain does not include reflection losses arising from mismatch of impedance.
>
> Note 3. Power gain is fully realized on reception only when the incident polarization is the same as the polarization of the antenna on transmission."

Radiation intensity is defined as follows:

> "In a given direction, the power radiated from an antenna per unit solid angle."

As a result of these definitions, power gain is an inherent property of the antenna and does not include impedance mismatch or polarization losses; and

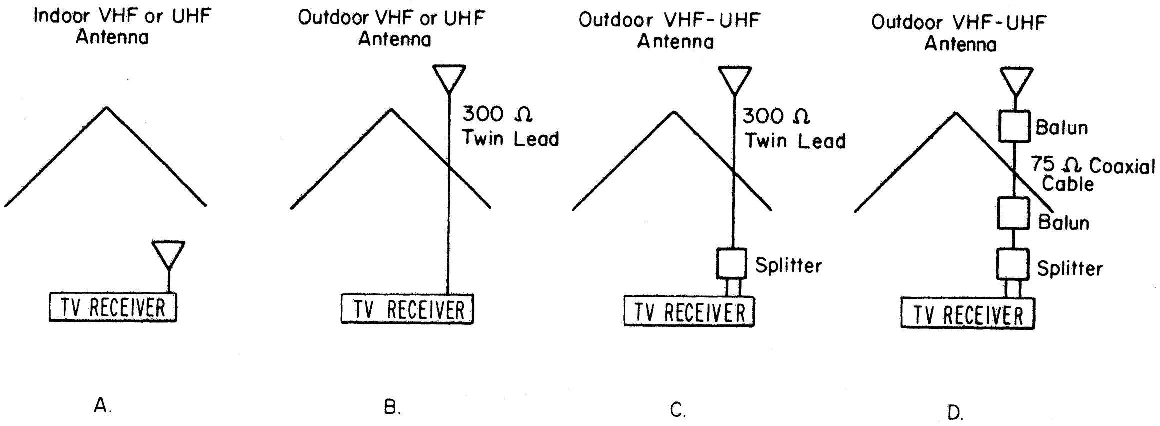

Figure 1. Typical single-set, single-antenna TV installations.

A. Indoor antenna on receiver, VHF or UHF.

B. Antenna to receiver with "twin lead" transmission line, VHF or UHF.

C. Antenna to receiver with "twin lead" transmission line, VHF and UHF.

D. Antenna to receiver with coaxial cable transmission line, VHF and UHF.

the standard for gain comparison is the isotropic radiator which radiates equally in all directions, is lossless, and has a gain of unity.

Most technical work with antenna gain measurements results in power gain data because the antenna user is assumed to have the capability of minimizing impedance mismatch and polarization losses through proper system design. However, for the television receiving antenna measurements described here, the gain data include mismatch losses because the typical user has no device to minimize these losses at each receivable channel frequency.

For maximum gain, the electrical design of the TV antenna must minimize VSWR (and the resulting mismatch loss) and maximize power gain. This is a difficult task for the antenna engineer to solve over the entire VHF-UHF TV band.

3. ANTENNA CONSTANT

Effective area of an antenna is defined by the IEEE (1969) as follows:

> "In a given direction, the ratio of the power available at the terminals of an antenna to the power per unit area of a plane wave incident on the antenna from that direction, polarized co-incident with the polarization that the antenna would radiate."

As a result of this definition, a half-wave dipole in a plane-wave field with a power flow of 1 W/m^2 will have 1 W.of power available at its antenna terminals if the frequency is 108.38 MHz. Figure 2 is a plot of the power available at the terminals of any lossless half-wave dipole in the frequency range of interest here, relative to that at the terminals of a 108.38 MHz half-wave dipole when the received field is maintained at a constant power flow. The choice of a lossless half-wave dipole as the reference gain antenna enables us to use the antenna constant, as we have defined it, expressed in decibels, directly in our power budget equation, thus relating power flow in the wave incident on the TV antenna to the power available at the TV receiver terminals.

An important point is illustrated by the power ratio plotted in Figure 2--the receiving antenna delivers power to a matched load that is proportional to the square of the wavelength. Antennas with equal gain but designed to operate in different parts of the VHF/UHF TV band may deliver to a TV receiver terminal's power levels differing by more than 20 dB.

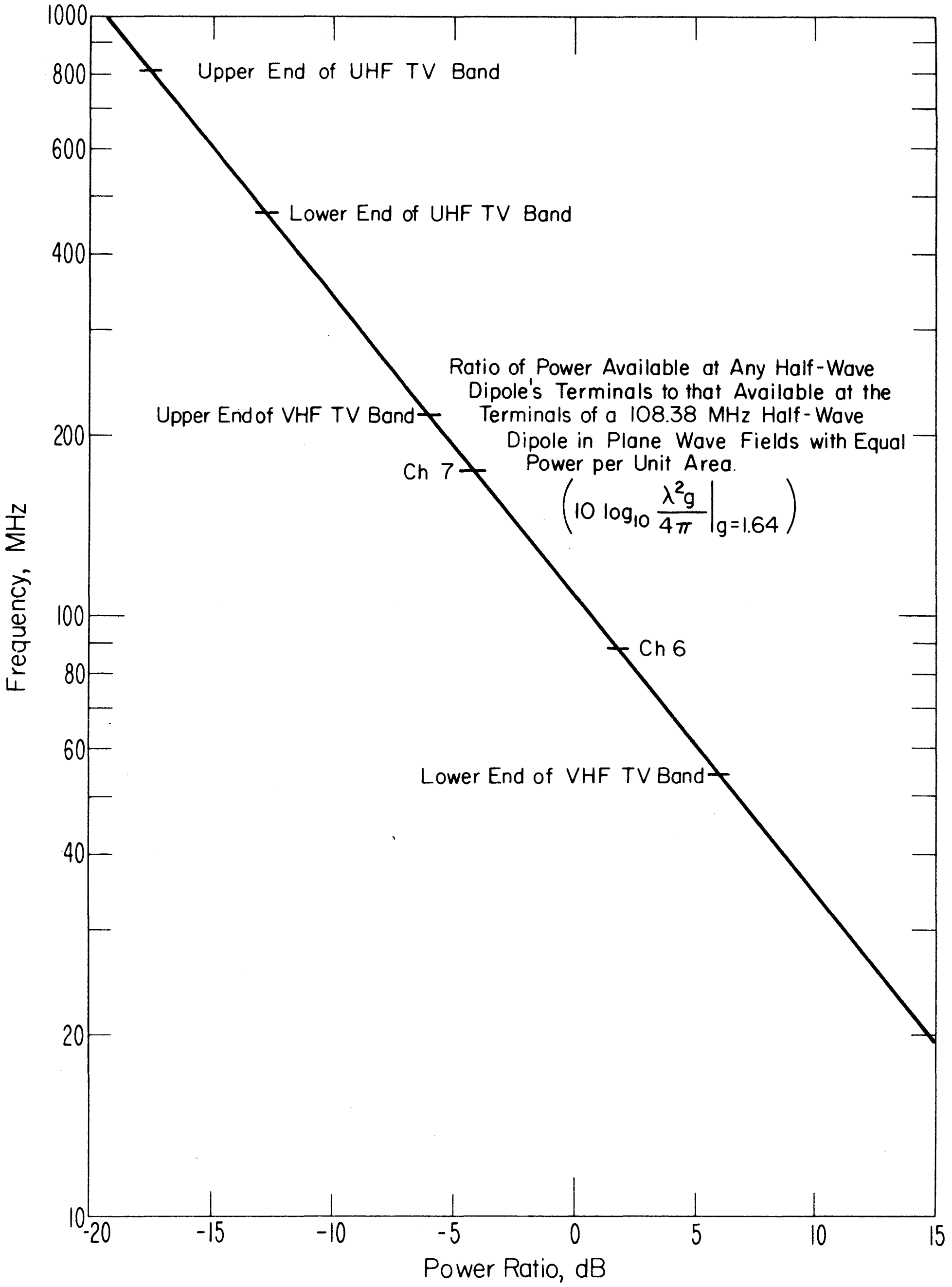

Figure 2. Dipole antenna constant versus frequency.

4. ANTENNA GAIN MEASUREMENTS

The VSWR and azimuthal antenna gain pattern were measured for fifteen different VHF and UHF home receiving antennas. This antenna complement included five VHF only antennas, four VHF/UHF combination antennas, and six UHF only antennas. Four of the five VHF antennas were designed for outdoor use; one was an indoor antenna. All VHF/UHF combination antennas were outdoor antennas. Two of the UHF antennas were indoor antennas and four were outdoor antennas. In selecting the antennas, we attempted to sample from expensive, intermediate priced, and inexpensive offerings from sources likely utilized by antenna installation technicians as well as sources more likely catering to home do-it-yourselfers. Purchase cost for the antennas we tested ranged from $78.00 down to $1.00. Average antenna cost was $29.00.

For one type of outdoor UHF antenna, we tested a wind-damaged antenna as well as a new, undamaged duplicate. Also, the performance of an indoor UHF loop antenna was measured for two loop orientations--vertical loop plane alignment and horizontal loop plane alignment. Therefore, with the fifteen types of antennas, seventeen sets of measurements were recorded.

As mentioned earlier, all VHF antennas were tested at 63 and 79 MHz in the low VHF band and at 183 and 213 MHz in the high VHF band. These frequencies are center frequencies for channels 3, 5, 8, and 13, respectively. All UHF antennas were tested at 473, 641, and 803 MHz, corresponding to channels 14, 42, and 69. None of these channels is used for television broadcasting in the vicinity of the test site. Our tests included swept-frequency measurements of VSWR (discussed in Section 7) and 360 deg azimuthal gain patterns for each frequency listed above, calibrated so that main-beam gain, half-power beam width, etc. could be calculated.

All VSWR measurements were made out-of-doors between wings of the laboratory building. Each antenna was erected so that the effect of the building on the VSWR measurement was minimized, yet the building helped shield the antenna from interfering signals. All gain measurements were conducted at the Table Mountain Test Range, north of Boulder, which is a flat mesa free of irregular terrain and man-made terrain clutter. This test range includes a turntable, flush with test range ground, upon which each antenna was erected for testing.

The best technique for making these gain measurements at our test site is defined and discussed in NBS Circular 598 (Cottony, 1958). All antennas were tested in the receive mode. The transmitting antenna used to produce a uniform, plane-wave field at the test site was a commercially available VHF/UHF combination TV receiving antenna (not one of the fifteen types of antennas tested) erected about 6 m above ground and 724 m away from the test antenna.

Half-wave dipole antennas tuned for the test frequencies were used at the same height above ground as reference antennas to calibrate the measurement system. Hence, the gains we report are with respect to a tuned half-wave dipole antenna at the same height which are numerically equal to free-space gain relative to the gain of a tuned half-wave dipole antenna (Cottony, 1958).

Television receiving antennas normally are designed and constructed to provide nominal 300 ohm impedance for connection to 300-ohm balanced transmission line. Matching transformers are available to allow connection to coaxial transmission cable with 75 ohms characteristic impedance. Our measurement system is designed for connection to devices with 50 ohms impedance; however, high quality, precision impedance matching devices for 300 ohm to 50 ohm or 75 ohm to 50 ohm connections are commercially unavailable. We selected a high-quality, commercially available 300 ohm to 75 ohm matching transformer, which we used with each antenna during testing. Mismatch and insertion losses for this matching transformer, as well as for similar devices used with the reference half-wave dipole antennas, were measured; and these losses have been calculated out of the gain results reported here. Loss associated with the 75 ohm to 50 ohm mismatch in connecting each antenna to our measurement system was ignored, since this loss was less than 0.1 dB. (In our discussion of measurement accuracy, we point out that our results are considered accurate to ± 0.5 dB.) Mismatch loss associated with the measured VSWR of each antenna, however, has not been removed from the gain results. We feel that this loss is a real quality of each antenna as a consequence of its design and that a typical antenna installation will not include any tuning device to overcome this loss.

Turning now to the measured data, Figures 3 and 4 are azimuth gain patterns typical for a VHF antenna and a UHF antenna, respectively. (All the measured patterns are included in the Appendix.) Figure 5 shows a similar

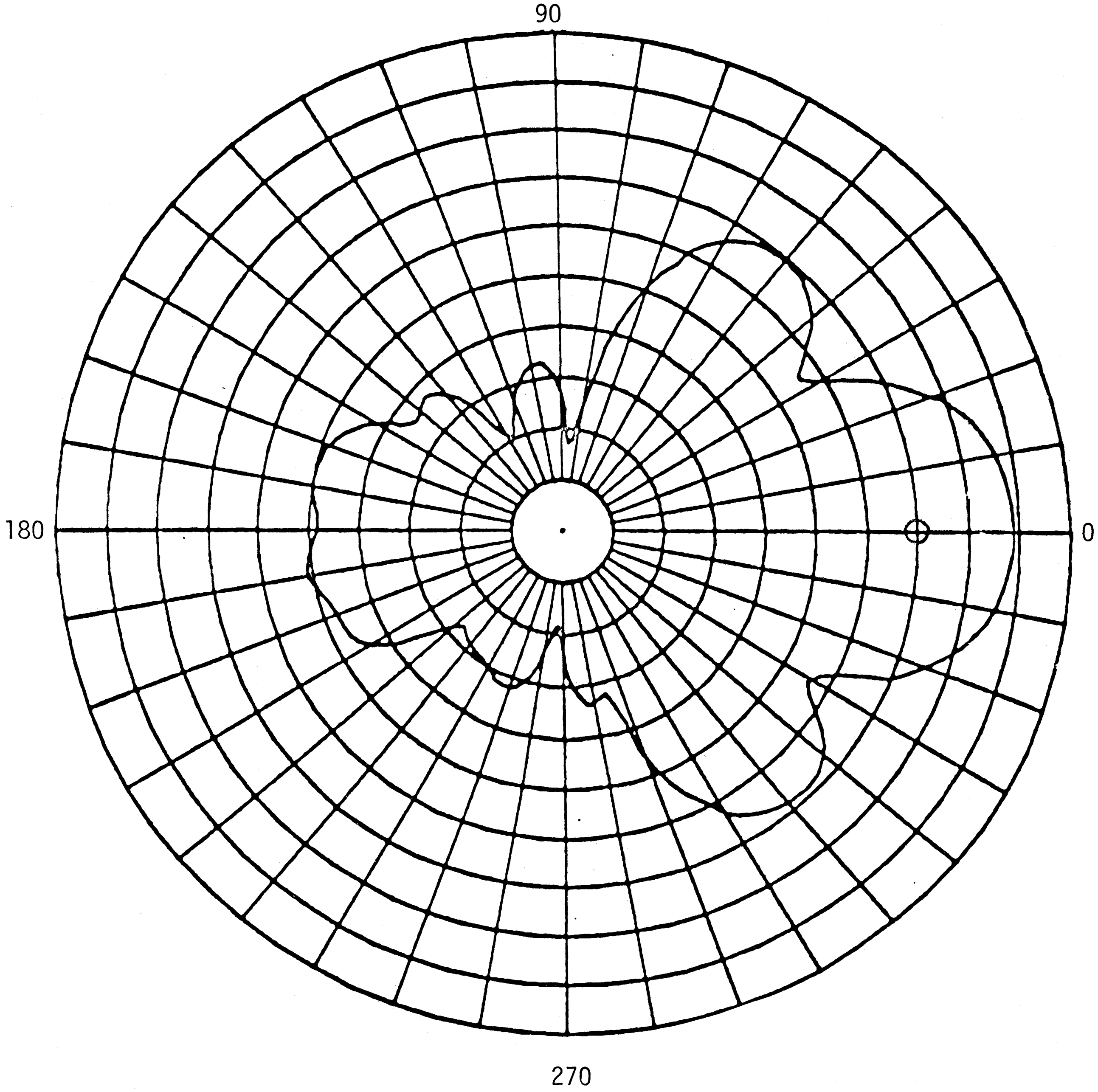

Figure 3. Typical VHF antenna gain pattern measured at 183 MHz (channel 8). The gain increments are 5 dB and the reference dipole gain level is shown by the circle on the 180 deg - 0 deg axis.

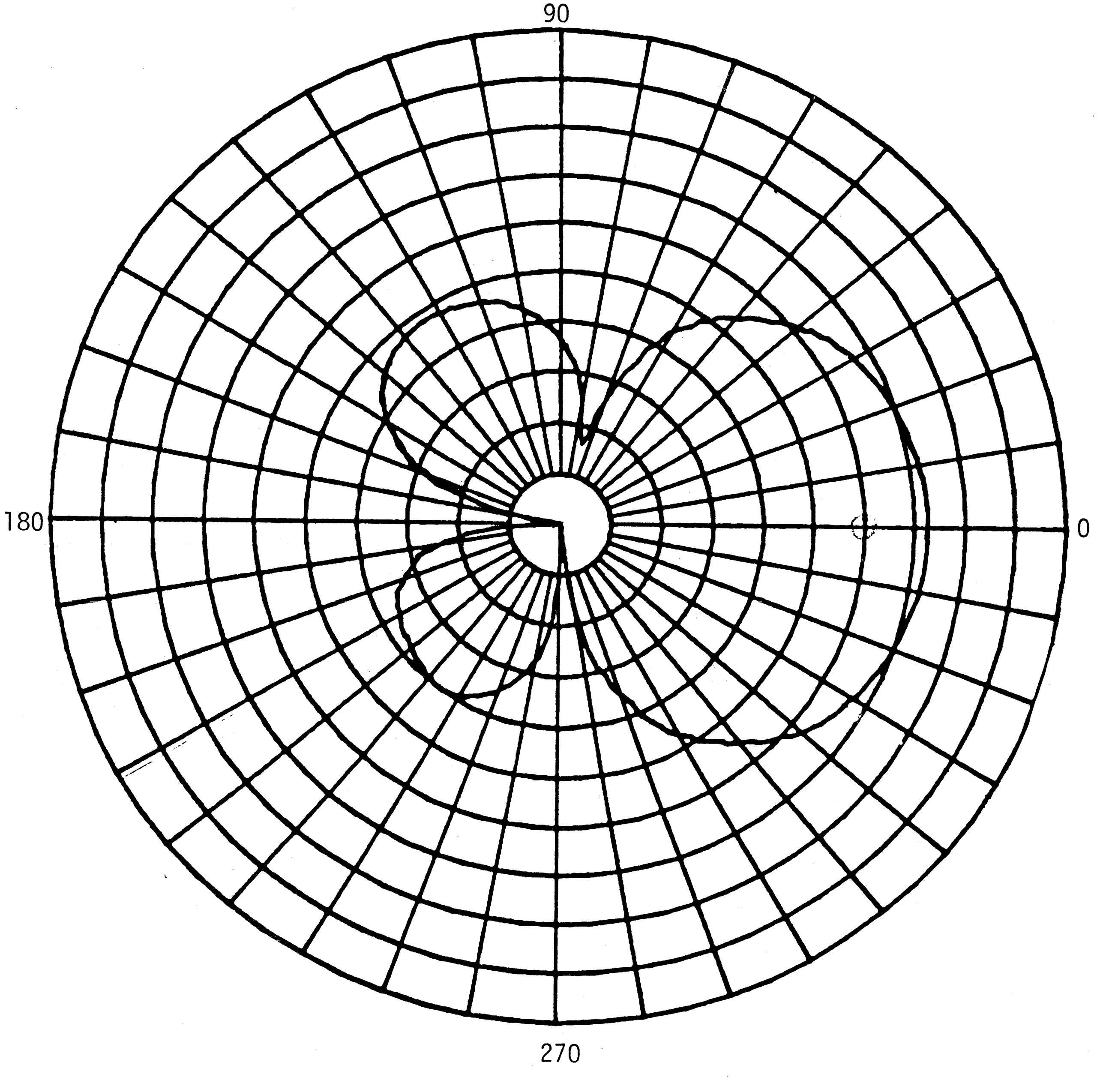

Figure 4. Typical UHF antenna gain pattern measured at 641 MHz (channel 42). The gain increments are 5 dB and the reference dipole gain level is shown by the circle on the 180 deg - 0 deg axis.

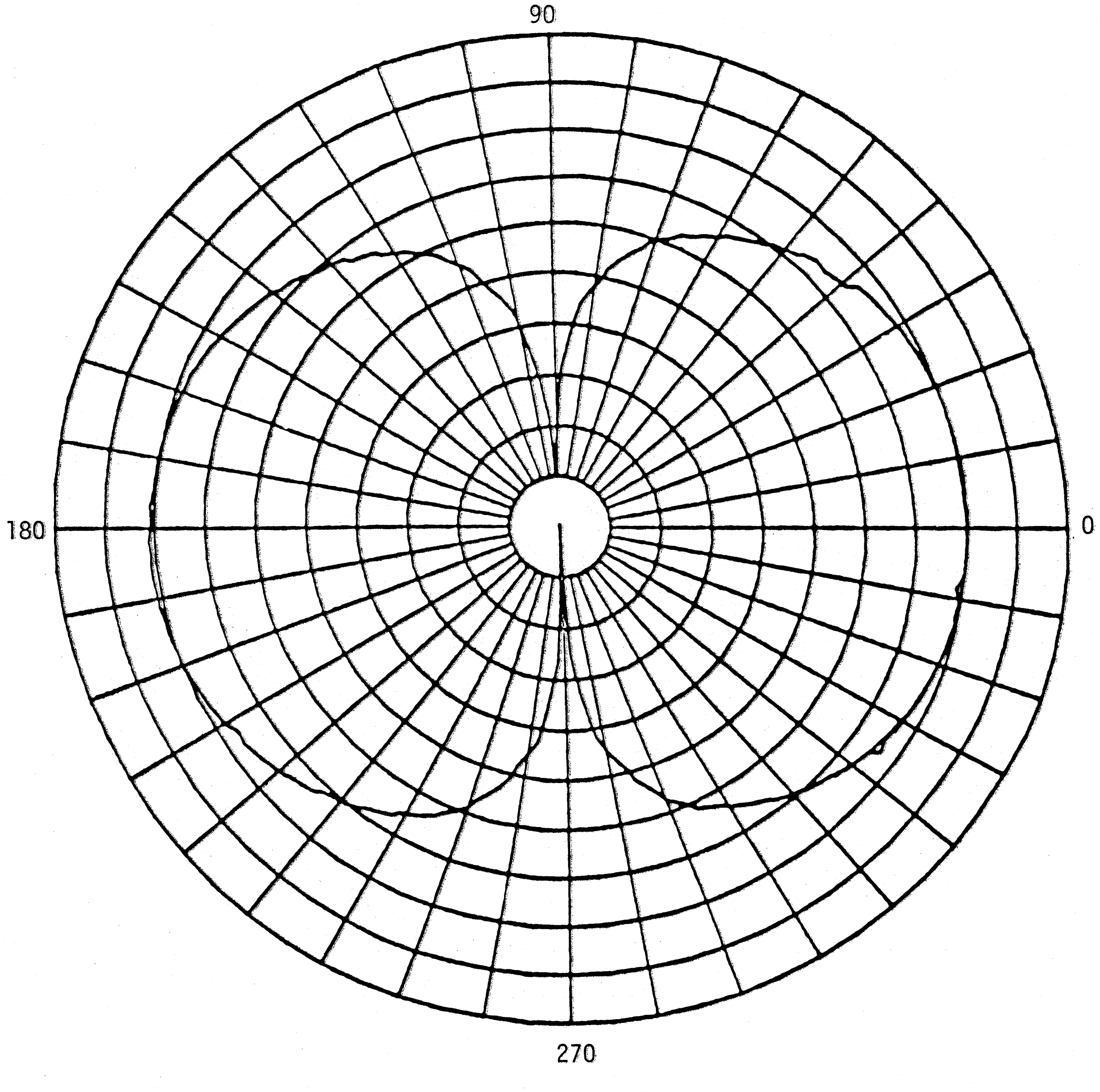

Figure 5. Typical half-wave dipole reference antenna gain pattern. The gain increments are 5 dB.

gain pattern typical for the half-wave dipole reference antennas. Main-beam antenna gain is the maximum value measured at any specific frequency regardless of the azimuth angle at which it occurs. Table 1 is a tabulation of main-beam gain for each antenna along with half-power beam width at each test frequency. At the bottom of the table, some average gain values versus frequency have been included for the convenience of the reader. From the first column of average-value entries one can calculate that at 63 MHz the average main-beam gain for eight VHF and VHF/UHF combination antennas designed for outdoor erection is 3.2 dB, the average main-beam gain for four outdoor VHF (only) antennas is 4.2 dB, and the average gain for four outdoor VHF/UHF antennas is 2.0 dB. Examination of these main-beam gain average values shows that, for the sample of outdoor antennas used in our measurements, the VHF/UHF combination antennas yield lower main-beam gains than those realized with VHF (only) antennas at VHF frequencies and for UHF (only) antennas at UHF frequencies.

Table 2 presents a summary of the data from Table 1. Maximum, minimum, and average values of main-beam gain and half-power beam width for each antenna are shown. That is, looking at Table 1, we see for antenna 1 the maximum main-beam gain is 4.1 dB at 183 MHz (channel 8), and the minimum main-beam gain is 1.2 dB at 79 MHz (channel 5). The average main-beam gain for antenna 1 is 1.4 dB in the low VHF band and 3.9 dB in the high VHF band. These are the data shown in Table 2 for antenna 1. Similar data describing antenna half-power beam width characteristics also are shown.

Excluding the indoor and broken antennas from the antenna gain averages, there are several interesting features of the data shown in Tables 1 and 2.

- Along with tabulated main-beam gain versus frequency for each antenna, Table 1 shows <u>average</u> main-beam gain at each test frequency. These average gains for VHF antennas range from 2.0 dB for combination antennas at 63 MHz (channel 3) to 8.8 dB for VHF only antennas at 183 MHz (channel 8) and for UHF antennas from 2.8 dB for combination antennas at 803 MHz (channel 69) to 8.6 dB for UHF only antennas at 641 MHz (channel 42).
- Maximum main-beam gain for VHF antennas usually occurred at the channel 8 frequency; minimum main-beam gain occurred

Table 1. Main-beam Antenna Gain and Half-Power Beam Width at Each Test Frequency (Channel Number)

	Main-beam Gain Relative to a Tuned Half-Wave Dipole, dB and Half-Power Beam Width (HPBW), Degrees													
	Test Frequency, MHz (Channel Number)													
Antenna ID Number	63(3)		79(5)		183(8)		213(13)		473(14)		641(42)		803(69)	
	(Gain)	(HPBW)	(Gain)	(HPBW)	(Gain)	(HPBW)	(Gain)	(HPBW)	(Gain)	(HPBW)	(Gain)	(HPBW)	(Gain)	(HPBW)
1.	1.6	89	1.2	78	4.1	37	3.6	38						
2.	2.7	70	3.6	69	8.7	33	7.0	43						
3.	5.5	60	6.6	58	9.7	32	8.2	31						
4.	5.5	61	5.6	60	10.4	34	10.2	33						
5. (Indoor)	-6.3	89	-3.1	79	-3.1	34	-2.5	38						
6.	3.0	76	2.1	78	7.2	30	5.5	39	4.8	74	8.9	37	0.6	19*
7.	2.2	65	2.9	68	7.9	35	5.5	38	3.3	55	6.9	50	1.3	39
8.	3.7	75	3.6	67	9.2	34	7.0	39	6.1	47	8.4	55	6.6	34
9.	-4.3	72	0.6	79	1.4	31	2.7	29	4.1	45	2.6	42	-3.2	42
10.									5.8	56	7.1	56	-1.9	57
11.									4.3	62	7.4	62	3.8	54
12a. (New)									5.3	56	8.6	39	1.1	17*
12b. (Broken)									3.1	55	3.4	39	-1.2	20*
13.									7.8	33	10.4	28	8.1	20
14. (Indoor)									-1.7	64	-0.9	59	-3.4	50
15a. (Indoor, Loop Vert.)									-3.2	79	1.4	64	-3.2	65
15b. (Indoor, Loop Horz.)									-6.2	103	-5.9	122	-8.4	58
Average, All Antennas (Outdoor Types)	3.2		3.7		8.1		6.8		5.4		8.0		3.6	
Average, VHF Antennas (Outdoor Types)	4.2		4.7		8.8		7.9		-		-		-	
Average, UHF Antennas (Outdoor Types)	-		-		-		-		6.0		8.6		4.3	
Average, VHF/UHF Antennas (Outdoor Types)	2.0		2.4		7.2		5.4		4.7		7.3		2.8	

*Beam Splitting Observed.

Table 2. Maximum, Minimum, and Average Measured Values of Main-beam Gain Relative to a Tuned Half-Wave Dipole and Half-Power Beam Width for Each Antenna

	VHF Antennas (Tests on Channels 3, 5, 8, 13)							
	Main-beam Gain, dB				Half-Power Beam Width, Degrees			
Antenna ID Number	Maximum	Minimum	Low Band Average	High Band Average	Maximum	Minimum	Low Band Average	High Band Average
1.	4.1(8)	1.2(5)	1.4	3.9	89	37	83.5	37.5
2.	8.7(8)	2.7(3)	3.2	7.9	70	33	69.5	38.0
3.	9.7(8)	5.5(3)	6.1	9.0	60	31	59.0	31.5
4.	10.4(8)	5.5(3)	5.6	10.3	61	33	60.5	33.5
5. (Indoor)	-2.5(13)	-6.3(3)	-4.4	-2.8	89	34	84.0	36.0
6.	7.2(8)	2.1(5)	2.6	6.4	78	30	77.0	34.5
7.	7.9(8)	2.2(5)	2.6	6.9	68	35	66.5	36.5
8.	9.2(8)	3.6(5)	3.7	8.2	75	34	71.0	36.5
9.	2.7(13)	-4.3(3)	-1.2	2.1	79	29	75.5	30.0
Average, VHF Only (Excluding No. 5)	8.8	4.1	4.4	8.3				
Average, VHF/UHF Combination Only	7.3	1.7	2.2	6.4				
Average, All Data (Excluding No. 5)	8.1	3.1	3.5	7.5				

Table 2. (continued)

UHF Antennas (Tests on Channels 14, 42, 69)

Antenna ID Number	Main-beam Gain, dB			Half-Power Beam Width, Deg		
	Maximum	Minimum	Average	Maximum	Minimum	Average
6.	8.9(42)	0.6(69)	6.0	74	19*	44.3
7.	6.9(42)	1.3(69)	4.5	55	39	48.0
8.	8.4(42)	6.1(14)	7.2	55	34	45.3
9.	4.1(14)	-3.2(69)	2.1	45	42	43.0
10.	7.1(42)	-1.9(69)	5.0	57	56	56.3
11.	7.4(42)	3.8(69)	5.5	62	54	59.3
12a. (New)	8.6(42)	1.1(69)	6.0	56	17*	37.3
12b. (Broken)	3.4(42)	-1.2(69)	2.2	55	20*	38.0
13.	10.4(42)	7.8(14)	8.9	33	20	27.0
14. (Indoor)	-0.9(42)	-3.4(69)	-1.9	64	50	57.7
15a. (Indoor, Loop Vert.)	1.4(42)	-3.2(14,69)	-1.1	79	64	69.3
15b. (Indoor, Loop Horz.)	-5.9(42)	-8.4(69)	-6.7	122	58	94.3
Average UHF Only (Excluding Nos. 12b,14,15a,15b)	8.6	4.1	6.7			
Average, VHF/UHF Combination Only	7.4	2.5	5.3			
Average, All Data (Excluding Nos. 12b,14,15a,15b)	8.0	3.4	6.0			

*Beam Splitting Observed

Note: Numbers in parentheses denote channels at which gain values were observed.

about equally often on the channel 3 and channel 5 frequencies. For UHF antennas, maximum main-beam gain occurred at the channel 42 frequency with only one exception. Minimum main-beam gain occurred at the channel 69 frequency about 83 percent of the time.

- The average main-beam gain performance of VHF only or UHF only antennas is better than the average main-beam gain performance of VHF/UHF combination antennas. The average main-beam gain for VHF only antennas was about 2 dB higher than the average main-beam gain of the combination antennas at VHF, with the average for all antennas being about 3.5 dB in the low band and 7.5 dB in the high band. Average main-beam gain for the UHF antennas was about 6 dB, with average UHF performance for combination antennas about 1.4 dB less than for the UHF only antennas.
- For our sample of antennas, the average maximum main-beam gain for VHF antennas was about 8.1 dB, ranging from about 7.3 dB for combination antennas to about 8.8 dB for VHF only antennas. The average minimum main-beam gain ranged from 1.7 dB to 4.1 dB.
- Our sample shows average maximum main-beam gain of about 8 dB for UHF antennas. The average maximum main-beam gain for the UHF only antennas was about 0.6 dB greater, and the average maximum main-beam gain for the combination antennas was about 0.6 dB less than the overall average maximum main-beam gain. Average minimum main-beam gain at UHF was about 3.4 dB with a somewhat lower average for combination antennas and a somewhat higher average for UHF only antennas.

It is interesting to compare our measured data with similar data reported by other investigators. Nearly 20 years ago the performance of 11 commercial VHF TV receiving antennas was measured at the National Bureau of Standards (Wilson, 1960) employing the same measurement techniques we have followed. Summarized results, in a format easy to compare with our summarized data, are shown in Table 3.

Table 3. Summary of Measured Values of VHF Antenna Main-beam Gain Reported in NBS Report 6099 (1960)

(Channel numbers are in parentheses. Power gain was measured on all channels. The mismatch losses are added to give data tabulated here.)

Antenna Identifier	Main-beam Gain Relative to a Tuned Half-Wave Dipole, dB							
	63(3)	79(5)	183(8)	213(13)	Maximum	Minimum	Low Band Average	High Band Average
A	0.1	1.2	3.2	5.5	5.5(13)	-0.4(2)	0.6	4.6
B	0.4	0.7	4.6	4.0	4.6(8)	0.1(2)	0.6	4.1
C	0.4	-0.7	5.5	5.5	6.1(10)	-1.0(6)	-0.1	5.8
D	2.6	5.1	6.6	9.5	9.8(12)	2.6(3)	4.5	8.2
E	3.4	5.1	6.8	9.9	9.9(13)	2.9(7)	4.3	8.1
F		Antenna designed only for 177 MHz, channel 7.						
G		Antenna designed only for 177 MHz, channel 7.						
H	3.5	2.3	12.8	9.0	13.0(9)	2.3(5)	3.4	12.1
I	Designed for high band only.		6.4	5.5	6.8(10)	5.5(13)	-	6.4
J	1.8	1.5	6.9	4.9	7.3(7)	-0.3(6)	1.4	6.6
K	3.1	4.5	10.0	7.1	10.7(7)	2.3(2)	3.7	9.1
Average	2.1	2.9	7.6	7.3	9.0	2.0	2.6	7.9

About the same time, the Television Allocations Study Organization (TASO) reported (TASO, 1959; Swinyard, 1960) the summarized results for VHF and UHF antenna gains shown in Table 4. The data from which their summaries were developed were obtained from three sources.

(1) The TASO Panel 2 developed a questionnaire which was sent to 52 antenna manufacturers. Seven manufacturers responded, collectively providing data on 26 VHF and 4 UHF antennas.

(2) Data were provided by The Association of Maximum Service Telecasters (AMST) covering 13 all-channel VHF and two special antennas.

(3) The RCA Service Company provided data for nine all-channel VHF antennas, one high-band VHF antenna, one single channel VHF antenna, six all-channel UHF antennas, and two special UHF antennas.

More recently, UHF antenna performance has been investigated (Free and Smith, 1978) using 29 different types of antennas. Two of each type antenna were tested yielding 58 sets of data. The types of antennas tested included:

- Eleven types in the "most popular UHF only" category representing nine different manufacturers.
- Nine types in the "most popular VHF/UHF combination" category representing eight different manufacturers.
- Two types in the "best performance/most expensive UHF only" category representing two different manufacturers.
- Two types in the "best performance/most expensive VHF/UHF combination" category representing two different manufacturers.
- Four types in the "most popular indoor" category representing three different manufacturers.
- One type in the "best performance/most expensive indoor" category representing one manufacturer.

This work was done at the Engineering Experiment Station, Georgia Institute of Technology, under sponsorship of the Public Broadcast Service. A summary of these measurement results is presented in Table 5.

Table 4. Summary of Measured Values of VHF and UHF Antenna Main-beam Gain Reported by the Television Allocations Study Organization (TASO) (1959)

Source	Freq, MHz (Channel)	Number of Units	Main-beam Gain Relative to a Tuned Half-wave Dipole, dB		
			Maximum	Minimum	Average
Questionnaire to Manufacturers	63 (2)	26	11.0	-5.0	4.1
	69 (4)	26	11.0	-1.0	4.6
	85 (6)	26	11.0	0.0	5.0
	177 (7)	27	11.0	2.0	6.2
	195 (10)	27	12.0	2.0	7.4
	213 (13)	27	11.7	0.5	7.4
	473 (14)	4	10.5	6.0	8.3
	611 (37)	4	12.0	6.2	9.6
	749 (60)	4	13.0	6.5	11.0
Association of Maximum Service Telecasters (AMST)*	63 (2)	13	4.7	-1.8	2.7
	69 (4)	12	7.1	-1.7	3.7
	79 (5)	13	5.1	-0.4	3.0
	177 (7)	13	10.7	3.3	7.4
	189 (9)	13	15.2	4.1	9.8
	201 (11)	13	10.5	0.7	6.8
	213 (13)	13	9.0	-0.6	6.0
RCA Service Company	63 (2)	10	6.5	-7.0	2.3
	69 (4)	10	7.0	-3.5	2.5
	85 (6)	10	7.5	-4.5	2.3
	177 (7)	10	8.5	0.0	4.7
	195 (10)	10	11.3	0.2	6.0
	213 (13)	10	11.0	-2.5	6.0
	473 (14)	7	12.6	-0.2	6.2
	611 (37)	6	10.8	0.7	6.8
	749 (60)	7	12.2	2.5	6.6
VHF Low Band			11.0	-7.0	3.7
VHF High Band			12.8	-2.5	6.8
UHF (Channel 83 data have not been included.)			13.0	-0.2	8.0

*For 13 units tested by AMST, Channel 5 data were used for Channel 6, and average of Channel 9 and Channel 11 data were used for Channel 10.

Table 5. Summary of Measured Values of UHF Antenna Main-beam Gain Reported by Georgia Institute of Technology (GIT) (Free and Smith, 1978) for the Public Broadcast Service (PBS)

Type Antenna Category	Main-beam Gain Relative to a Tuned Half-Wave Dipole, dB									
				Average Values by Frequency, MHz (Channel)						
	Maximum	Minimum	Average	473(14)	533(24)	593(34)	653(44)	713(54)	773(64)	833(74)
All Data	17.0	-18.5	8.7	6.6	6.7	6.8	9.7	9.0	11.5	8.1
Outdoor Only	17.0	-16.5	9.3	7.2	7.3	7.3	10.3	9.7	12.2	8.6
UHF Outdoor Only	17.0	-16.5	9.9	8.5	7.6	7.2	10.5	9.9	13.0	9.7
VHF/UHF Combination Outdoor Only	15.5	- 7.5	8.6	5.3	7.0	7.5	10.0	9.5	11.0	7.0
UHF Indoor Only	4.0	-18.5	-1.1	-1.0	-1.8	-0.3	- 0.9	-5.0	- 1.8	1.0

an extraction from Tables 2, 3, and 4 of maximum, minimum, and average VHF antenna gains is shown in Table 6, top portion. There are at least two points worth noticing.

- The gain of a combination antenna is about 2 dB poorer on the average than the gain of a VHF only antenna.
- The types of VHF antennas tested 20 years ago likely were quite different from the types of outdoor VHF antennas which we recently tested (mostly variations of log periodic antennas), yet the average main-beam gains for all tests are quite similar--maximum differences of about 0.9 dB for low band antennas when our VHF only and VHF/UHF combination antenna data are averaged to one value for low band performance and one value for high band performance. We do note that the maximum and minimum main-beam gains reported by the NBS and TASO were more extreme than we have measured.

Similar UHF gain data extracted from Tables 2, 4, and 5 are shown in the lower portion of Table 6. We note that the VHF/UHF combination antenna performance is about 1.4 dB poorer on the average than performance of the UHF only antennas. The average UHF antenna main-beam gain reported by the TASO is about 1.3 dB less than average main-beam gain reported from the GIT/PBS measurements. And average main-beam gain reported from our measurements is about 3.3 dB lower than the GIT/PBS average. We attempted to sample fairly from the population of UHF antennas offered the public. Our guidelines were to obtain antennas of various prices and of as many different types as possible. Since most of the combination antennas used some sort of corner reflector as the UHF portion of the antenna, our total sample indeed did contain more corner reflectors than any other type antenna. We did not have any very expensive UHF only antennas in our test sample, since UHF antennas are not marketed in the Eastern Colorado area and some orders for antennas were delayed by suppliers/manufacturers past the conclusion of our measurements.

Table 6. Comparisons of Maximum, Minimum, and Average Measured Values of VHF and UHF Antenna Main-beam Gain

Data Source and Type Antenna Category	Main-beam Gain Relative to a Tuned Half-Wave Dipole, dB				
	Maximum	Minimum	VHF Low Band Average	VHF High Band Average	UHF Average
ITS-VHF Only (Outdoor)	10.4	1.2	4.4	8.3	
ITS-VHF Combination Only (Outdoor)	9.2	-4.3	2.2	6.4	
ITS-VHF, All Data (Outdoor)	10.4	-4.3	3.5	7.5	
NBS-VHF	13.0	-1.0	2.6	7.9	
TASO-VHF (Outdoor)	12.8	-7.0	3.7	6.8	
ITS-UHF Only (Outdoor)	10.4	-1.9			6.7
ITS-UHF Combination Only (Outdoor)	8.9	-3.2			5.3
ITS-UHF, All Data (Outdoor)	10.4	-3.2			6.0
TASO-UHF (Outdoor)	13.0	-0.2			8.0
GIT/PBS-UHF Only (Outdoor)	17.0	-16.5			9.9
GIT/PBS-UHF Combination Only (Outdoor)	15.5	-7.5			8.6
GIT/PBS-UHF, All Data (Outdoor)	17.0	-16.5			9.3

5. BALUN INSERTION LOSS

Thirteen 75-ohm unbalanced (coaxial) to 300-ohm balanced line transformers, or baluns, were used to obtain the insertion loss data tabulated here. As mentioned in Section 2, insertion loss is a measure of energy dissipated in an rf component and is unavoidable.

Balun insertion loss is presented in Table 7 for the five frequency ranges of interest. Baluns 8 and 9 are identical models purchased several years apart, and baluns 3 and 4 are identical models purchased several years apart.

Figure 6 is a schematic drawing of the measurement system used to determine the insertion loss data.

6. SIGNAL SPLITTER INSERTION LOSS

Signal splitters were supplied with five combination VHF/UHF antennas purchased for this study. One of these antennas was used as the source of test site illumination and was not included in the gain measurements. It was manufactured by a company which made one of the tested combination antennas; therefore, two of the splitters were identical in appearance and very similar in electrical performance.

All splitters had an antenna terminal and VHF and UHF terminals to attach to their respective terminals on the TV receiver. Four splitters had FM terminals provided for output to an FM receiver. Since the FM band of frequencies was included during insertion loss measurements, the FM data are also presented here.

Table 8 presents the maximum and minimum values of insertion loss measured in six frequency bands. Figure 7 is a schematic drawing of the splitter loss measurement system. The connections shown are for the UHF tests; appropriate changes are made for VHF and FM measurements. For calibrating the system, the splitter was removed and the balun terminals were connected together. A plot of signal level in decibel increments from 0 to -10 was produced by varying the output level from the signal generator. The splitter was then inserted between the balun's terminals, and the insertion loss was plotted. Measurement accuracy is assumed to be ±0.5 dB, but this is merely an estimate. It is interesting to note the high losses that occur in the FM band caused by the resistive coupling used for the FM port.

Table 7. Minimum, Maximum Balun Insertion Loss, dB

Device Code Number	Test Frequency Range, MHz				
	Low VHF 54-88	High VHF 174-216	Low UHF 470-582	Mid UHF 582-694	High UHF 694-806
1	0.2, 0.4	1.0, 1.1	0.5, 0.8	0.5, 0.5	0.5, 0.7
2	0.1, 0.2	0.5, 0.6	0.1, 0.3	0.2, 0.4	0.4, 0.5
3	0.2, 0.6	2.0, 2.5	3.4, 3.4	2.1, 3.4	1.3, 2.1
4	0.2, 0.5	1.4, 2.1	3.2, 3.2	1.3, 2.4	1.1, 1.6
5.	0.1, 0.3	0.7, 0.8	0.7, 1.3	1.0, 1.6	0.7, 1.0
6	0.1, 0.3	0.7, 1.9	0.5, 1.0	1.0, 2.1	1.0, 2.0
7	0.2, 0.3	0.6, 0.7	0.3, 0.4	0.4, 0.6	0.6, 0.6
8	0.2, 0.4	0.9, 0.9	0.7, 1.3	1.3, 1.9	1.8, 2.2
9	0.2, 0.4	0.8, 0.9	1.0, 1.2	0.9, 1.2	0.9, 0.9
10	0.2, 0.3	1.0, 1.1	0.5, 0.6	0.6, 0.9	0.9, 1.2
11	0.2, 0.4	1.2, 1.4	0.9, 1.3	1.2, 1.5	1.1, 1.2
12*	0.3, 1.2	0.7, 0.9	1.0, 1.7	0.7, 1.7	0.7, 6.3
13	0.1, 0.3	0.6, 0.8	0.6, 0.6	0.8, 0.9	0.9, 1.6
Range	0.1, 1.2	0.5, 2.5	0.1, 3.4	0.2, 3.4	0.4, 6.3

*This balun has a built-in FM trap; that is, it is designed to reject the FM frequency band of 88 to 108 MHz.

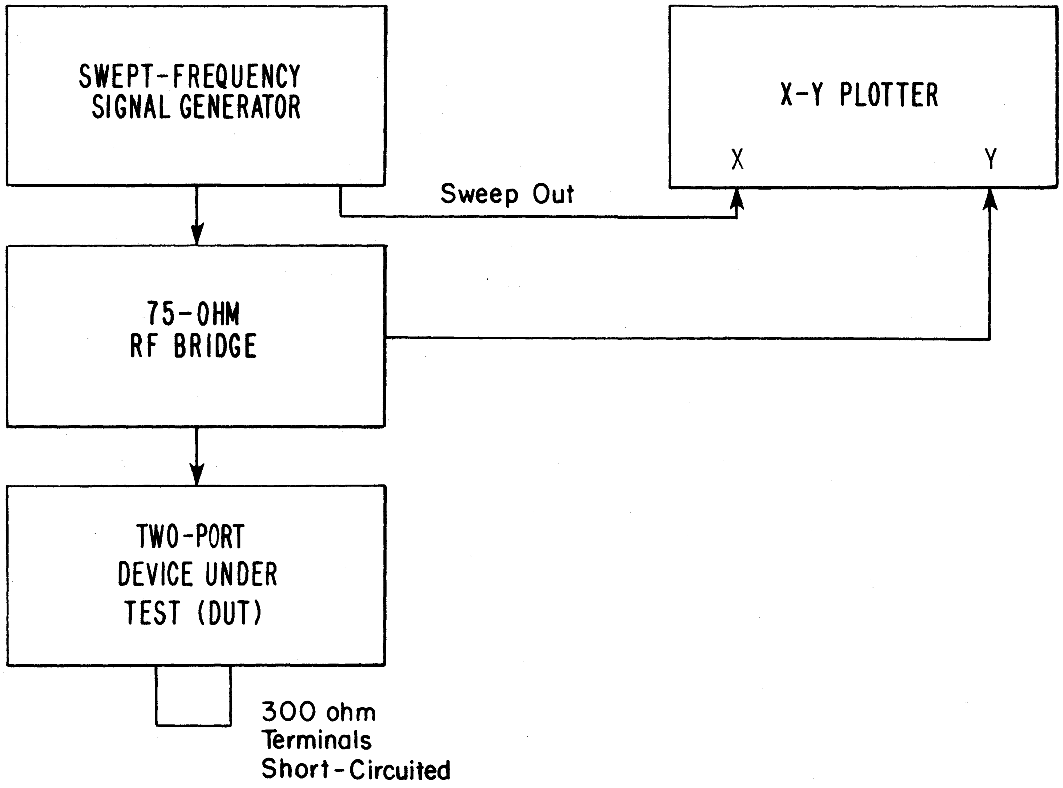

Figure 6. Schematic drawing of insertion loss measurement system.

Note: The rf bridge provides a dc output voltage proportional to the square of the voltage reflected by the DUT. The system is calibrated for infinite insertion loss with a short on the Y-axis terminal of the X-Y plotter and for 0 dB insertion loss with a short on the DUT terminal.

Table 8. Minimum-Maximum Signal Splitter Insertion Loss, dB

Device Code Number	Test Frequency Range, MHz					
	Low VHF 54-88	FM 88-108	High VHF 174-216	Low UHF 470-582	Mid UHF 582-694	High UHF 694-806
1	0,0	-	0.7,1.0	0.3,1.0	0.3,1.0	1.0,1.8
2	0,1.0	3.5,7.0	0.5,0.6	1.0,1.3	1.0,2.5	2.0,3.3
3	2.0,2.3	8.0,8.2	2.8,3.7	0.2,1.5	0.9,1.2	1.3,3.2
4	2.0,2.4	8.0,8.3	2.9,3.8	0.3,1.7	1.0,1.5	1.5,3.5
5	2.7,2.8	8.0,8.2	2.0,2.8	0.7,1.5	0.7,0.8	0.8,3.0
Range	0,2.8	3.5,8.3	0.5,3.8	0.2,1.7	0.3,2.5	0.8,3.5

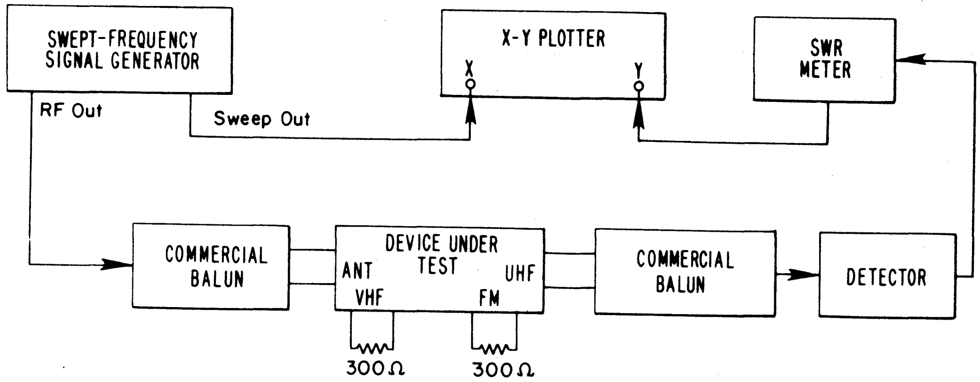

Figure 7. Schematic drawing of splitter insertion loss measurement system. Connections shown are for the UHF tests.

7. VSWR'S OF ANTENNAS, BALUNS, AND SPLITTERS

The VSWR is an important measure of rf component quality, especially when used in conjunction with insertion loss. It may also be used as a quality control check for antennas in particular, since an extensive test range is not required for VSWR measurements in the VHF UHF TV frequency range. For these reasons, antenna, balun, and splitter VSWR's were measured and are presented in this section.

Table 9 presents the minimum and maximum antenna VSWR values in five frequency bands of interest.

Table 10 presents the minimum and maximum balun VSWR values in five frequency bands of interest measured at the 300 ohm balanced terminal with the 75-ohm unbalanced, coaxial terminal attached to a 75-ohm load.

Table 11 presents the minimum and maximum splitter VSWR values in the five frequency bands of interest and the FM band measured at the 300-ohm terminal marked "antenna" with 300-ohm balanced loads on the other terminals.

Figure 8 is a schematic drawing of the measurement system used to obtain VSWR data. Measured VSWR accuracy is poor at the extreme edges of the TV band, 54 and 806 MHz, and is dependent on the measured VSWR value. The VSWRs equal to 2 are estimated to be accurate to within 2 ±0.2 at 54 MHz and accurate to within $2\,^{+0.5}_{-0.3}$ at 806 MHz. The VSWRs of 3 are estimated to be accurate to within $3\,^{+0.5}_{-0.3}$ at 54 MHz and accurate to within $3\,^{+2}_{-0.6}$ at 806 MHz. The VSWRs equal to 6 are estimated to be accurate to within $6\,^{+3}_{-1.2}$ at 54 MHz and $6\,^{+24}_{-2.2}$ at 806 MHz. In the high VHF and low and middle UHF bands, VSWRs of 2 are estimated to be accurate within 2 ±0.1. These measurement problems result from the apparent lack of 300 ohm balanced rf bridges for determining VSWR.

The use of a rigid, open, 300-ohm balanced transmission line and sliding probes together with slotted line techniques at discrete frequencies was not considered to be a cost-effective measurement technique, although it may yield accurate impedance data.

Table 9. Minimum, Maximum Antenna VSWR

Device Code Number	Test Frequency Range, MHz				
	Low VHF 54-88	High VHF 174-216	Low UHF 470-582	Mid UHF 582-694	High UHF 694-806
1	1.2, 2.6	1.8, 2.3			
2	1.1, 3.0	1.1, 3.3			
3	1.2, 4.0	1.5, 5.2			
4	1.2, 3.5	1.3, 2.3			
5	4.0, 18	2.7, 6.5			
6	1.2, 2.3	1.4, 2.7	1.6, 2.6	2.0, 3.3	1.7, 5.4
7	1.1, 2.8	1.3, 2.0	3.3, 6.5	5.5, 9.2	3.7, 25
8	1.7, 4.0	1.6, 2.8	1.6, 2.2	1.7, 2.9	1.6, 3.3
9	1.1, 3.5	1.2, 3.0	1.2, 2.9	1.2, 2.8	1.1, 3.4
10			1.05, 1.8	1.05, 8.0	4.5, 14
11			1.7, 2.2	1.2, 1.8	1.05, 3.5
12			1.4, 2.3	1.1, 2.1	1.1, 1.8
12B			2.8, 4.5	2.2, 3.3	2.1, 3.2
13			1.6, 6.5	1.05, 2.5	1.05, 2.9
14			1.8, 2.5	2.0, 2.7	1.4, 3.5
15			3.3, 10	1.05, 3.3	1.2, 6.5
Range	1.1, 18.0	1.1, 6.5	1.05, 10.0	1.05, 9.2	1.05,25.0

Table 10. Minimum, Maximum Balun VSWR

Device Code Number	Test Frequency Range, MHz				
	Low VHF 54-88	High VHF 174-216	Low UHF 470-582	Mid UHF 582-694	High UHF 694-806
1	1.1, 1.2	1.2, 1.3	2.6, 3.8	3.8, 4.2	3.8, 4.5
2	1.2, 1.2	1.2, 1.3	2.3, 3.9	3.9, 4.2	2.3, 3.9
3	1.7, 2.0	1.7, 1.9	1.7, 1.8	1.3, 1.8	1.3, 1.3
4	1.8, 2.1	1.8, 2.1	1.4, 1.7	1.2, 1.4	1.2, 1.5
5	1.2, 1.2	1.2, 1.2	2.1, 3.0	3.0, 3.5	2.8, 3.5
6	1.1, 1.2	1.05, 1.05	2.7, 5.0	5.0, 6.9	6.7, 7.0
7	1.1, 1.2	1.2, 1.3	1.3, 1.6	1.4, 1.6	1.3, 1.4
8	1.1, 1.2	1.1, 1.1	1.5, 1.7	1.4, 1.5	1.4, 1.4
9	1.1, 1.2	1.2, 1.3	1.1, 1.3	1.1, 1.3	1.3, 1.8
10	1.1, 1.3	1.4, 1.5	1.6, 2.2	2.2, 2.8	2.8, 2.9
11	1.3, 3.3	1.1, 1.2	1.4, 2.4	1.9, 2.4	1.4, 3.0
12	1.1, 1.2	1.05, 1.2	1.3, 1.7	1.7, 2.1	2.1, 2.6
Range	1.1, 3.3	1.05, 2.1	1.1, 5.0	1.1, 6.9	1.2, 7.0

Table 11. Minimum, Maximum Splitter VSWR

Device Code Number	Test Frequency Range, MHz					
	Low VHF 54-88	FM 88-108	High VHF 174-216	Low UHF 470-582	Mid UHF 582-694	High UHF 694-806
1	1.1,1.5	1.5,1.6	1.4,1.7	1.1,1.4	1.1,2.2	2.2,4.7
2	1.4,2.6	1.2,2.6	1.0,1.1	1.4,2.2	1.7,2.3	1.7,2.4
3	1.6,1.7	1.5,1.6	2.0,2.5	2.1,2.3	1.1,2.1	1.1,2.3
4	1.6,1.7	1.5,1.6	1.9,2.3	2.1,2.3	1.3,2.2	1.3,2.3
5	1.7,1.8	1.8,1.8	1.2,1.5	1.3,1.6	1.1,1.2	1.1,1.7
Range	1.1,2.6	1.2,2.6	1.0,2.5	1.1,2.3	1.1,2.3	1.1,4.7

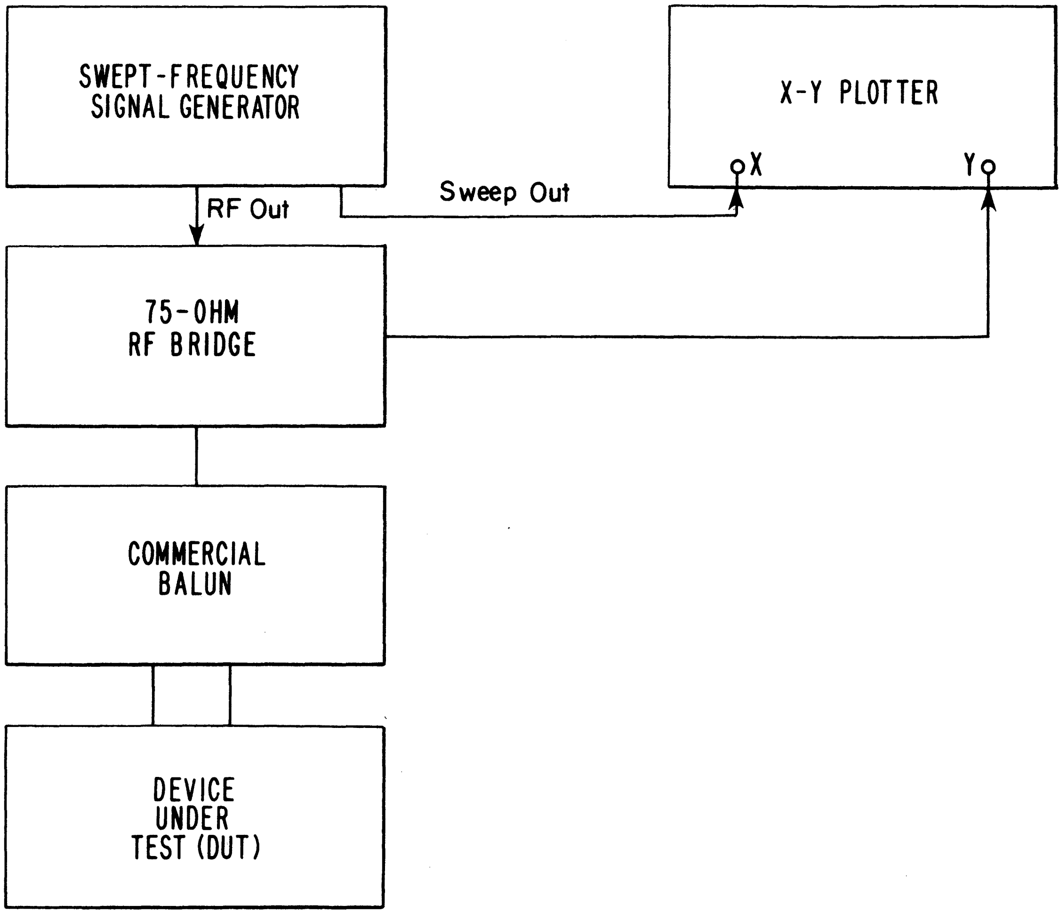

Figure 8. Schematic drawing of VSWR measurement system.

Note: System is calibrated for VSWR = 1 with a short on the Y-axis terminal of the plotter and for a VSWR = ∞ with a short on the DUT terminal of the bridge-balun combination.

8. TRANSMISSION LINE LOSS

Our investigations of transmission line characteristics, as mentioned before, encompassed only a collection of manufacturer's attenuation data--no measurements. Attenuation versus frequency data for three types of transmission line most likely used in any home receiving system are reported. The types of transmission line are (1) 300-ohm balanced transmission line, commonly referred to as "twin-lead;" (2) RG-6 type coaxial cable with 75-ohms characteristic impedance; and (3) RG-59 type coaxial cable which also has characteristic impedance of 75 ohms. We have summarized data from five manufacturers/suppliers of 300-ohm "twin-lead," seven manufacturers/suppliers of RG-6 type coaxial cable, and eight manufacturers/suppliers of RG-59 type coaxial cable.

The 300-ohm "twin-lead" probably is the most commonly used transmission line for home installations, connecting an antenna and TV receiver. "Twin-lead" typically is manufactured by embedding two stranded conductors in a dielectric material which maintains spacing of the conductors for proper impedance characteristics and protects the conductors from direct contact with other unprotected conductors which could ground the rf signal. Typically, no rf shielding is provided on "twin-lead" transmission line as protection against unwanted radiated rf signals, although there are types of "twin-lead" marketed with aluminum foil shield and copper drain wire.

"Twin-lead" often is quite flat with polyethylene used as the dielectric material. Oval and nearly round (cross-section) 300-ohm transmission line is available, however, where cellular polyethylene (commonly termed "foam") is used as the dielectric material, and a jacket of ordinary polyethylene surrounds the dielectric material and embedded conductors. This type of transmission line generally withstands exposure to weather (sunlight and moisture penetration) better than the more ordinary flat "twin-lead."

The conductors are made of stranded copper or copper-covered steel wire. Conductor size ranges from AWG size 26 (smallest) to size 20 (largest). Conductor size is the dominant influence upon attenuation. To a lesser extent, the dielectric material also influences attenuation characteristics.

Figure 9 shows attenuation bounds versus frequency developed from the manufacturer's data which we obtained for 300-ohm, "twin-lead" transmission line. The lower curve in Figure 9 portrays the least attenuation (best

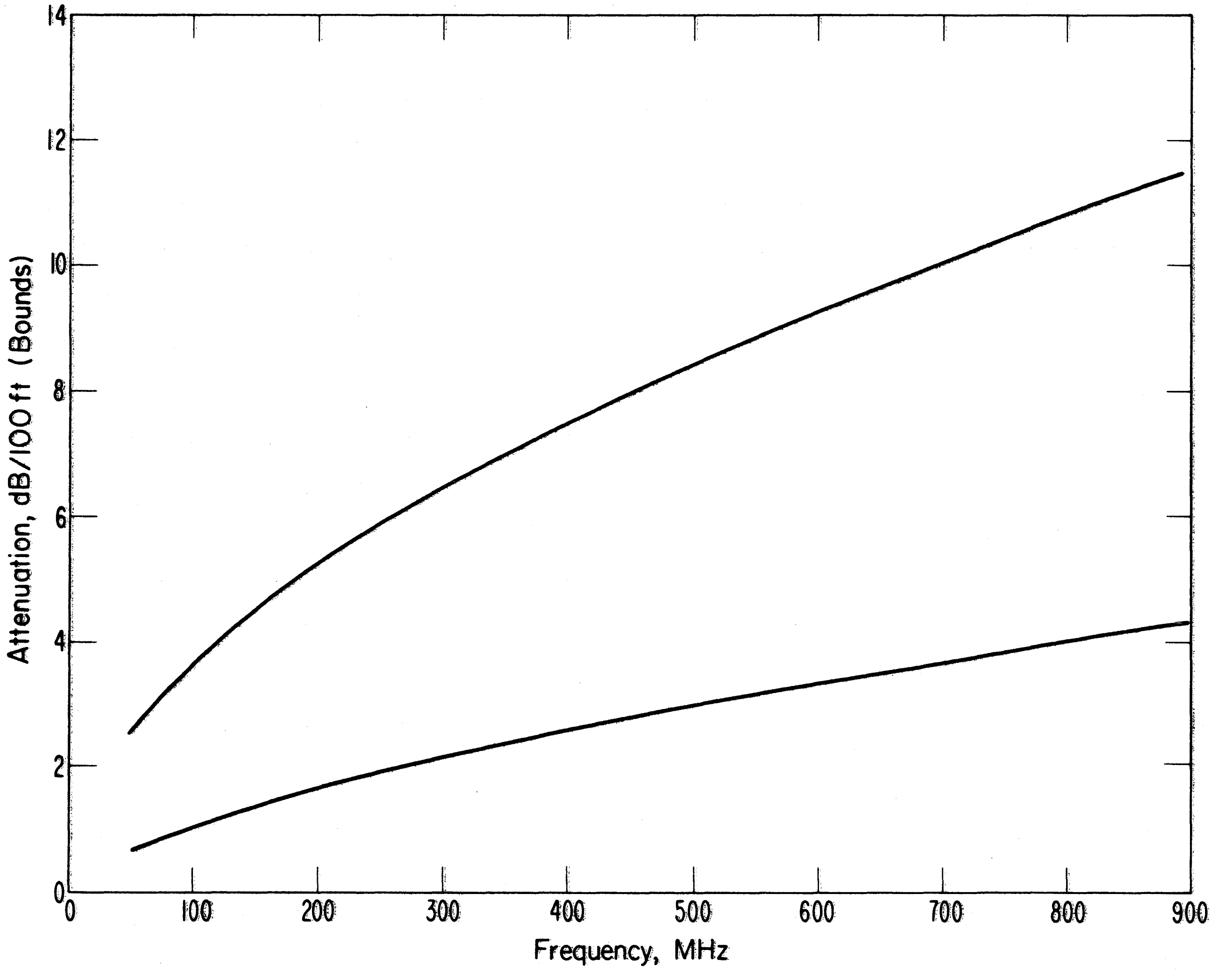

Figure 9. Attenuation bounds (best and worst case) versus frequency for new, dry 300-ohm balanced transmission line, derived from manufacturers' data.

condition) to be expected from "twin-lead," and the upper curve portrays the most attenuation (worst condition) that should be expected from new, dry "twin-lead" transmission line. The TASO (1959) and Swinyard (1960) have reported estimated degradation in transmission line attenuation due to age and moisture. This degradation could cause up to 5 dB more attenuation at UHF in a 30-ft (9.1 m) length of transmission line than is shown by our data for new, dry transmission line.

As an example of using Figure 9, if a TV antenna installation uses 300-ohm transmission line which has been constructed using AWG size 20 conductors and cellular polyethylene dielectric material with a polyethylene jacket, attenuation at 473 MHz (UHF channel 14) probably will be near 3 dB per 100 ft (30.5 m) of transmission line or about 1 dB for a 30-ft (9.1 m) length of transmission line. For comparison, if the same installation is made using ordinary flat "twin-lead" constructed with AWG size 26 conductors and polyethylene dielectric material, the attenuation at 473 MHz probably will be near 8 dB per 100 ft (30.5 m) of transmission line or about 2.5 dB for a 30-ft (9.1 m) length of transmission line.

If radiated interference, picked up by unshielded transmission line, is a problem, an antenna installation may be made using coaxial cable with appropriate impedance matching transformers. Although shielded "twin-lead" is available as indicated earlier, coaxial cable can provide shielding as great as 80 dB.

Coaxial cable for TV applications typically is constructed using a solid copper or copper covered steel center conductor (to facilitate use of the type F connectors)--usually AWG size 18 for RG-6 type cable and AWG size 22 or 20 for RG-59 type cable. This conductor is enclosed by a dielectric material which may be polyethylene, but more often it is cellular polyethylene. An outer conductor (shield) of aluminum foil covers the dielectric material. An additional braided shield of aluminum or copper or one to four drain wires completes the shield, and the cable is covered with a jacket of polyvinyl-chloride or polyethylene. Differences in conductor size and dielectric material again cause differences in attenuation. The attenuation bounds versus frequency for RG-6 type cable are shown in Figure 10 and in Figure 11 for RG-59 type cable. We note the spread between "best" and "worst" attenuation bounds typically is not as great for the coaxial cables

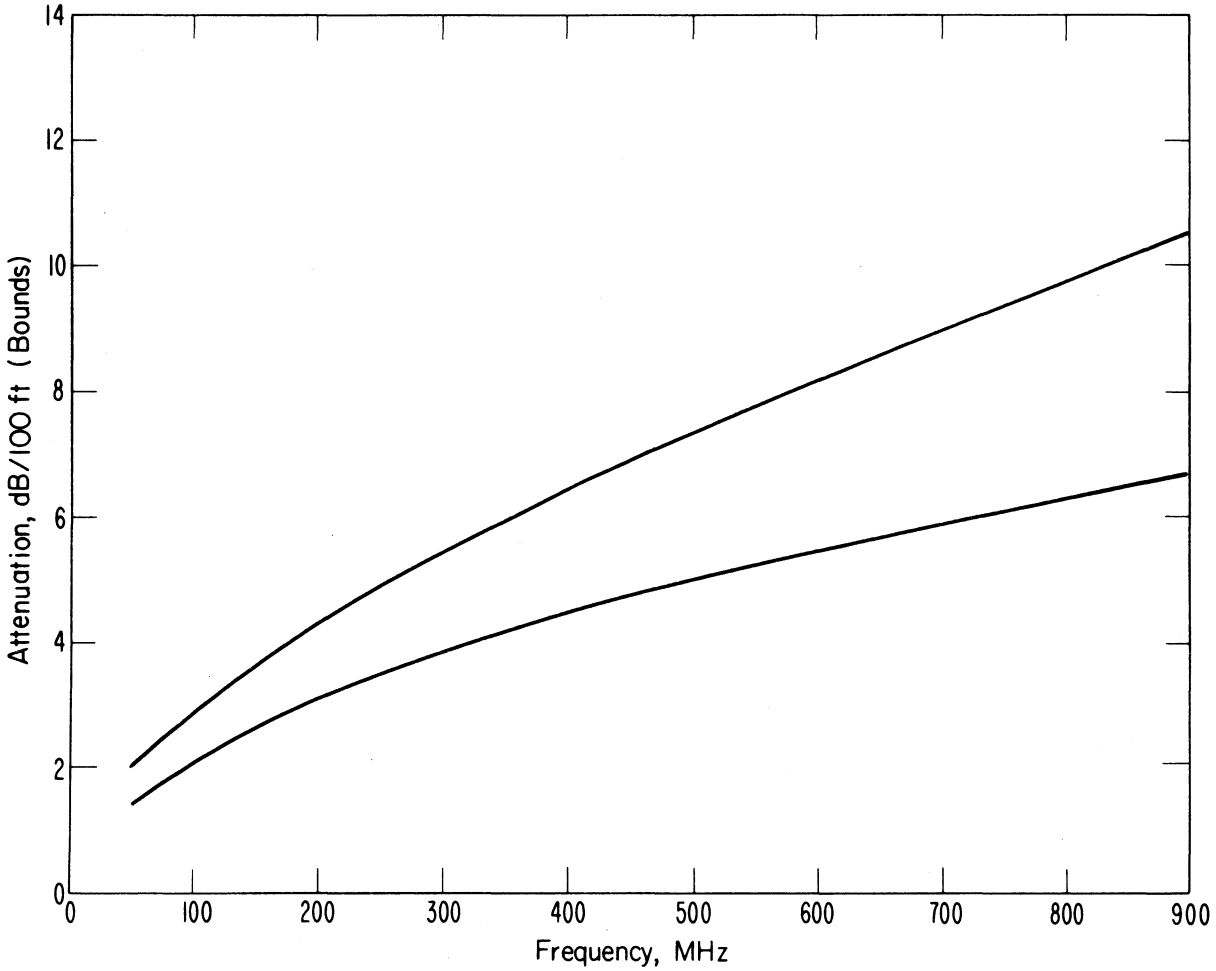

Figure 10. Attenuation bounds (best and worst case) versus frequency for new, dry RG-6 type coaxial cable, derived from manufacturers' data.

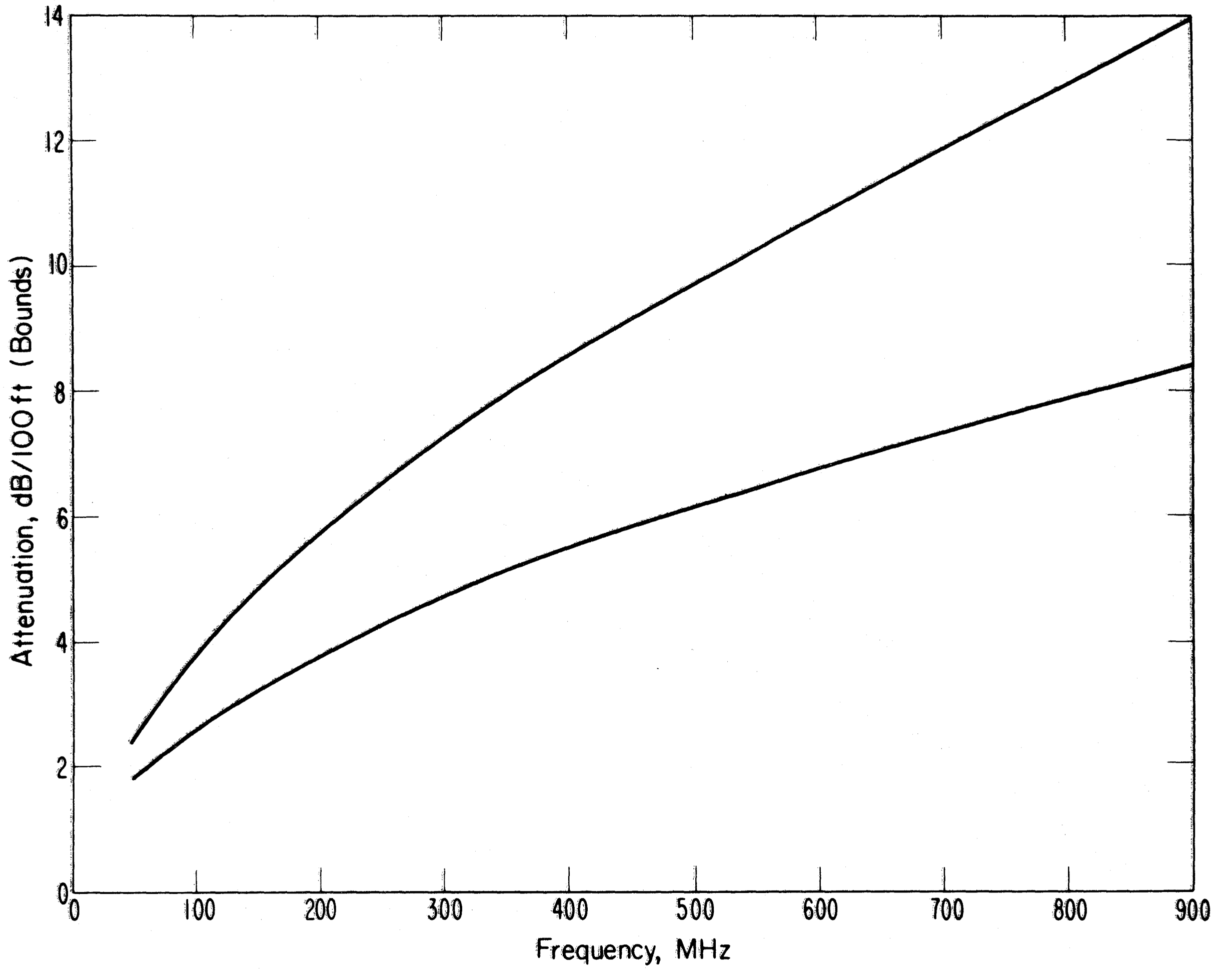

Figure 11. Attenuation bounds (best and worst case) versus frequency for new, dry RG-59 type coaxial cable, derived from manufacturers' data.

as for the 300-ohm "twin-lead." However, the least attenuation is realized using "good" "twin-lead." The worst attenuation is realized using "poor" RG-59 type coaxial cable. In addition, coaxial cable use usually requires that matching transformers be used, which further attenuate the rf signal.

Our discussions with distributors of transmission line indicate that RG-6 type coaxial cable would usually be used between the antenna and the wall outlet or an intermediate signal distribution device or preamplifier. For connection between the TV receiver and the wall outlet RG-59 type coaxial cable usually is used. Television signal distribution cables "wired" into the house also may be RG-59 type coaxial cable, and it is quite probable that RG-59 type coaxial cable is used entirely in some installations.

In addition to transmission line attenuation, there is a loss caused by dissipation of energy in the transmission line due to standing waves. This additional loss will exceed 1 dB when a transmission line with an attenuation of 3 dB or more is terminated with an rf component with a VSWR $\geq$ 3. This additional loss may be a problem, especially at UHF when a long transmission line from the antenna is terminated with a balun or splitter, having a VSWR $\geq$ 3 at the receiver terminals (or if the receiver itself had an input VSWR $\geq$ 3). Figure 12, from the 1972 ARRL Handbook, p. 561, is a plot of this additional loss versus VSWR and line attenuation.

9. DISCUSSION-CONCLUSIONS

This report was compiled almost exactly 20 years after the publication of "Engineering Aspects of Television Allocations - Report of the Television Allocations Study Organization to the Federal Communications Commission," March 16, 1959. This TASO Report evidently prompted the work at NBS, Boulder, Colorado, resulting in NBS Report 6099, by A. C. Wilson, entitled "Performance of VHF TV Receiving Antennas." Apparently, little has changed in this period of time in the performance of home television receiving antenna systems likely to be used by the consumer.

Typical system gains for best and worst selection of system components, assuming 9.1 m (30 ft) of transmission line in the system, are presented in Table 12 for the five frequency bands of interest.

The data in this table are added to the antenna constant curve of Figure 2 to express the power budget equation graphically in Figure 13.

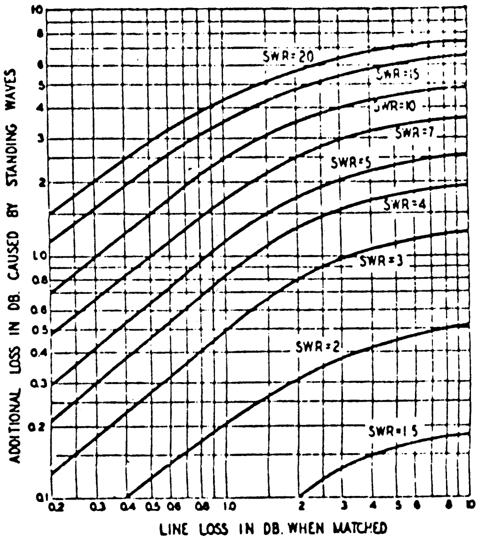

Figure 12. Increase in line loss because of standing waves (SWR value at the load). To determine the total loss in decibels in a line having an SWR greater than 1, first determine the loss for the particular type of line, length and frequency, on the assumption that the line is perfectly matched. Locate this point on the horizontal axis and move up to the curve corresponding to the actual SWR. The corresponding value on the vertical axis gives the additional loss in decibels caused by the standing waves.

Table 12. System Gain, dB, Versus Frequency, MHz

System Type	Frequency Range, MHz				
	Low VHF 54-88	High VHF 174-216	Low UHF 470-582	Mid UHF 582-694	High UHF 694-806
Indoor					
A, best	- 3.1	-2.5	-1.7	1.4	-3.2
A, worst	- 6.3	-3.1	-3.2	-0.9	-3.4
Outdoor					
B, best	6.3	10.0	6.9	9.4	6.9
B, worst	0.2	2.0	1.9	4.2	-5.1
Outdoor					
C, best	3.4	8.2	5.1	7.6	4.6
C, worst	-8.1	-3.9	-0.8	-2.8	-9.7
Outdoor					
D, best	3.0	6.8	4.3	6.5	3.1
D, worst	-10.3	-9.0	-8.0	-10.1	-23.0

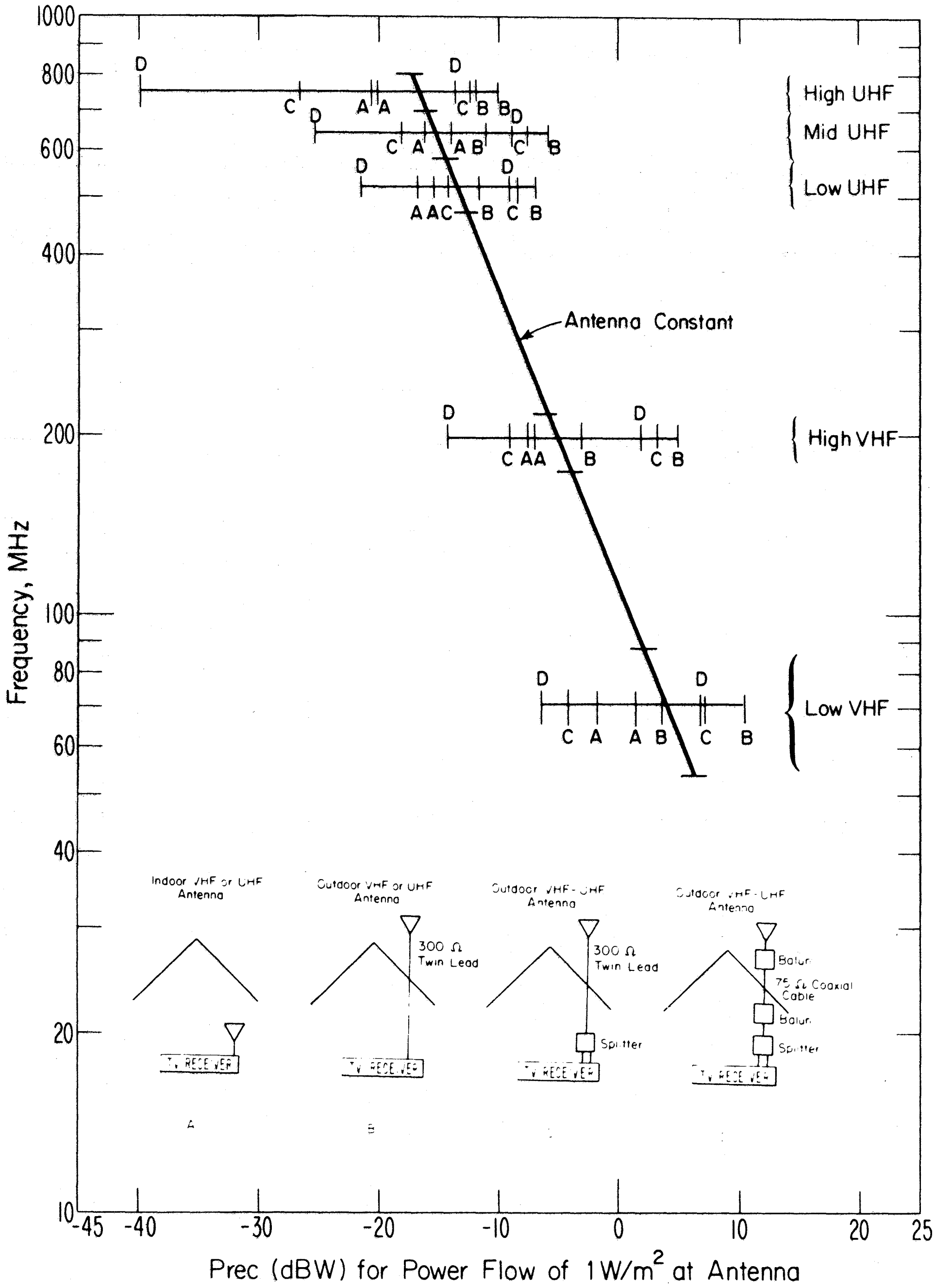

Figure 13. Graphical presentation of the range of the power budget equation versus frequency for the four systems considered.

To convert the P_{rec} scale to dB relative to 10^{-6} V at the 300 ohm receiver terminals with a field strength of 60 dB relative to 10^{-6} V/m at the antenna, add 59 dB.

Note, however, that there is no allowance made for building attenuation in the type A system-indoor antennas; in fact, no propagation effects of any kind are included in this antenna-to-receiver power budget--only plane-wave fields with equal power flow at the antennas were assumed.

To provide a simple antenna gain model, some data from Table 1 have been plotted in Figure 14.

10. REFERENCES

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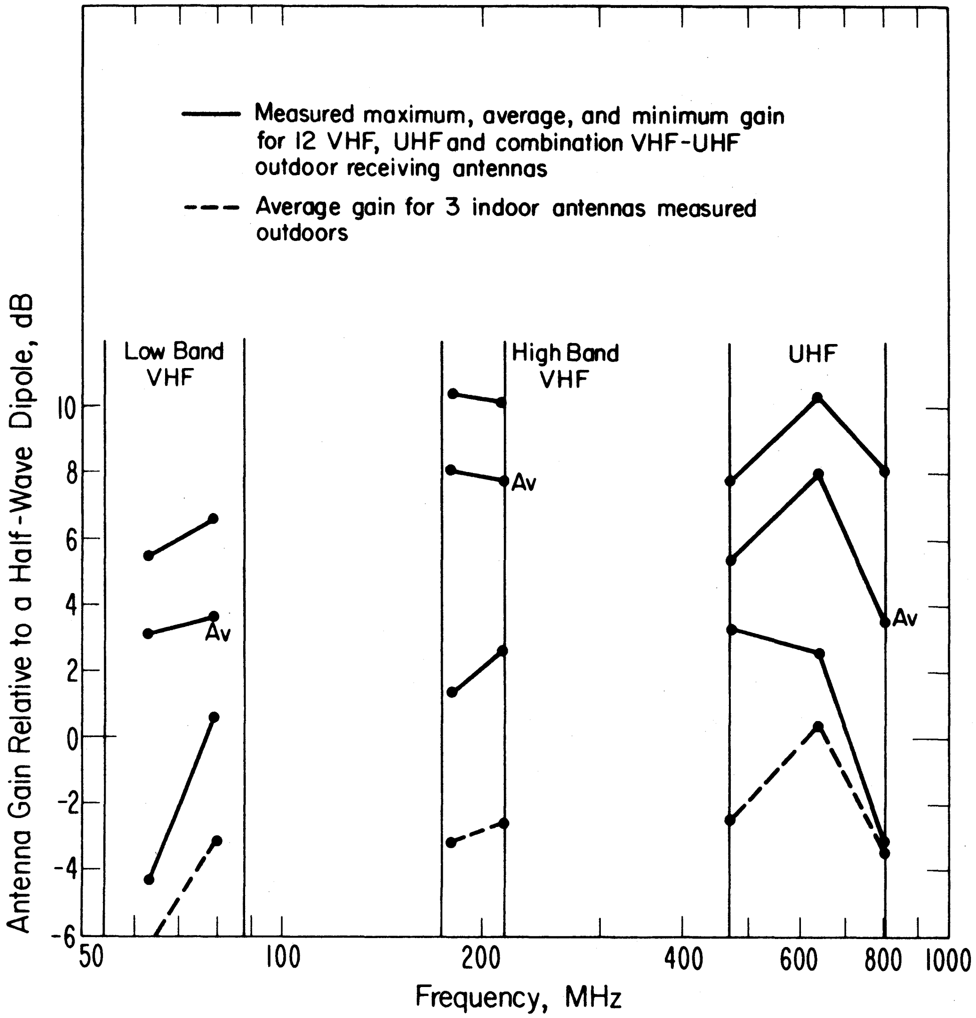

Figure 14. Measured antenna gain versus frequency.

APPENDIX. MEASURED RELATIVE GAIN PATTERNS

Antenna relative gain patterns in the azimuthal plane for nine different types of VHF antennas measured at 63, 79, 183, and 213 MHz and for ten different types of UHF antennas measured at 473, 641, and 803 MHz are presented in this Appendix. Four of the antennas were VHF/UHF combination antennas.

The gain increments for these plots are 5 dB, and the reference dipole gain level is shown by the circle on the 180 deg - 0 deg line--20 dB below maximum except for antenna number one, for which it is 15 dB below maximum.

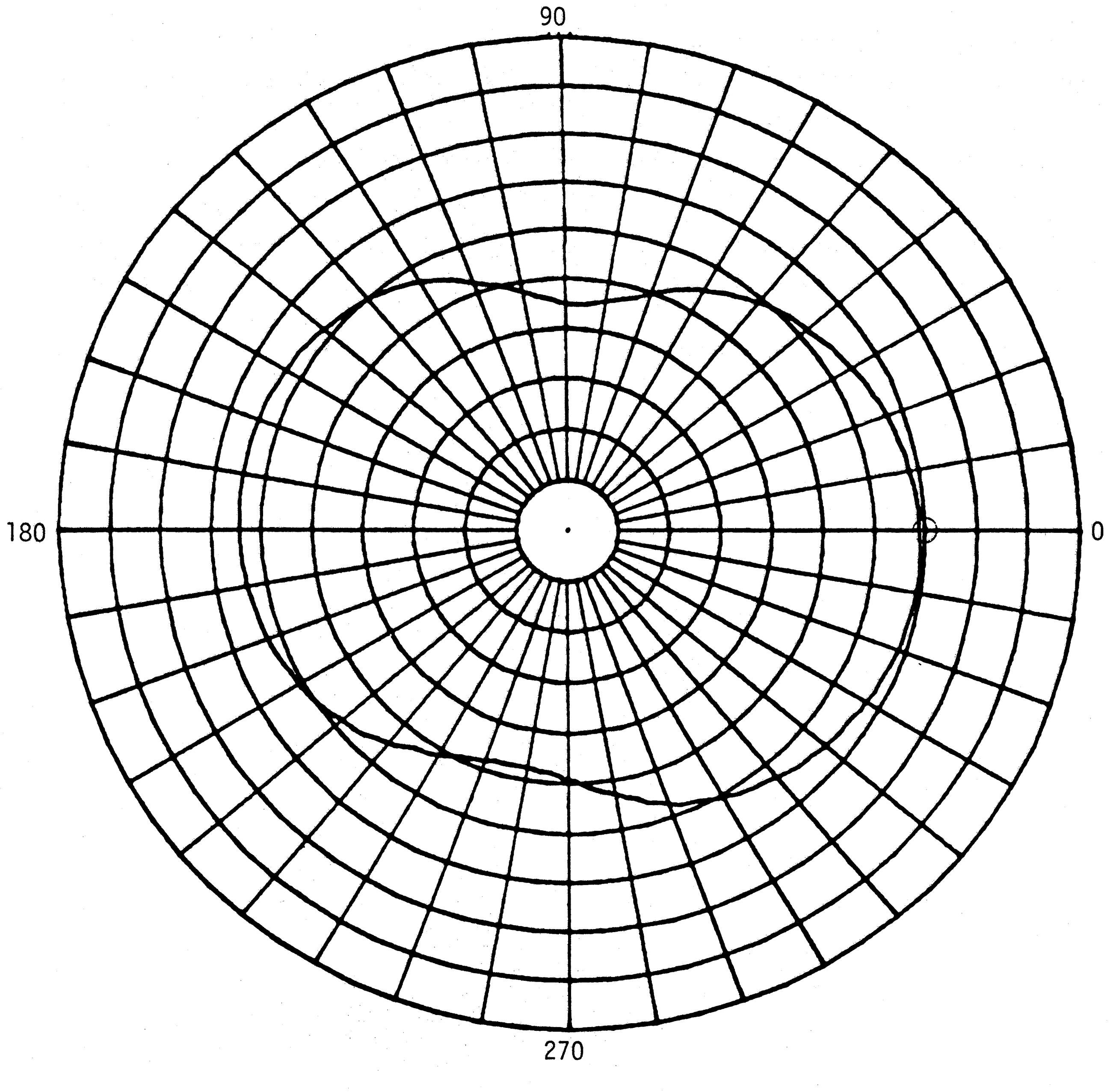

Figure A-1. Relative gain pattern in the azimuthal plane at 63 MHz for antenna No. 1.

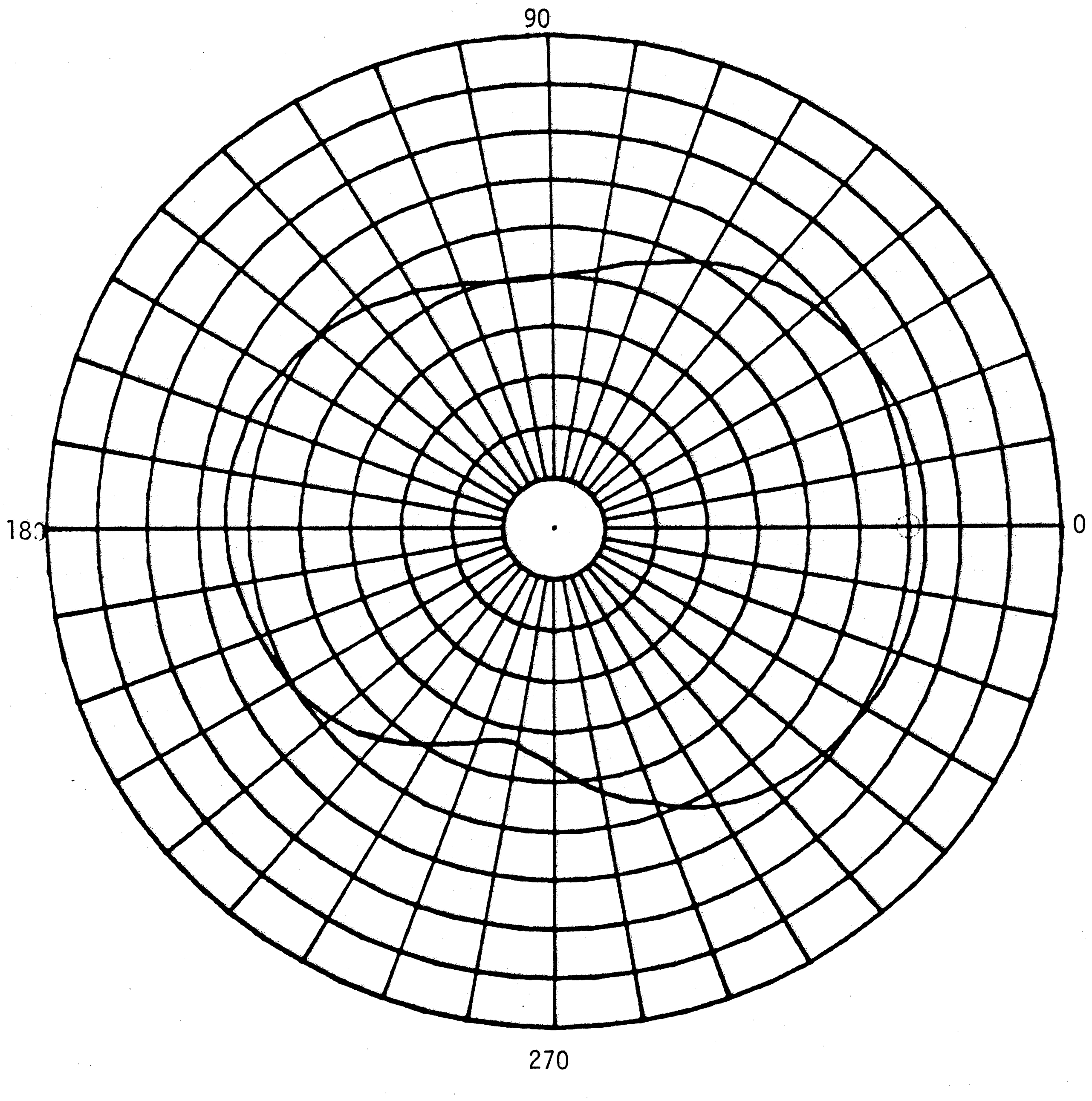

Figure A-2. Relative gain pattern in the azimuthal plane at 79 MHz for antenna No. 1.

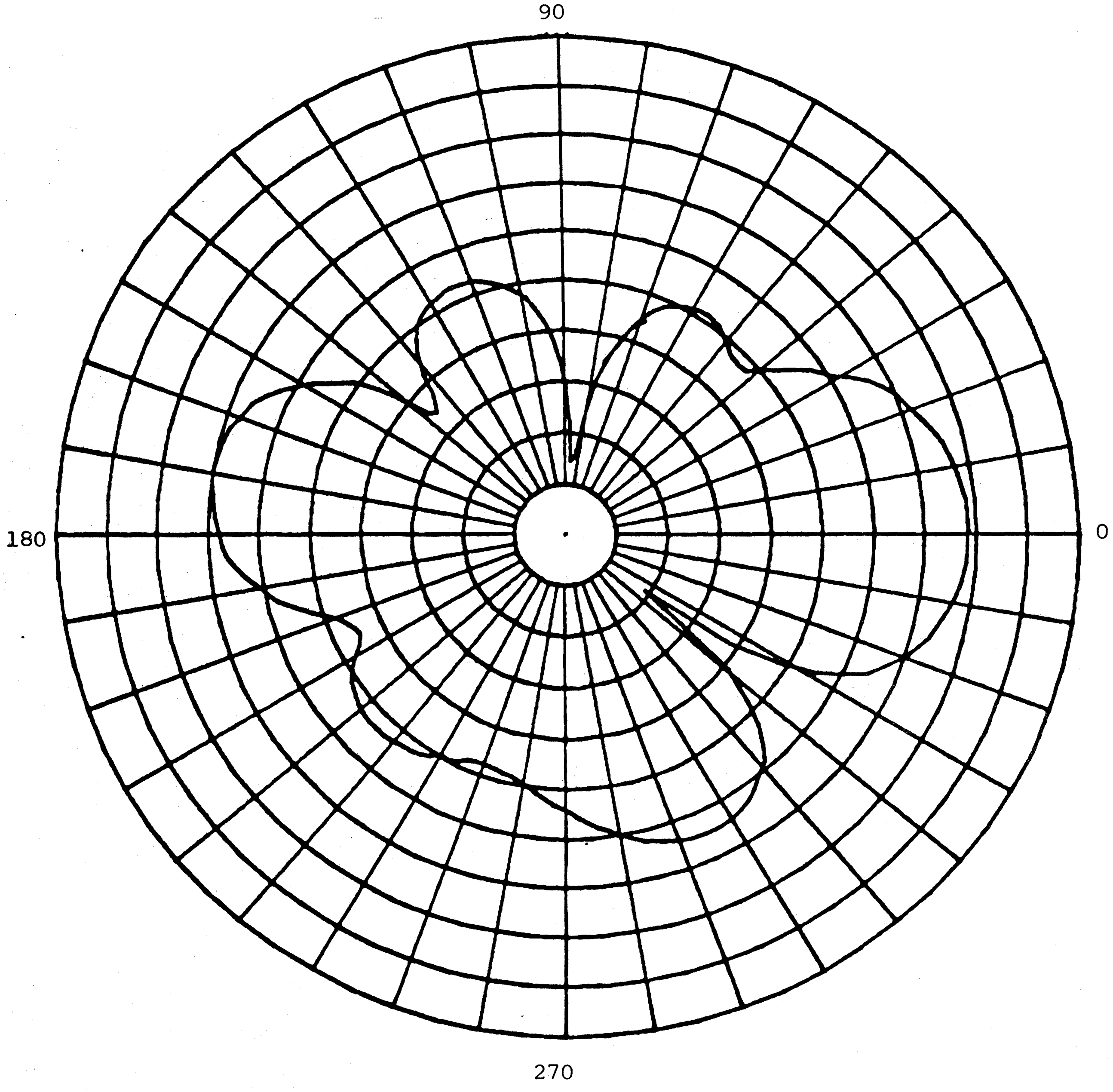

Figure A-3. Relative gain pattern in the azimuthal plane at 183 MHz for antenna No. 1.

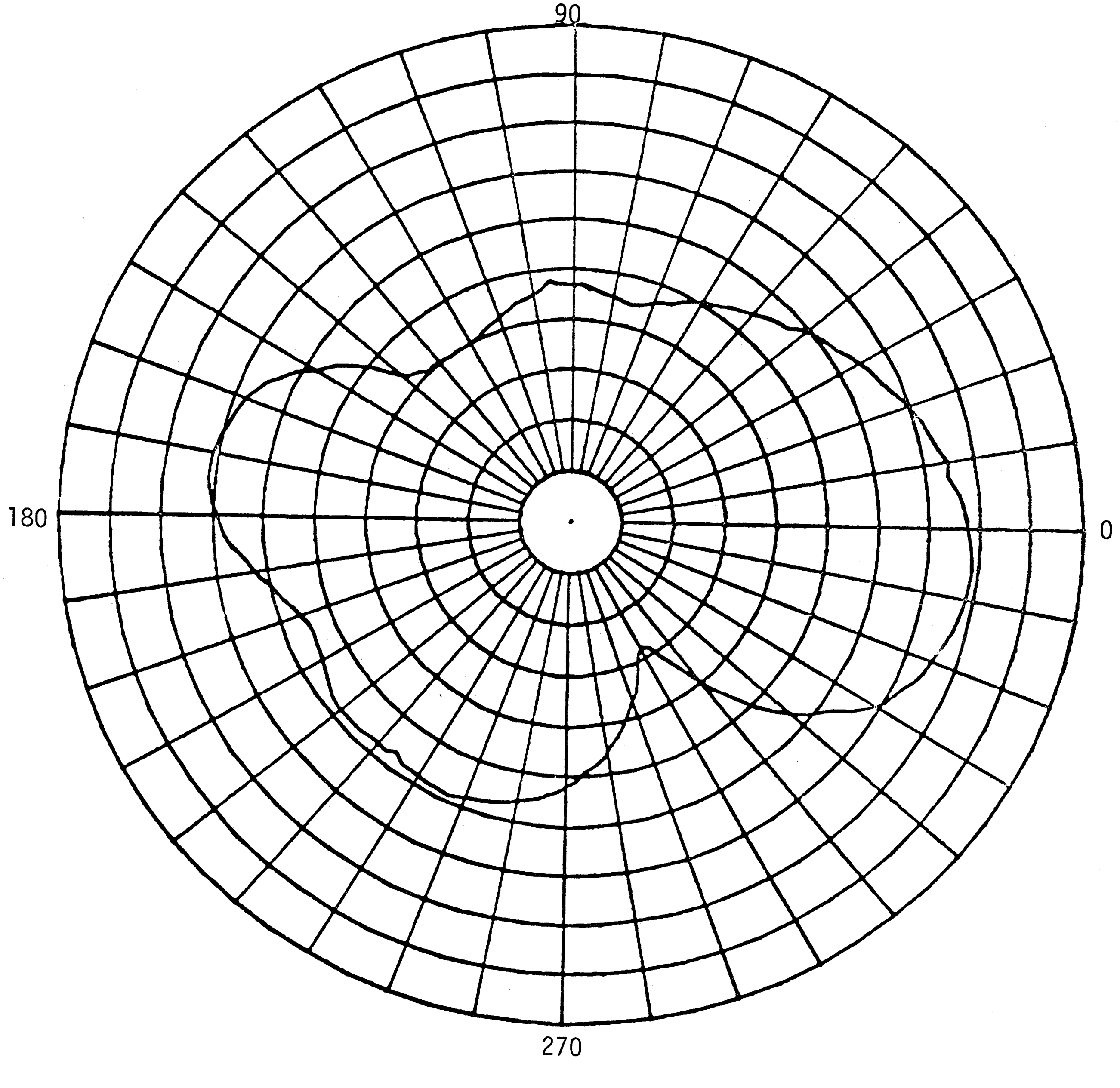

Figure A-4. Relative gain pattern in the azimuthal plane at 213 MHz for antenna No. 1.

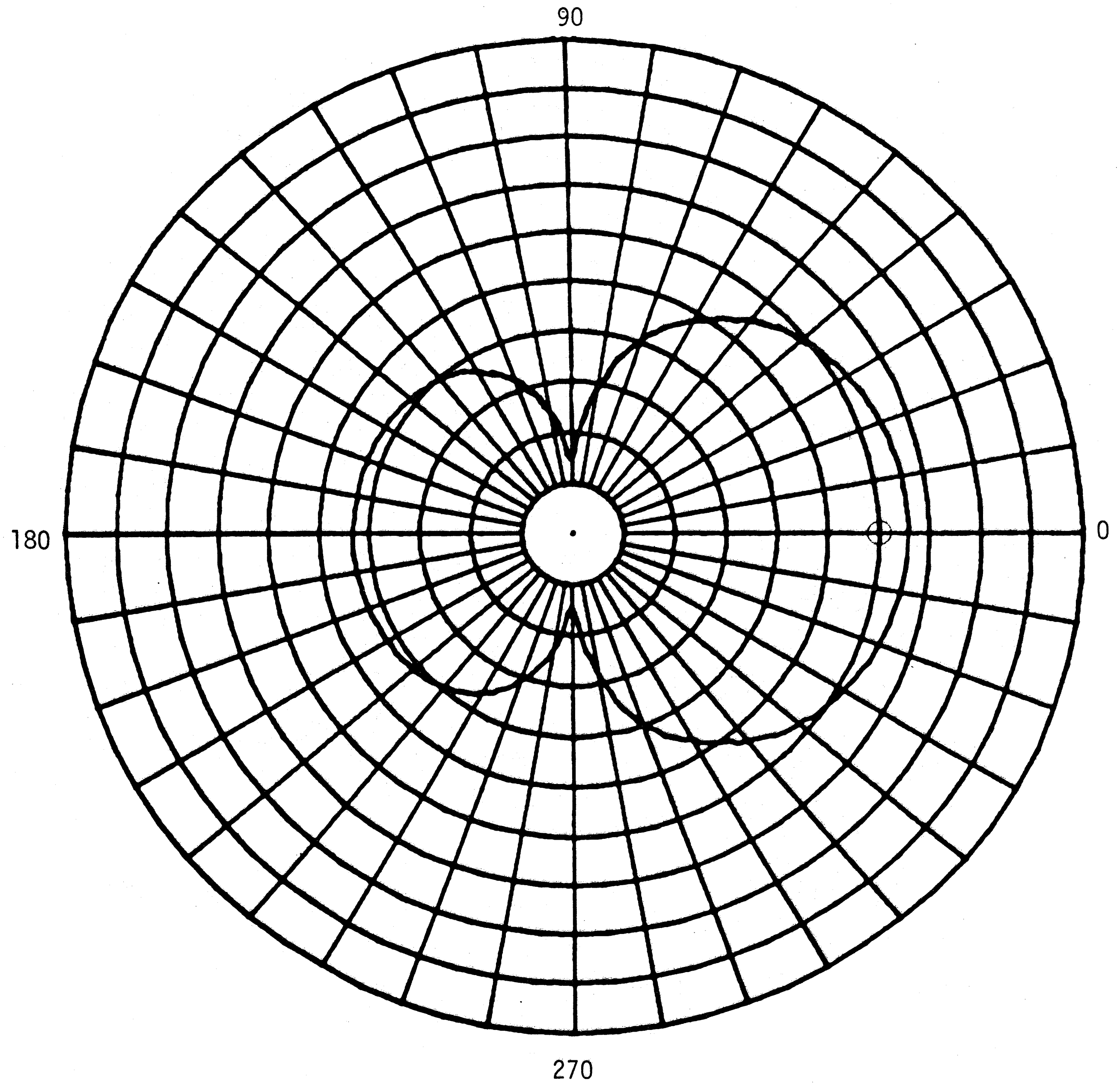

Figure A-5. Relative gain pattern in the azimuthal plane at 63 MHz for antenna No. 2.

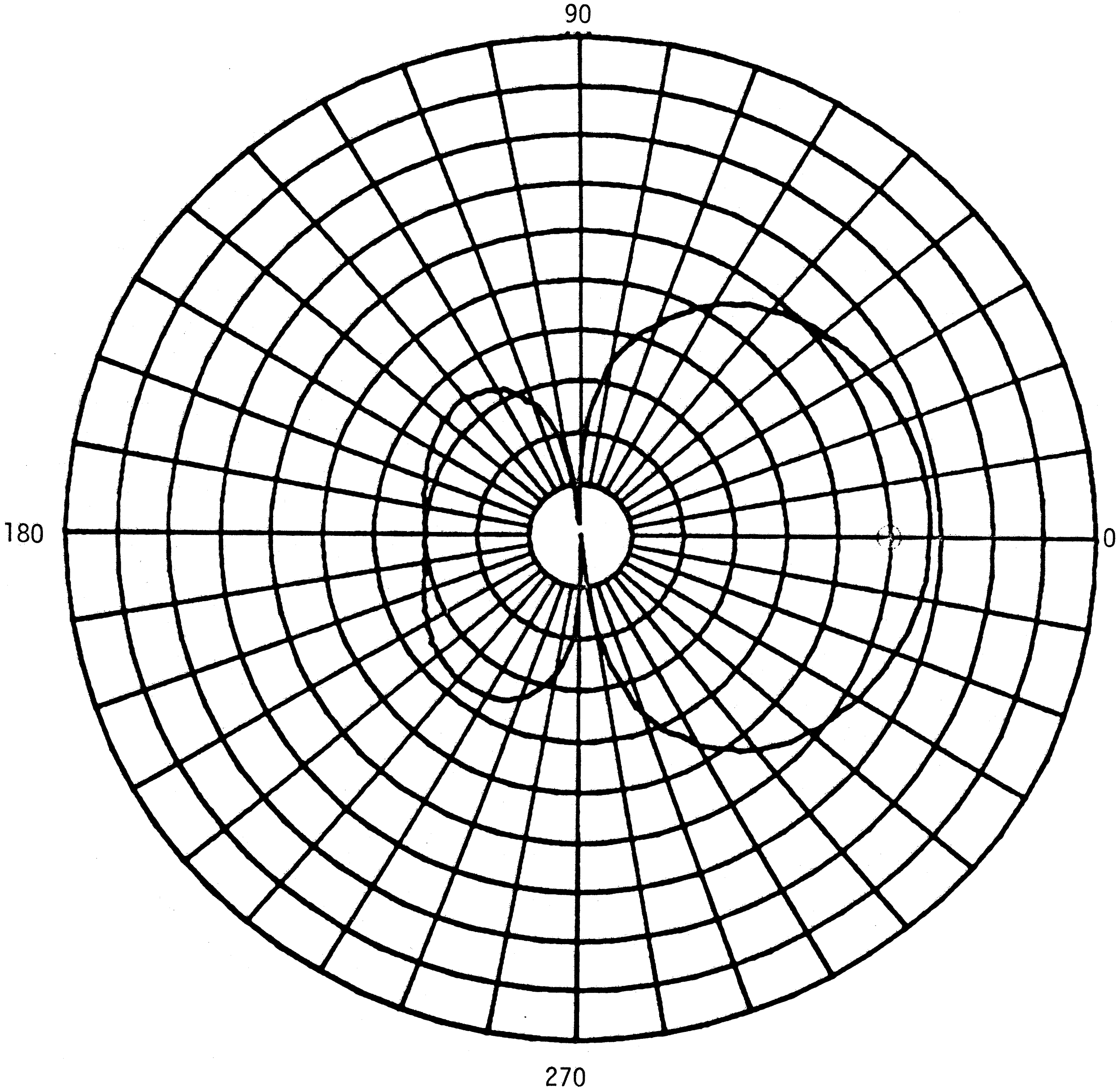

Figure A-6. Relative gain pattern in the azimuthal plane at 79 MHz for antenna No. 2.

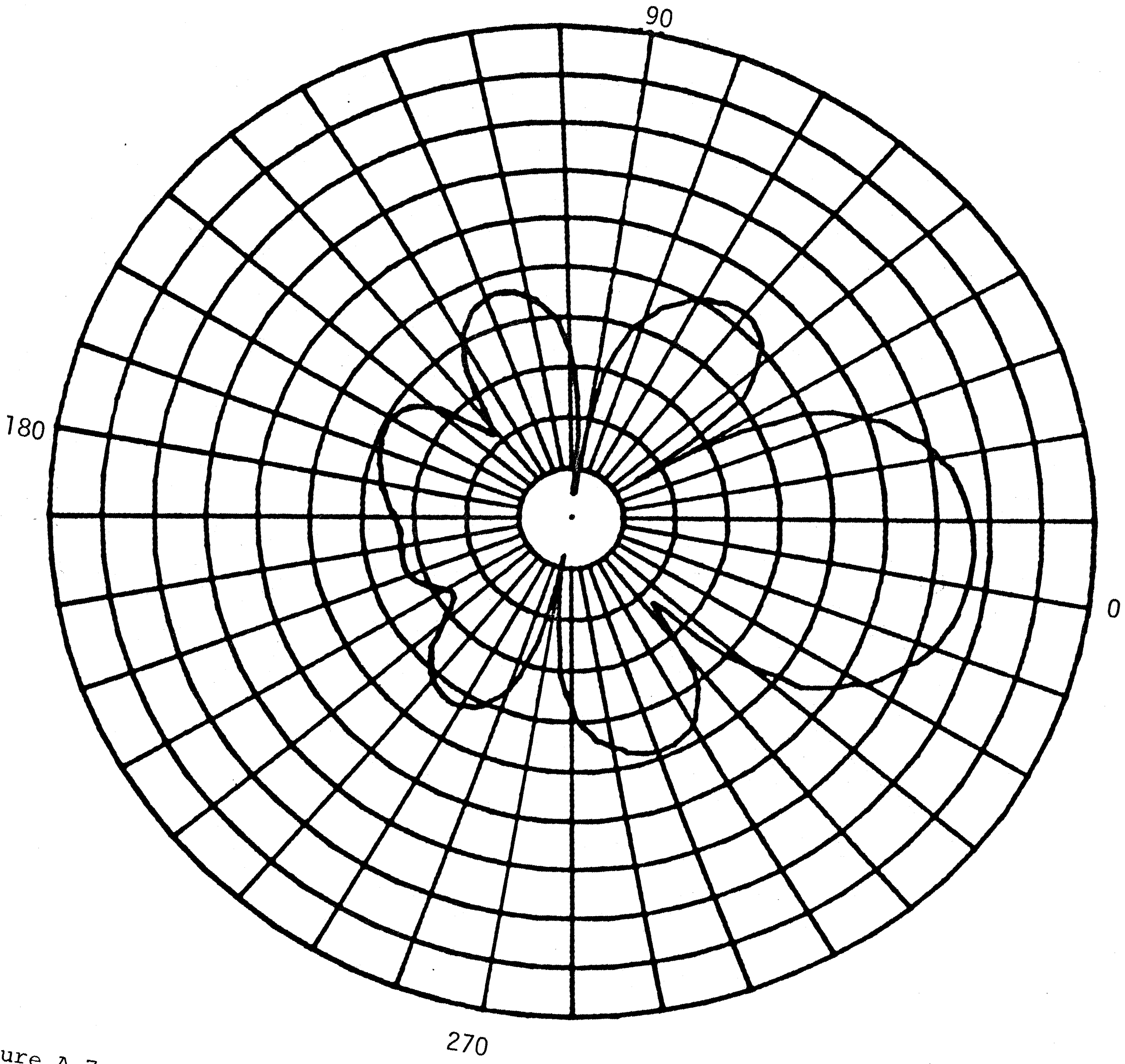

Figure A-7. Relative gain pattern in the azimuthal plane at 183 MHz for antenna No. 2.

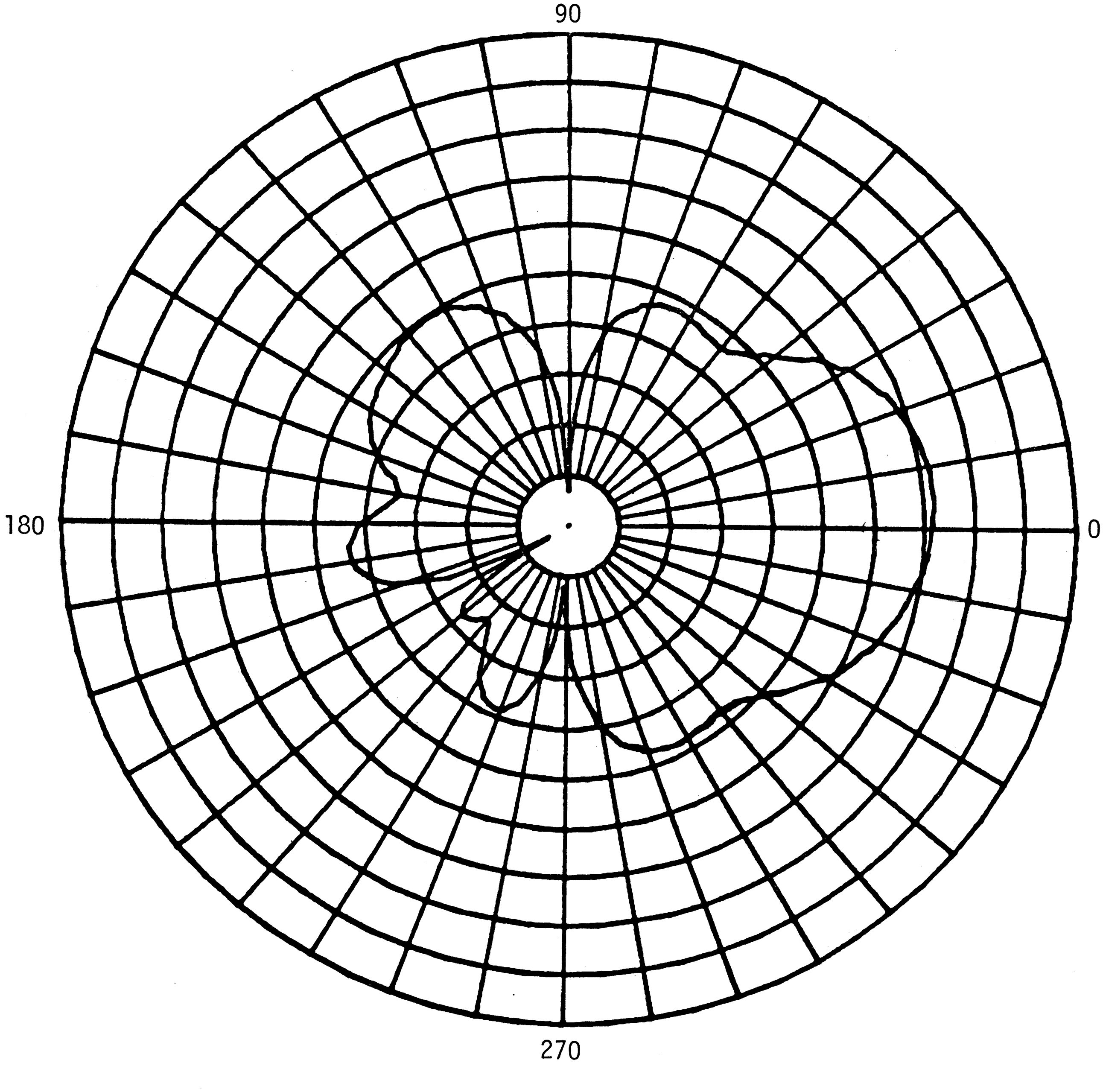

Figure A-8. Relative gain pattern in the azimuthal plane at 213 MHz for antenna No. 2.

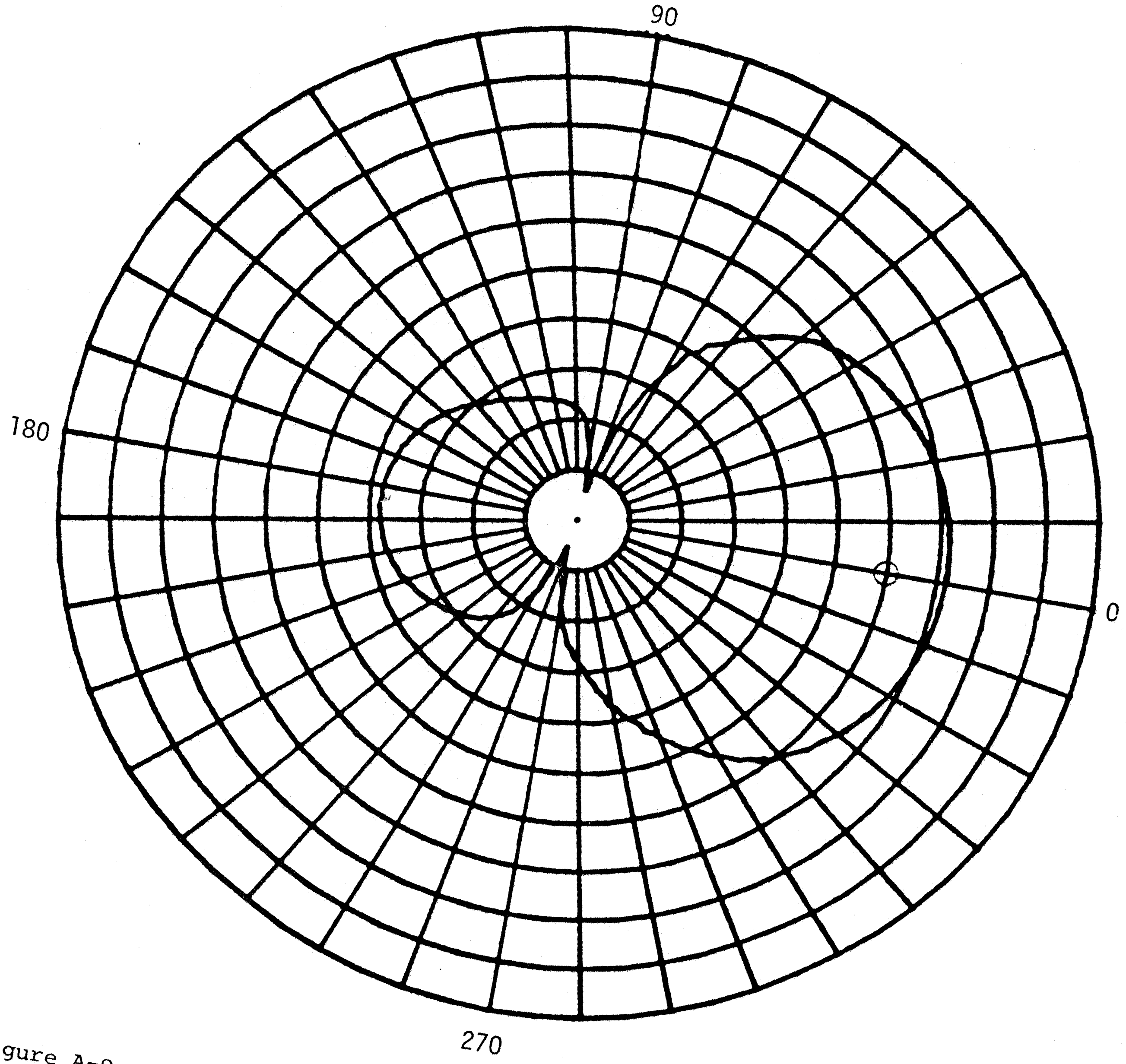

Figure A-9. Relative gain pattern in the azimuthal plane at 63 MHz for antenna No. 3.

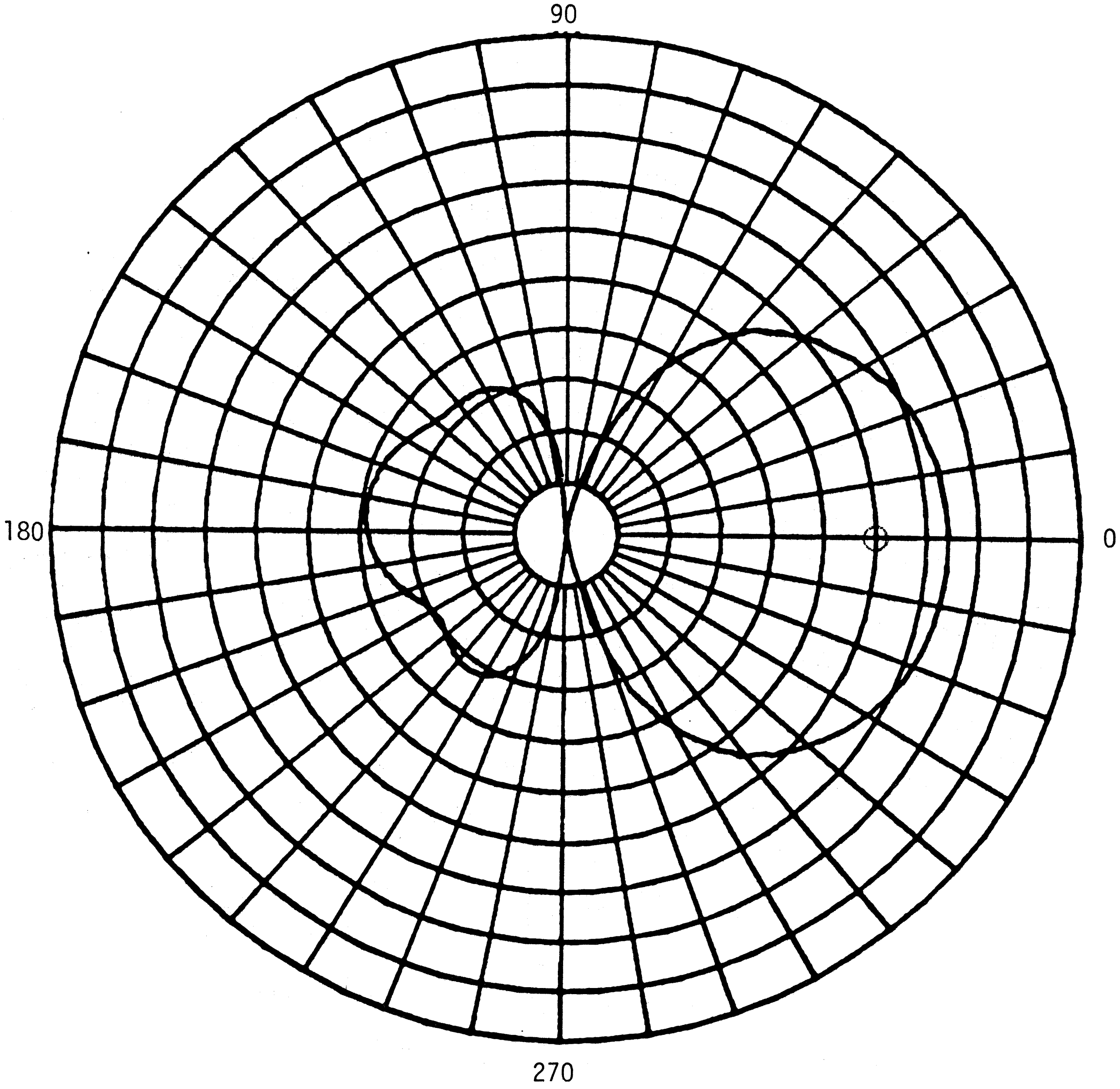

Figure A-10. Relative gain pattern in the azimuthal plane at 79 MHz for antenna No. 3.

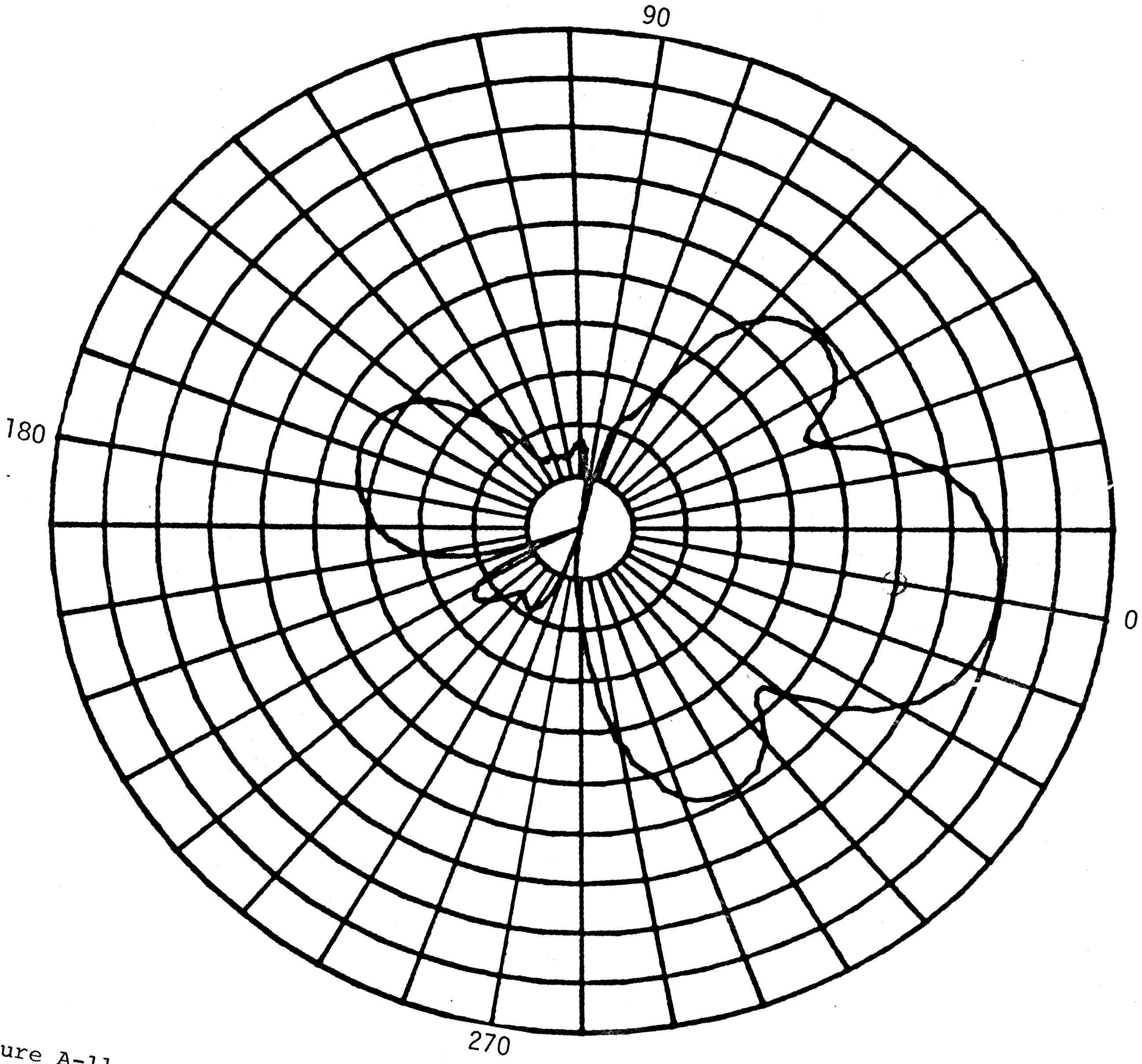

Figure A-11. Relative gain pattern in the azimuthal plane at 183 MHz for antenna No. 3.

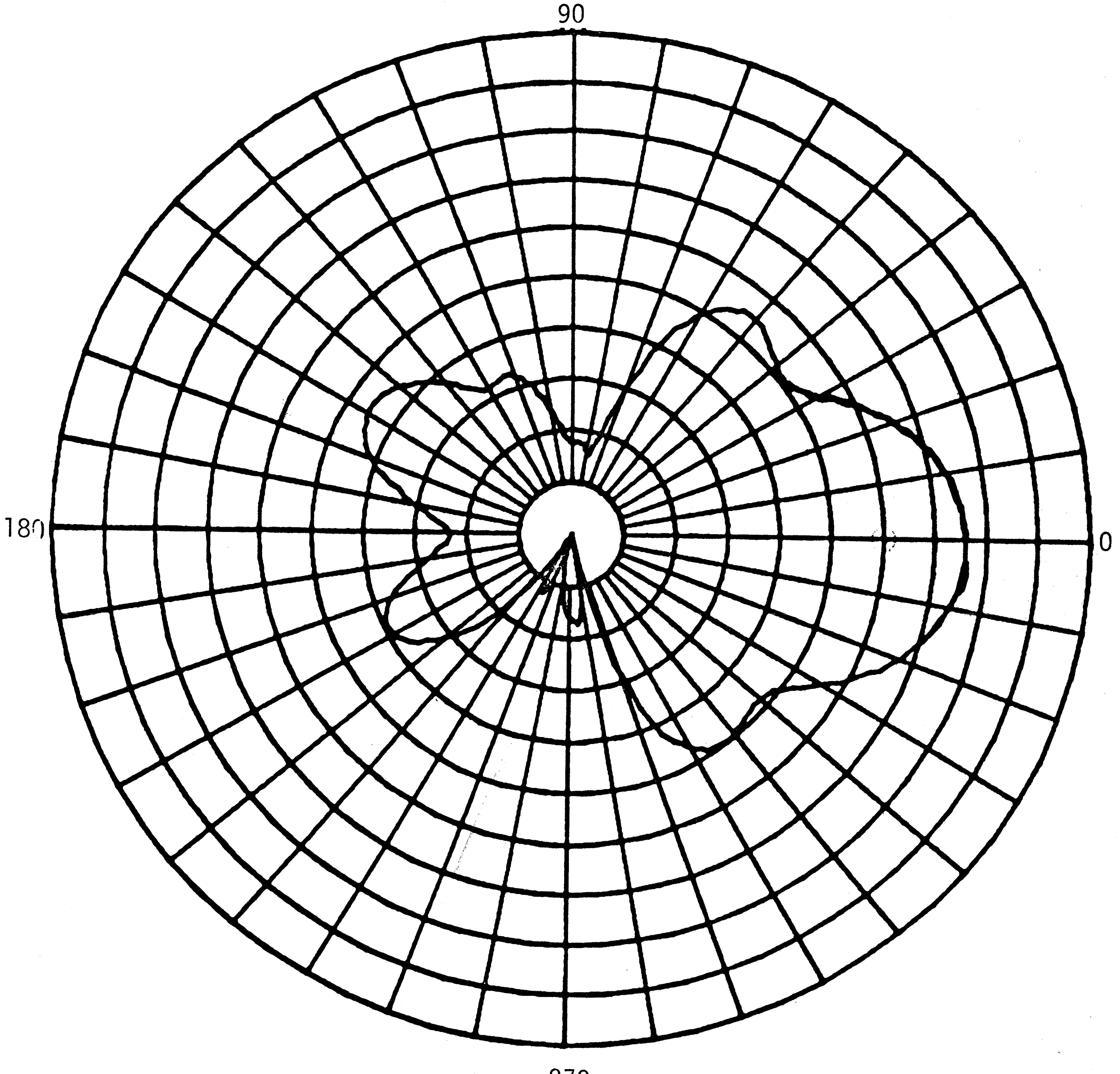

Figure A-12. Relative gain pattern in the azimuthal plane at 213 MHz for antenna No. 3.

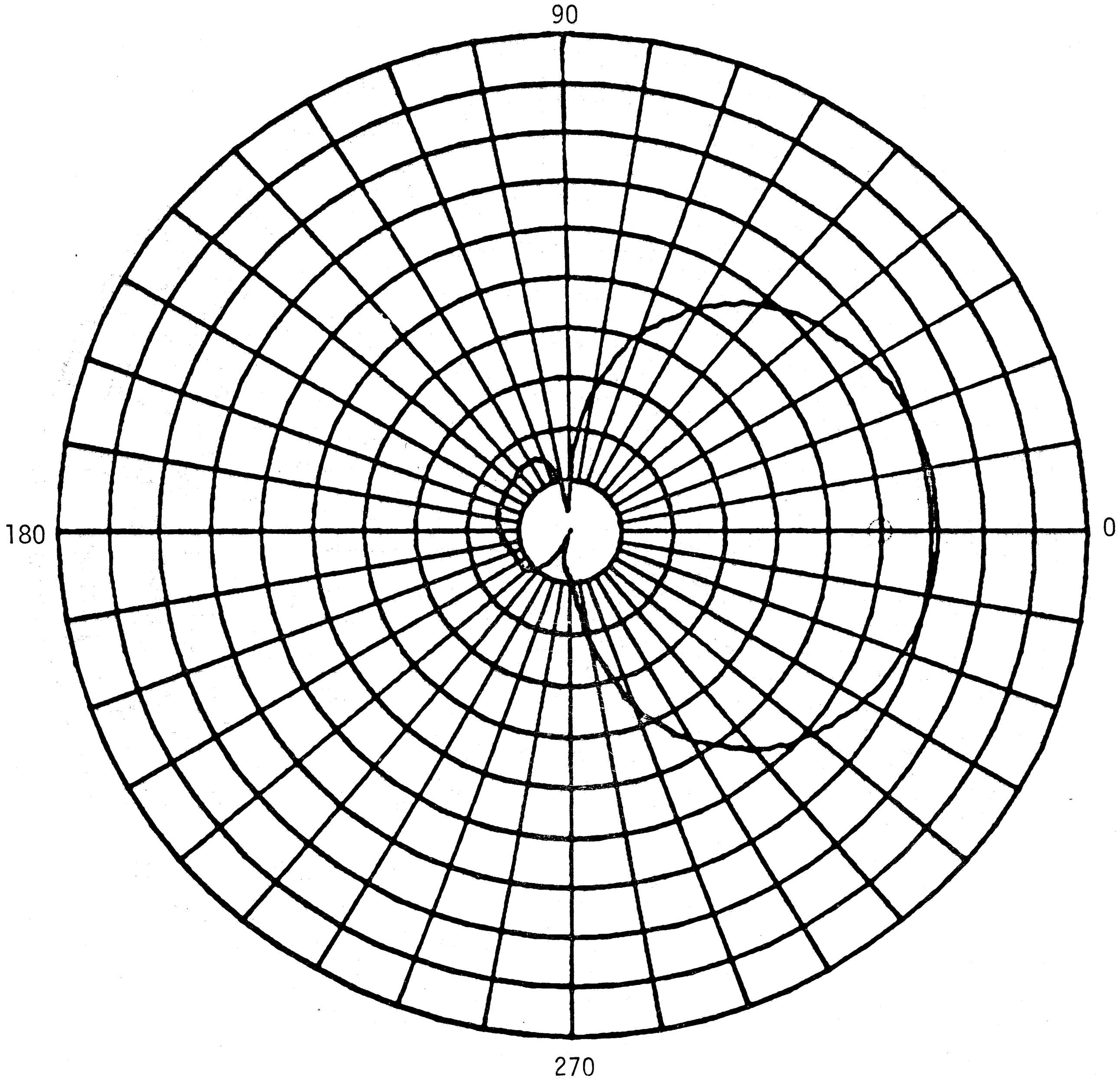

Figure A-13. Relative gain pattern in the azimuthal plane at 63 MHz for antenna No. 4.

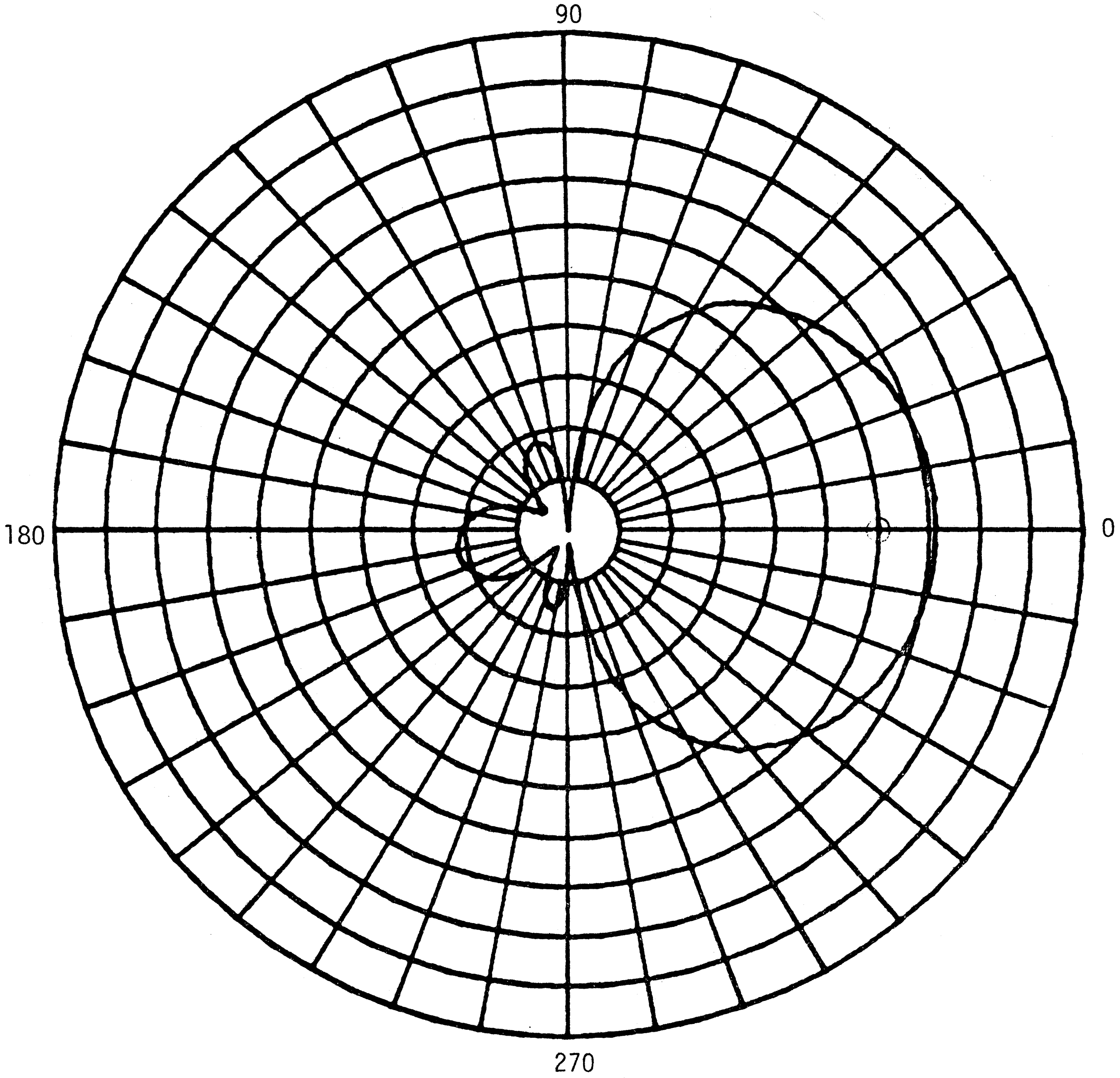

Figure A-14. Relative gain pattern in the azimuthal plane at 79 MHz for antenna No. 4.

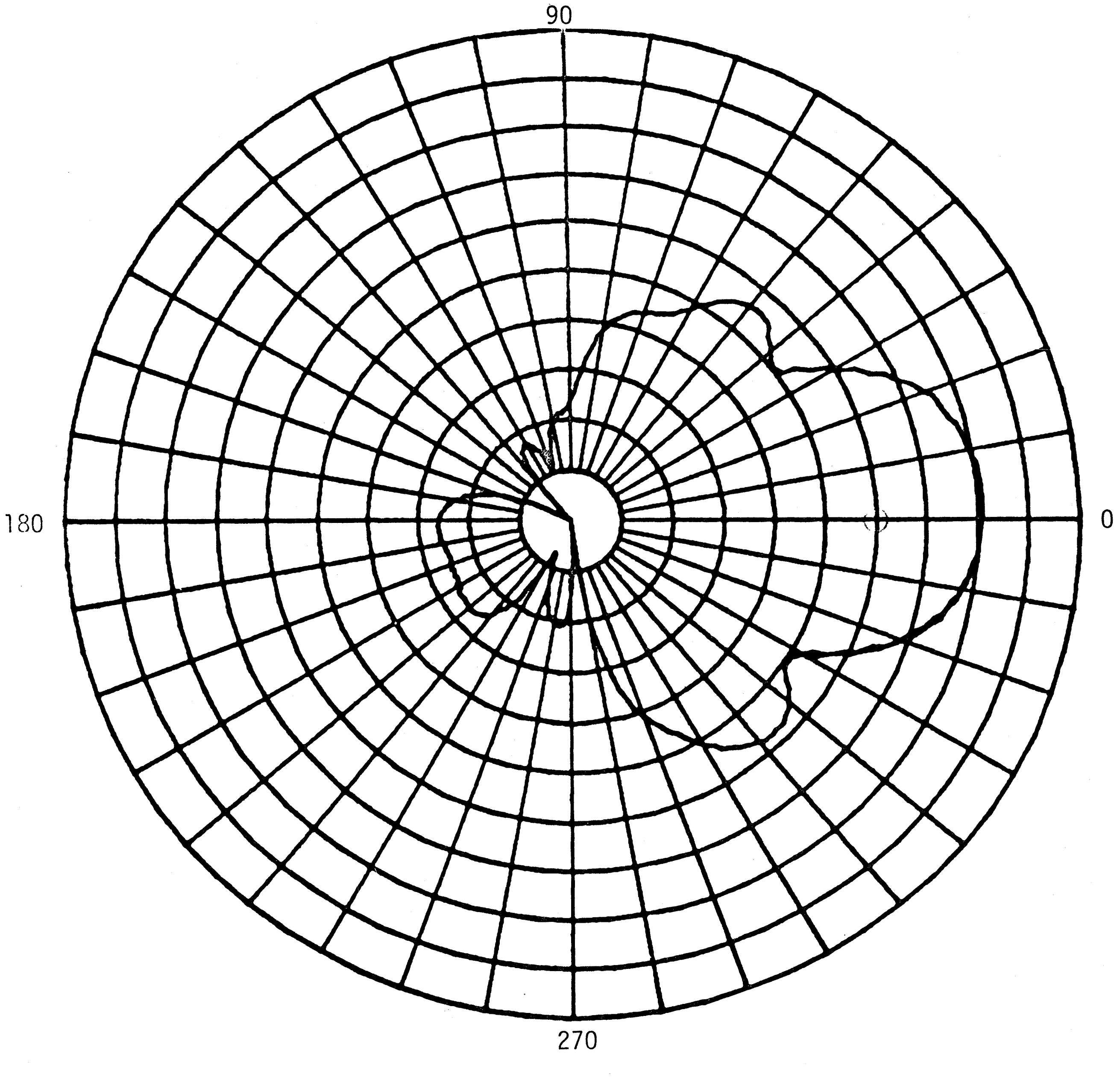

Figure A-15. Relative gain pattern in the azimuthal plane at 183 MHz for antenna No. 4.

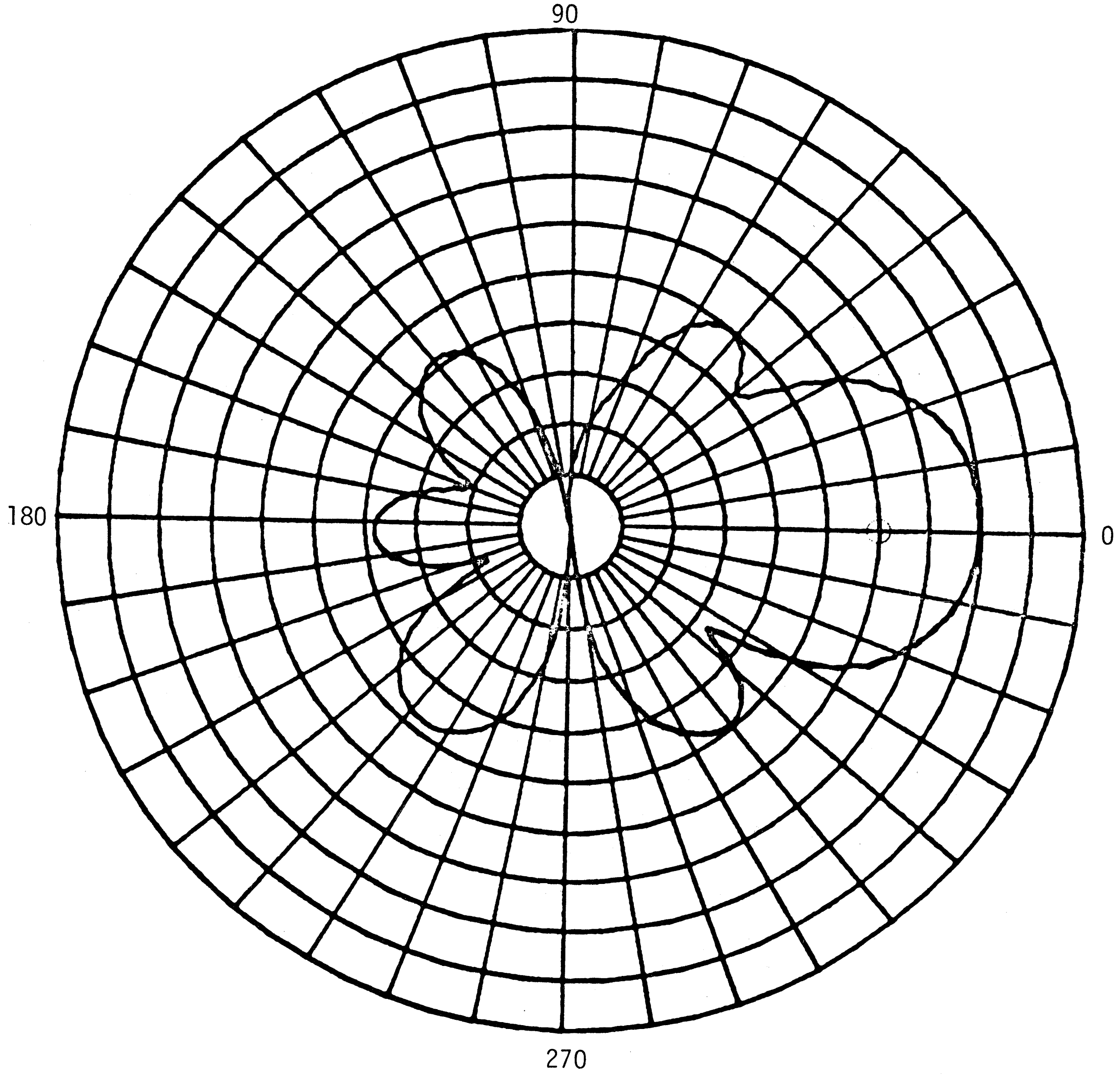

Figure A-16. Relative gain pattern in the azimuthal plane at 213 MHz for antenna No. 4.

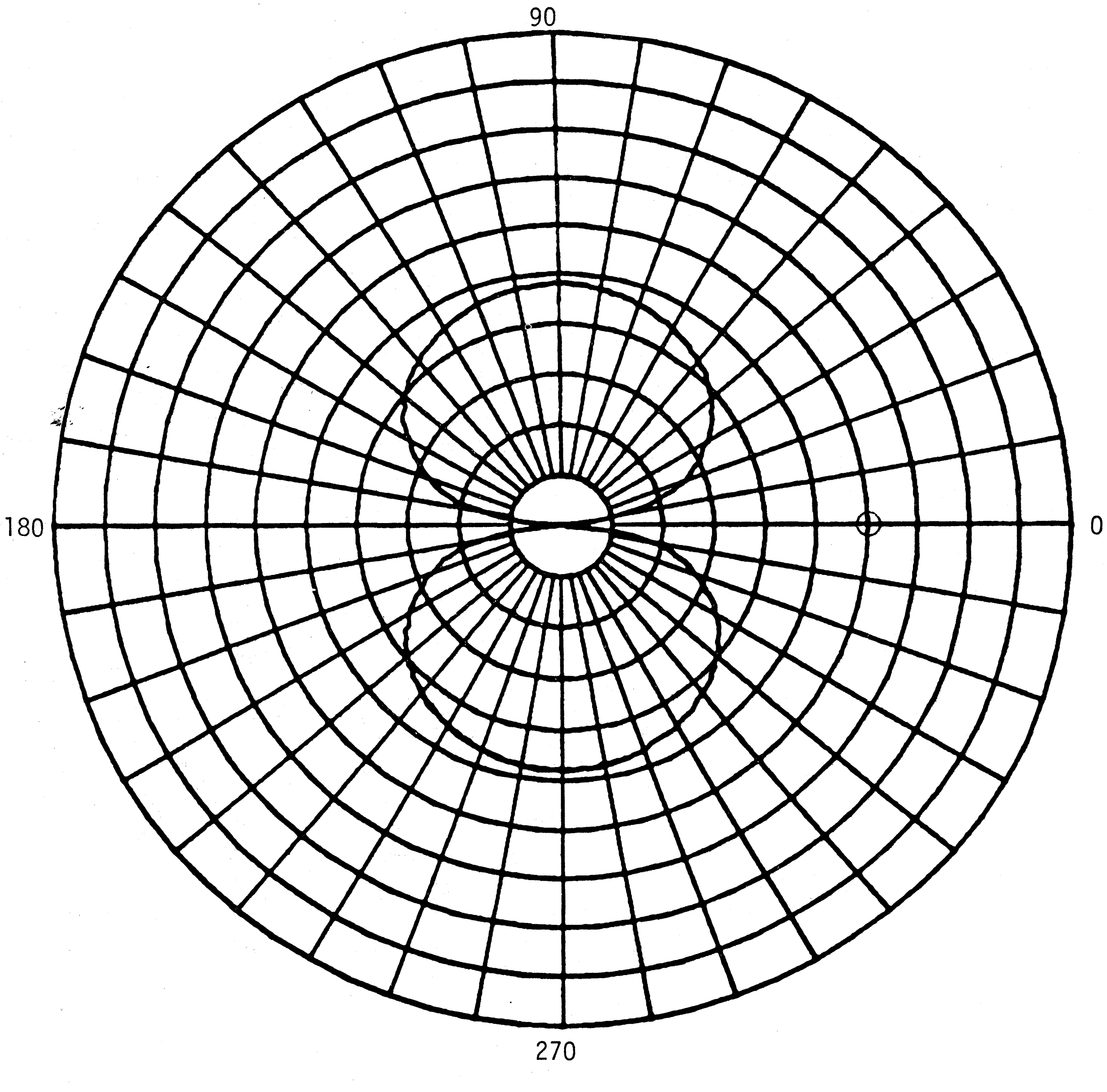

Figure A-17. Relative gain pattern in the azimuthal plane at 63 MHz for antenna No. 5. Antenna was mounted on test stand 90 deg off optical "boresight" to transmitting antenna.

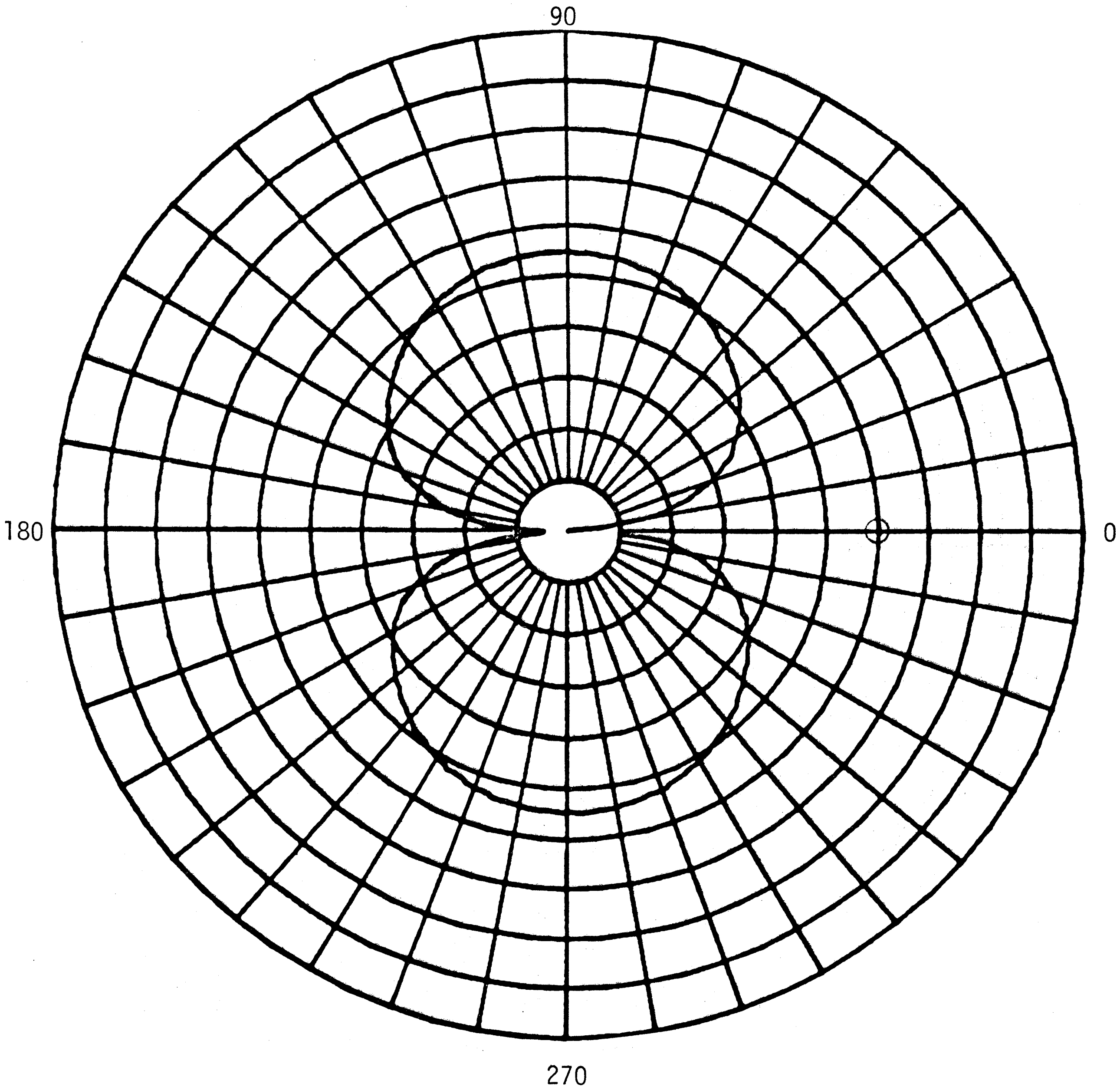

Figure A-18. Relative gain pattern in the azimuthal plane at 79 MHz for antenna No. 5. Antenna was mounted on test stand 90 deg off optical "boresight" to transmitting antenna.

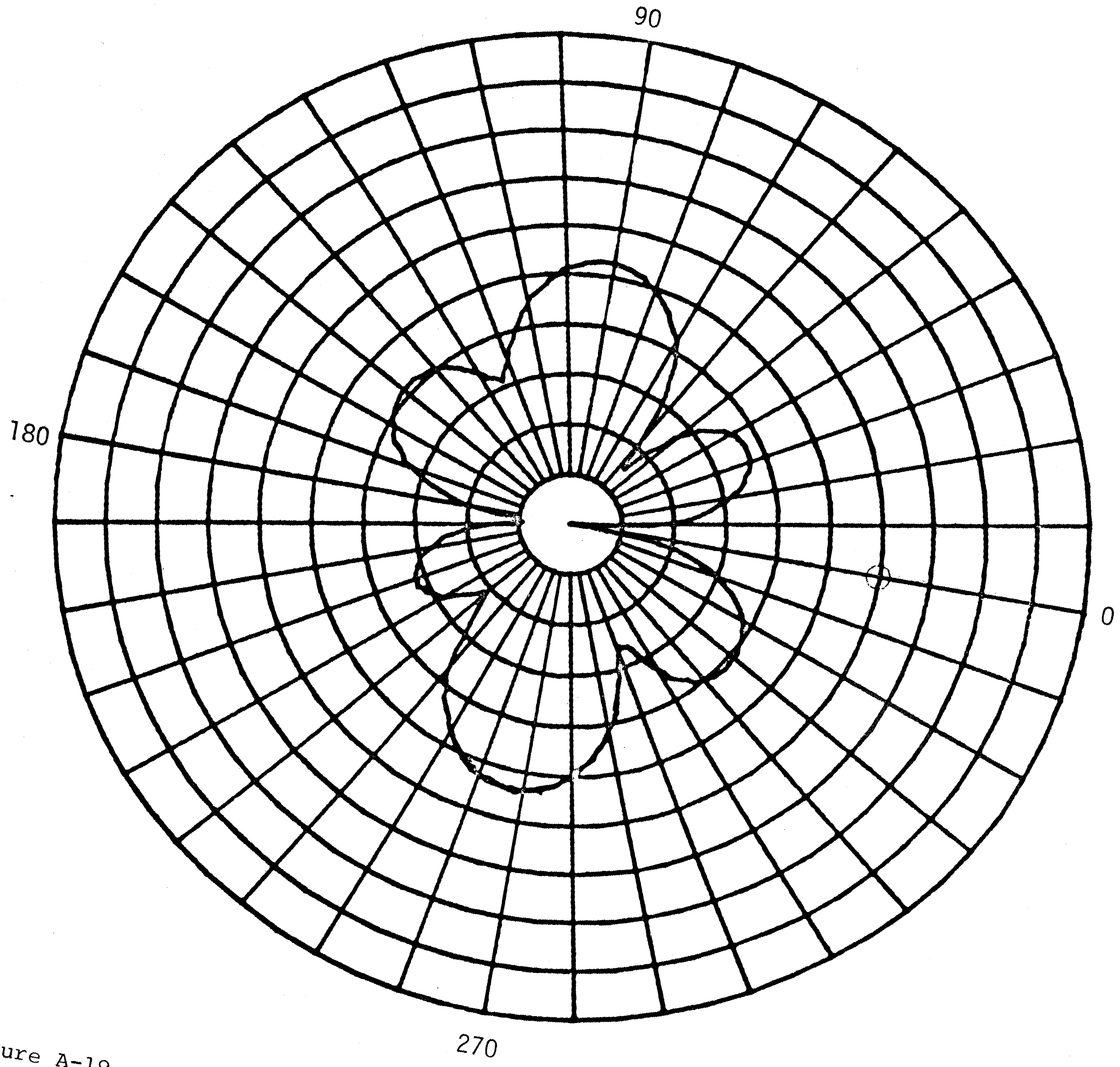

Figure A-19. Relative gain pattern in the azimuthal plane at 183 MHz for antenna No. 5. Antenna was mounted on test stand 90 deg off optical "boresight" to transmitting antenna.

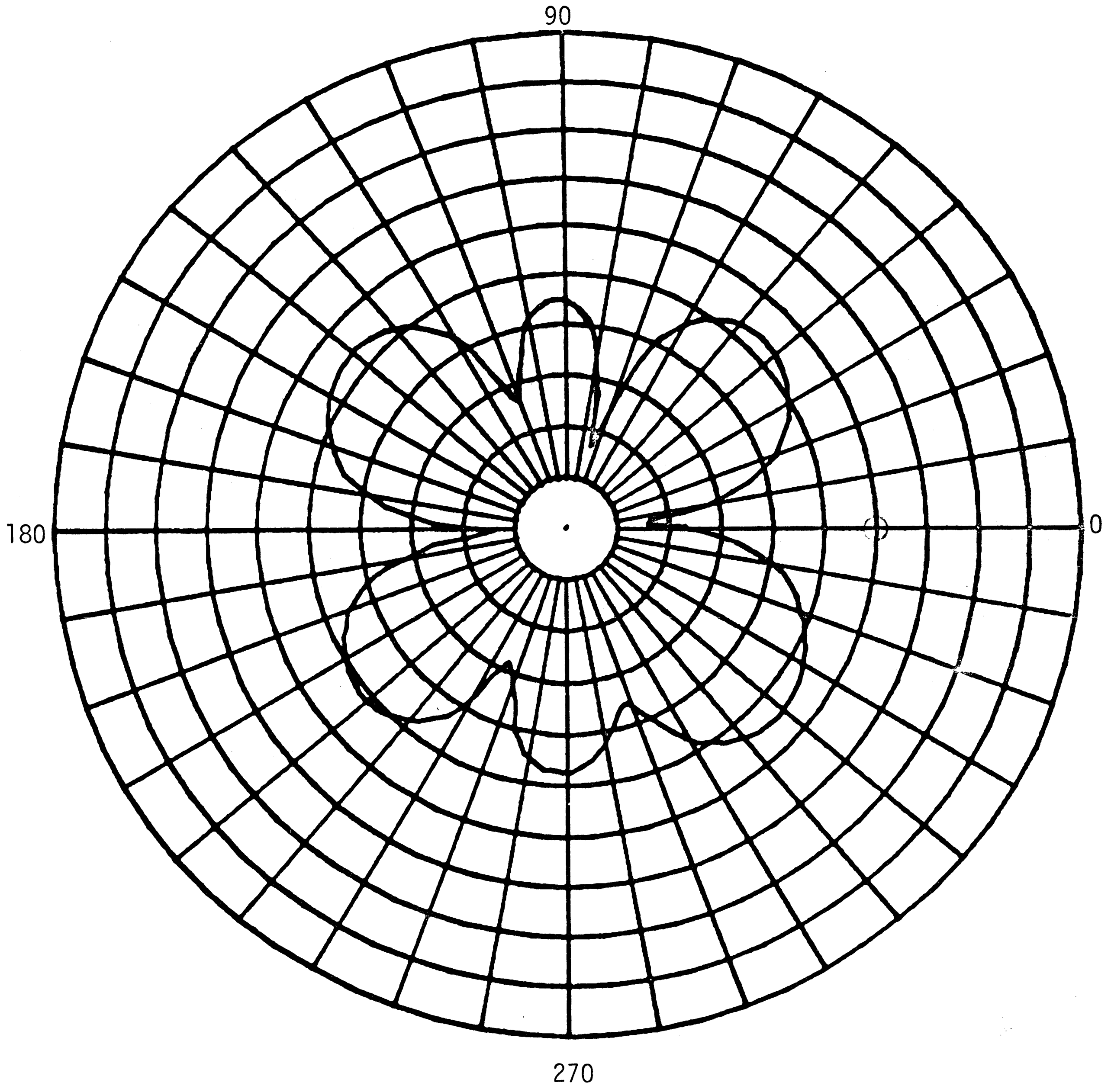

Figure A-20. Relative gain pattern in the azimuthal plane at 213 MHz for antenna No. 5. Antenna was mounted on test stand 90 deg off optical "boresight" to transmitting antenna.

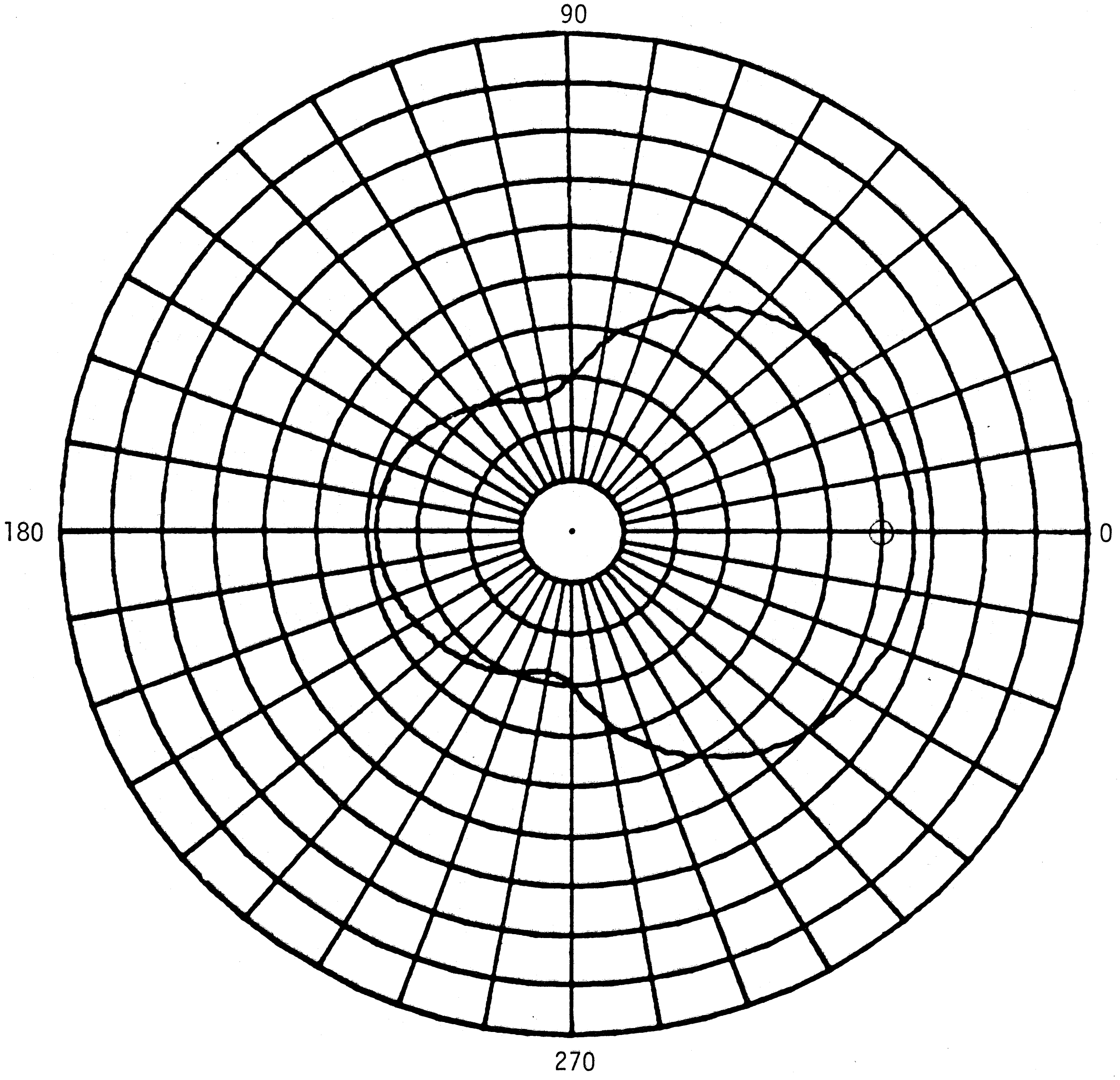

Figure A-21. Relative gain pattern in the azimuthal plane at 63 MHz for antenna No. 6.

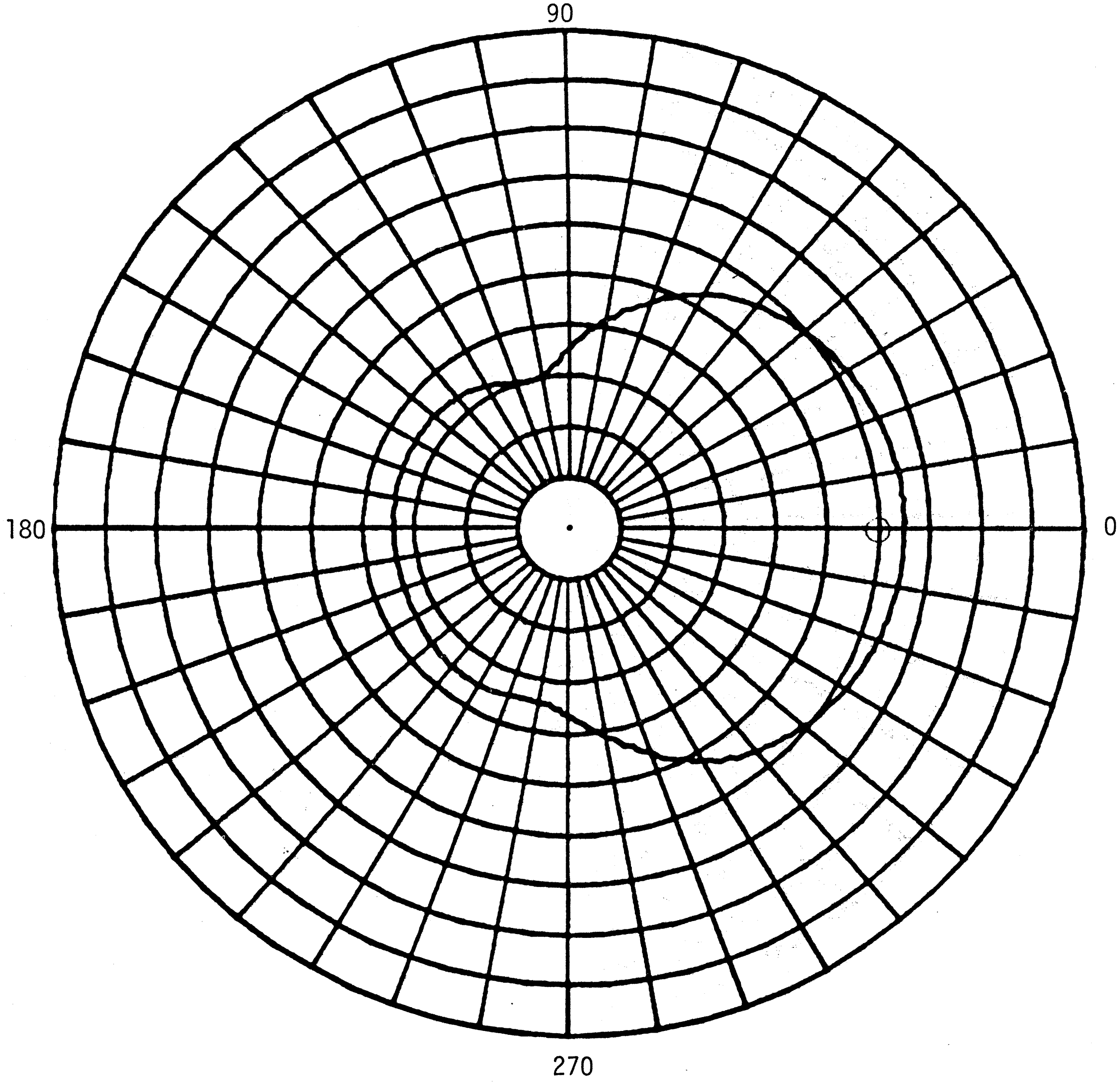

Figure A-22. Relative gain pattern in the azimuthal plane at 79 MHz for antenna No. 6.

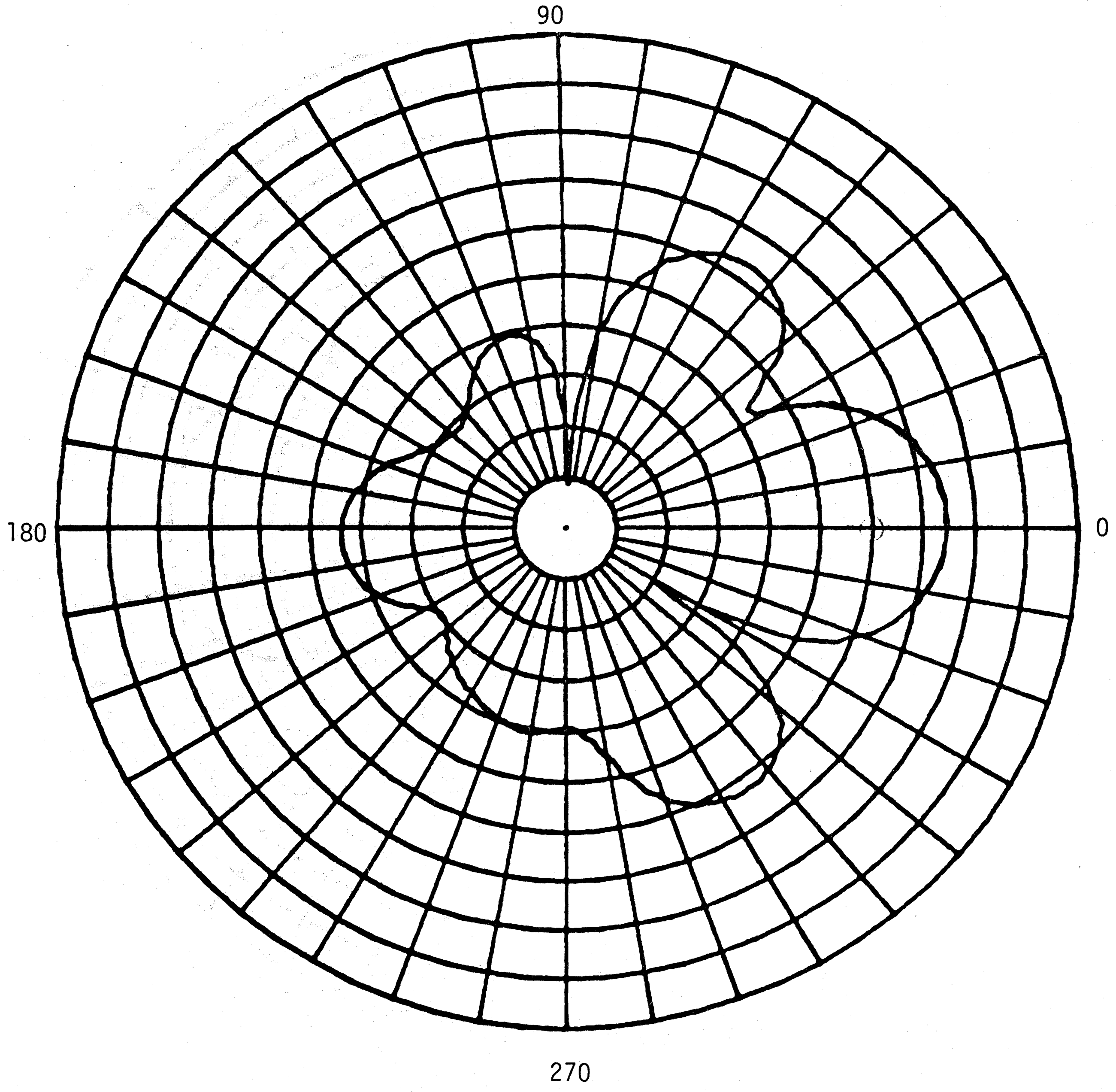

Figure A-23. Relative gain pattern in the azimuthal plane at 183 MHz for antenna No. 6.

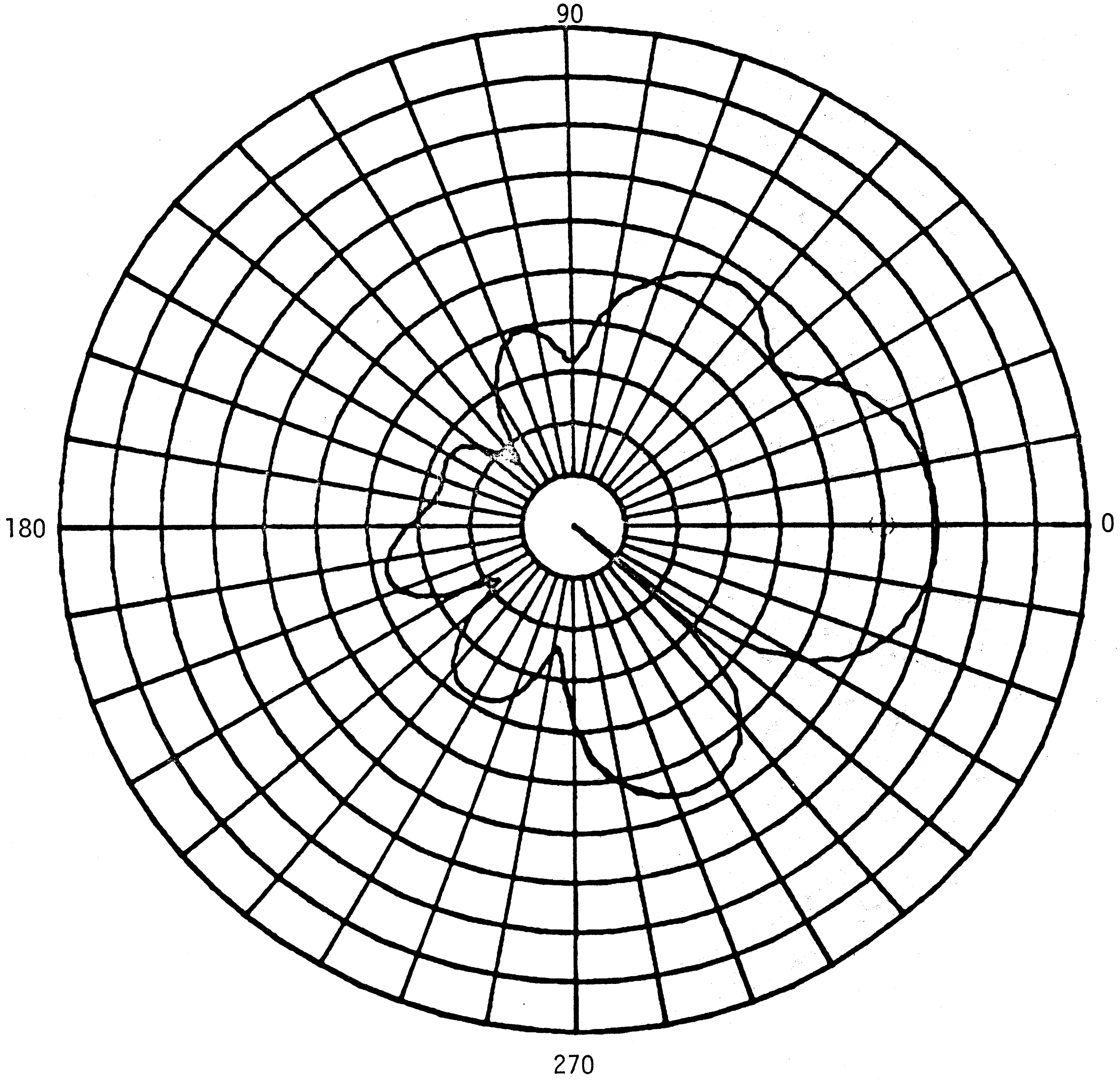

Figure A-24. Relative gain pattern in the azimuthal plane at 213 MHz for antenna No. 6.

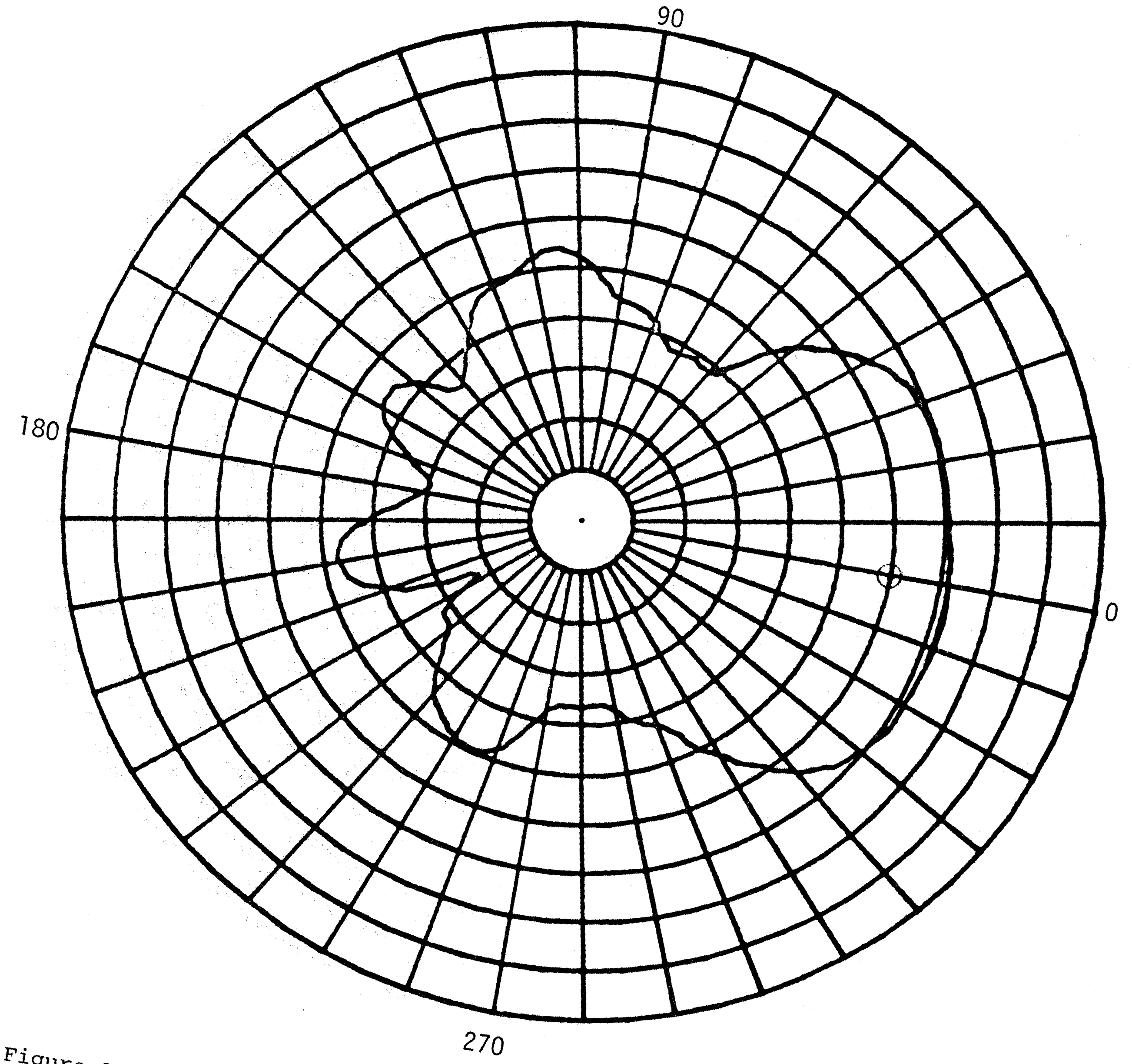

Figure A-25. Relative gain pattern in the azimuthal plane at 413 MHz for antenna No. 6.

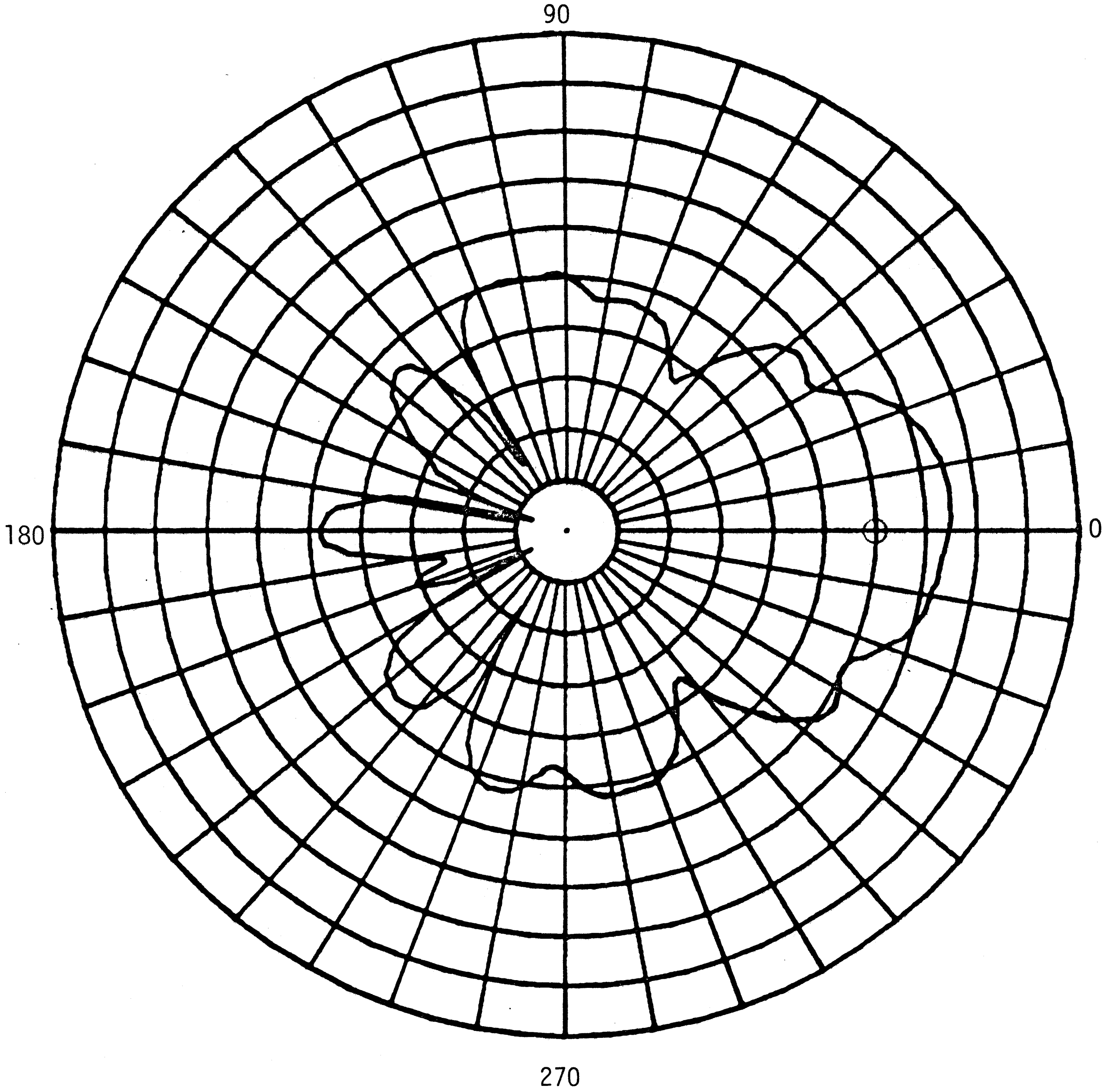

Figure A-26. Relative gain pattern in the azimuthal plane at 641 MHz for antenna No. 6.

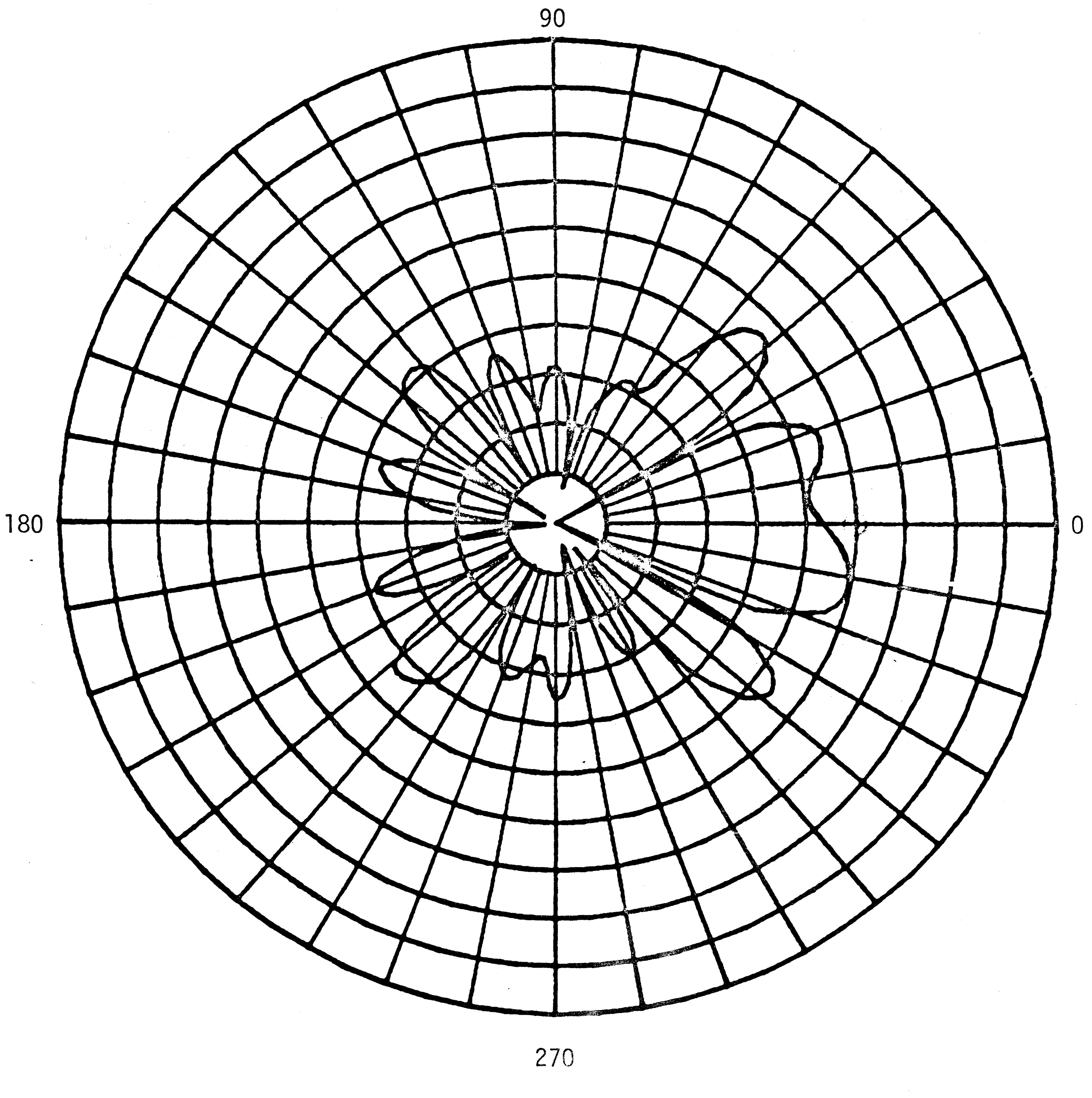

Figure A-27. Relative gain pattern in the azimuthal plane at 803 MHz for antenna No. 6. Beam splitting can be noted.

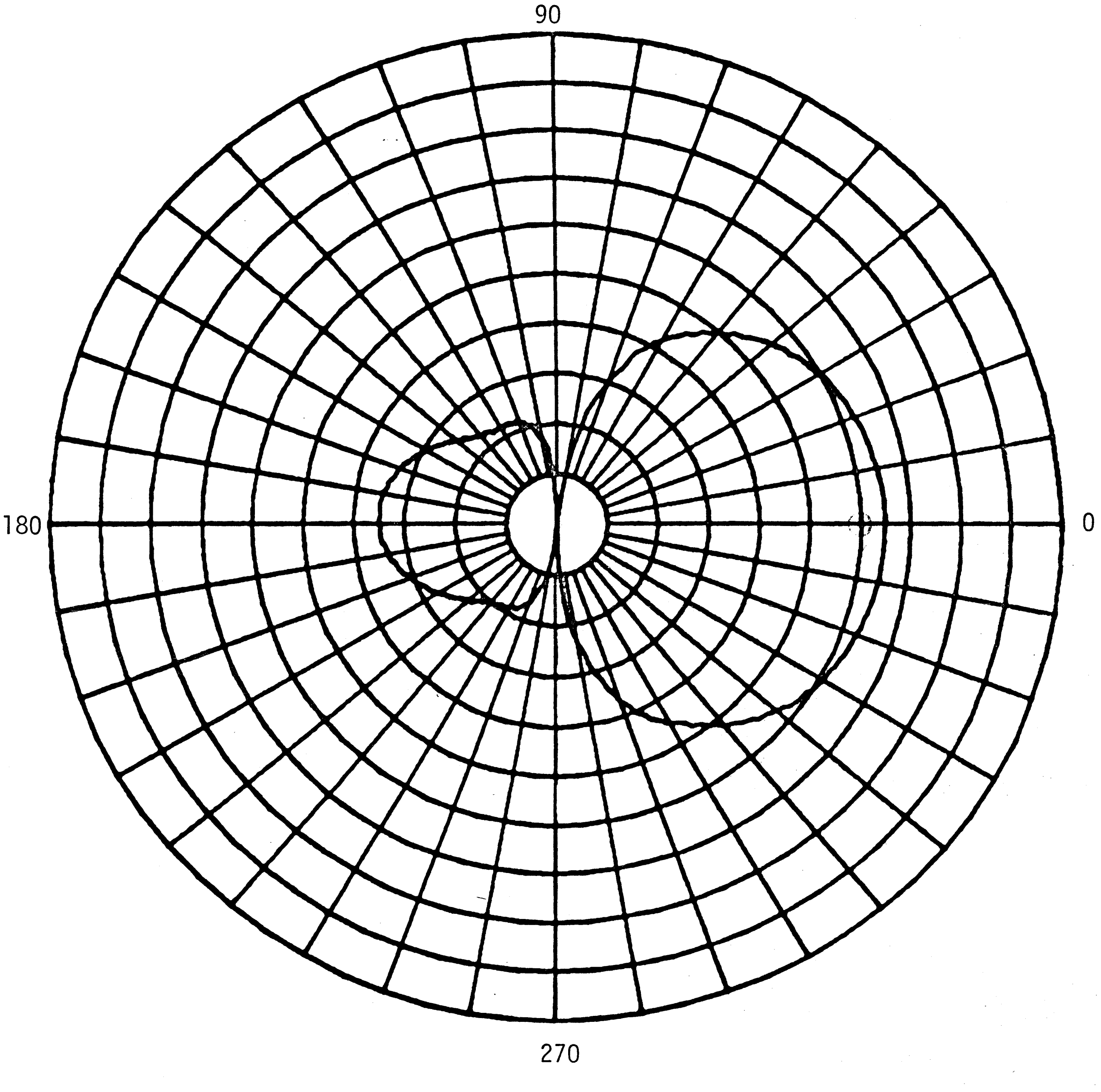

Figure A-28. Relative gain pattern in the azimuthal plane at 63 MHz for antenna No. 7.

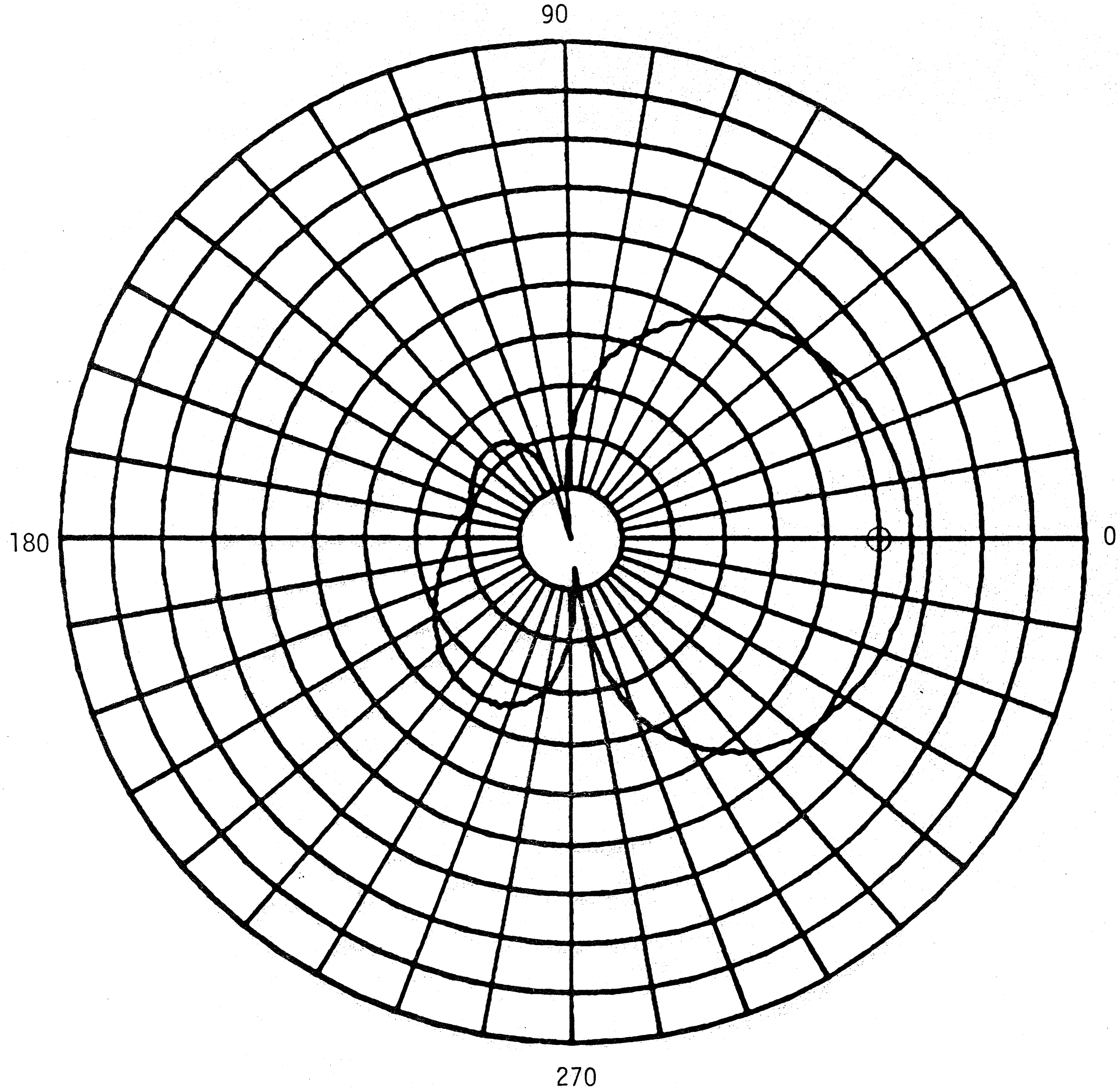

Figure A-29. Relative gain pattern in the azimuthal plane at 79 MHz for antenna No. 7.

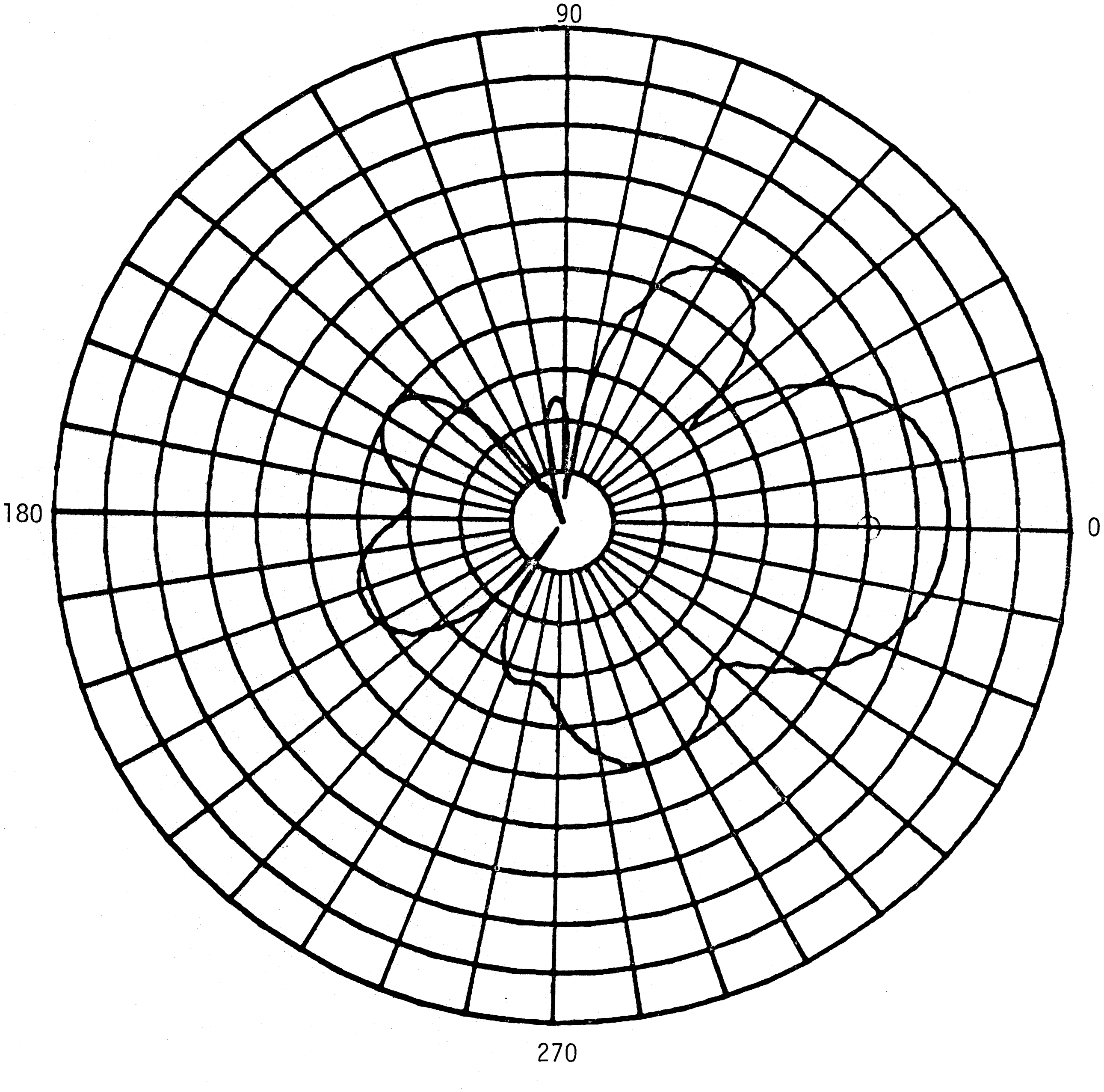

Figure A-30. Relative gain pattern in the azimuthal plane at 183 MHz for antenna No. 7.

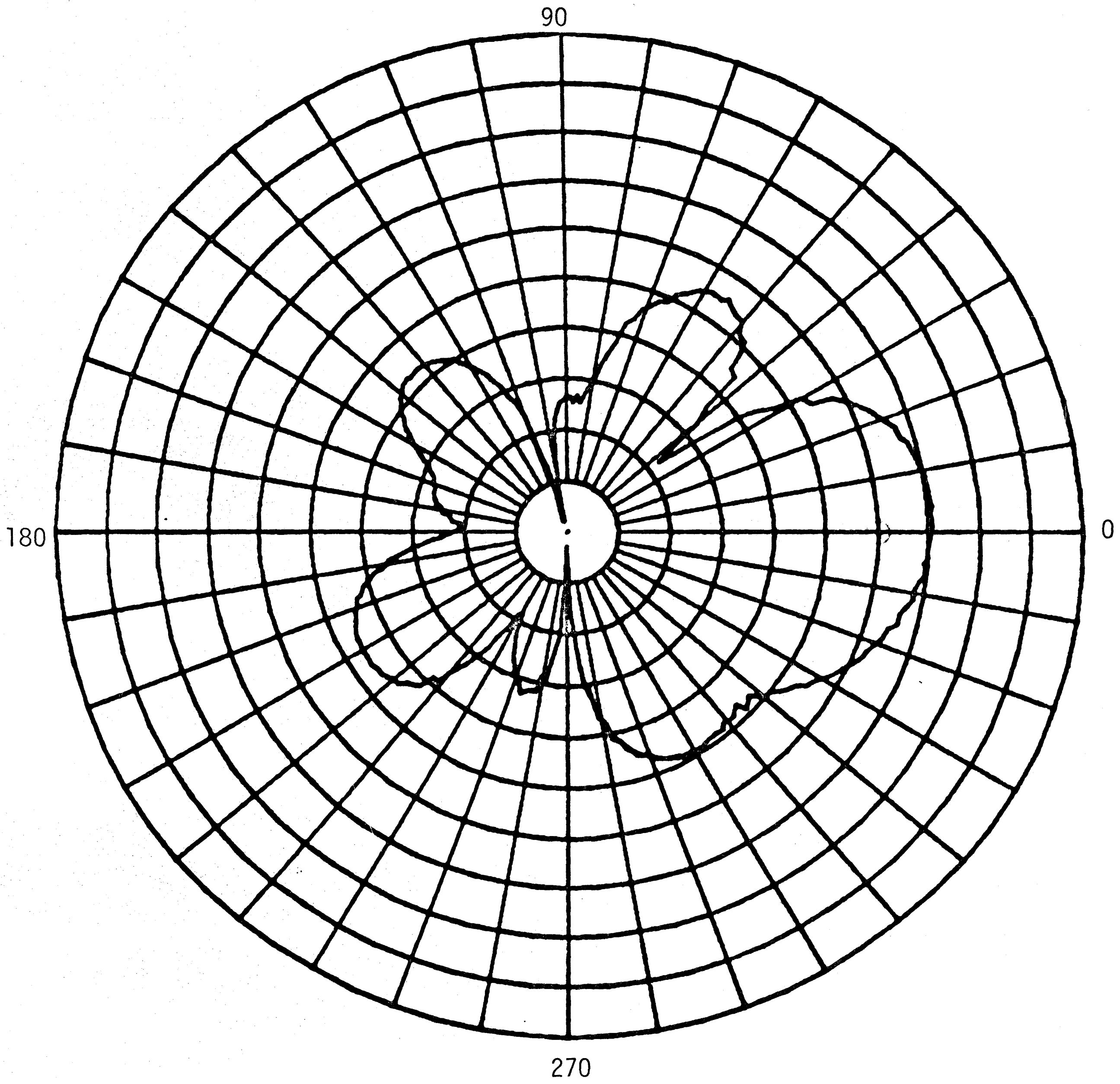

Figure A-31. Relative gain pattern in the azimuthal plane at 213 MHz for antenna No. 7.

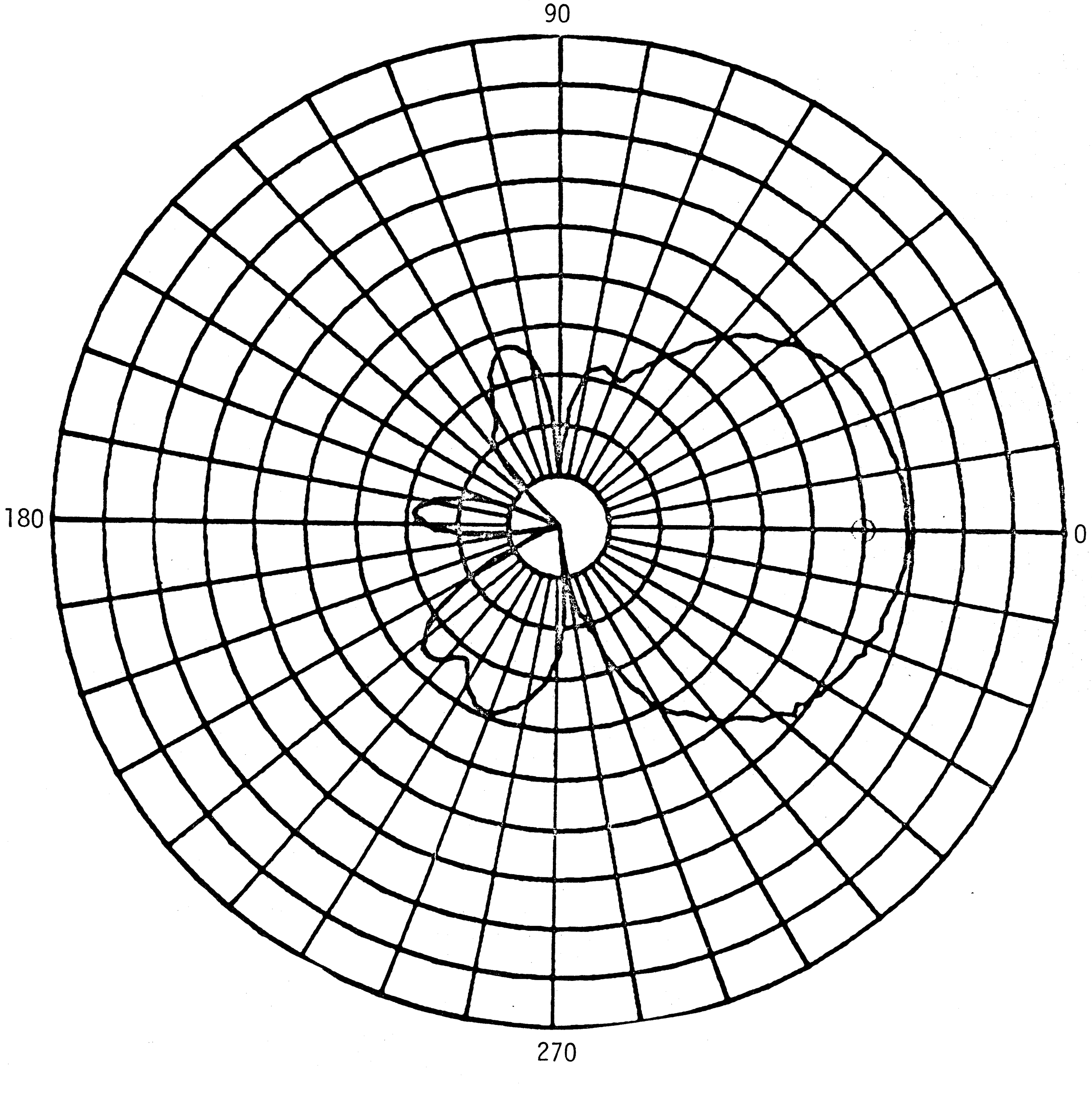

Figure A-32. Relative gain pattern in the azimuthal plane at 473 MHz for antenna No. 7.

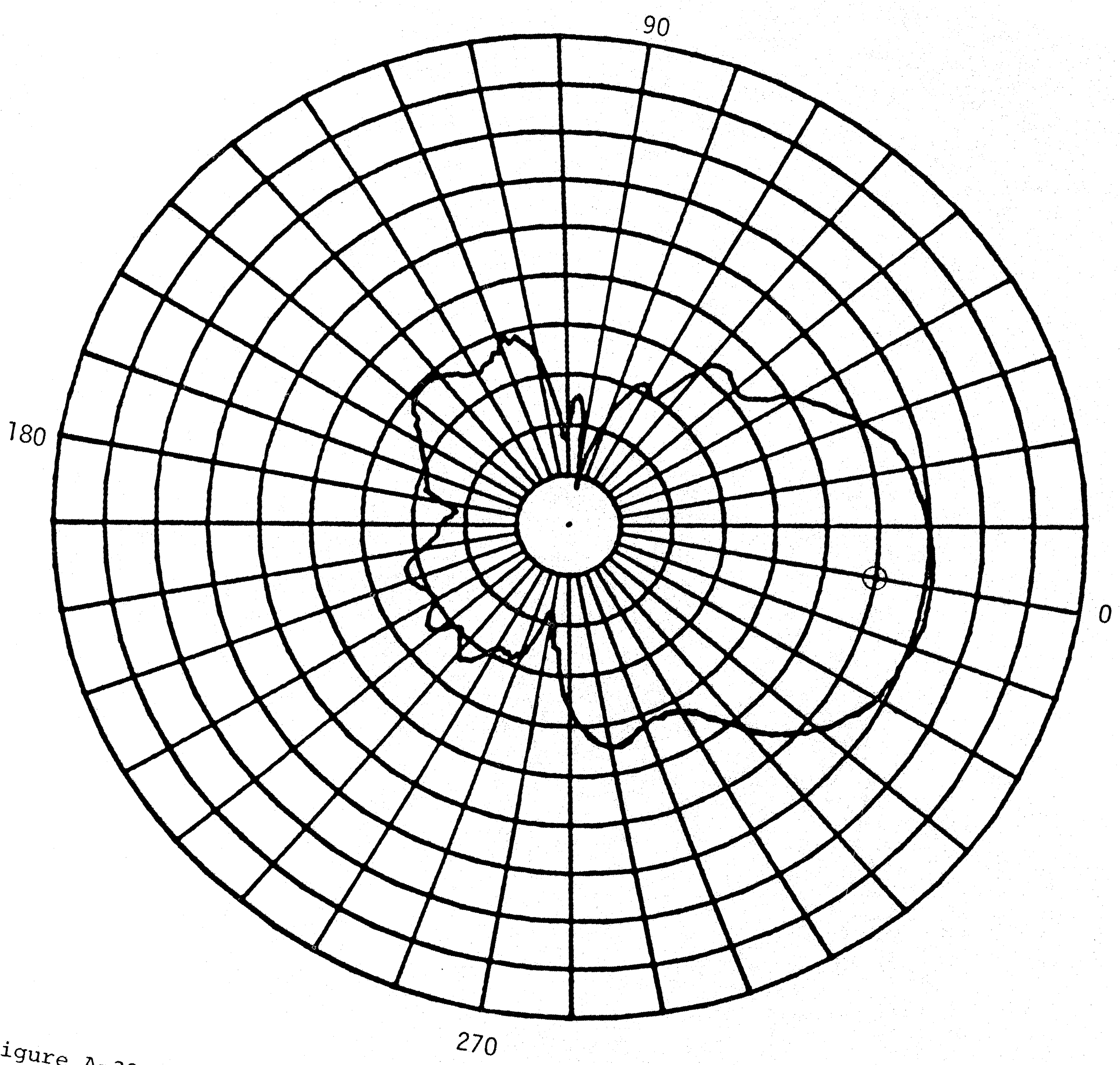

Figure A-33. Relative gain pattern in the azimuthal plane at 641 MHz for antenna No. 7.

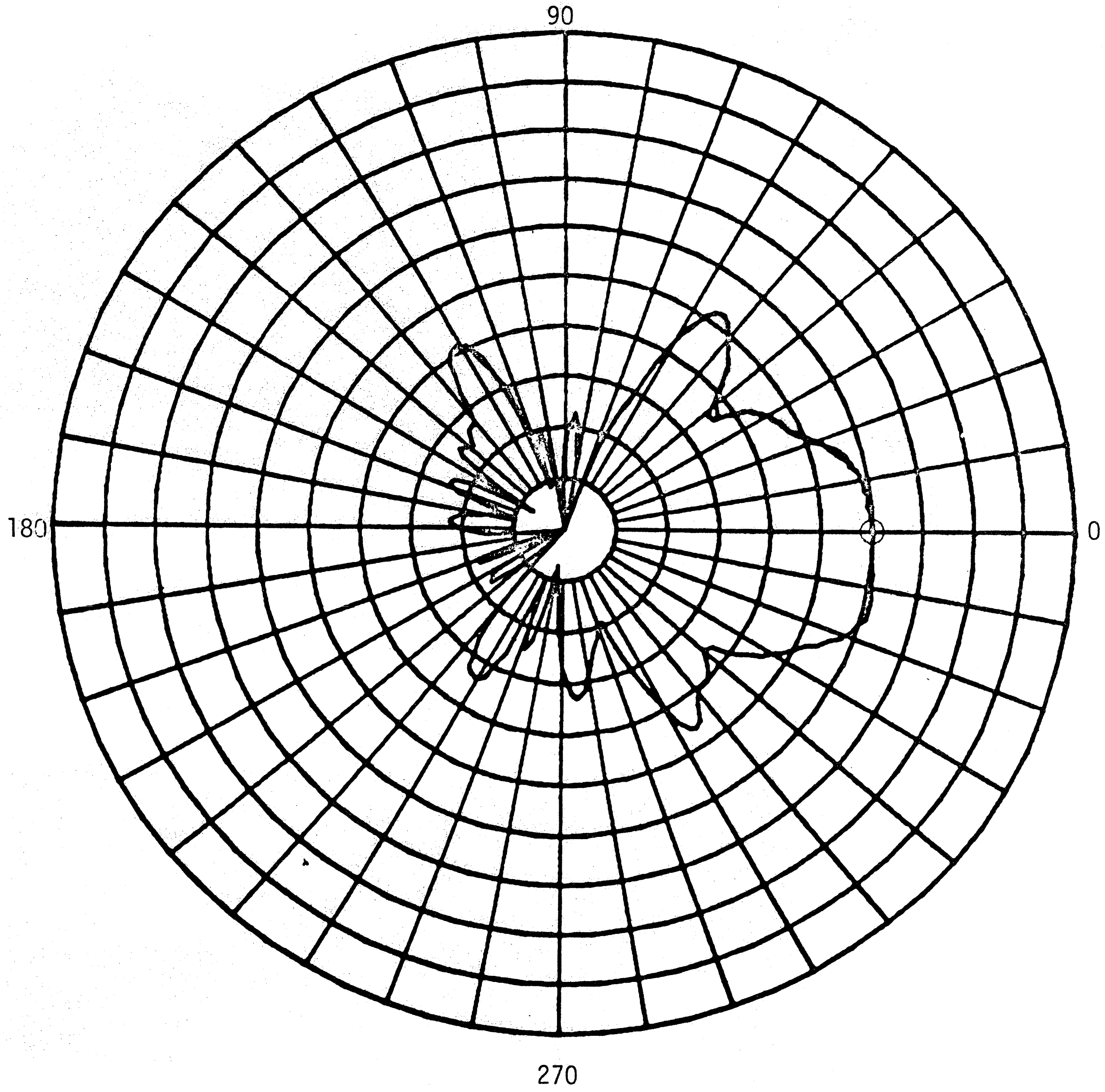

Figure A-34. Relative gain pattern in the azimuthal plane at 803 MHz for antenna No. 7.

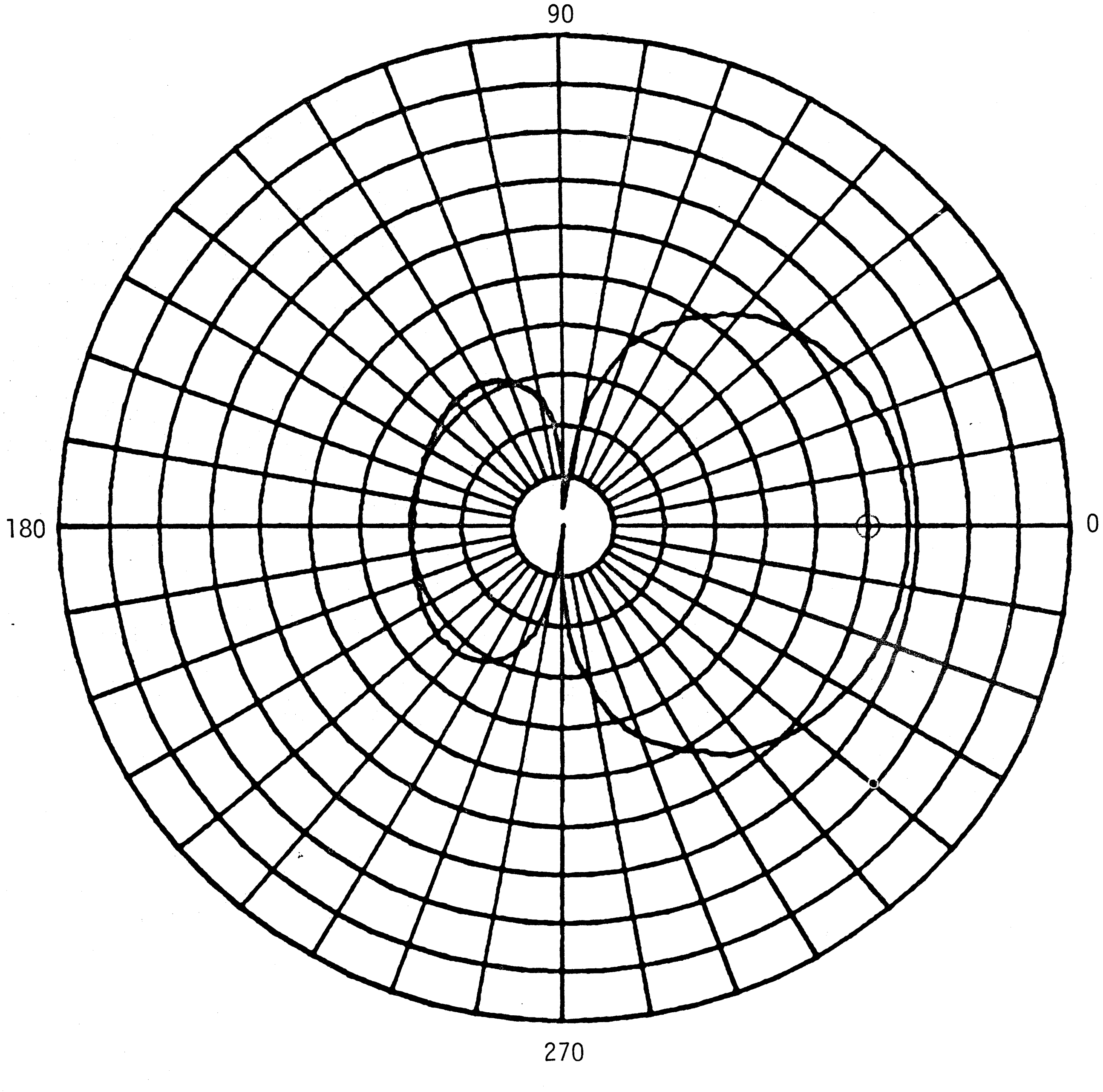

Figure A-35. Relative gain pattern in the azimuthal plane at 63 MHz for antenna No. 8.

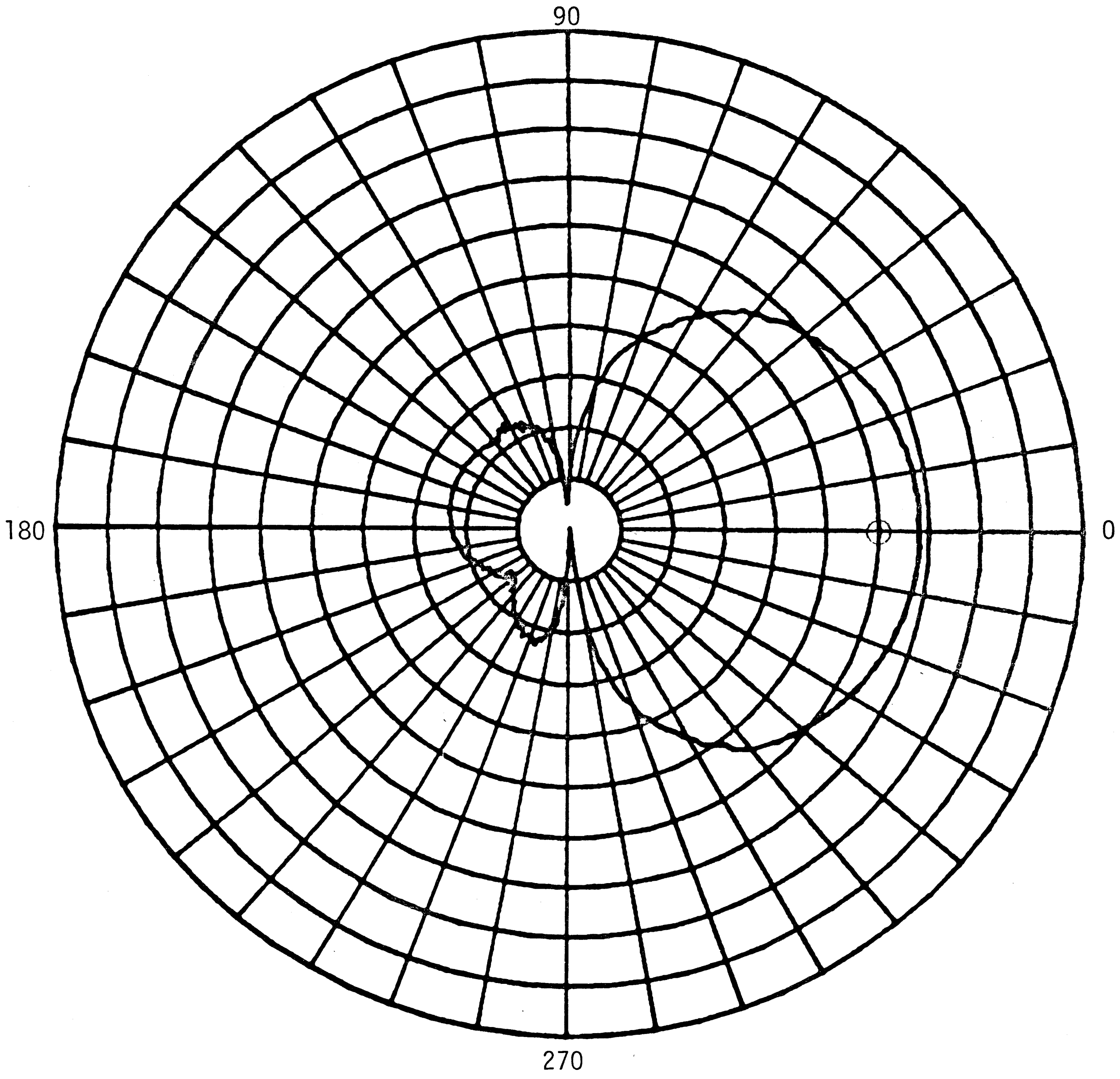

Figure A-36. Relative gain pattern in the azimuthal plane at 79 MHz for antenna No. 8.

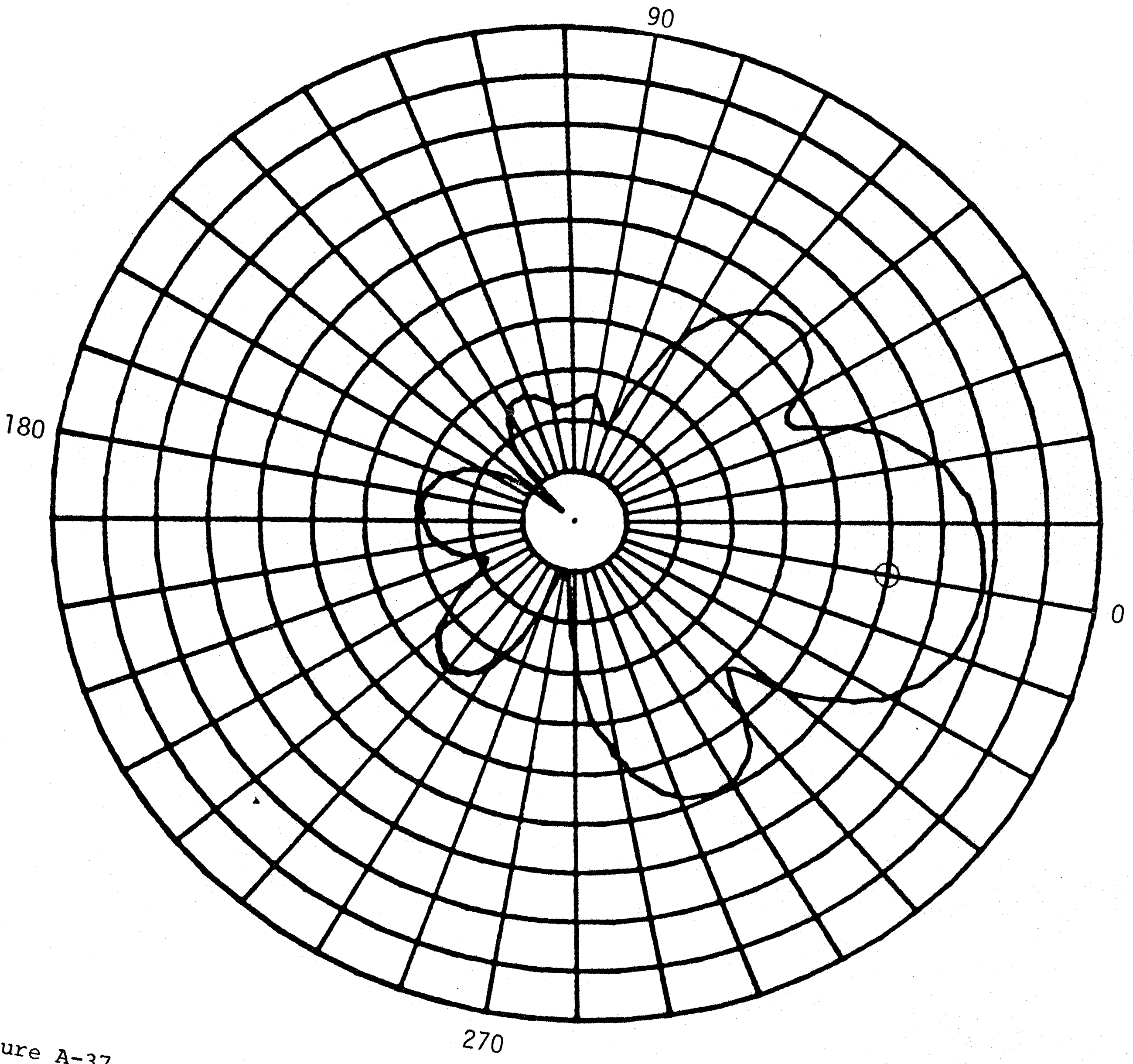

Figure A-37. Relative gain pattern in the azimuthal plane at 183 MHz for antenna No. 8.

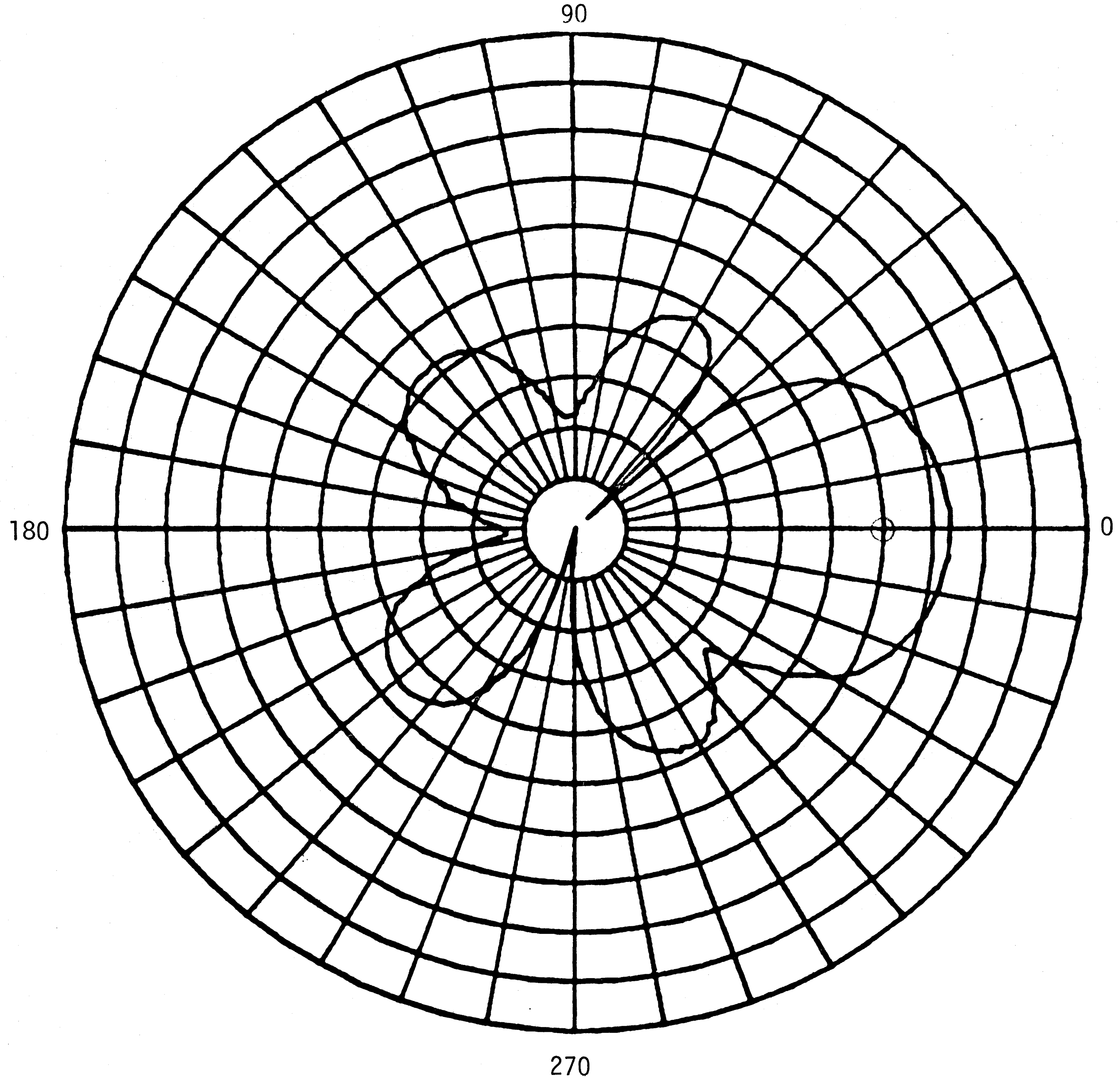

Figure A-38. Relative gain pattern in the azimuthal plane at 213 MHz for antenna No. 8.

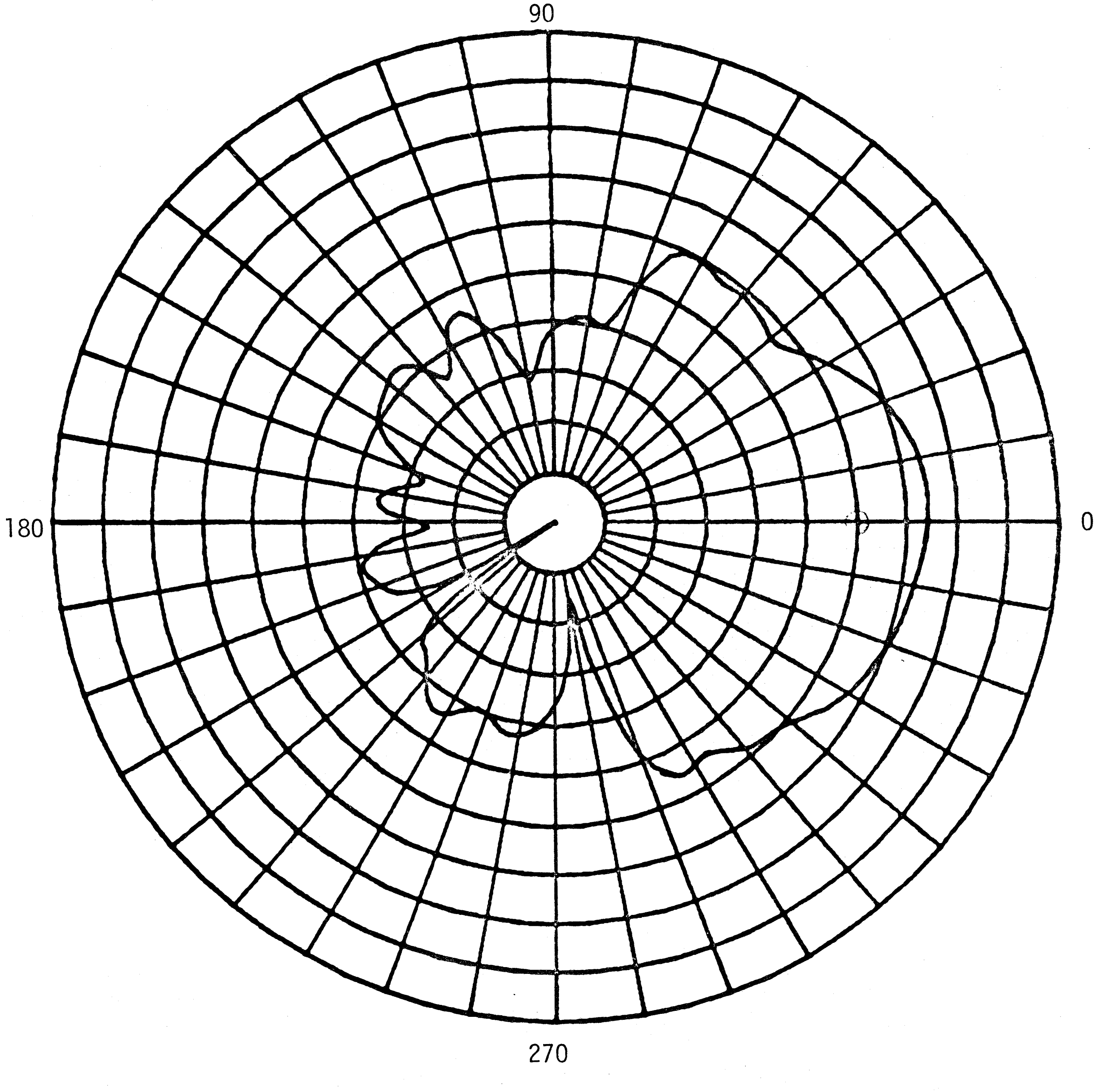

Figure A-39. Relative gain pattern in the azimuthal plane at 473 MHz for antenna No. 8.

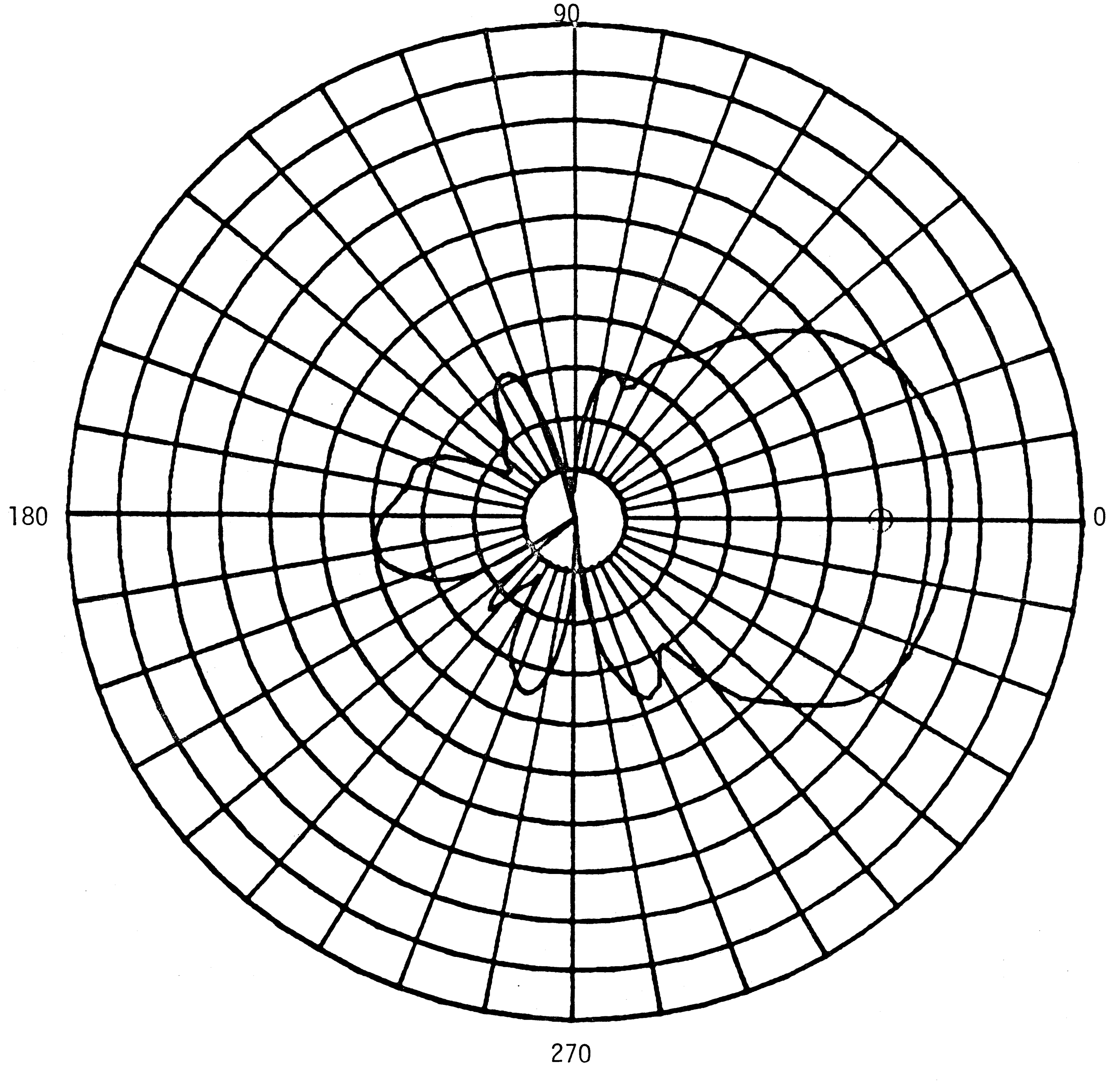

Figure A-40. Relative gain pattern in the azimuthal plane at 641 MHz for antenna No. 8.

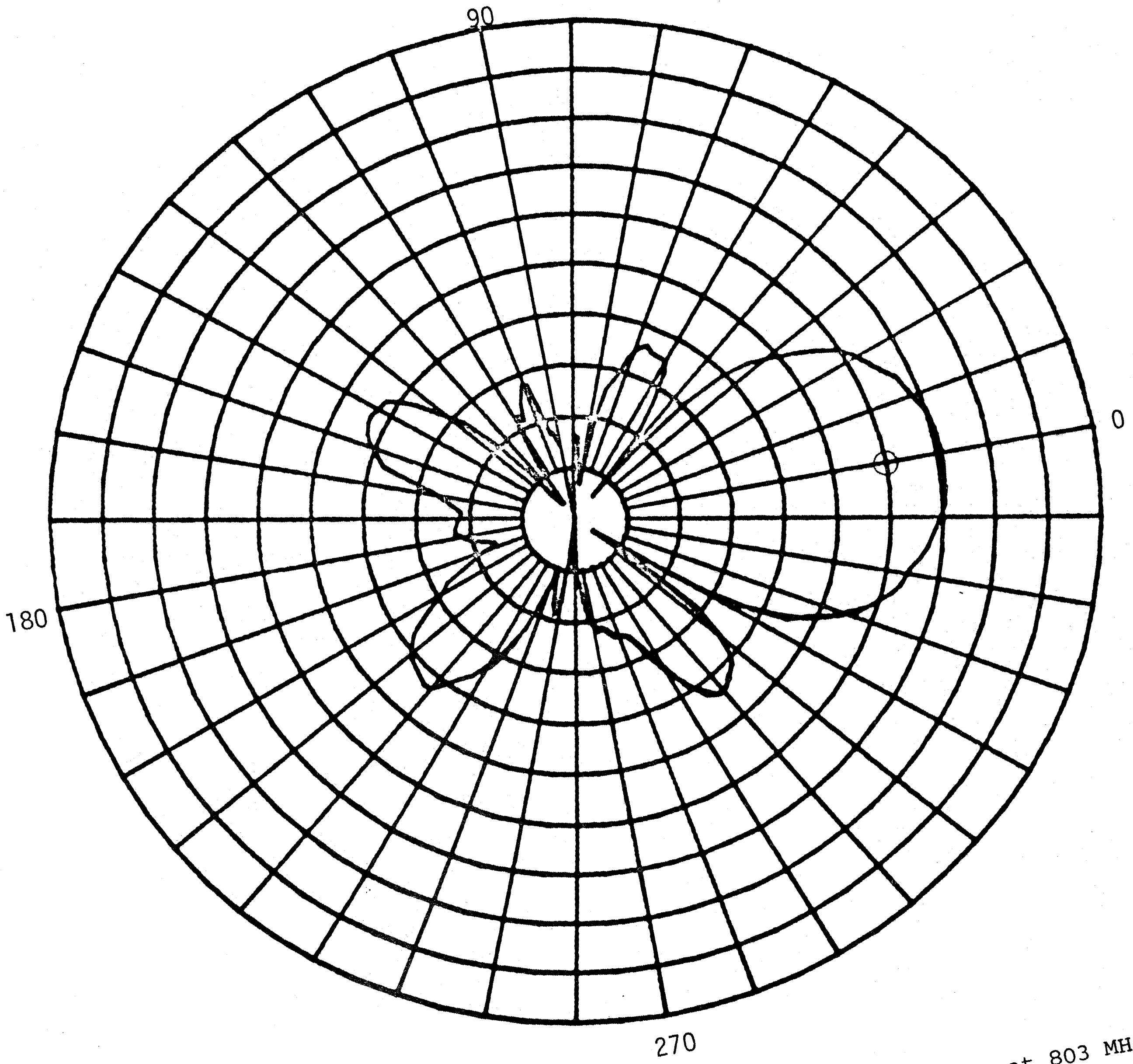

Figure A-41. Relative gain pattern in the azimuthal plane at 803 MHz for antenna No. 8.

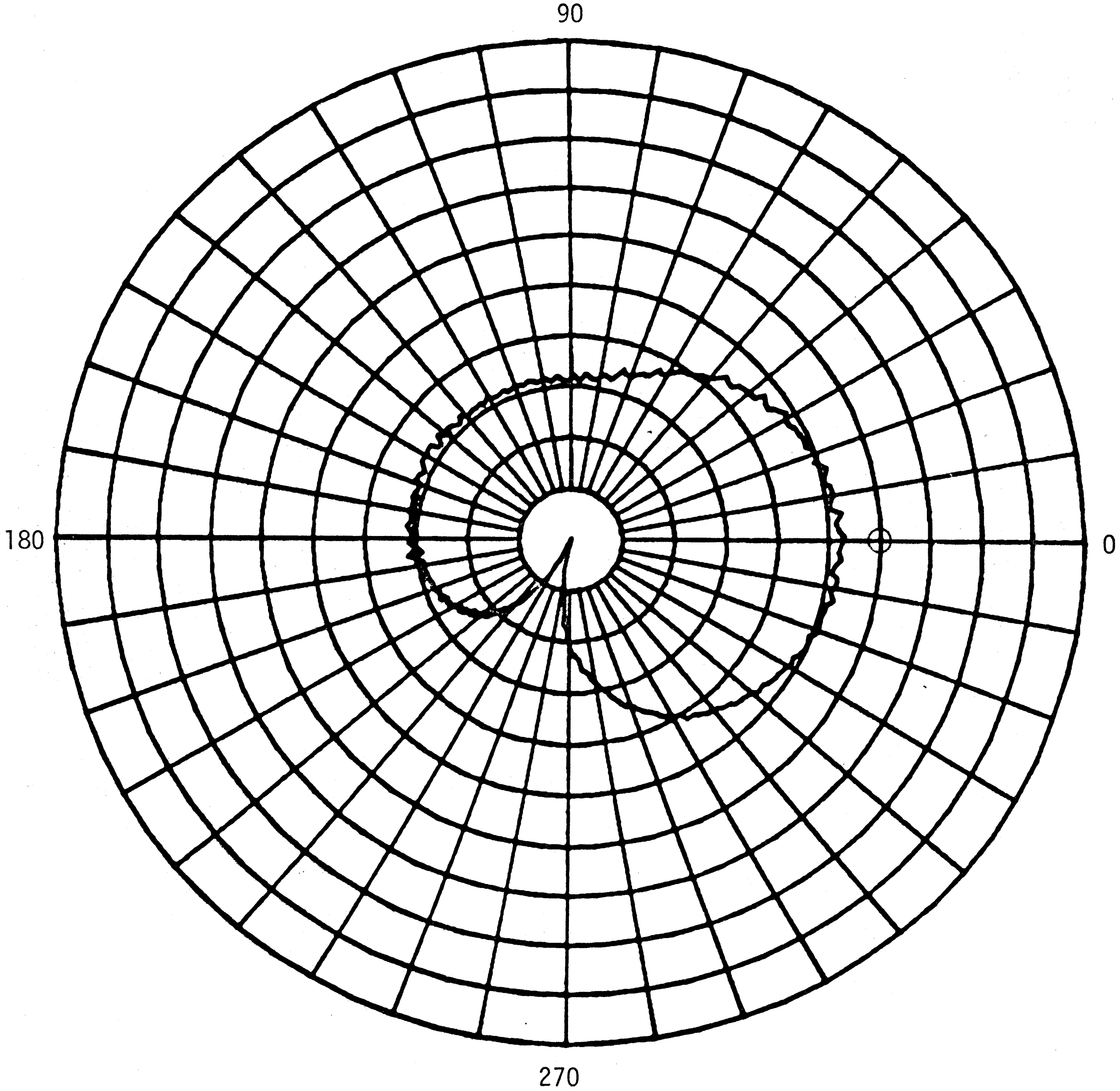

Figure A-42. Relative gain pattern in the azimuthal plane at 63 MHz for antenna No. 9.

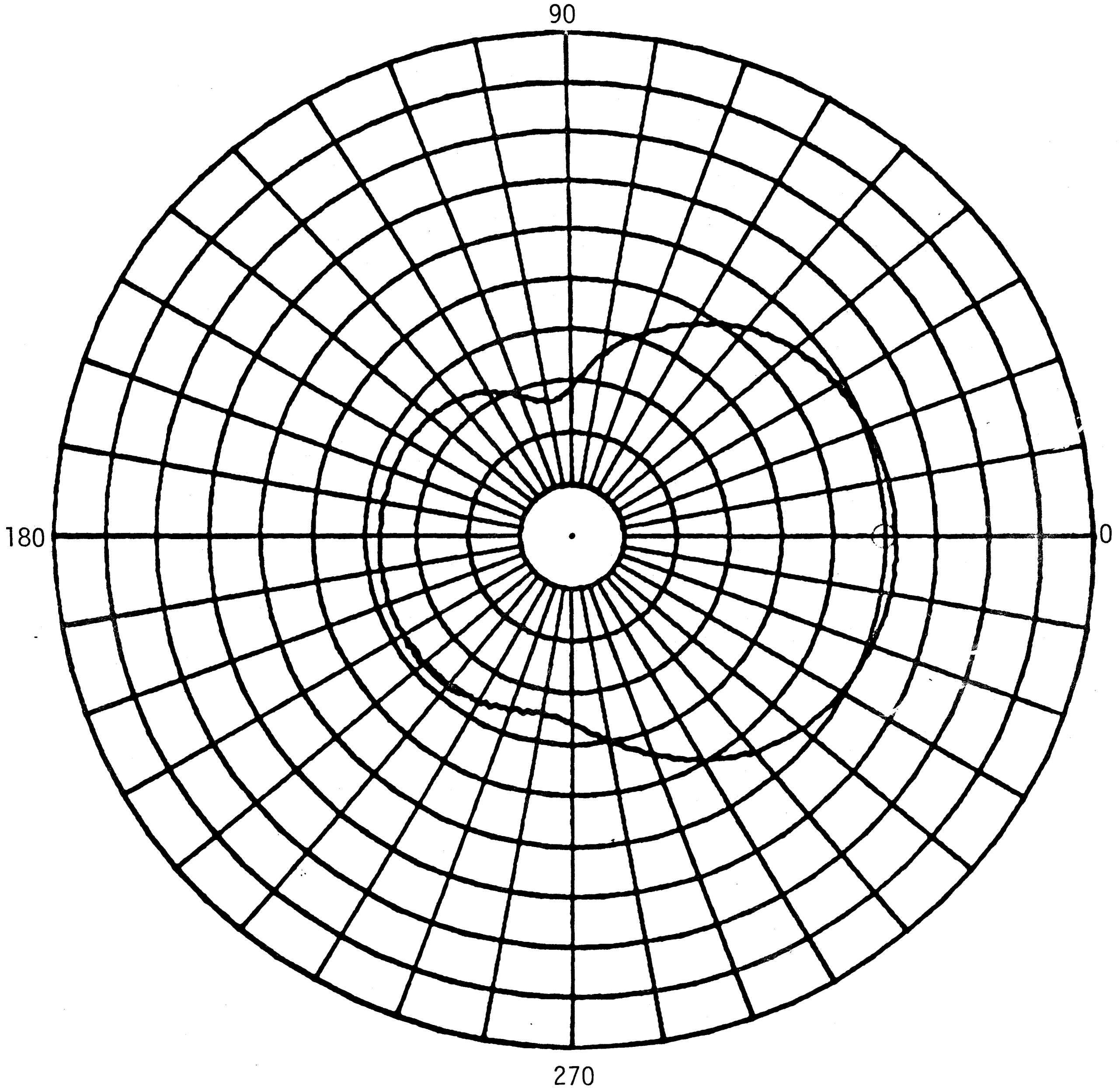

Figure A-43. Relative gain pattern in the azimuthal plane at 79 MHz for antenna No. 9.

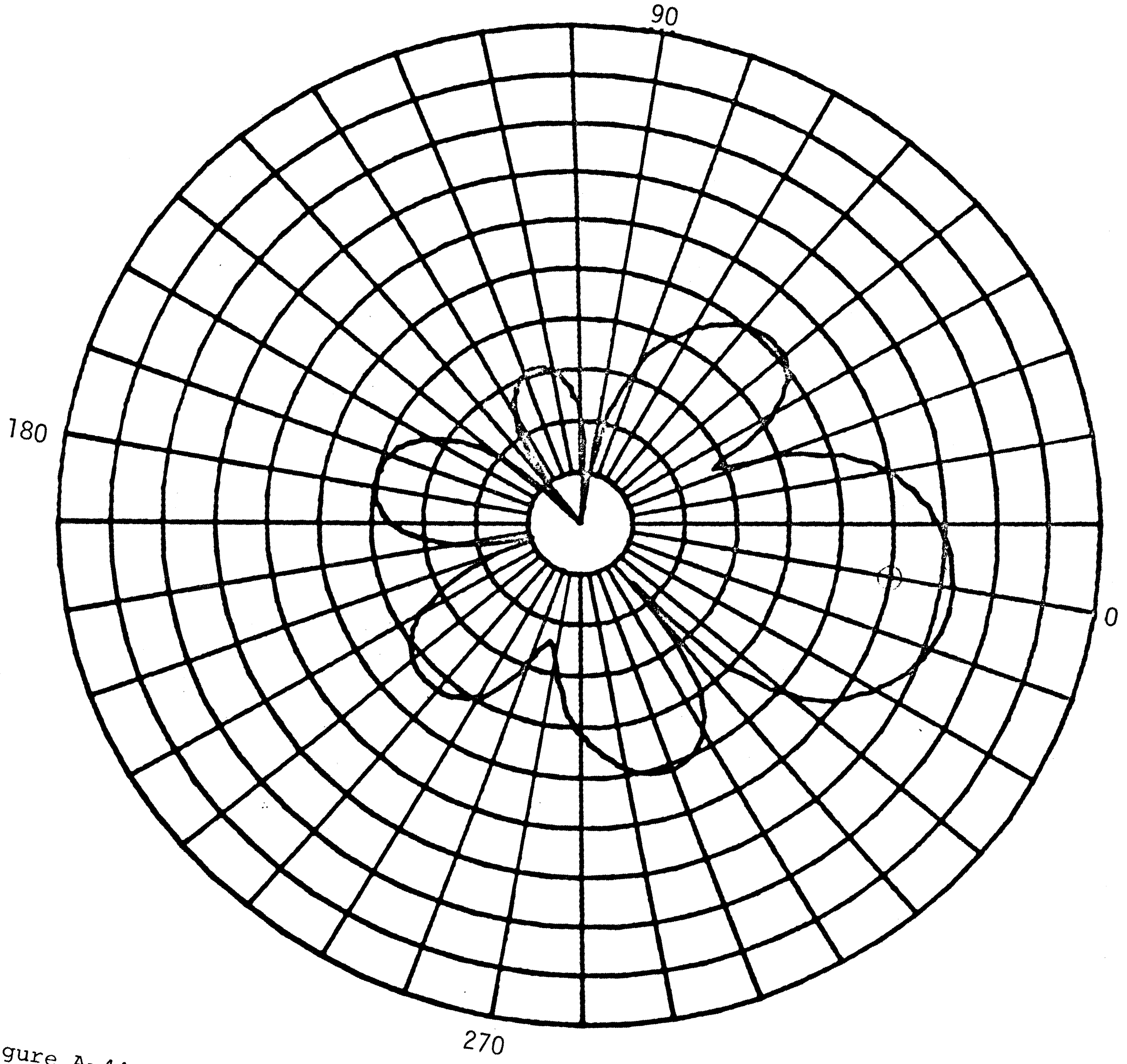

Figure A-44. Relative gain pattern in the azimuthal plane at 183 MHz for antenna No. 9.

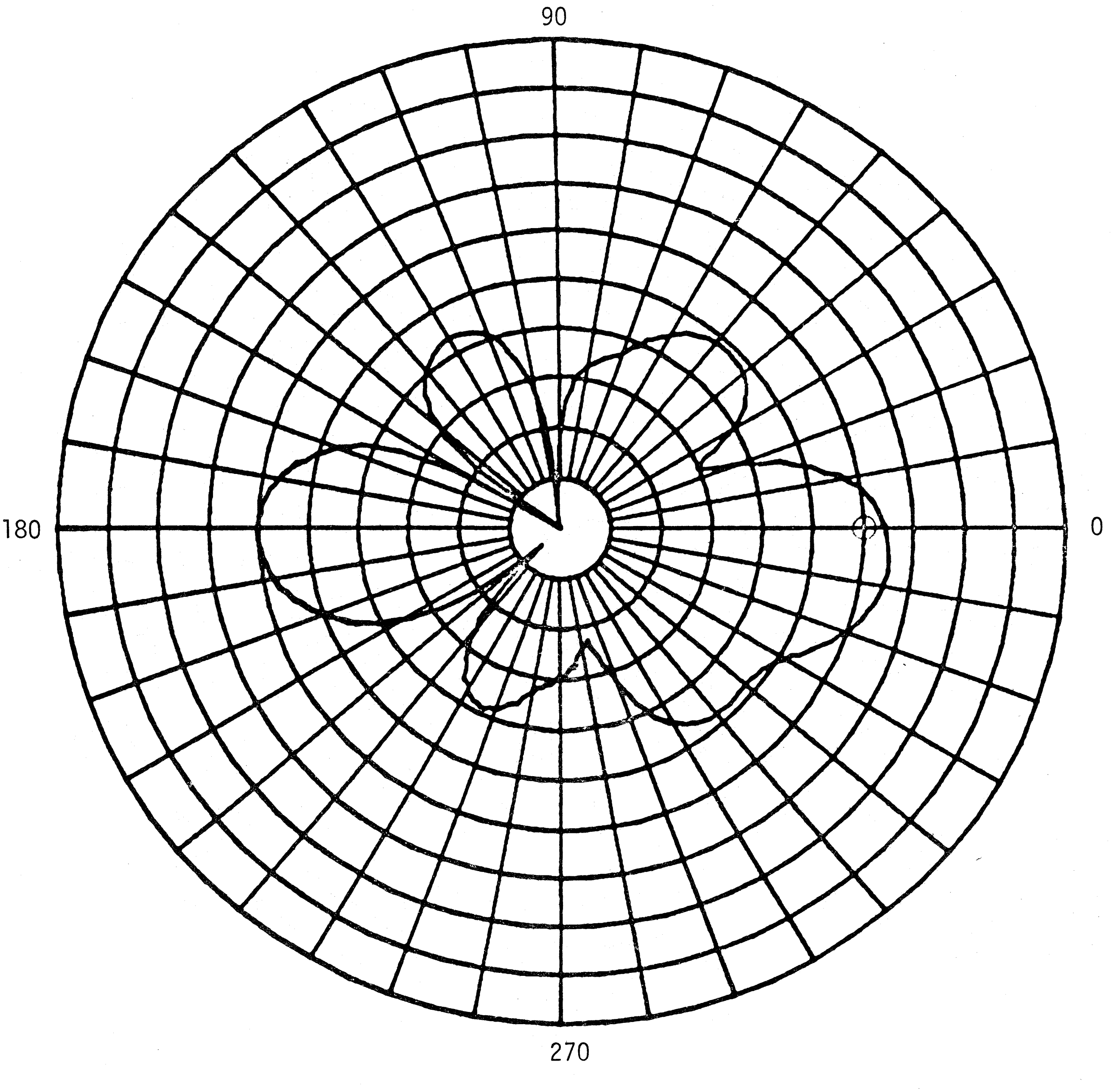

Figure A-45. Relative gain pattern in the azimuthal plane at 213 MHz for antenna No. 9.

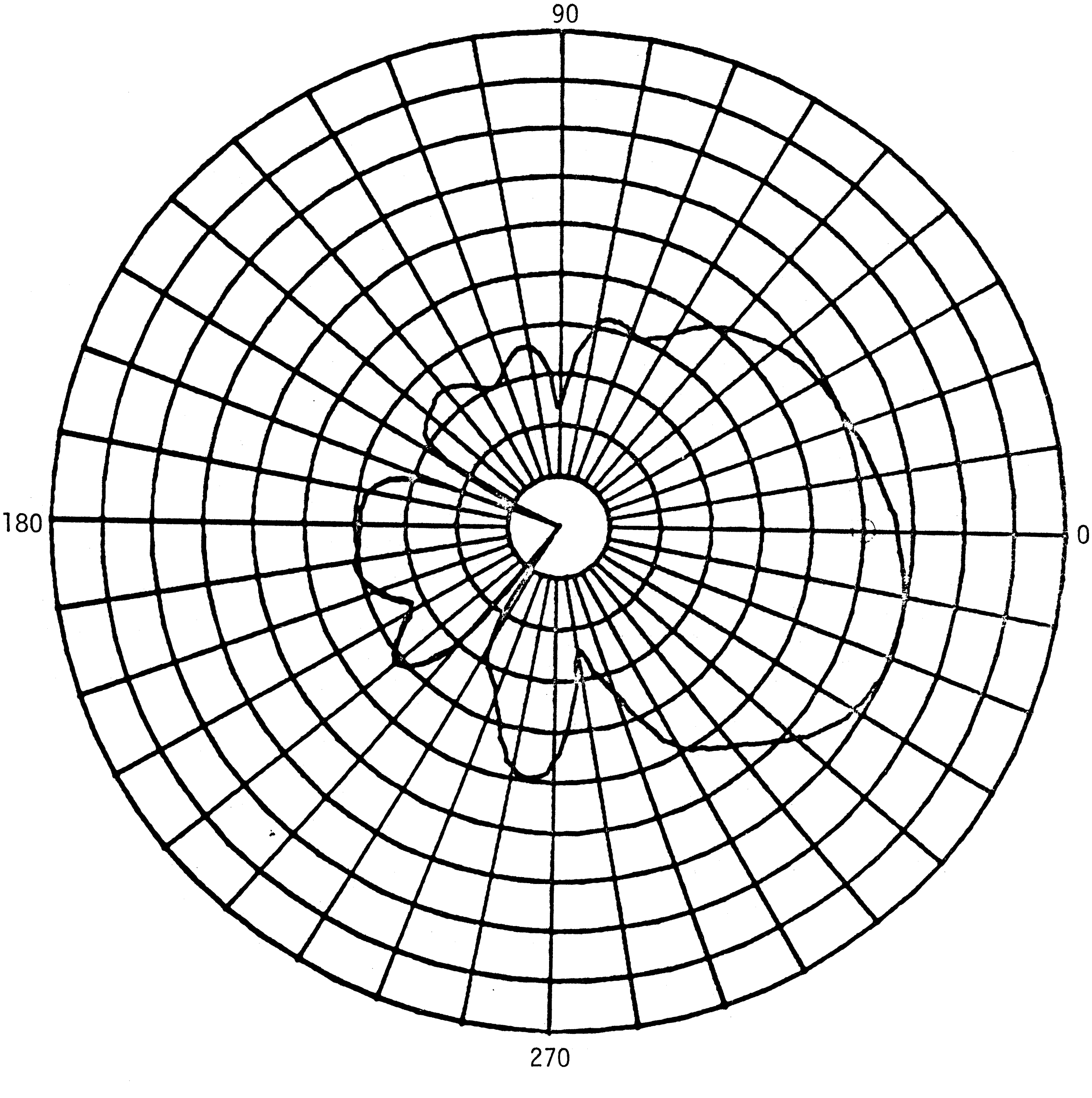

Figure A-46. Relative gain pattern in the azimuthal plane at 473 MHz for antenna No. 9.

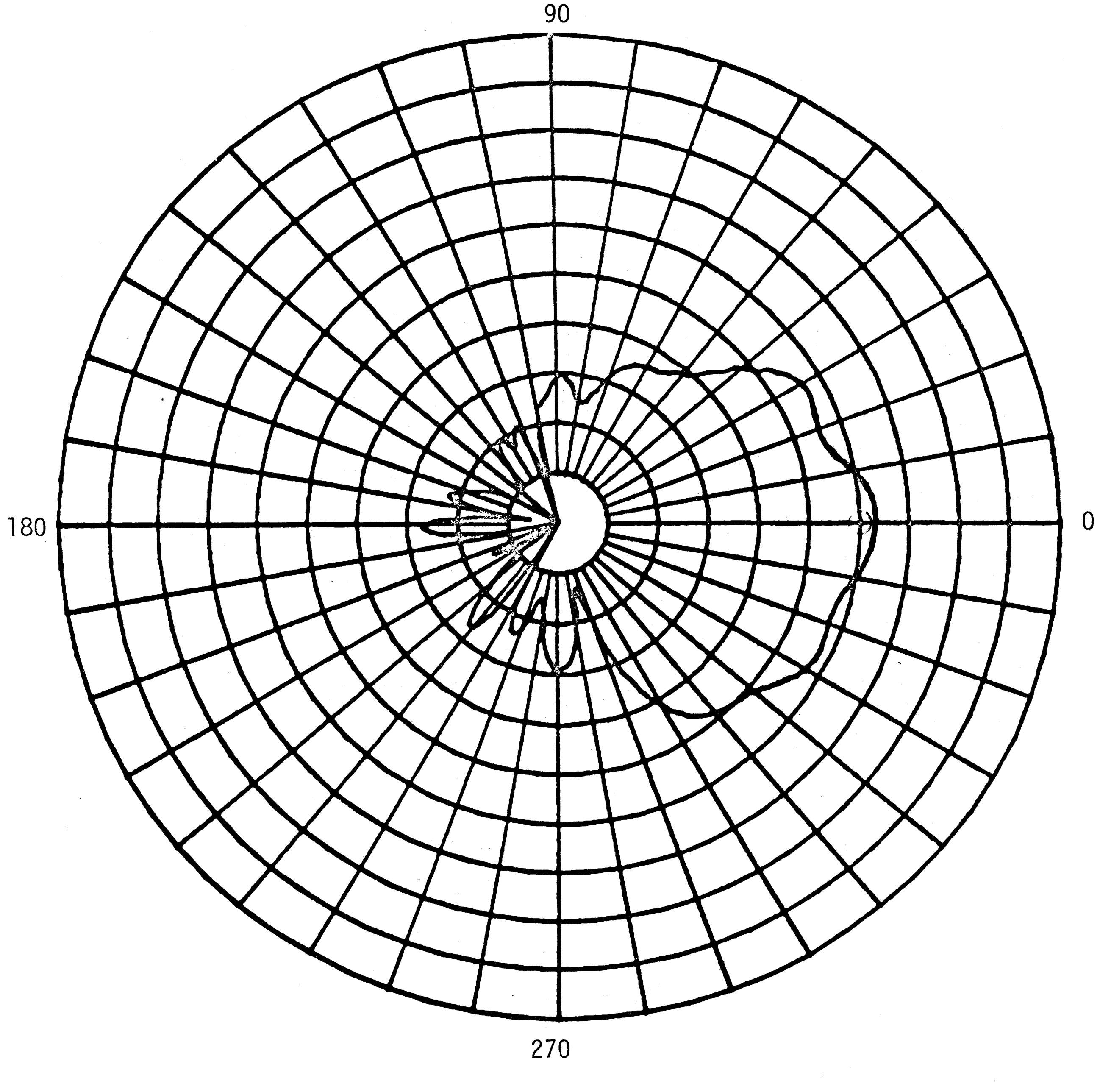

Figure A-47. Relative gain pattern in the azimuthal plane at 641 MHz for antenna No. 9.

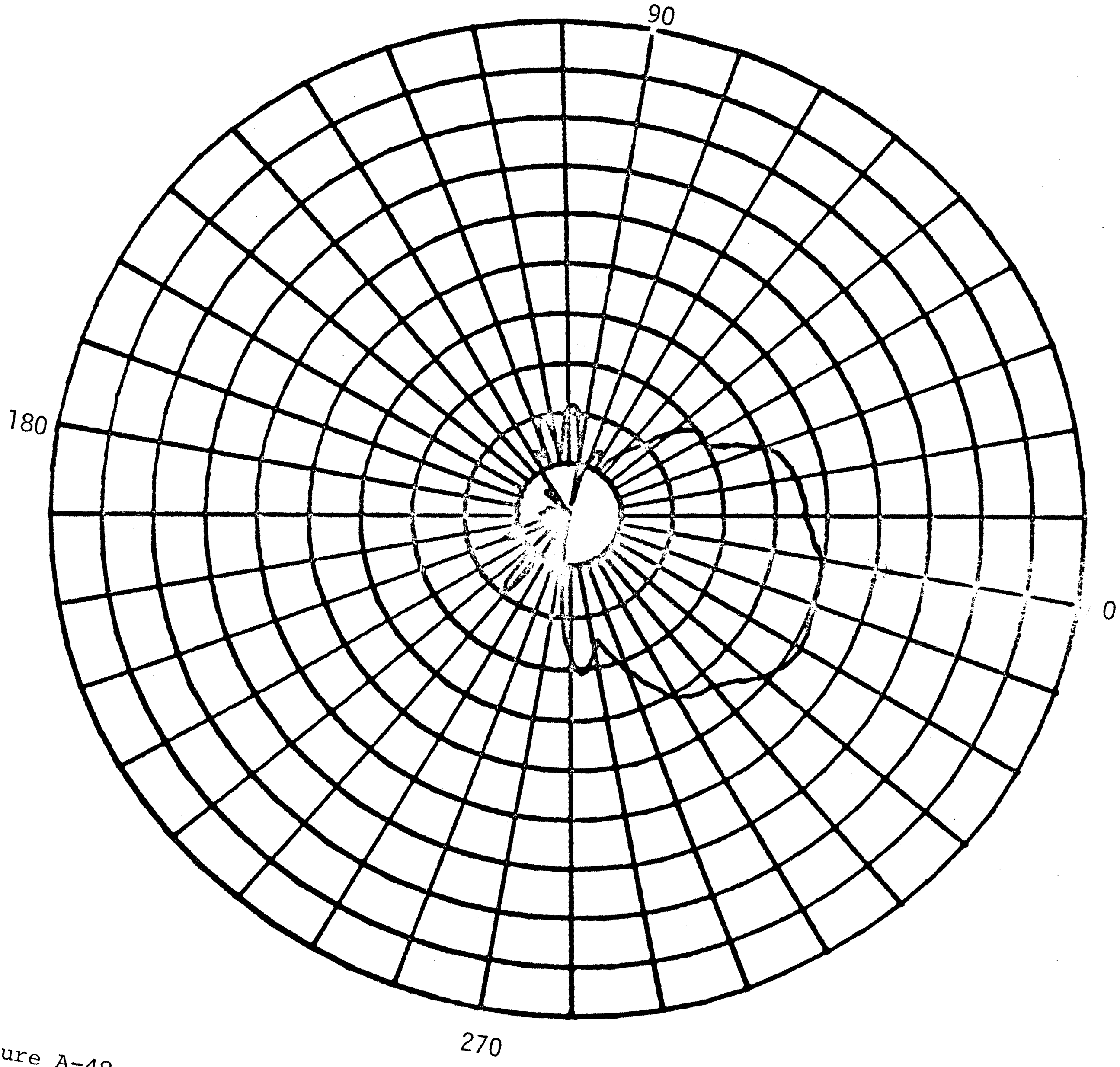

Figure A-48. Relative gain pattern in the azimuthal plane at 803 MHz for antenna No. 9.

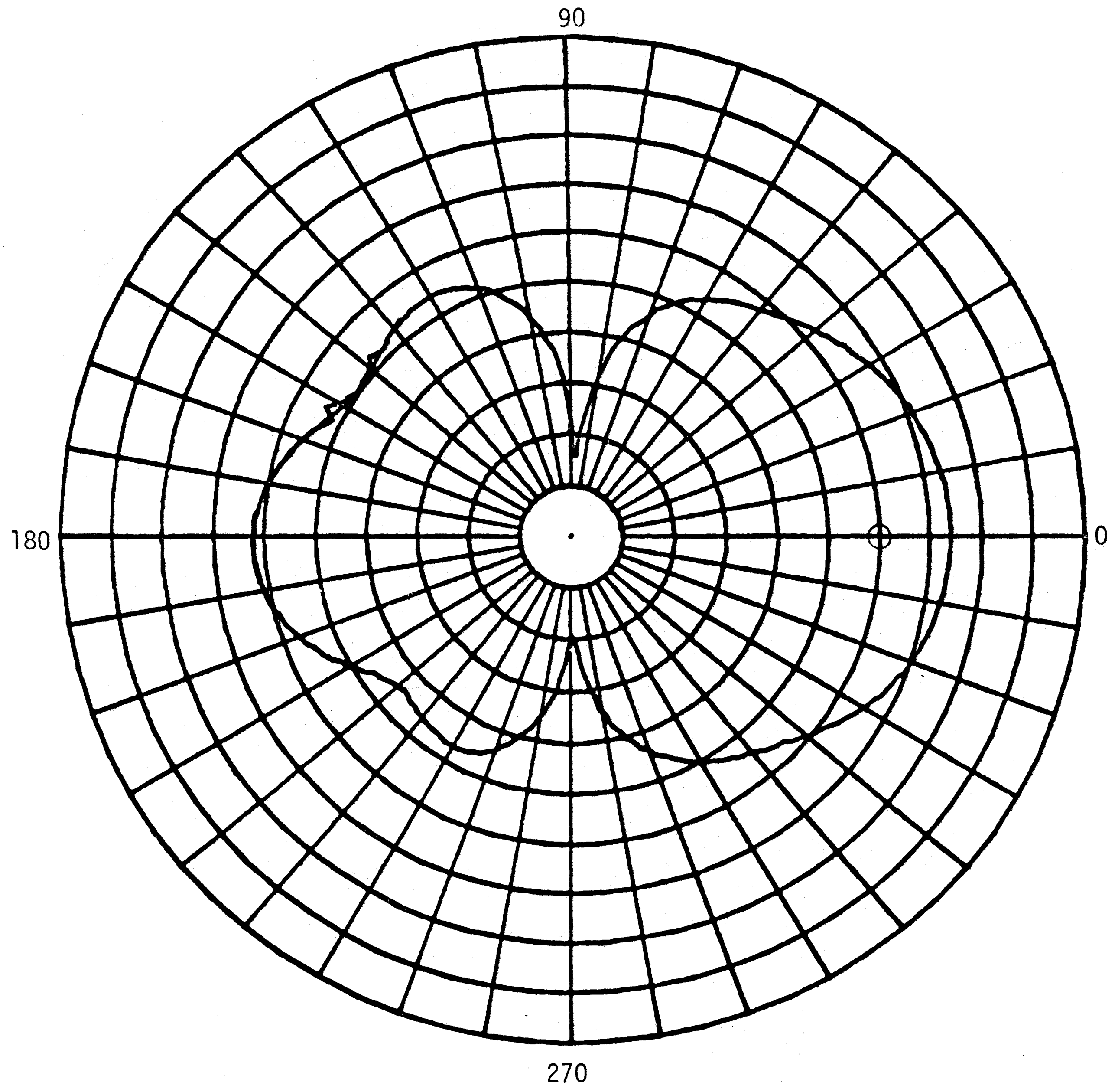

Figure A-49. Relative gain pattern in the azimuthal plane at 473 MHz for antenna No. 10.

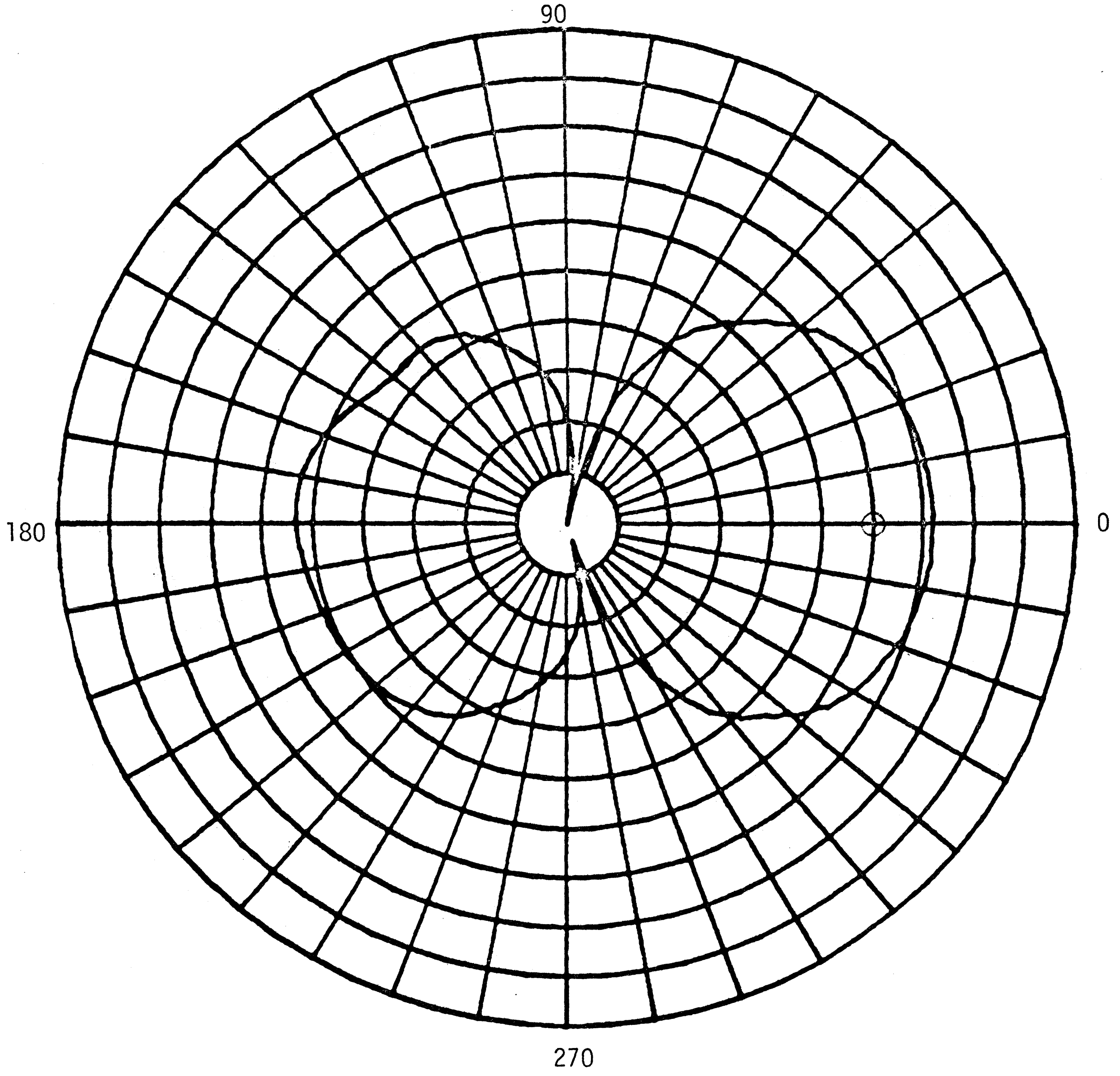

Figure A-50. Relative gain pattern in the azimuthal plane at 641 MHz for antenna No. 10.

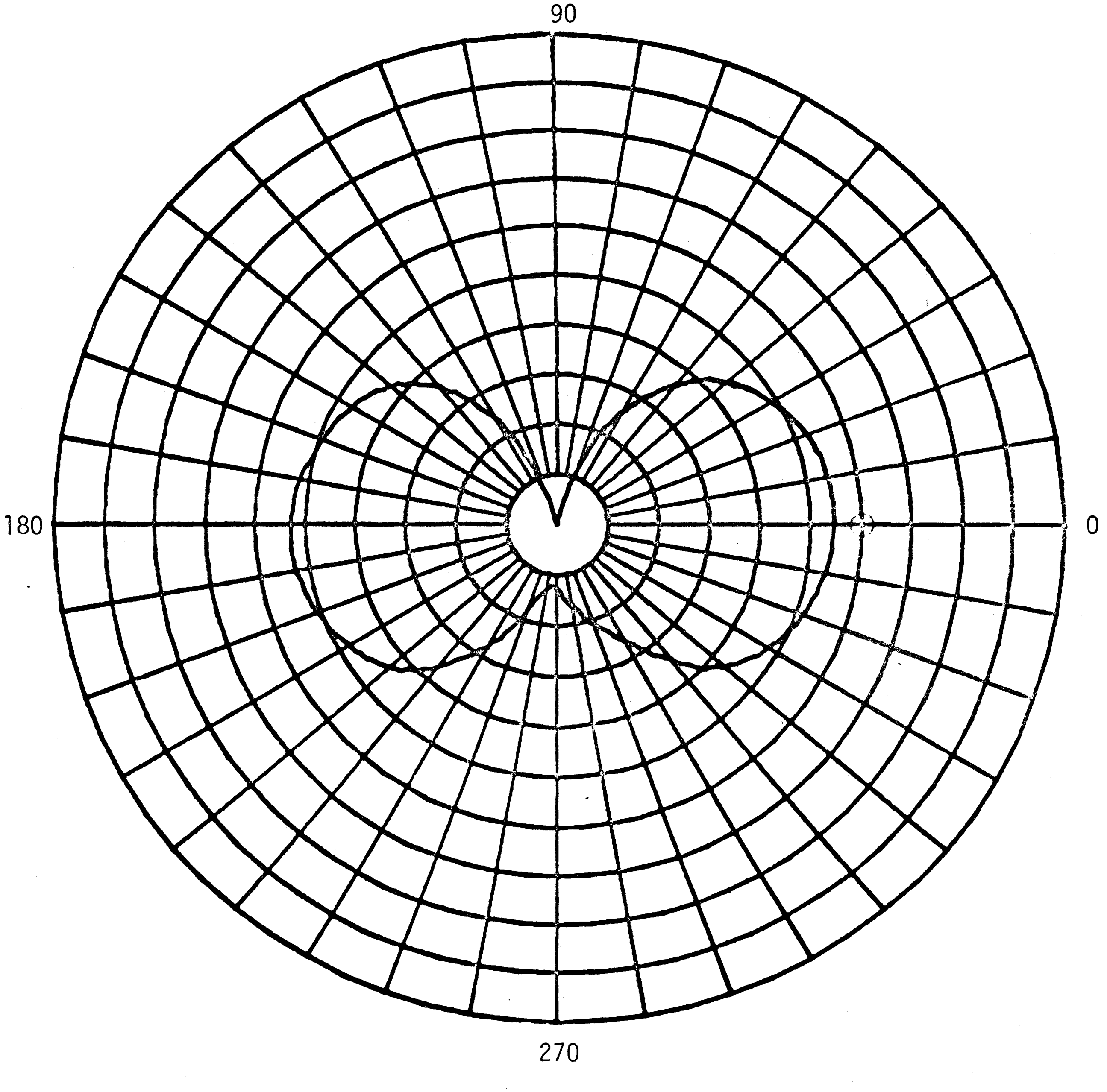

Figure A-51. Relative gain pattern in the azimuthal plane at 803 MHz for antenna No. 10.

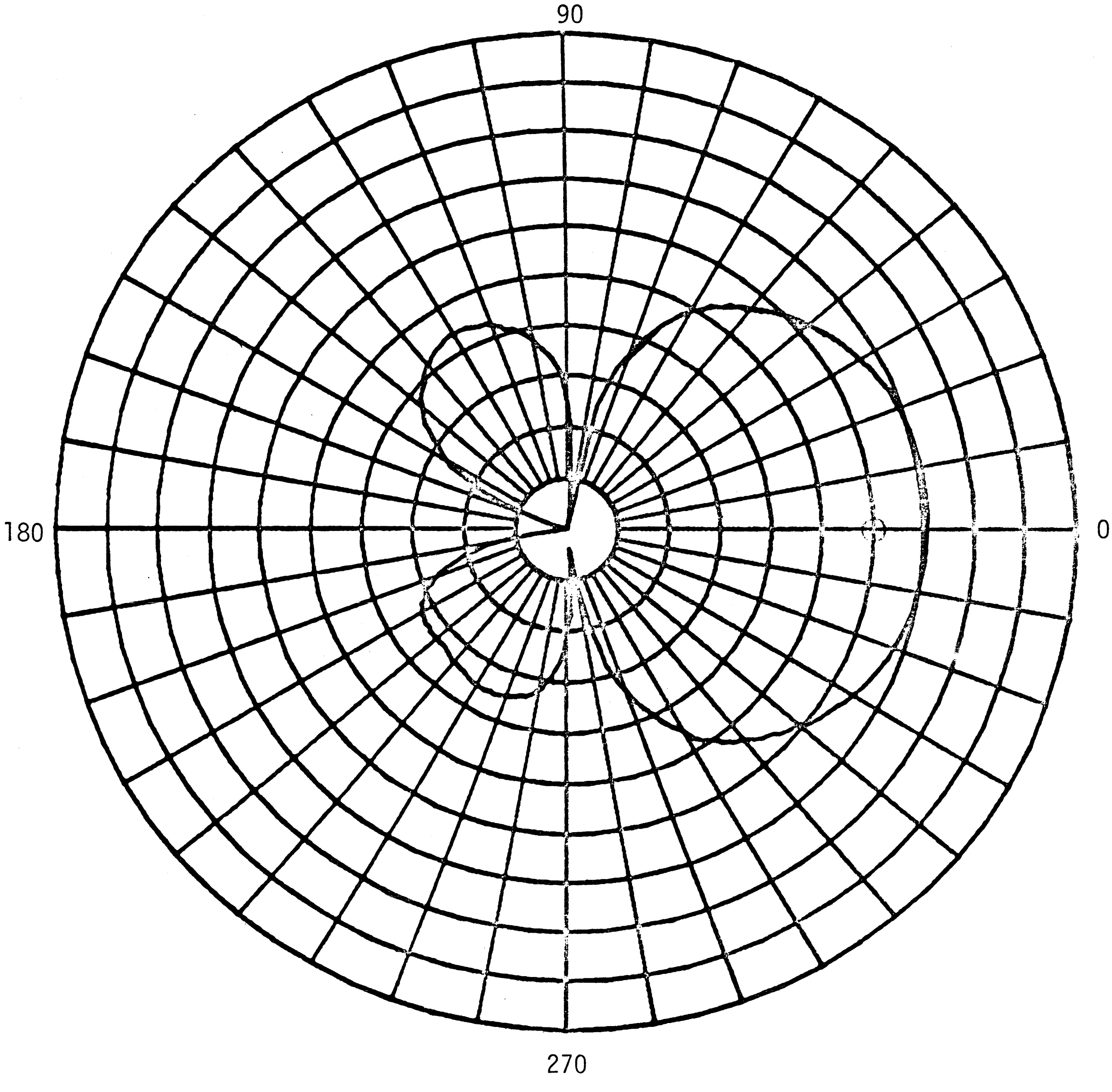

Figure A-52. Relative gain pattern in the azimuthal plane at 473 MHz for antenna No. 11.

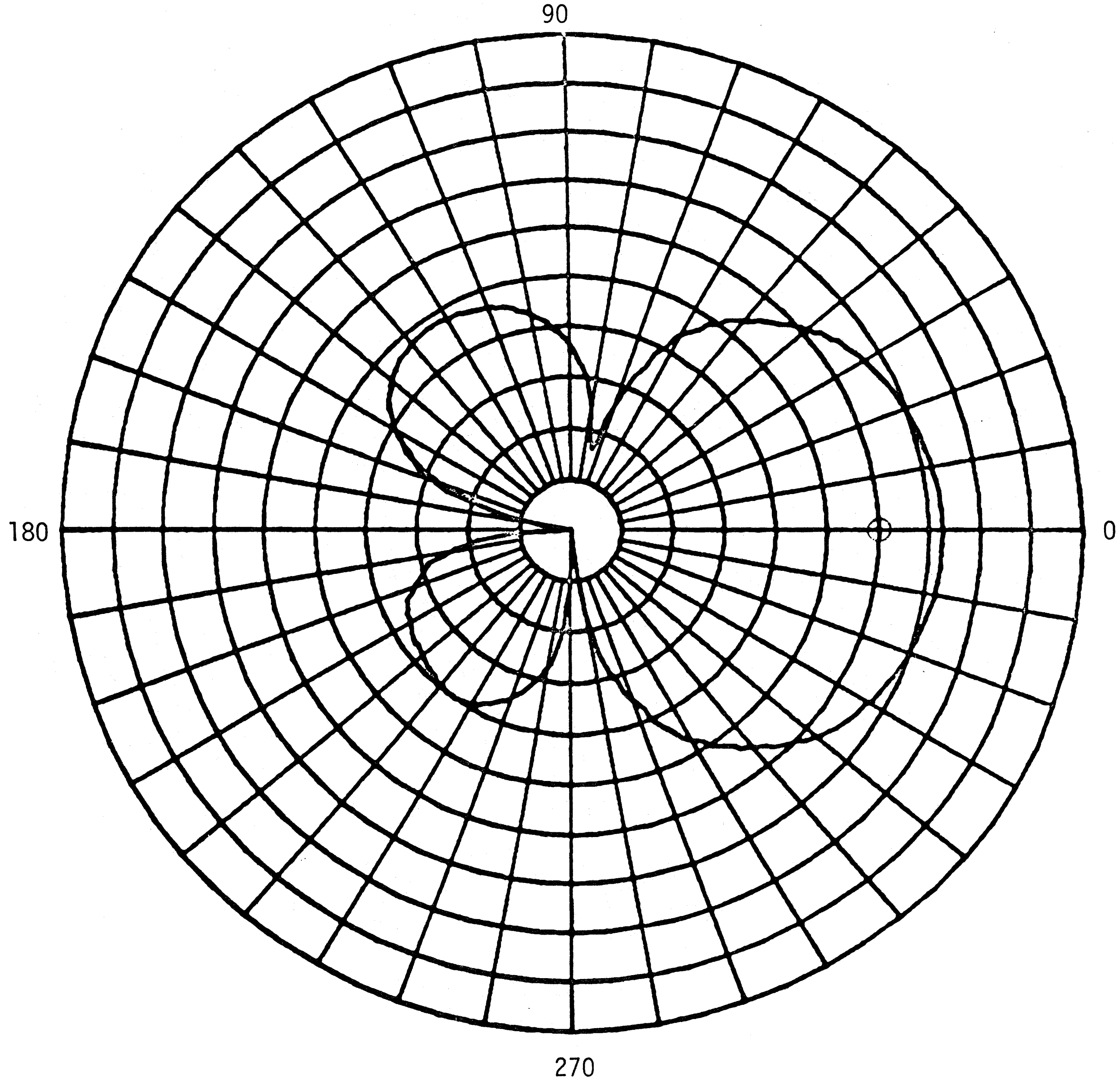

Figure A-53. Relative gain pattern in the azimuthal plane at 641 MHz for antenna No. 11.

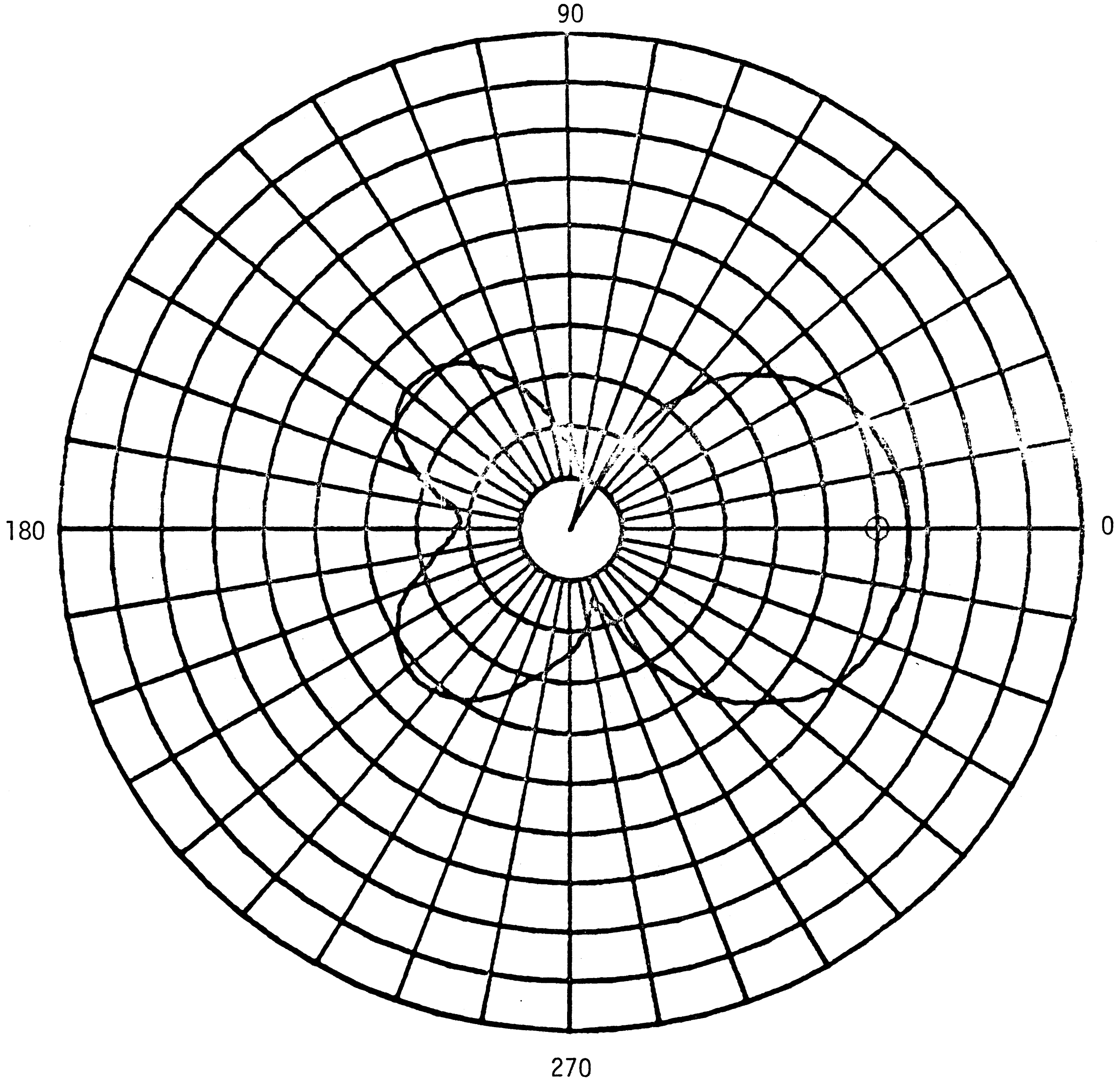

Figure A-54. Relative gain pattern in the azimuthal plane at 803 MHz for antenna No. 11.

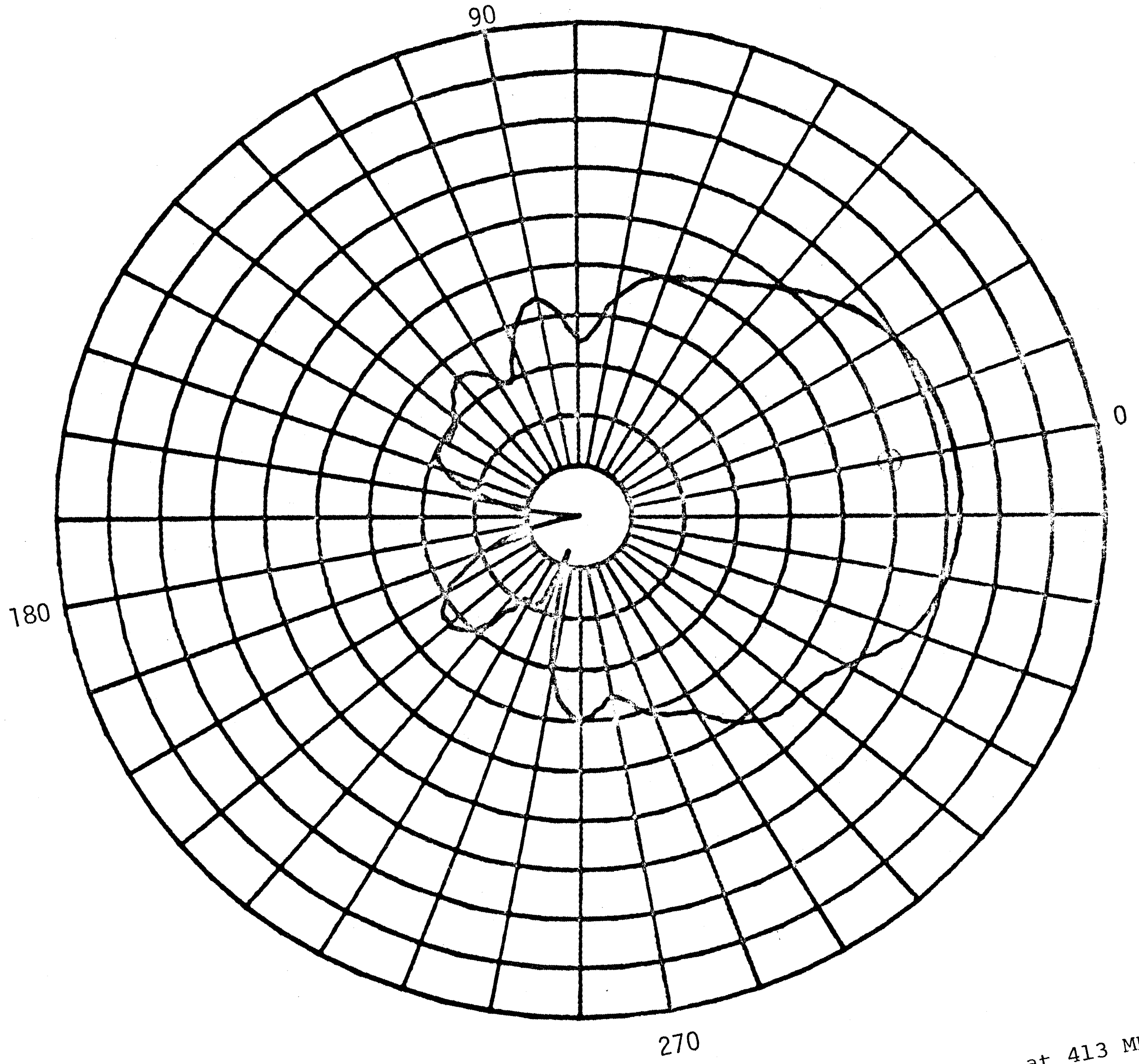

Figure A-55. Relative gain pattern in the azimuthal plane at 413 MHz for antenna No. 12a.

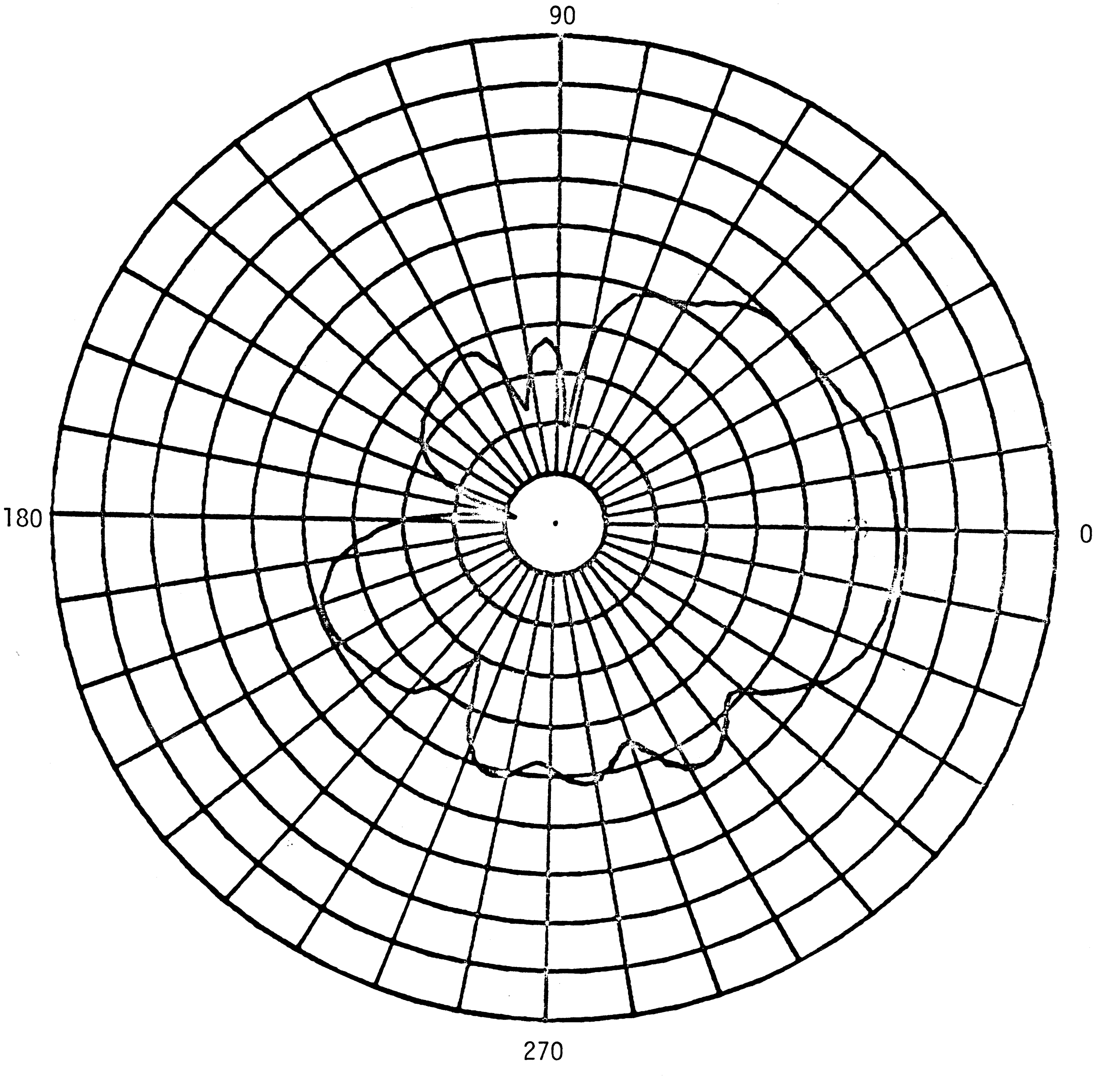

Figure A-56. Relative gain pattern in the azimuthal plane at 473 MHz for antenna No. 12b.

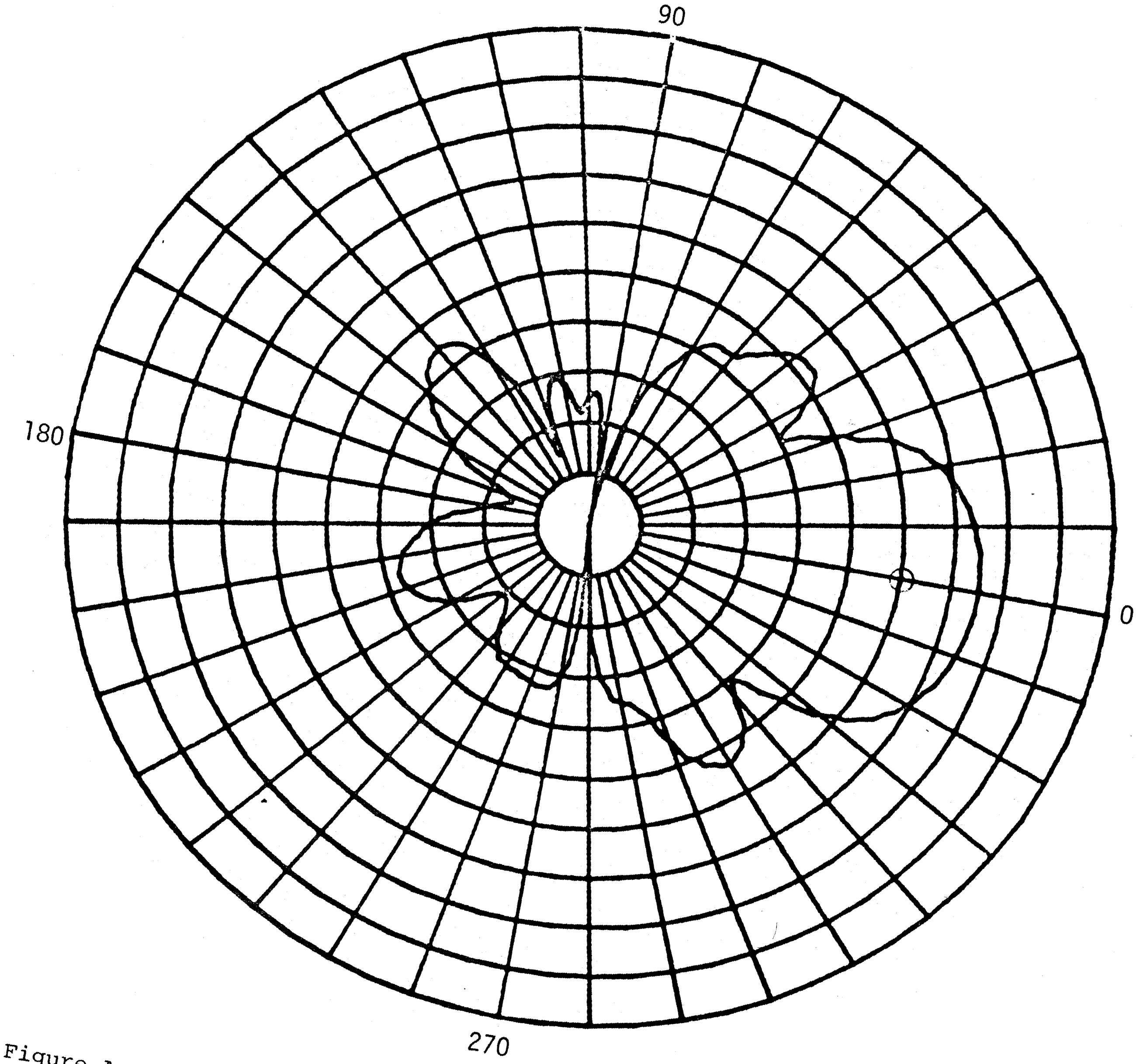

Figure A-57. Relative gain pattern in the azimuthal plane at 641 MHz for antenna No. 12a.

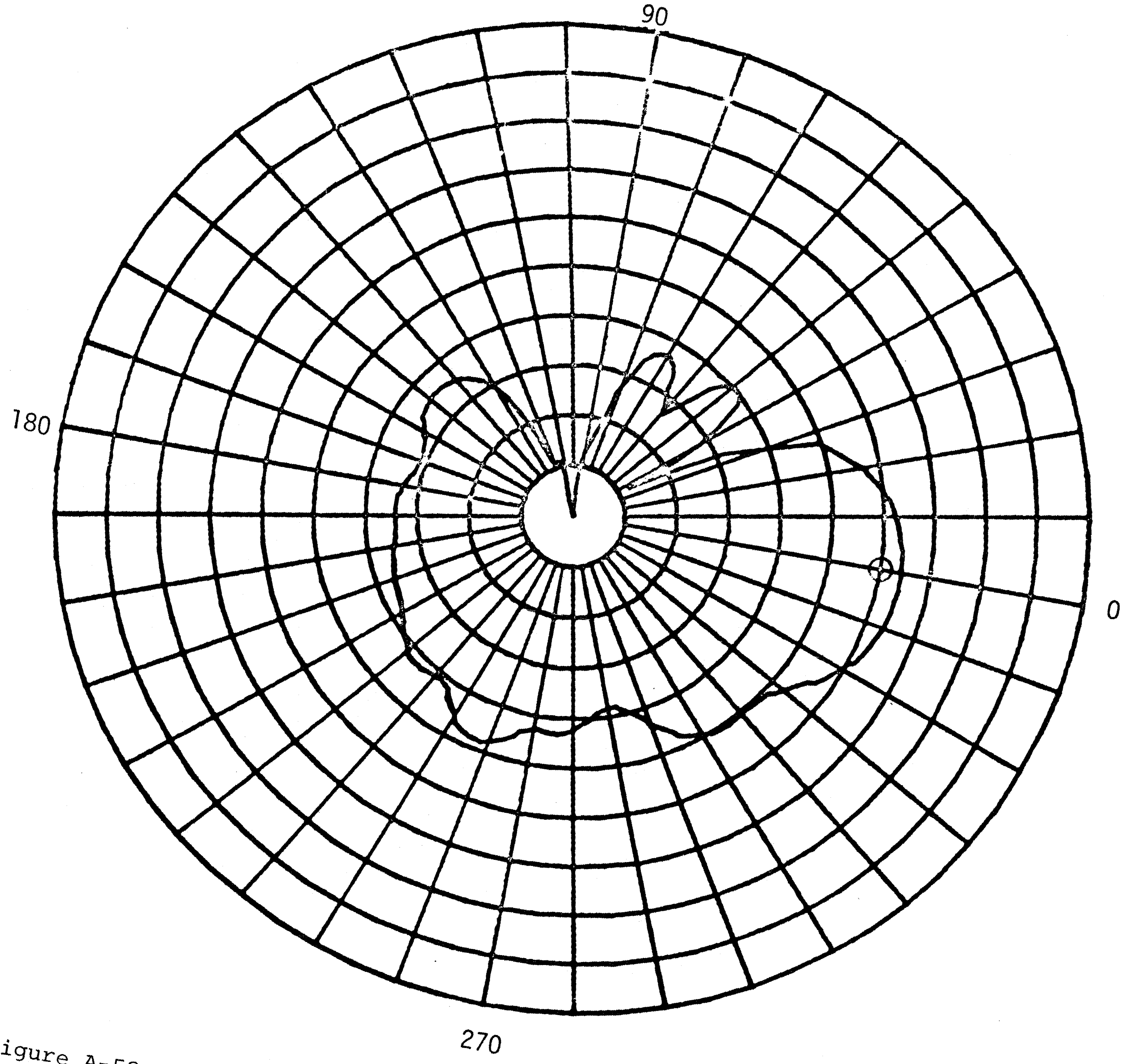

Figure A-58. Relative gain pattern in the azimuthal plane at 641 MHz for antenna No. 12b.

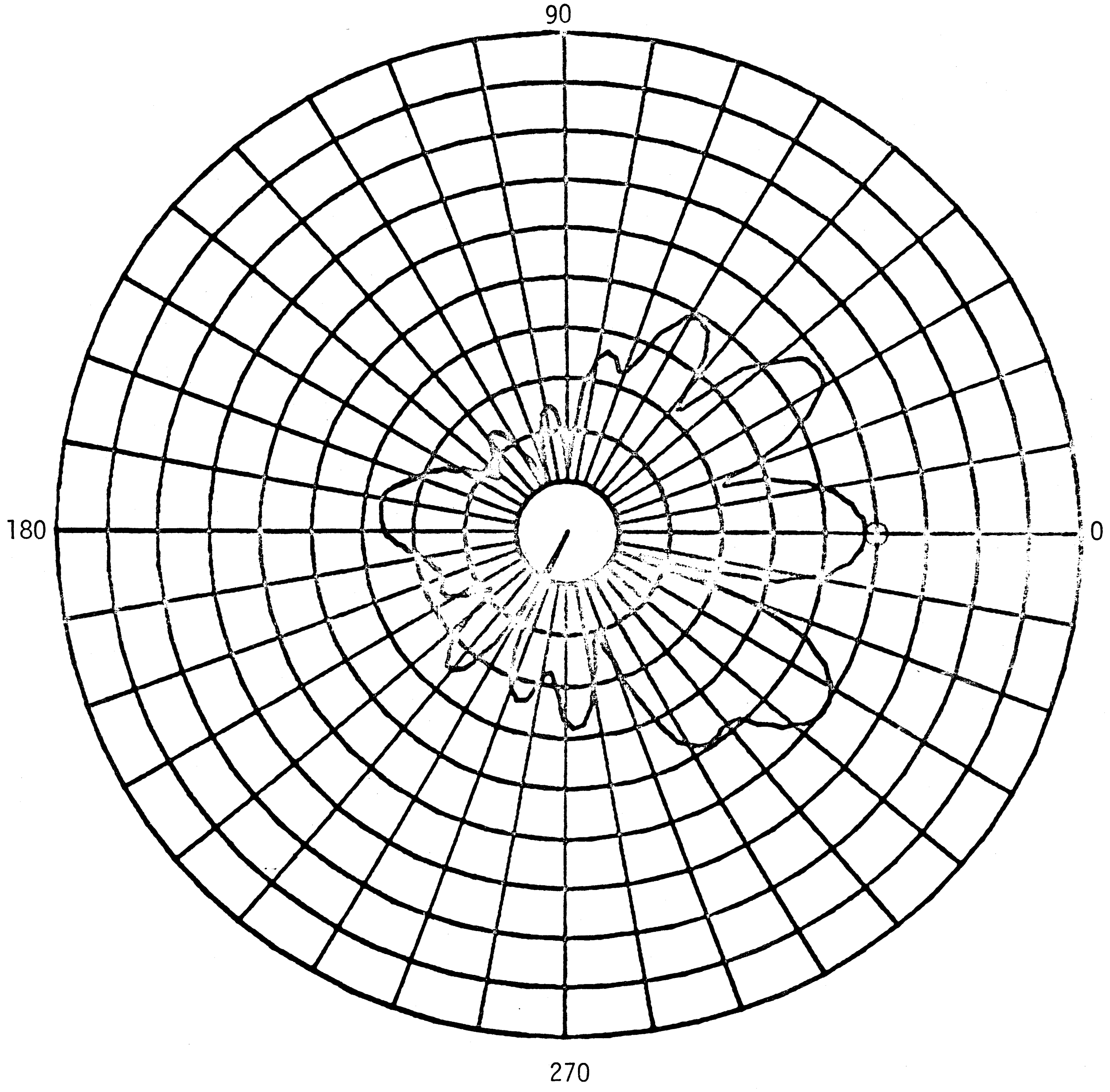

Figure A-59. Relative gain pattern in the azimuthal plane at 803 MHz for antenna No. 12a. Beam splitting can be noted.

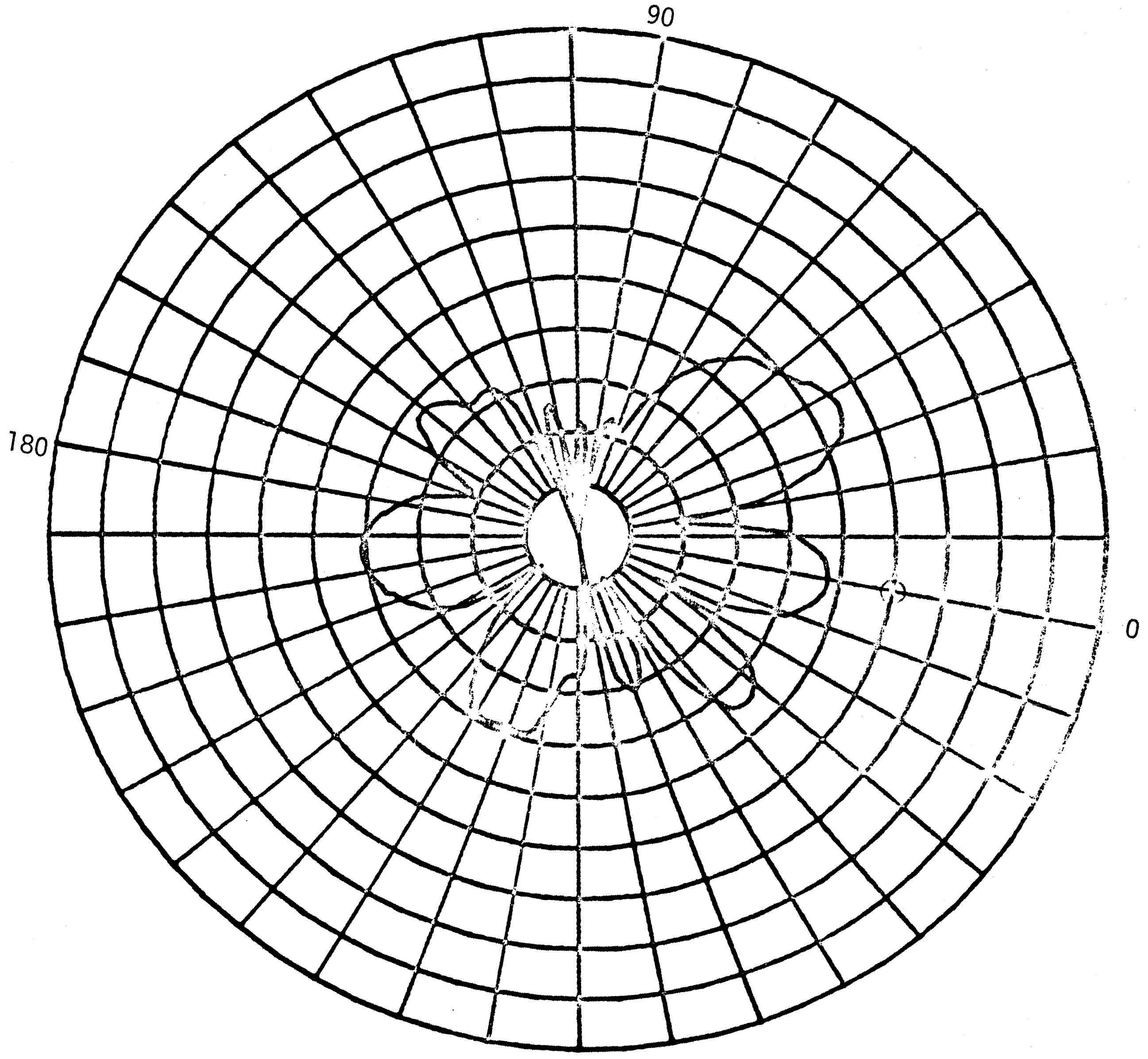

Figure A-60. Relative gain pattern in the azimuthal plane at 803 MHz for No. 12b. Beam splitting can be noted.

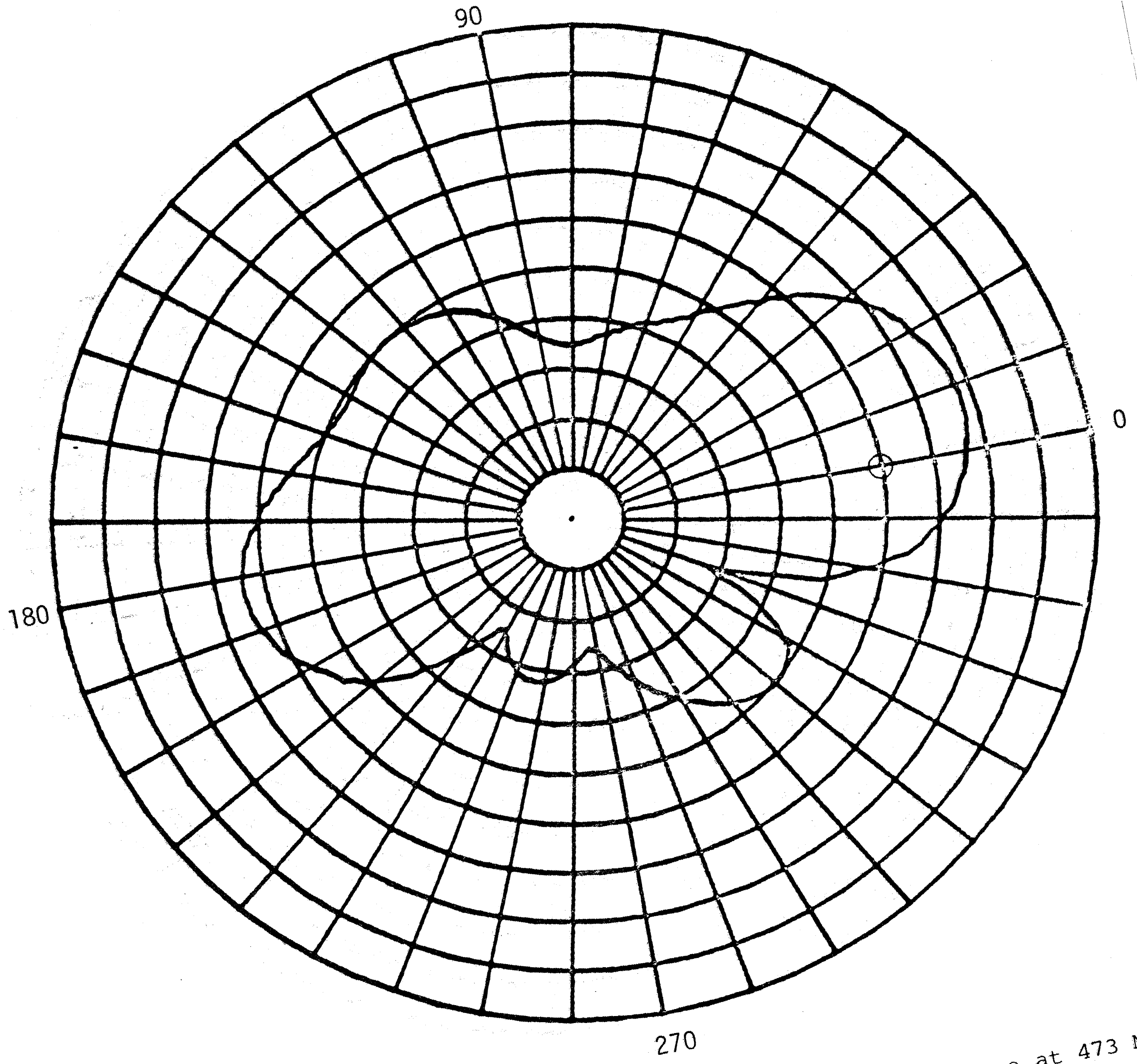

Figure A-61. Relative gain pattern in the azimuthal plane at 473 MHz for antenna No. 13.

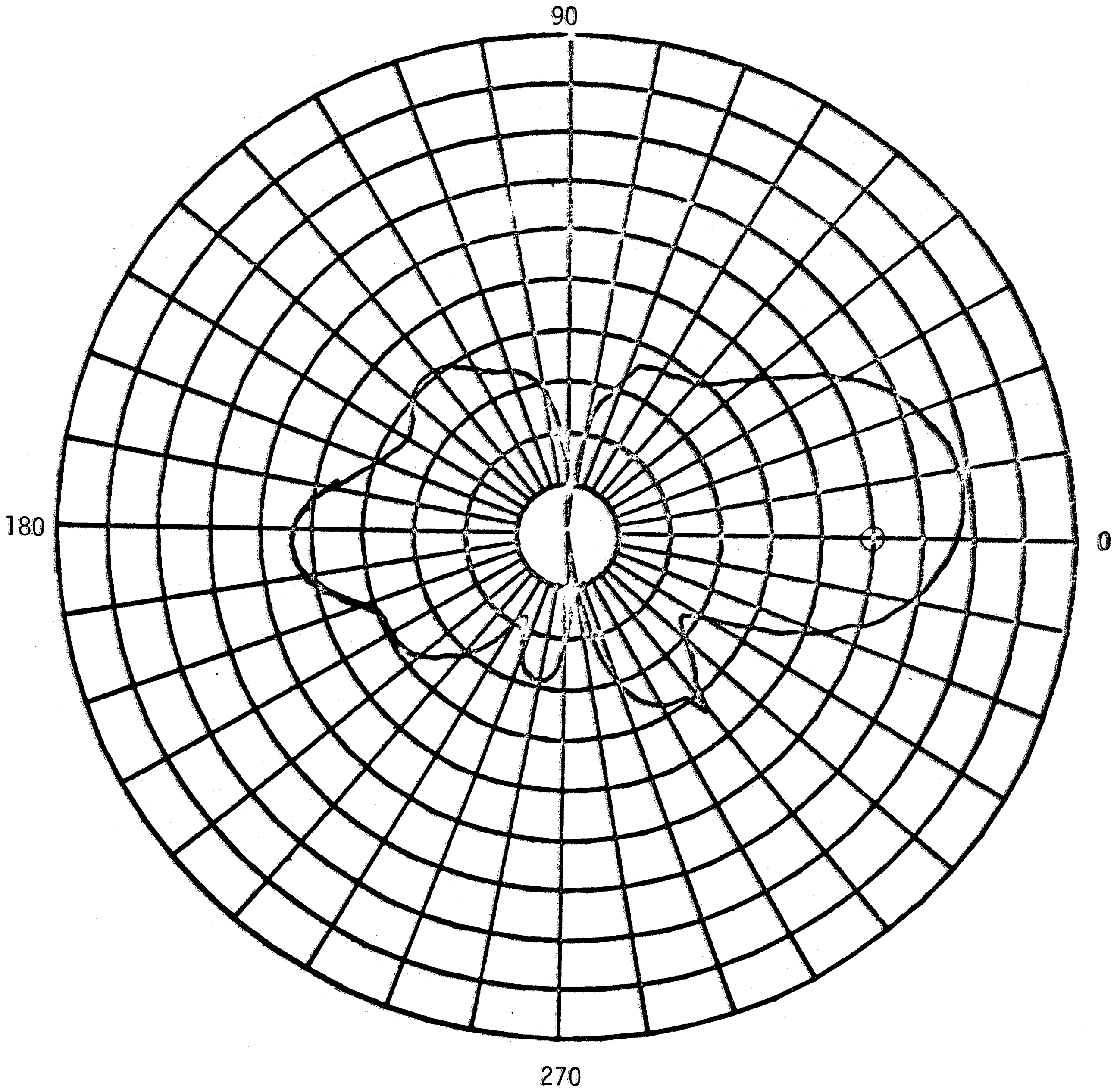

Figure A-62. Relative gain pattern in the azimuthal plane of 641 MHz for antenna No. 13.

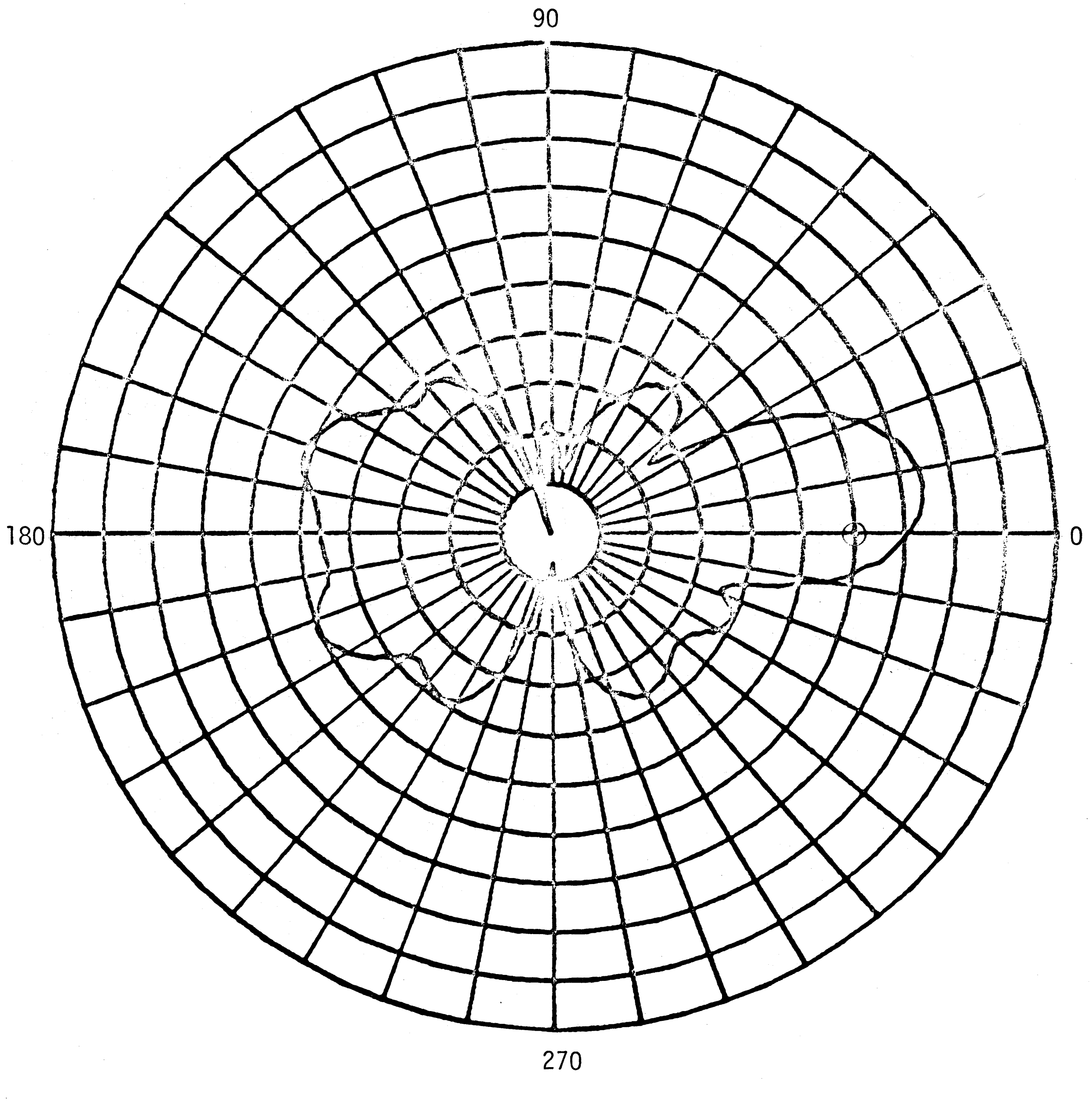

Figure A-63. Relative gain pattern in the azimuthal plane at 803 MHz for antenna No. 13.

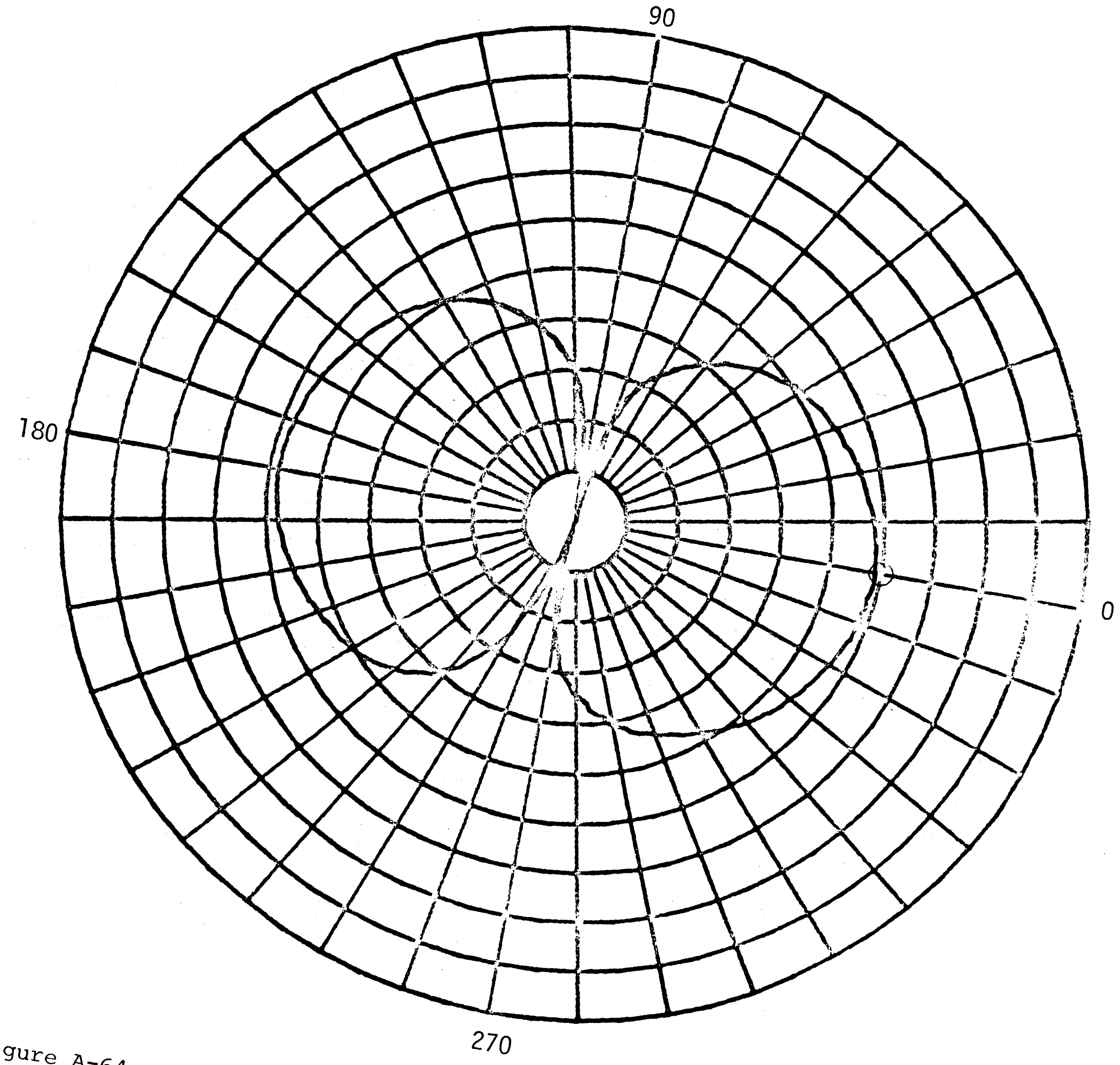

Figure A-64. Relative gain pattern in the azimuthal plane at 473 MHz for antenna No. 14.

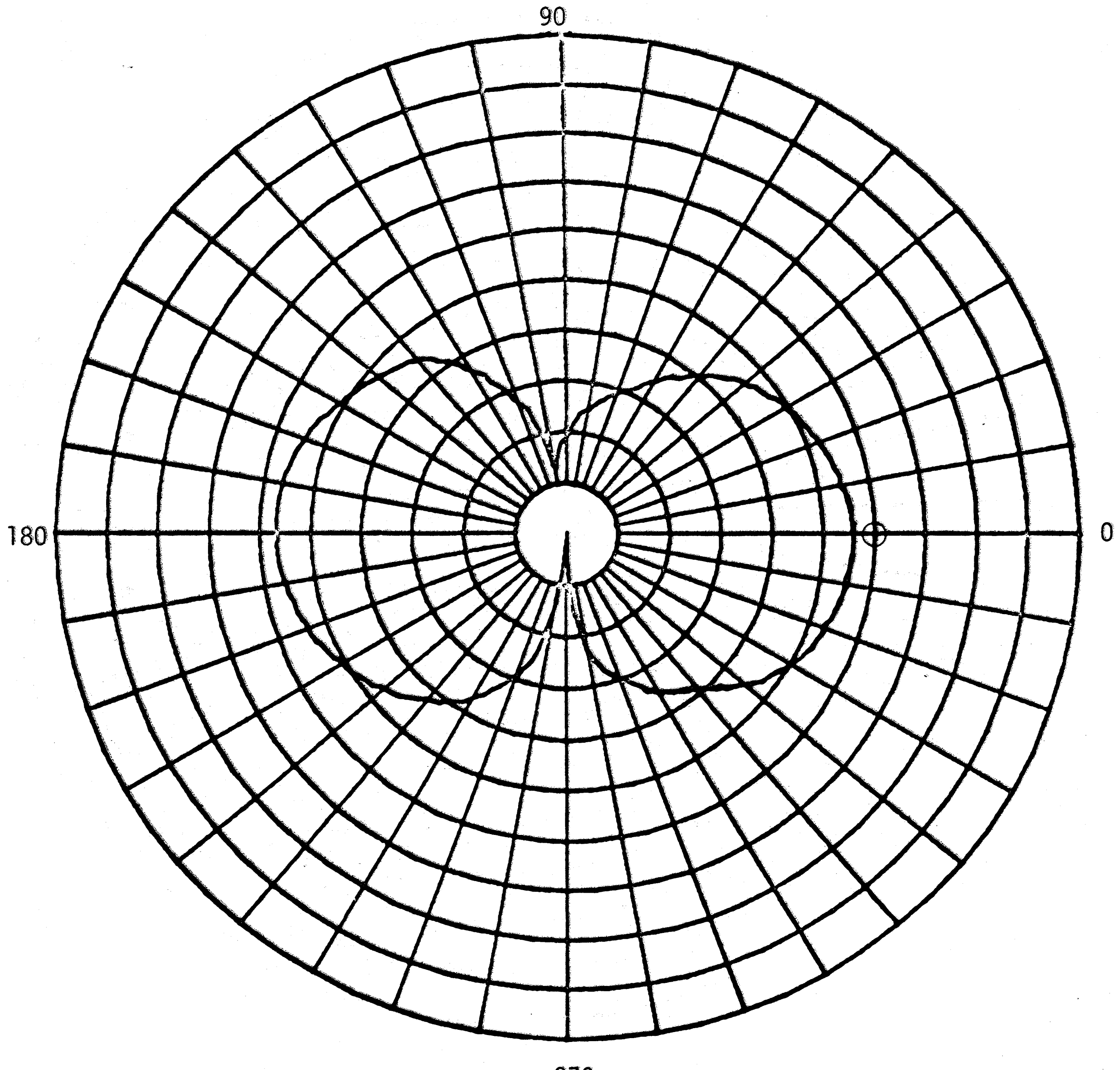

Figure A-65. Relative gain pattern in the azimuthal plane at 641 MHz for antenna No. 14.

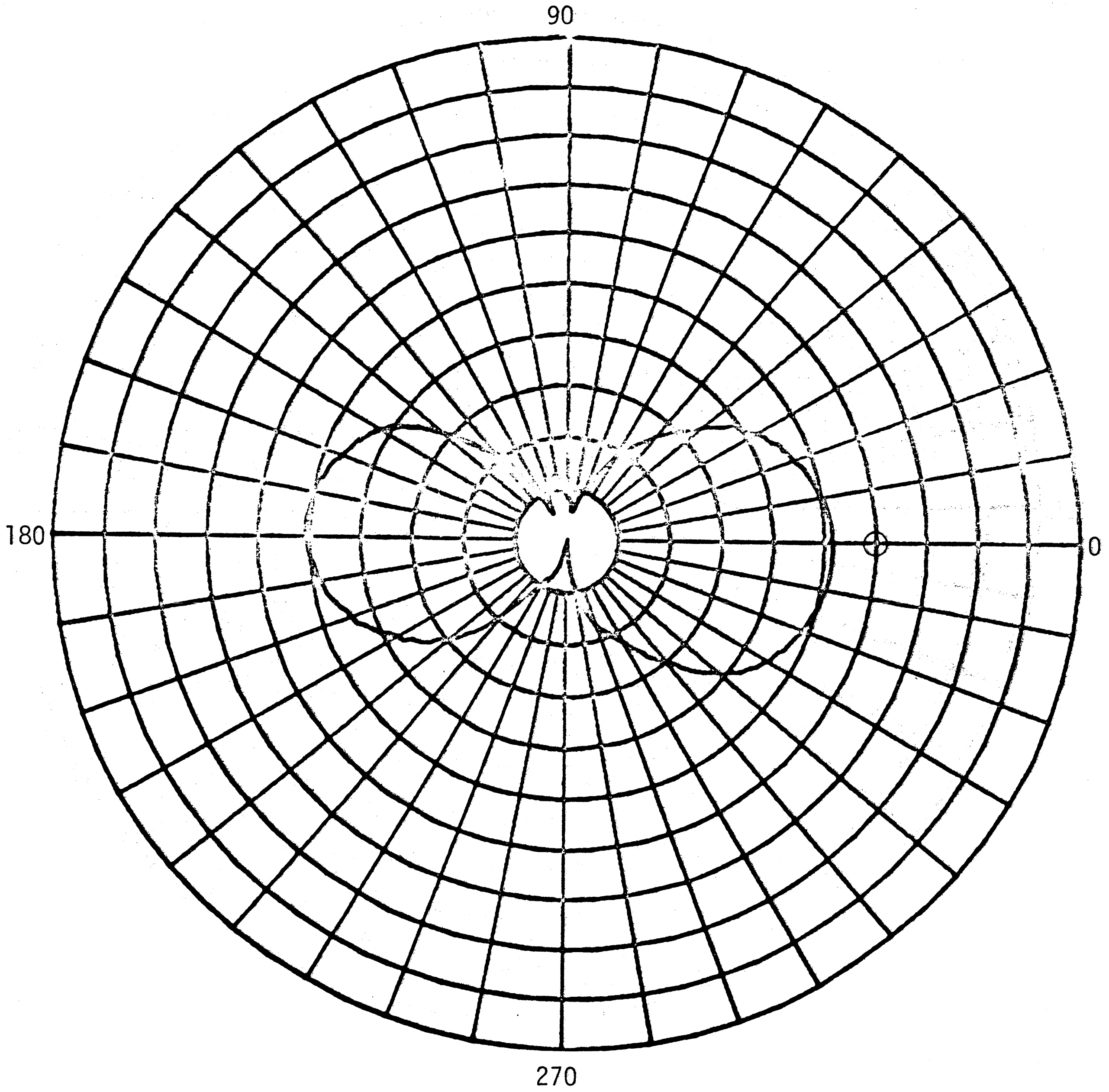

Figure A-66. Relative gain pattern in the azimuthal plane at 803 MHz for antenna No. 14.

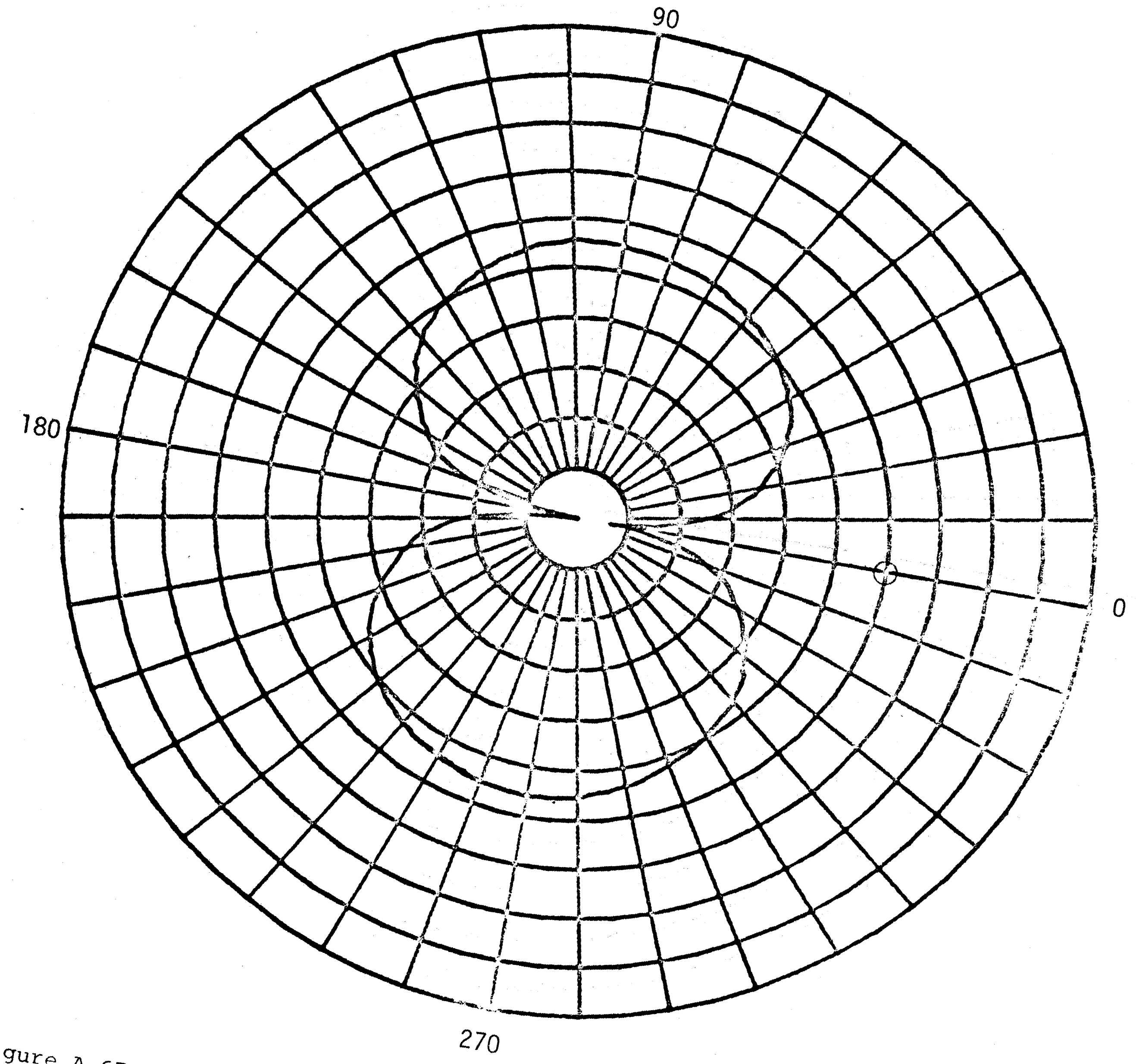

Figure A-67. Relative gain pattern in the azimuthal plane at 473 MHz for antenna No. 15a. Antenna was mounted on test stand 90 deg off optical "boresight" to transmitting antenna.

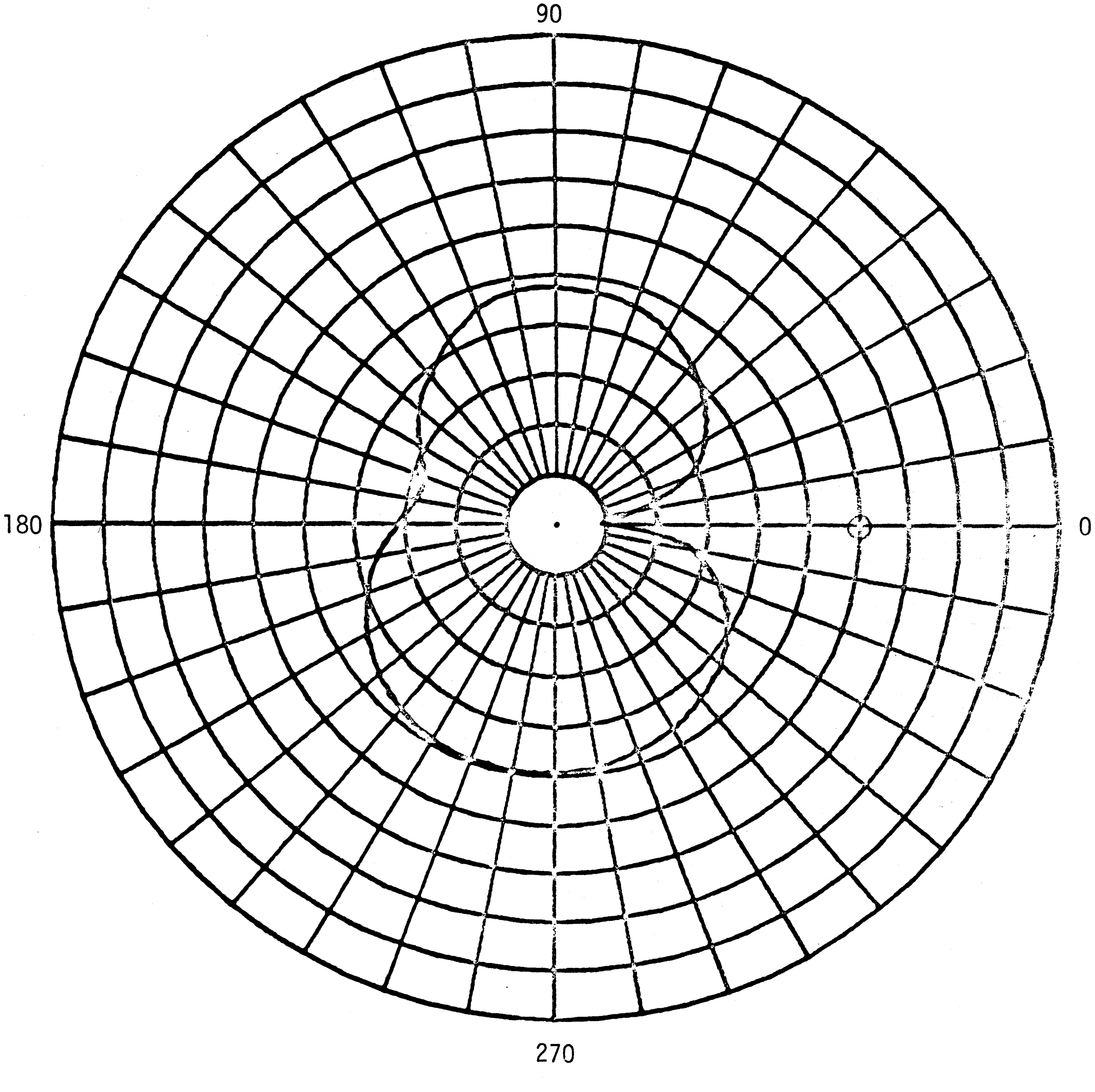

Figure A-68. Relative gain pattern in the azimuthal plane at 473 MHz for antenna No. 15b. Antenna was mounted on test stand 90 deg off optical "boresight" to transmitting antenna.

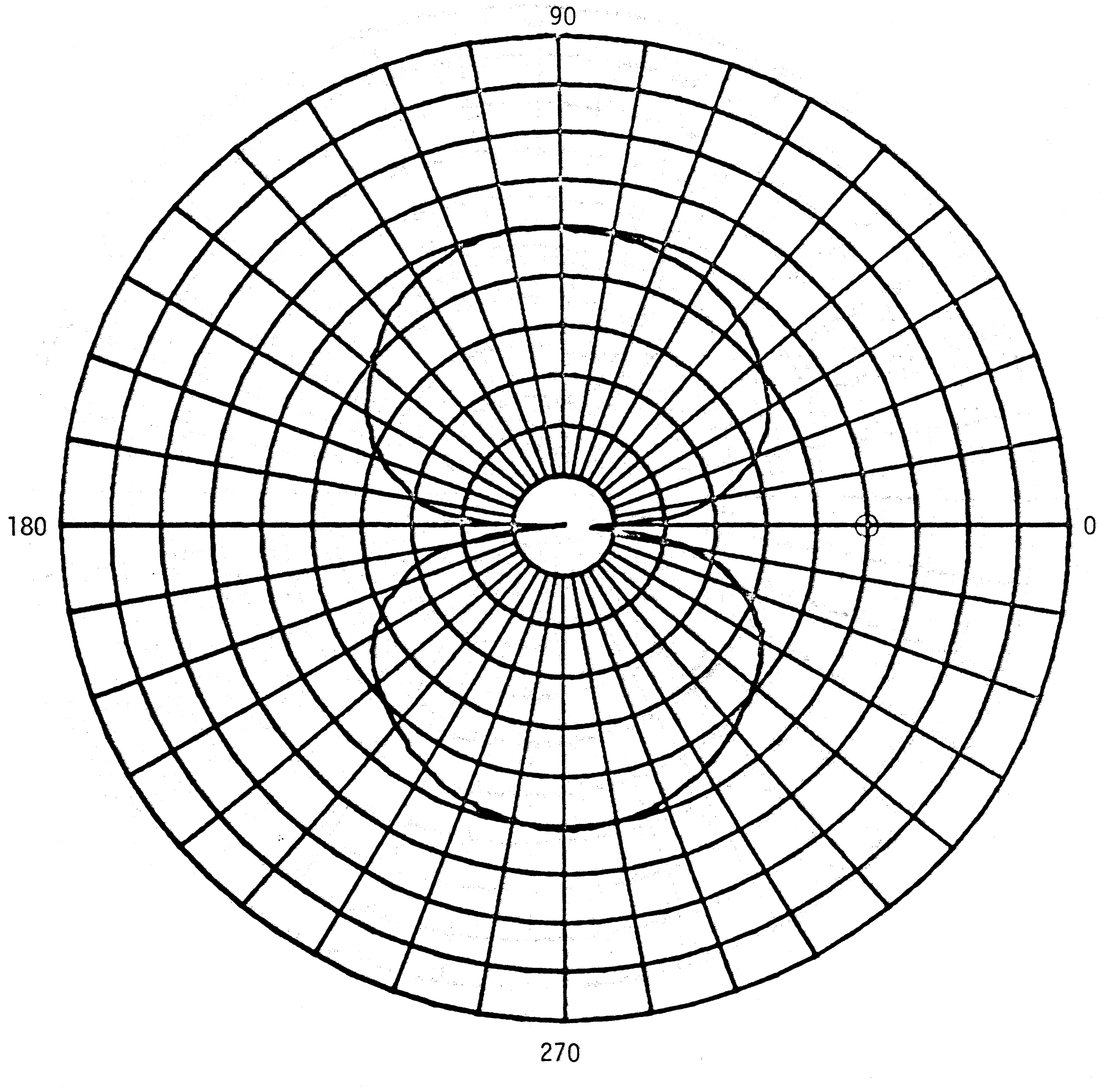

Figure A-69. Relative gain pattern in the azimuthal plane at 641 MHz for antenna No. 15a. Antenna was mounted on test stand 90 deg off optical "boresight" to transmitting antenna.

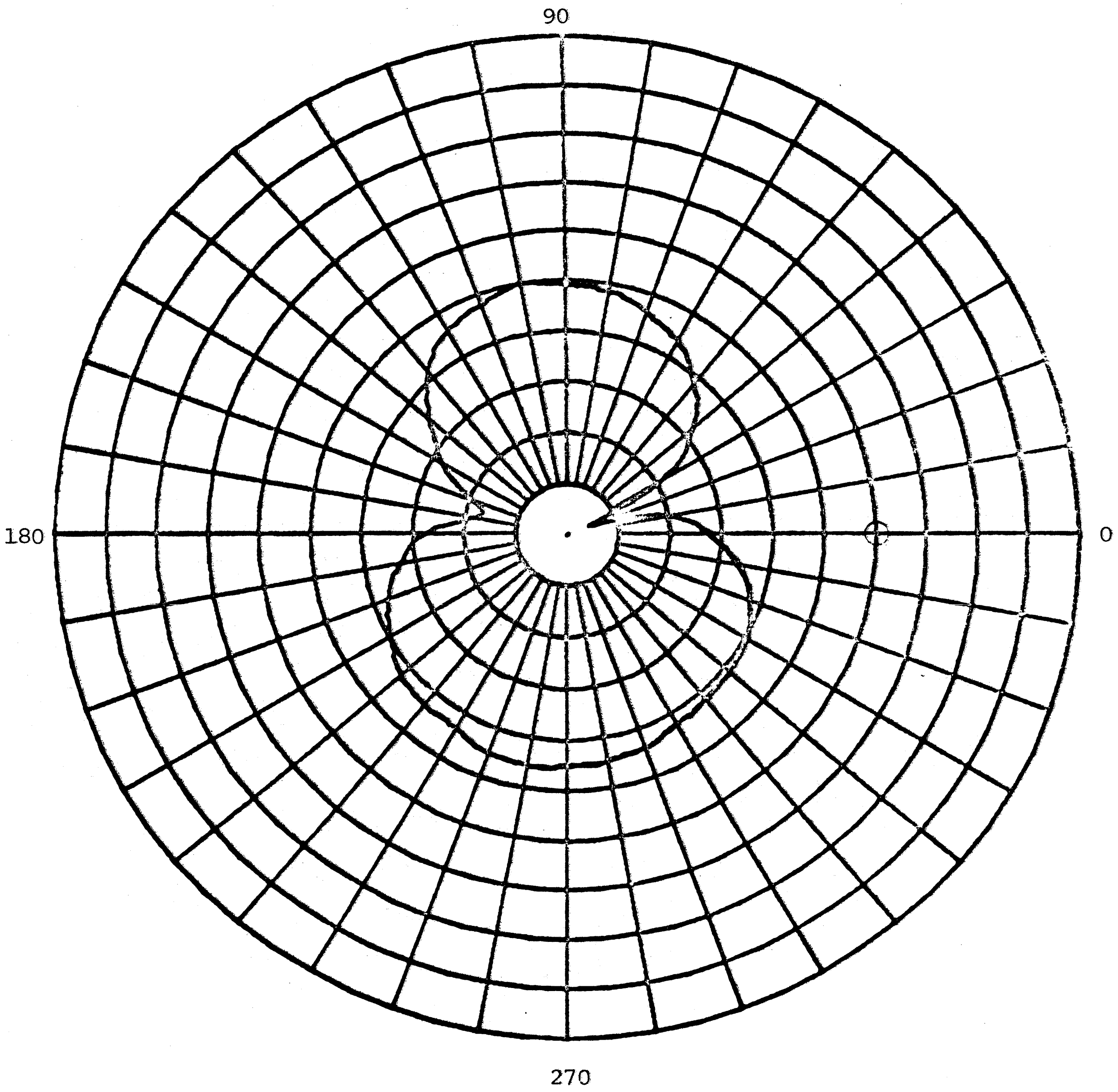

Figure A-70. Relative gain pattern in the azimuthal plane at 641 MHz for antenna No. 15b. Antenna was mounted on test stand 90 deg off optical "boresight" to transmitting antenna.

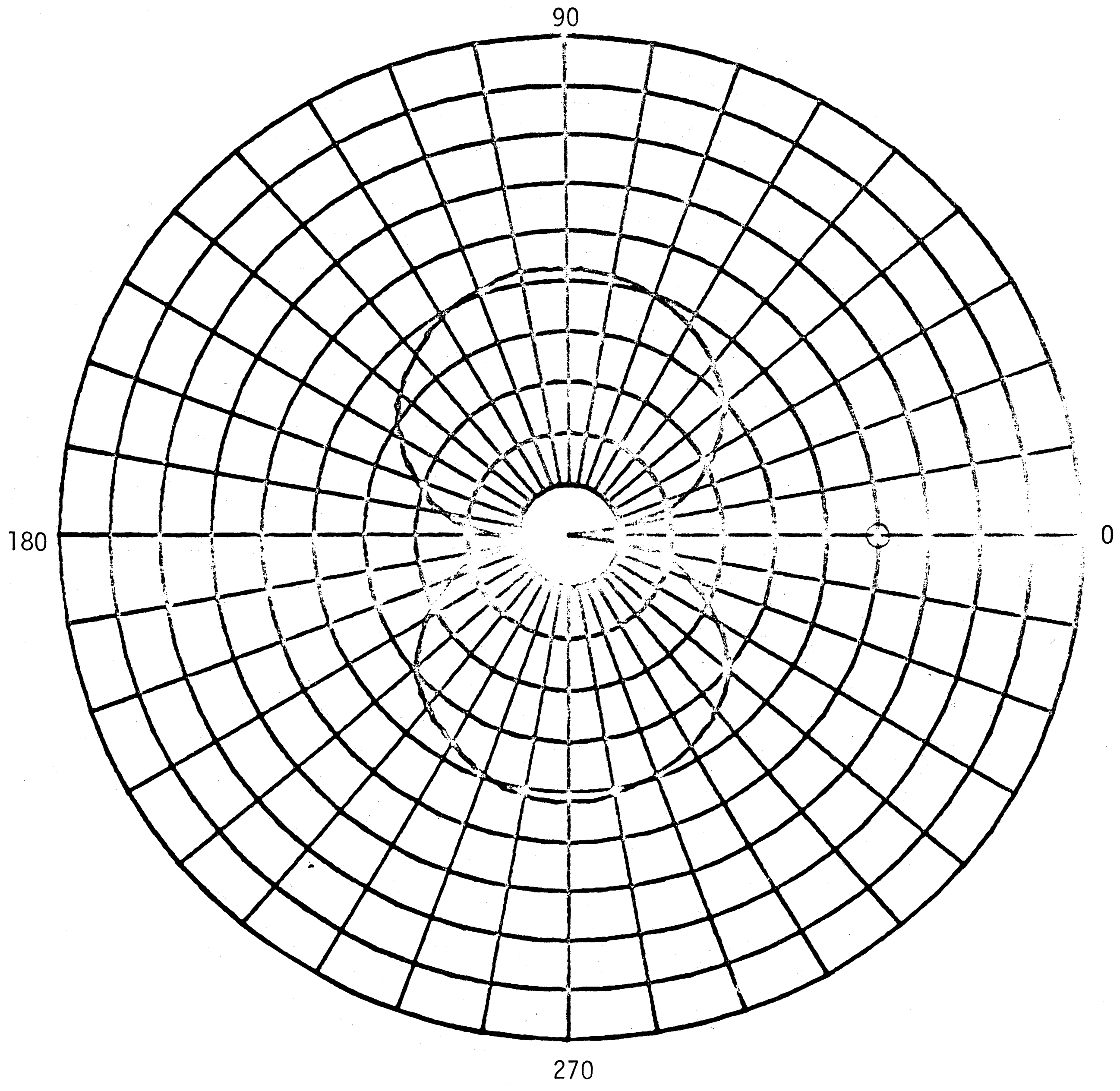

Figure A-71. Relative gain pattern in the azimuthal plane at 803 MHz for antenna No. 15a. Antenna was mounted on test stand 90 deg off optical "boresight" to transmitting antenna.

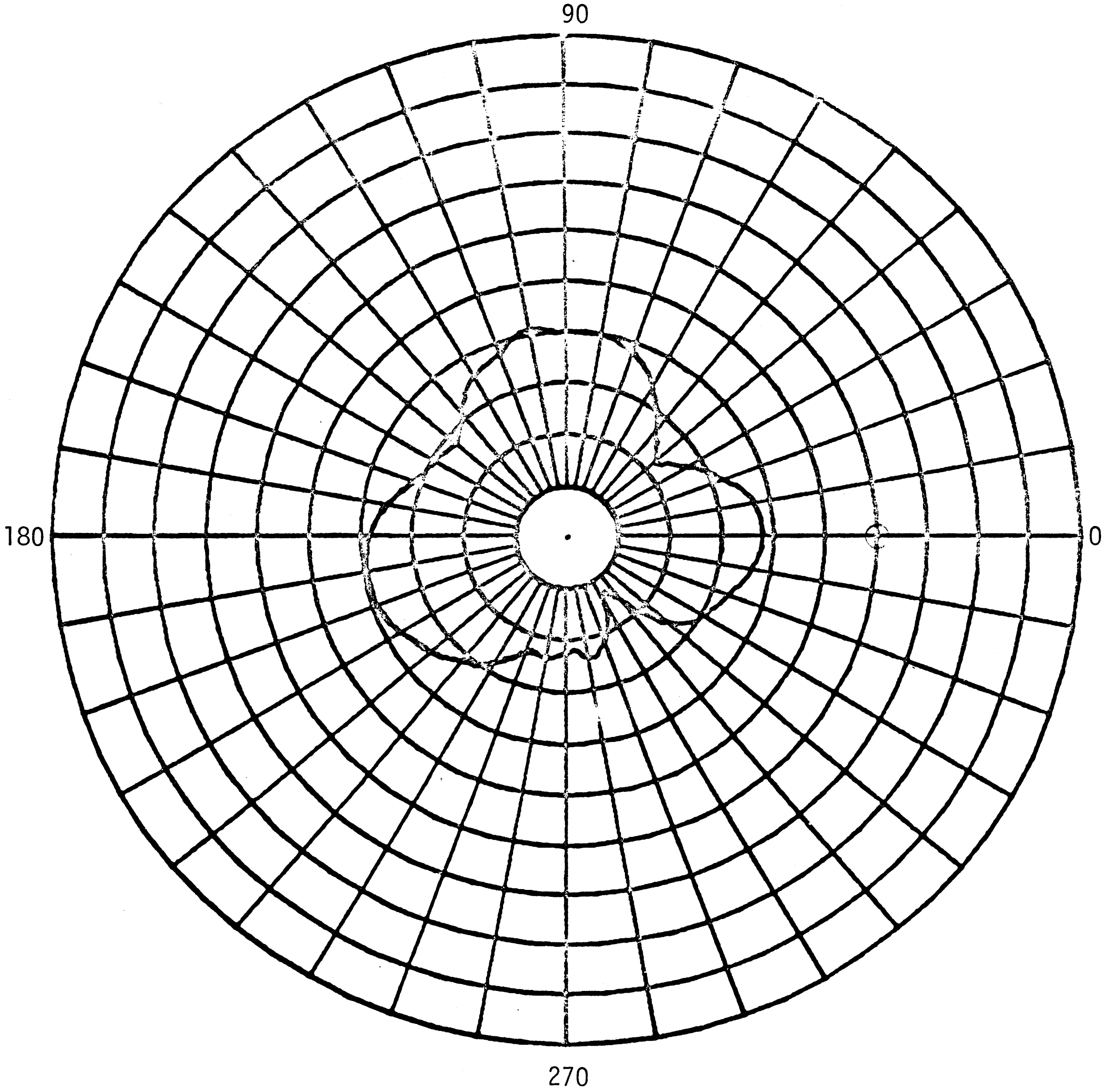

Figure A-72. Relative gain pattern in the azimuthal plane at 803 MHz for antenna No. 15b. Antenna was mounted on test stand 90 deg off optical "boresight" to transmitting antenna.

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14. SUPPLEMENTARY NOTES

15. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

Relative gain of fifteen television receiving antennas was measured as a function of frequency and azimuth angle. Input voltage standing-wave ratio was measured as a function of frequency to determine the scalar impedance properties of the antennas. These antennas, a sample of those available from sources likely to be utilized by TV antenna installation technicians as well as consumers, ranged in price from $1.00 to $78.00 and in length from 18 cm to 400 cm. Insertion loss of a sample of system components, balanced-to-unbalanced line transformers and VHF/UHF signal splitters, was measured, and transmission line attenuation was obtained from manufacturers' data. Antenna gain, component insertion loss, transmission line attenuation, and calculated dipole antenna constant are the significant components of a power budget equation relating power flow in the TV signal field incident upon the antenna to the signal power available at the receiver.

(continued)

16. Key Words *(Alphabetical order, separated by semicolons)*

Antenna gain; power budget calculations; TV.

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15. ABSTRACT (Cont'd.)

Results for four simple types of home installations are given. The range of the power budget data for best and worst combinations of antennas, transmission lines, and other system components illustrates the range of the power available at the receiver versus frequency for a specified power flow in the signal field.

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