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C band	airborne
K_u band	microwave landing system

20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

The design and fabrication of two antenna systems is described and experimental results are presented. Each includes two antennas, one of which operates in the C band and the other operates at K_u band. Both antennas in the first system are vertically polarized while those in the second system are horizontally polarized. The antenna systems are designed for airborne use and they are interchangeable with respect to the physical mounting arrangements. Extensive data is given on pattern characteristics, on interband isolation, on gain and on the input VSWR.

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I

INTRODUCTION

Two dual band antennas have been designed, fabricated, tested and delivered in accordance with the sponsor's Specification DS-EH-0101A(V) under Contract DAAB07-73-C-0337. Each of the dual band antennas was to operate in the C and K_u bands. The first antenna consisted of a vertically polarized C and K_u band antenna and the second consisted of a horizontally polarized C and K_u band antenna.

The electrical requirements for the antennas were:

1.) Frequency bandwidth: C band 5.0 to 5.25 GHz,
K_u band 15.4 to 15.67 GHz.
2.) VSWR < 2:1.
3.) Interband isolation > 40 dB.
4.) Patterns: Azimuth coverage 360°
Elevation coverage - lower hemisphere.
5.) Power rating: 2.5 kw peak, 25 w average.

The mechanical specifications were:

1.) Maximum diameter < 10".
2.) Maximum protrusion < 8".
3.) Input ports for the two antennas to be located in the same physical position.
4.) Input connectors were to be type N for the C band antennas and WR 62 waveguide flange for the K_u band antennas.

Section II of the report discusses the antenna feed system. Section III treats the vertically polarized antenna system and Section IV discusses the horizontally polarized antennas.

The report includes three appendices. Appendix A describes the test plan which was employed; Appendix B includes the test results and Appendix C presents detailed sketches of the two dual band antennas.

II

ANTENNA FEED SYSTEM

The feed system employs .085 coax for the C band antenna and a waveguide-to-coax transition for the K_u band antenna. Because of the requirement that the antenna be omnidirectional in azimuth, it was felt the antennas should be mounted coaxially and be cylindrically symmetrical. This was made possible by having the center conductor of the .085 coax for the feed of one antenna and its outer conductor as the feed for the second antenna. The .085 coax passed through the K_u waveguide in such a way that its outer conductor served as the feed for the waveguide. The coax was soldered to one side of the broad wall of the waveguide but made no electrical contact on the opposite side. In addition, the waveguide was fitted with a short tapered ridge transition which provided the proper transition from the TE_{10} mode of the waveguide to TEM mode in the coax, and also provided the necessary impedance transformation from the K_u band waveguide to the 50 ohm coax. Figure 1 is a sketch of the dual band transition.

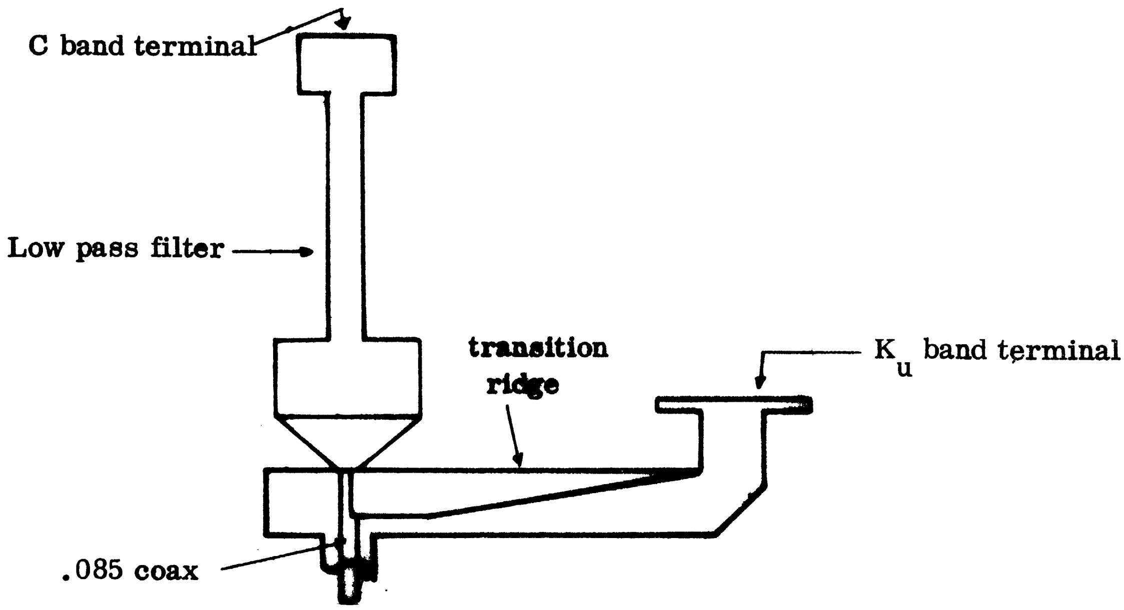


Figure 1: Dual band waveguide-coax transition.

The high pass filter characteristics of the K_u-band waveguide provides adequate isolation from the C-band energy. To prevent the K_u-band energy from entering the C-band port, a 6000 MHz low pass coaxial filter (Microlab FXR, Type LA 6000) was installed as shown in Figure 1.

The feed system discussed above was employed for both the vertically and horizontally polarized dual band antennas to be discussed in the following sections.

III

VERTICALLY POLARIZED DUAL BAND ANTENNA

To satisfy the impedance and pattern requirements of the vertically polarized dual band antenna a $\lambda/4$ monopole and a capacitively loaded monopole were employed respectively for the C and K_u band antennas. These antennas are mounted on an eight inch diameter ground plane which also serves as the antenna mounting structure. The ground plane helps to make the elevation radiation patterns less sensitive to the nearby surface area of the vehicle on which the antenna is to be mounted.

The principal factor which determined the antenna choice and its physical geometry was the elevation pattern requirement. The desired objective was to provide uniform elevation coverage for $-60^o \geq \theta \leq 0^o$; refer to the coordinate system of Figure 3. To satisfy this requirement it was necessary for each of the antennas to have their center-of-radiation located $\lambda/2$ or less from the ground plane. Therefore, the K_u band antenna was mounted adjacent to the ground plane with the C band antenna mounted immediately beneath it as shown in Figure 2. (It is assumed that the antennas will be mounted on the underneath side of the aircraft.)

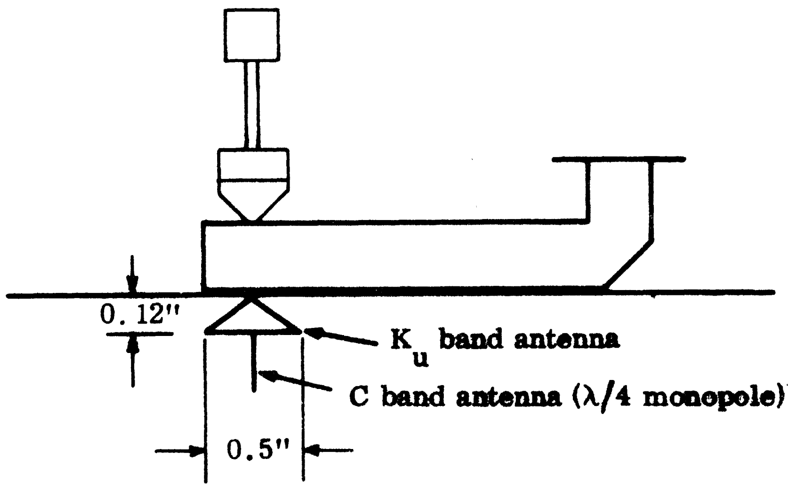


Figure 2: Dual band vertically polarized antenna.

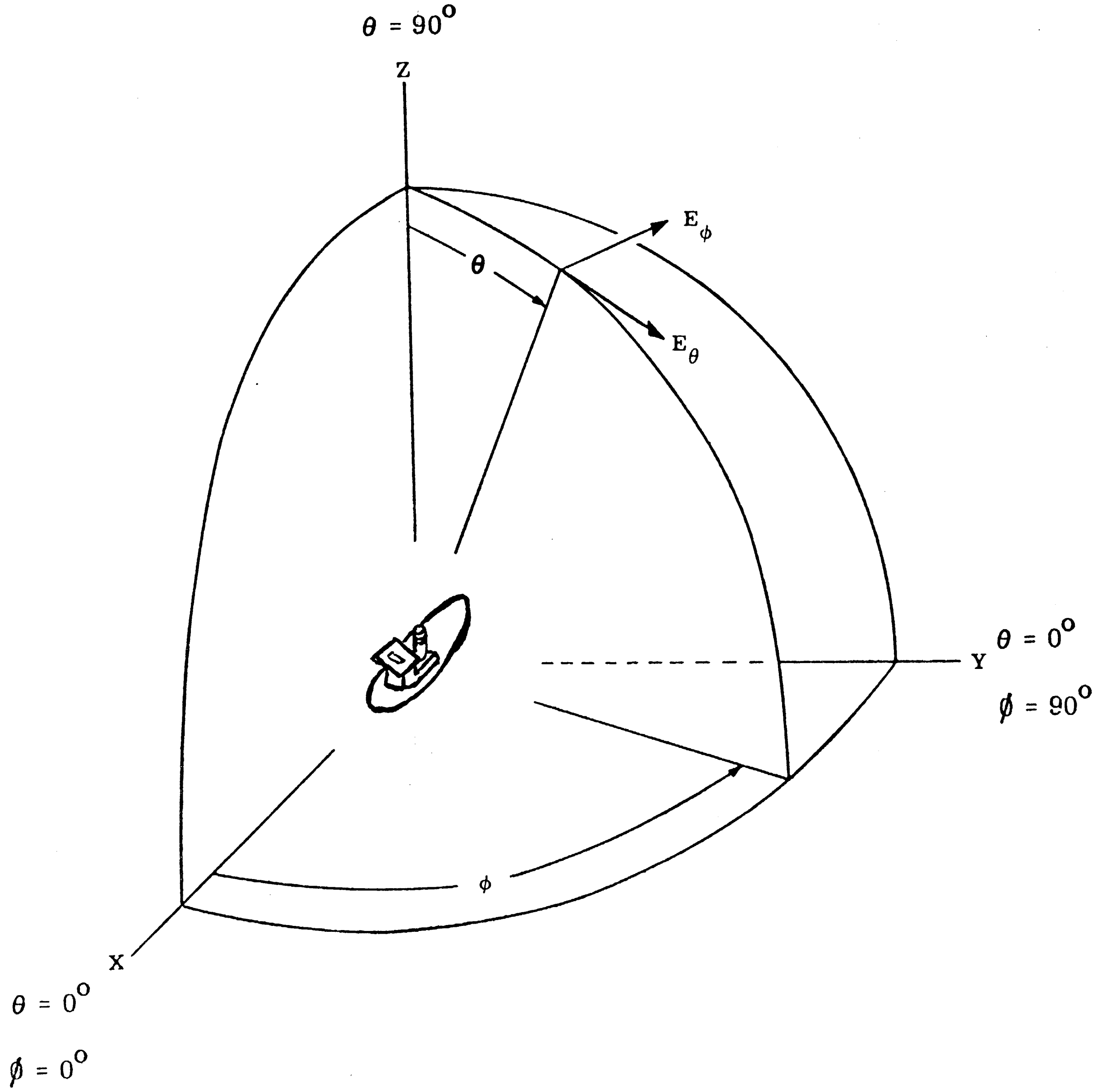
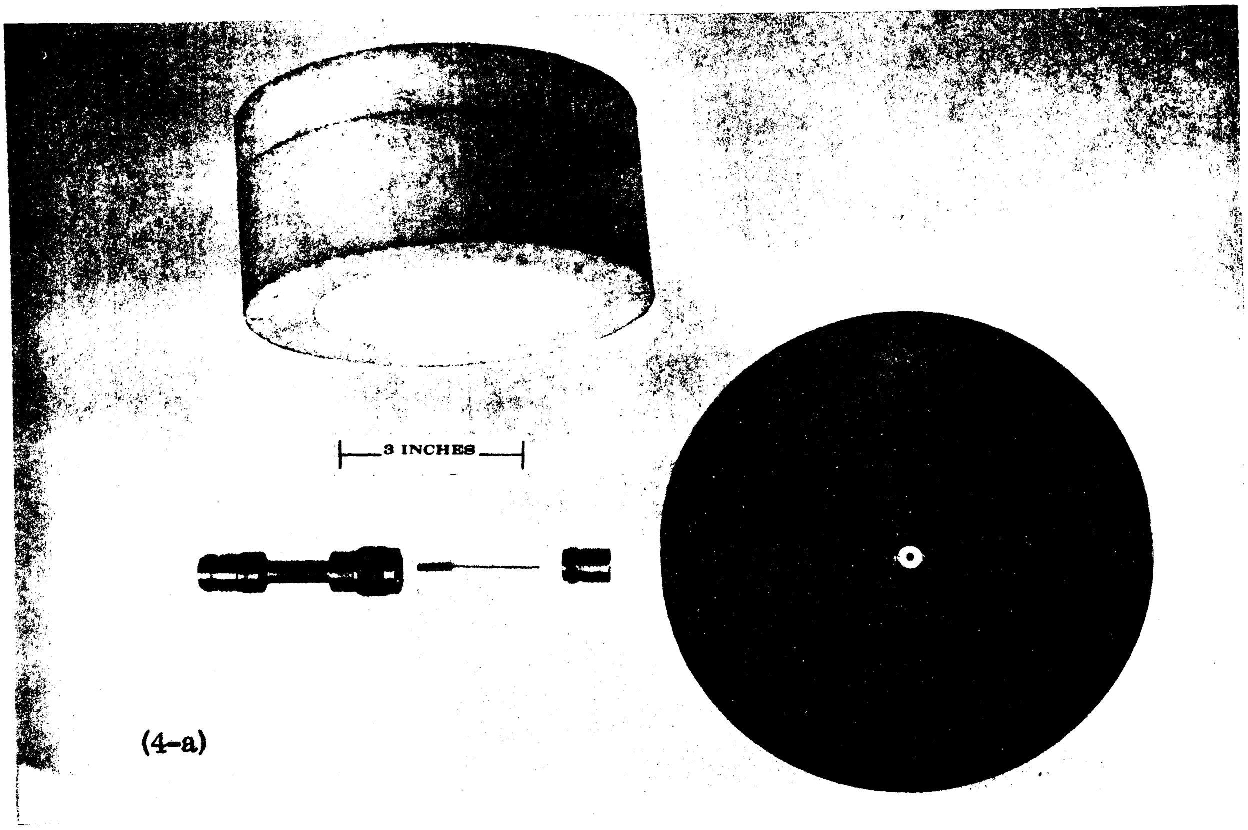


Figure 3: Spherical coordinate system.

To ensure that the elevation pattern of the C band antenna was not influenced by the presence of the K_u band antenna and vice versa, the K_u band antenna was to be a capacitively loaded antenna. The dimensions and structure of the K_u band antenna were dictated by the VSWR and elevation plane pattern requirements. From experimental data, it was found that the VSWR specifications could be satisfied by employing any of a wide range of disk (capacitive load) diameters. However, the elevation plane pattern exhibited a null structure near the zenith ($\theta = -90^{\circ}$) if the disk diameter was $> \lambda/2$. Further experimentation showed that a disk of the geometry shown in Figure 2 would satisfy the K_u pattern requirement and not interfere with the C band antenna. The center conductor of the .085 coax was extended a quarter wavelength below the K_u band disk, thus forming the C band monopole as shown in Figure 2.

To protect the dual band vertically polarized antennas during operation, a cover in the form of a short cylindrical polyethelyne foam radome was fabricated and placed over the antennas. This geometry was chosen to simplify fabrication; the walls and bottom of the radome are one inch thick and are covered with a layer (< .032 inch thick) of fiberglas cloth impregnated with epoxy resin. The fiberglas was placed over the foam to prevent mechanical damage to the fragile foam material. This structure was employed to ensure that the K_u band pattern characteristics would not be adversely affected by the presence of the radome. Figure 4 is a component picture of the dual band vertically polarized antenna. Figures 4a and 4b show respectively the inside and outside views of the ground plane. Figure 5 shows the antennas assembled before the radome was cemented in place. All of the test data discussed below was recorded with the radome cemented in place.



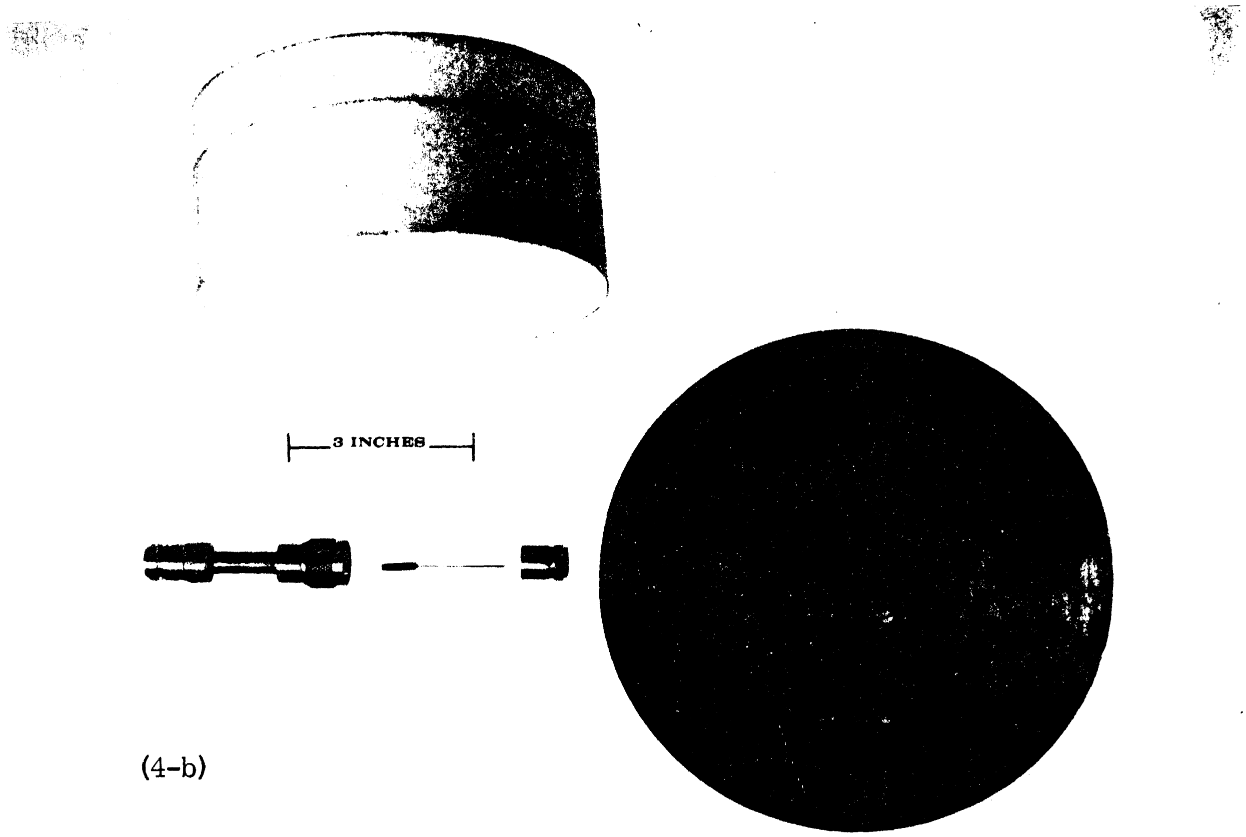


Figure 4: The vertically polarized antenna showing (a) the outside and (b) the inside view of the ground plane.

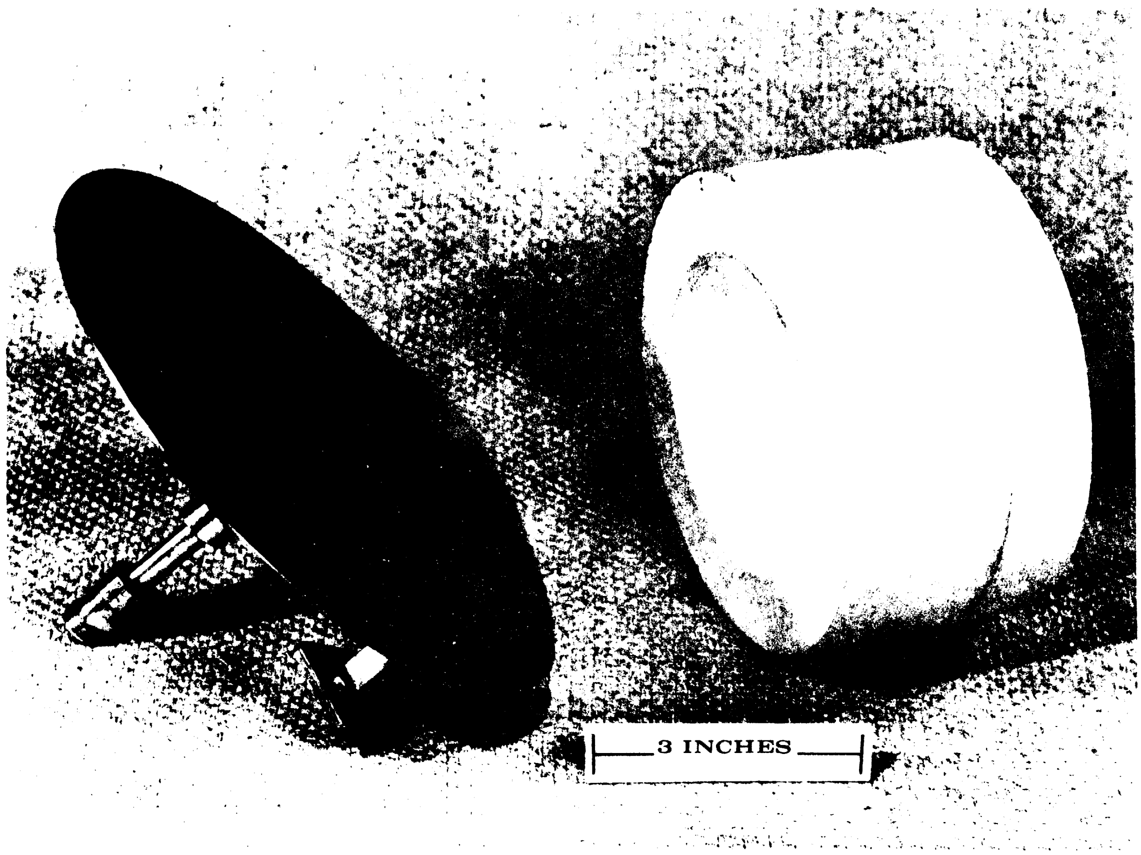


Figure 5: Assembled vertically polarized antenna and radome.

3.1 Vertically Polarized Dual Band Antenna Test Data

All test data for the antenna was recorded in accordance with the test plan submitted 18 January 1974 and presented in Appendix A.

The VSWR characteristics of the dual band vertically polarized antenna are tabulated below.

TABLE I

Dual Band Vertically Polarized Antenna VSWR

C Band		K_u Band	
Frequency (GHz)	VSWR	Frequency (GHz)	VSWR
4.95	1.65	15.35	1.45
5.00	1.4	15.40	1.40
5.05	1.2	15.45	1.40
5.10	1.05	15.50	1.39
5.15	1.12	15.55	1.34
5.20	1.22	15.60	1.34
5.25	1.36	15.65	1.35
5.30	1.50	15.70	1.34

The measured gain (at the pattern maximum) for the C and K_u band antennas were nominally 4dB above isotropic. Typical gain data are presented in Appendix B, Figure B-1 and B-2. Interband isolation measurements showed the isolation to be greater than 40dB for both the C and K_u band antennas. Typical interband isolation data is shown in Figure B-5 and B-6 of Appendix B.

Elevation plane pattern data were recorded at 5.0, 5.15 and 5.25 GHz for the C-band antenna and at 15.4, 15.5 and 15.7 GHz for the K_u band antenna. Further, data were recorded for the following ϕ increments: 0^o, 45^o, 90^o and 135^o for all frequencies noted above. All pattern data (C and K_u band) possessed good symmetry. Typical C and K_u band pattern data are shown in Figure 6 and 7 respectively for the C and K_u band antennas. A complete set of pattern data is presented in Appendix B. All pattern data was recorded with the dual band vertically polarized antenna mounted at the center of a 4-foot diameter flat metalic ground plane.

The periodic ripple apparent on the patterns of Figures 6 and 7 are due to energy being scattered from the edges of the large ground plane. These will generally be minimized if the antenna is mounted on a ground plane whose edges are curved (similar to the fuselage of an aircraft). The more erratic null structure observable on the K_u pattern of Figure 7 is caused by the fiberglas protective covering of the foam radome. The reader will note that the C band coverage near $\theta = -60^o$ is nominally 5dB below isotropic. Additional coverage could have been obtained by employing a capacitively loaded antenna similar to the K_u band antenna. However, the diameter of the capacitive disk would have had to be so large that the K_u band antenna would have been exceissvely shadowed. If the C band antenna had been placed above the K_u band antenna, then the K_u band antenna would have exhibited undesirable nulling near the horizon ($\theta=0^o$) as a result of having its center radiator greater than $\lambda/2$ from the ground plane.

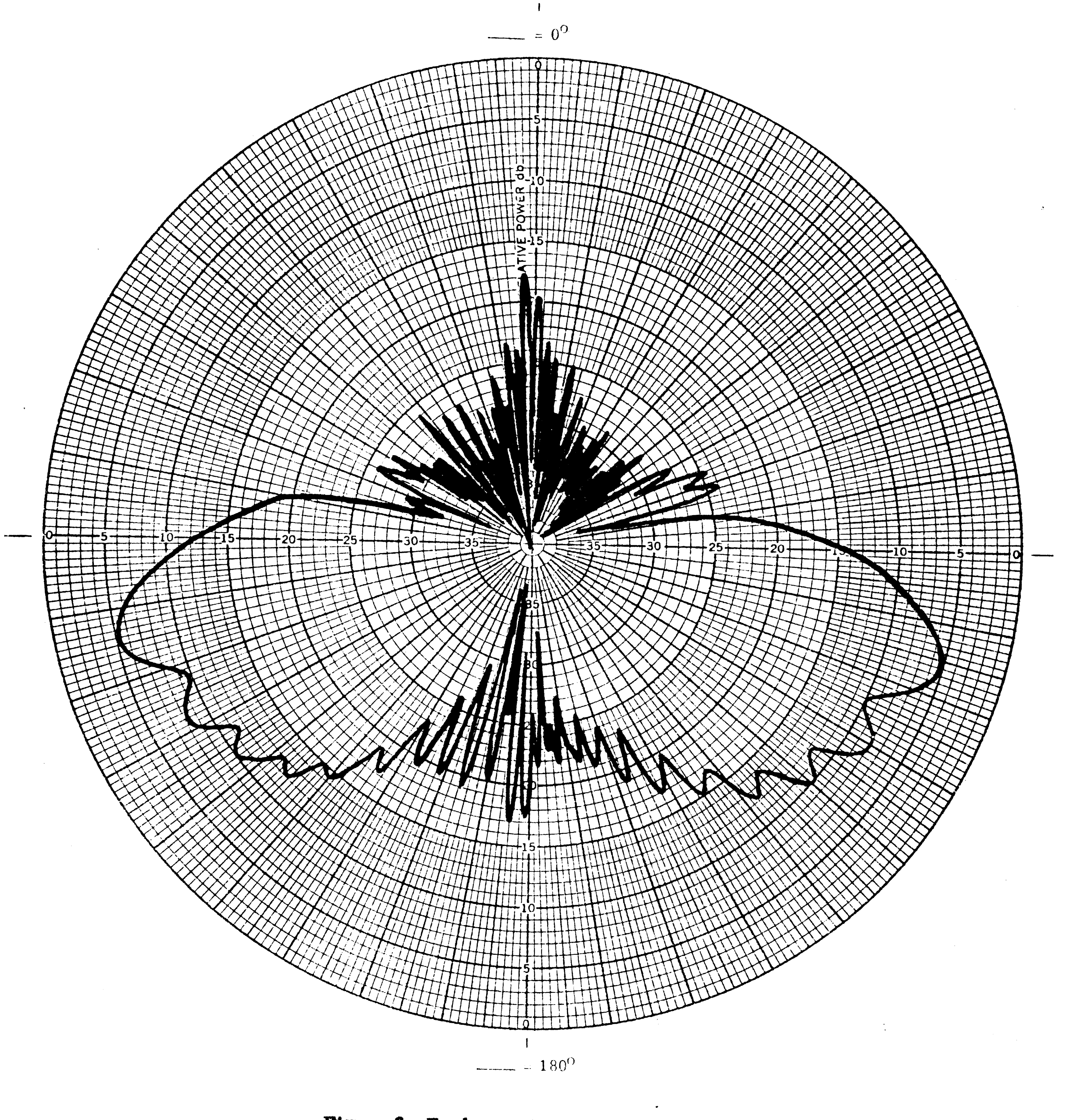


Figure 6: E-plane pattern, 5.15 GHz, Vertical polarization, $\phi = 0°$.

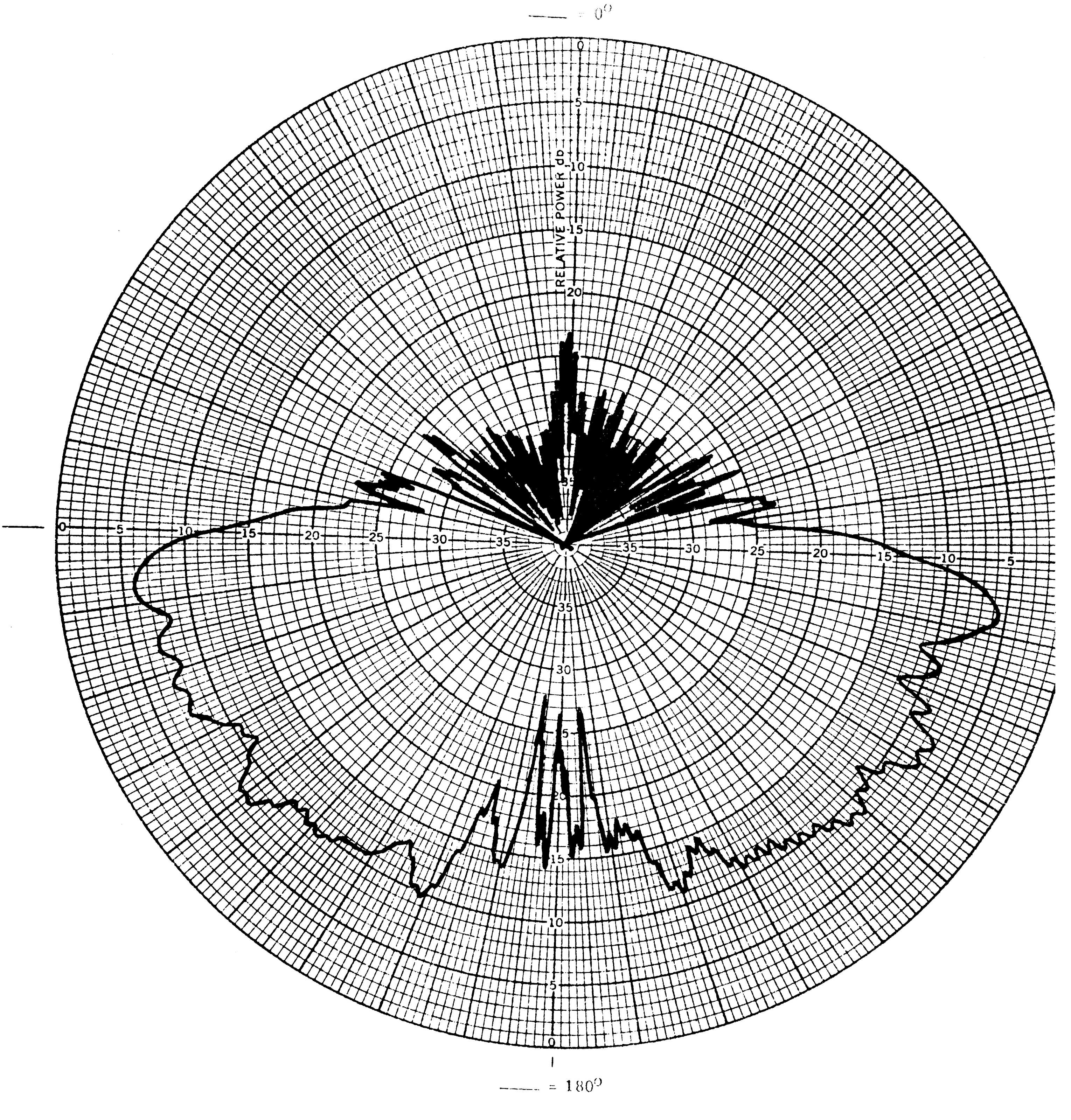


Figure 7: E-plane pattern, 15.5 GHz,
vertical polarization, $\phi = 0^{\circ}$.

IV

HORIZONTALLY POLARIZED DUAL BAND ANTENNA

To meet the specified requirements for the impedance and pattern characteristics of the horizontally polarized dual band antenna, a tridipole was used for the C-band antenna and a slotted coaxial cylinder was used for the K_u-band antenna. These antennas were mounted on an eight inch diameter ground plane which also serves as the antenna mounting structure.

The physical location of the antennas was dictated by the elevation pattern requirements. To minimize unwanted nulls the K_u band antenna was placed adjacent to the ground plane with the C band beneath it as shown in Figure 8. With this arrangement the radiation centers of each antenna was less than $\lambda/2$ from the ground plane. The four slots of the K_u band antenna and the three dipoles of the C band antenna ensured a relatively uniform azimuth pattern.

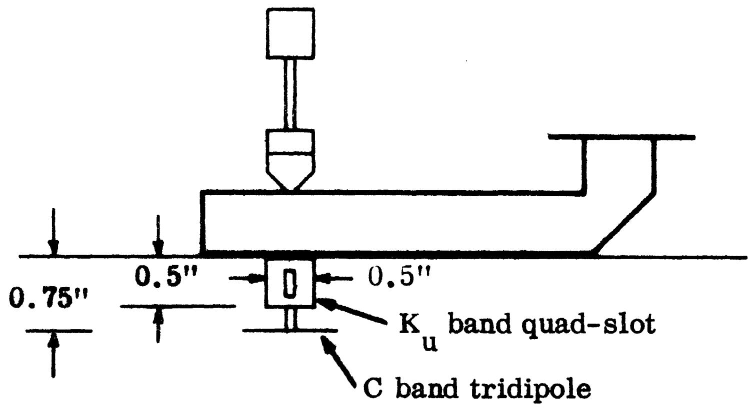


Figure 8: Dual band horizontally polarized antenna.

The final design of the K_u band antenna was arrived at experimentally. From the pattern data collected during the development of the K_u band vertically polarized antenna, it was known that the slotted cylinder could be no longer than 0.5 inches to avoid unwanted nulling in the C-band elevation plane. Further, since it was desirable to employ the same feed system for both antenna systems it was decided that the K_u band horizontally polarized antenna should employ a slotted TEM coaxial line. This would then facilitate feeding the C band antenna from a dual band feed system similar to that used for the vertically polarized antennas.

Since little information was available on the design of a four-slot TEM coaxial line antenna, an experimental program was initiated to determine the critical design parameters. It was learned that the impedance characteristics of the antenna were a function of the following parameters:

1.) Number of slots,
2.) Slot length,
3.) Slot width
4.) Coaxial line impedance,
5.) Coaxial line dimensions.

From this experimental effort and the knowledge gained during the design of the vertically polarized antenna we arrived at the following parameters for the horizontally polarized K_u band antenna and found that they satisfied both the impedance and pattern specifications.

1.) Number of slots = 4
2.) Slot length = 0.410"
3.) Slot width = 0.032"
4.) Coaxial line impedance = 50 ohms
5.) Coaxial line center conductor = 0.197"
6.) Coaxial line dielectric (air) = $\epsilon_o = 1.0$.

Four axial slots equally spaced around the outer conductor of the coaxial line provided omnidirectional ooverage to within 3 dB. Each slot is excited by a probe (0.030" diameter wire) extending from the outer conductor into the inner conductor of the coaxial line. A 0.032" diameter hole drilled approximately 0.032" from the edge of each slot and centered along the length of the slot helped to fix the probes in place. These holes were drilled radially through the outer conductor and approximately 0.020" into the center conductor. This helped to ensure the probes were installed properly and held firmly in place after they were soldered to the outer conductor of the coax.)

Since the center conductor for the K_u band coaxial line was greater than 0.085" it was necessary to employ a half-inch tapered transition section at the input of the K_u band antenna. An attempt was made to employ a step transition, however test results showed the large K_u band coax was supporting higher order modes which resulted in a poor omnidirectional pattern. The feasibility of employing 0.141" coax to feed the C band antenna whose outer conductor would function as the inner conductor for the K_u coax was investigated. However, it also caused higher order moding in the K_u coax and this idea was abandoned.

To feed the C band antenna it was necessary to drill a hole along the axis of the K_u band coax center conductor. This hole eventually housed the 0.085" coaxial feed and an impedance transformer for the C band antenna. The three dipoles were connected in parallel across the 50 ohm coaxial feed line. The design of the C band tridipole arrangement was relatively straightforward, but some experimental work was required to fine-tune the antenna to achieve the desired VSWR characteristics. Initially a tridipole antenna was fabricated and fed from the 50 ohm coaxial line installed in the K_u band antenna. Impedance tests showd that the tridipole (mounted as it would be in the finished design) exhibited an impedance (Z_{ant}) of about 13 ohms. It is known that the impedance of each of the three dipoles in free space would be 72 ohms at the resonant frequency. Since the three are fed in parallel, we would expect their combined impedance to be 24 ohms. Mounting the antennas above a ground plane typically has the effect of reducing the impedance by a factor of 2 and thus one would expect a combined impedance of 12 ohms which is in good agreement with the measured impedance. To transform the measured impedance to 50 ohms, a series matching section was employed. The length of the matching transformer is approximately $\lambda/4$ at the C band center frequency and it has a characteristic impedance (Z_k) of 30 ohms based on the relationship $Z_t = (Z_0 Z_{ant})^{1/2}$. It was also necessary to shorten the length of the dipoles to improve the match. The final length of each half element was 0.500".

Experimentally it was found that three elements were required to produce a radiation pattern uniform to within 3dB. in the azimuth plane. Since the dipole is inherently a balanced impedance device and since it was fed by the unbalanced coaxial transmission line, it was necessary to employ a balun. Judging from the pattern data, the simple balun that was employed adequately eliminated the stray currents.

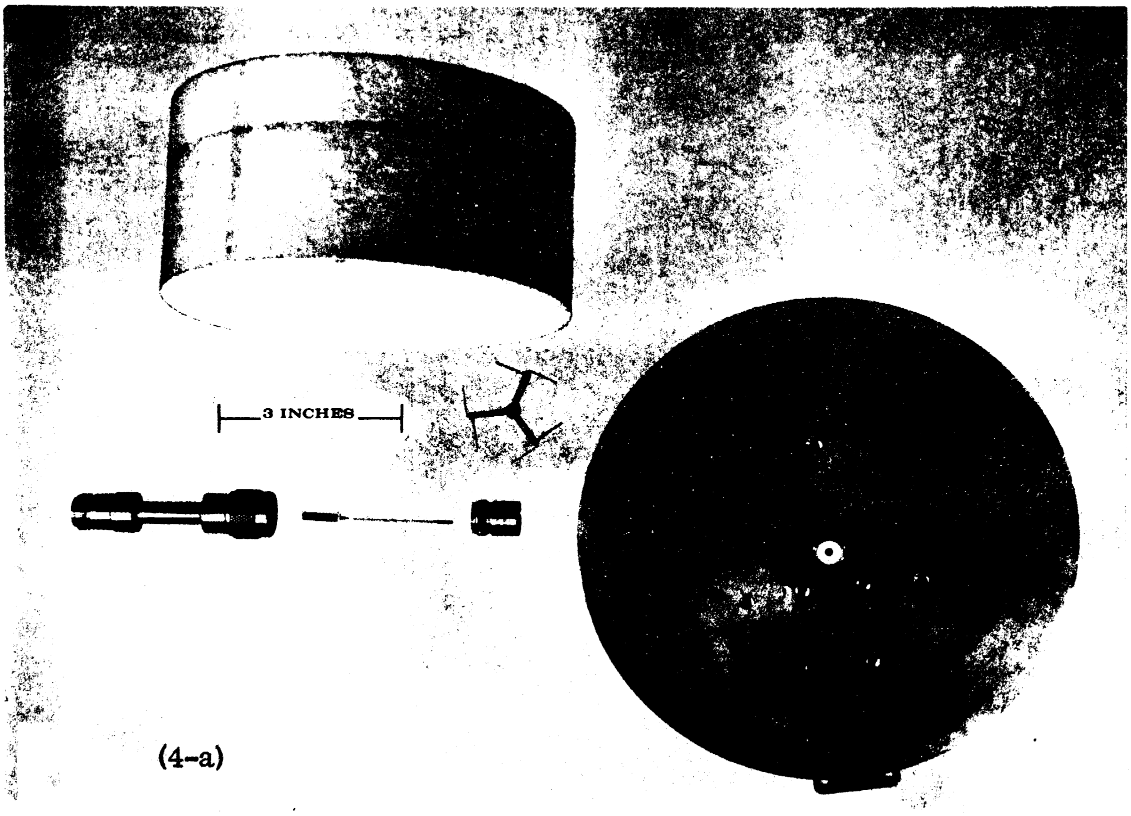
Figure 9 shows the horizontally polarized dual band antenna configuration with the inside view of the ground plane in Figure 9a and the outside view in 9b. The radome for this antenna is of the same design as that used for the vertically polarized antenna (see Section III for details). Figure 10 is an assembled view of the antenna before the radome was cemented in place. All test data discussed below were obtained with the radome cemented in place.

4.1 Horizontally Polarized Dual Band Antenna Test Data

All test data for the antenna were recorded in accordance with the test plan given in Appendix A. The VSWR characteristics of the dual band horizontally polarized antennas are given in Table II.

Table II
Dual Band Horizontally Polarized Antenna VSWR

C Band		K_u Band	
Frequency (GHz)	VSWR	Frequency (GHz)	VSWR
4.95	1.9	15.35	2.1
5.00	1.9	15.40	1.8
5.05	1.8	15.45	1.65
5.10	1.65	15.50	1.55
5.15	1.45	15.55	1.45
5.20	1.28	15.60	1.42
5.25	1.20	15.65	1.45
5.30	1.34	15.70	1.5



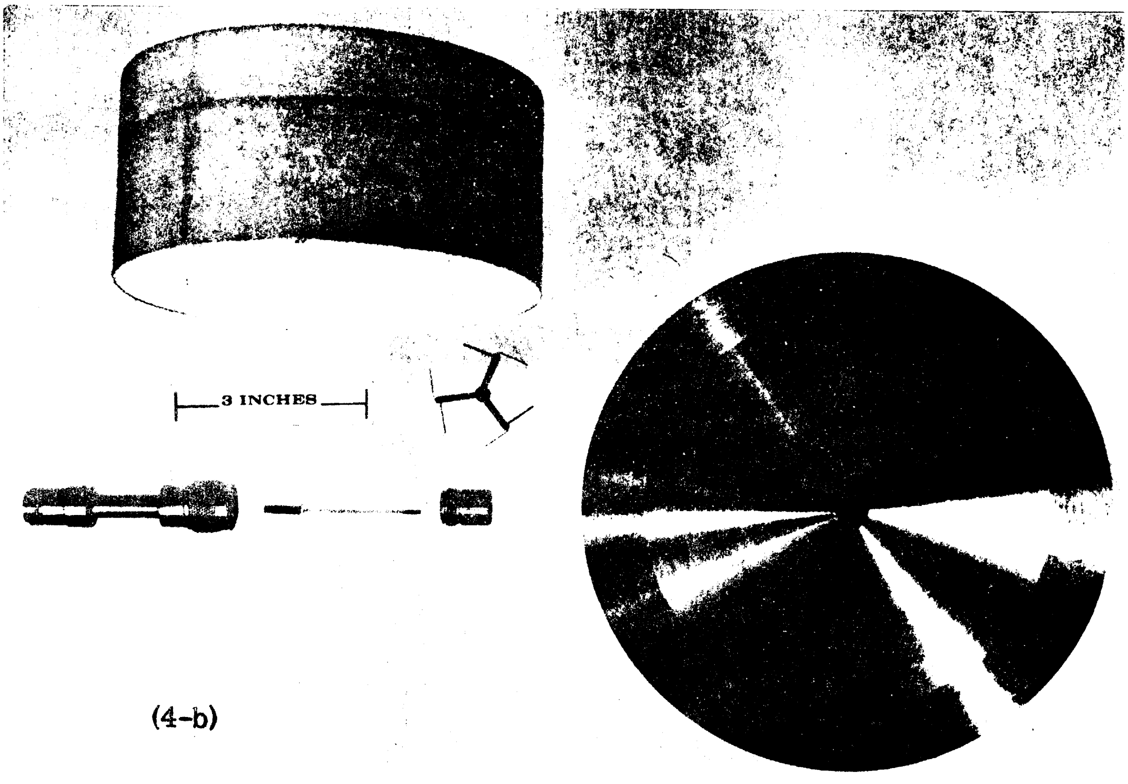


Figure 9: The horizontally polarized antenna showing (a) the outside and (b) the inside view of the ground plane.

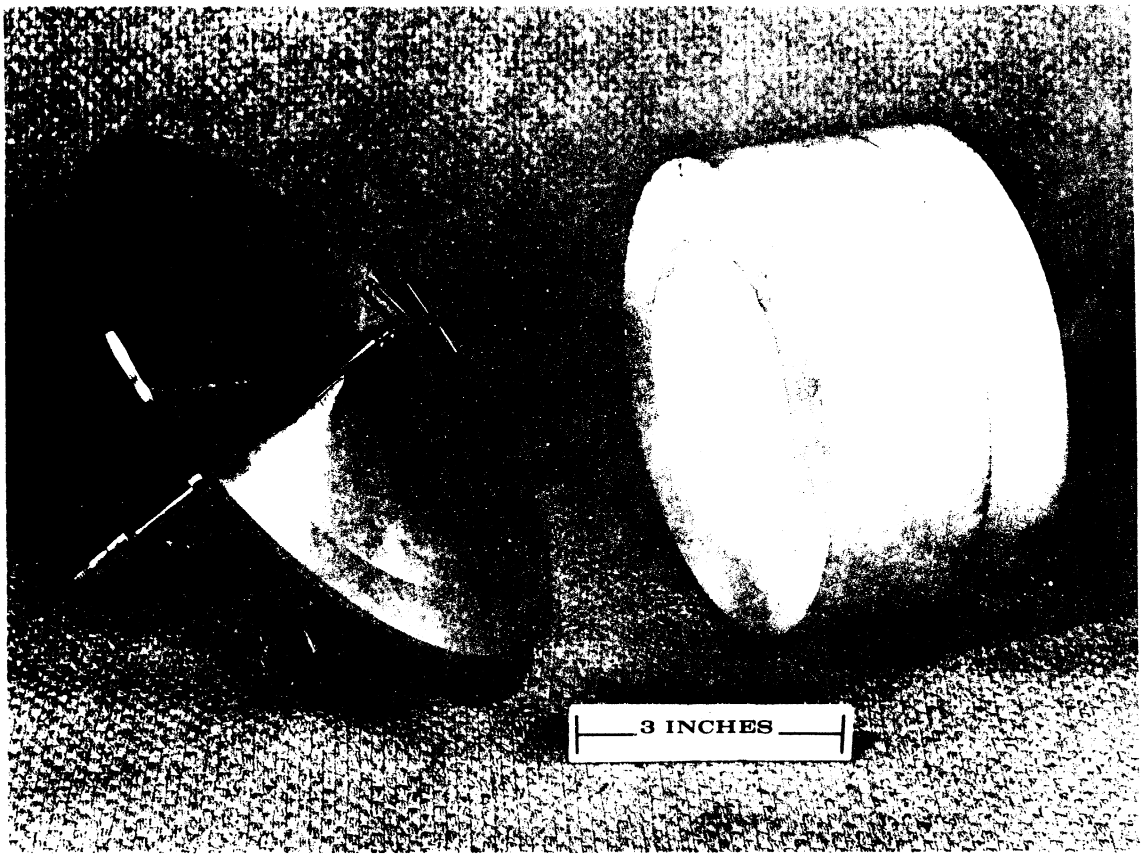


Figure 10: The assembled horizontally polarized antenna with radome.

The measured gain (at the pattern maximum) for the C and K_u band antennas was respectively 5 and 3 dB above isotropic. Typical gain data are presented in Appendix B. Interband isolation measurements showed the isolation to be greater than 40 dB for both the C and K_u band antennas. Typical interband isolation data are also presented in Appendix B.

Elevation plane pattern data were recorded at 5.0, 5.15 and 5.25 GHz for the C band antenna and at 15.4, 15.5 and 15.7 GHz for the K_u band antenna. Further, data were recorded for the following ϕ increments: 0^o, 45^o, 90^o and 135^o at each frequency noted above. The C band data exhibited good symmetry both as a function of ϕ and frequency. However, the K_u data indicated less symmetry; this may be due to some moding within the K_u band coax and also to some shadowing from the C band antenna.

Typical C and K_u band pattern data are shown in Figures 11 and 12 respectively. A complete set of pattern data is presented in Appendix B. All pattern data were recorded with the dual band horizontally polarized antenna mounted at the center of a 4-foot diameter flat metallic ground plane.

The null structure near $\theta = -90^o$ for the K_u band antenna is due largely to the diffraction effect between slots which are located on opposite sides of the K_u band coax. Initially efforts were made to reduce the K_u band coax diameter to less than 0.5", but this change caused difficult impedance matching problems. The cause for the relatively poor coverage near the horizon ($\theta = 0^o$) is due to a well known phenomenon. With horizontal polarization above a metallic ground plane the E field must be zero at the surface. To achieve additional coverage along the horizon in particular azimuth directions, it will be necessary to install the antenna near the edge of curved surfaces of the airframe, For example, if additional coverage is desired in the forward direction of a rotary-wing aircraft, the antenna should be located on the center line of the underside of the fuselage, near the section with the shortest radius of curvature.

From a comparison of Figures 11 and 12 it can beeseen that the radome has a minimum effect on the C band antenna but does cause some erratic nulling in the K_u band antenna similar to that discussed in Section 3.1.

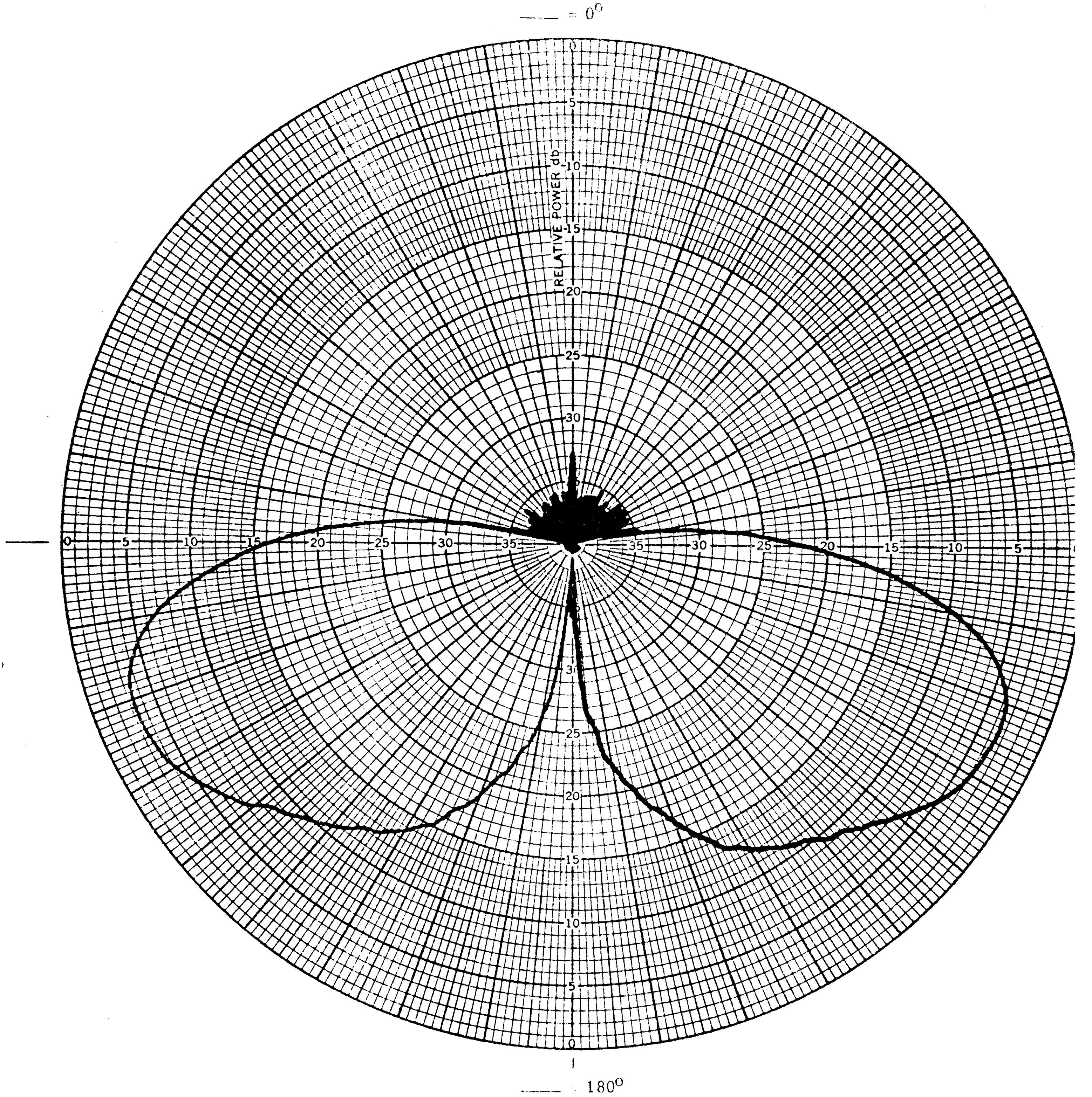


Figure 11: H-plane pattern, 5.15 GHz, horizontal polarization, $\phi = 0^{\circ}$.

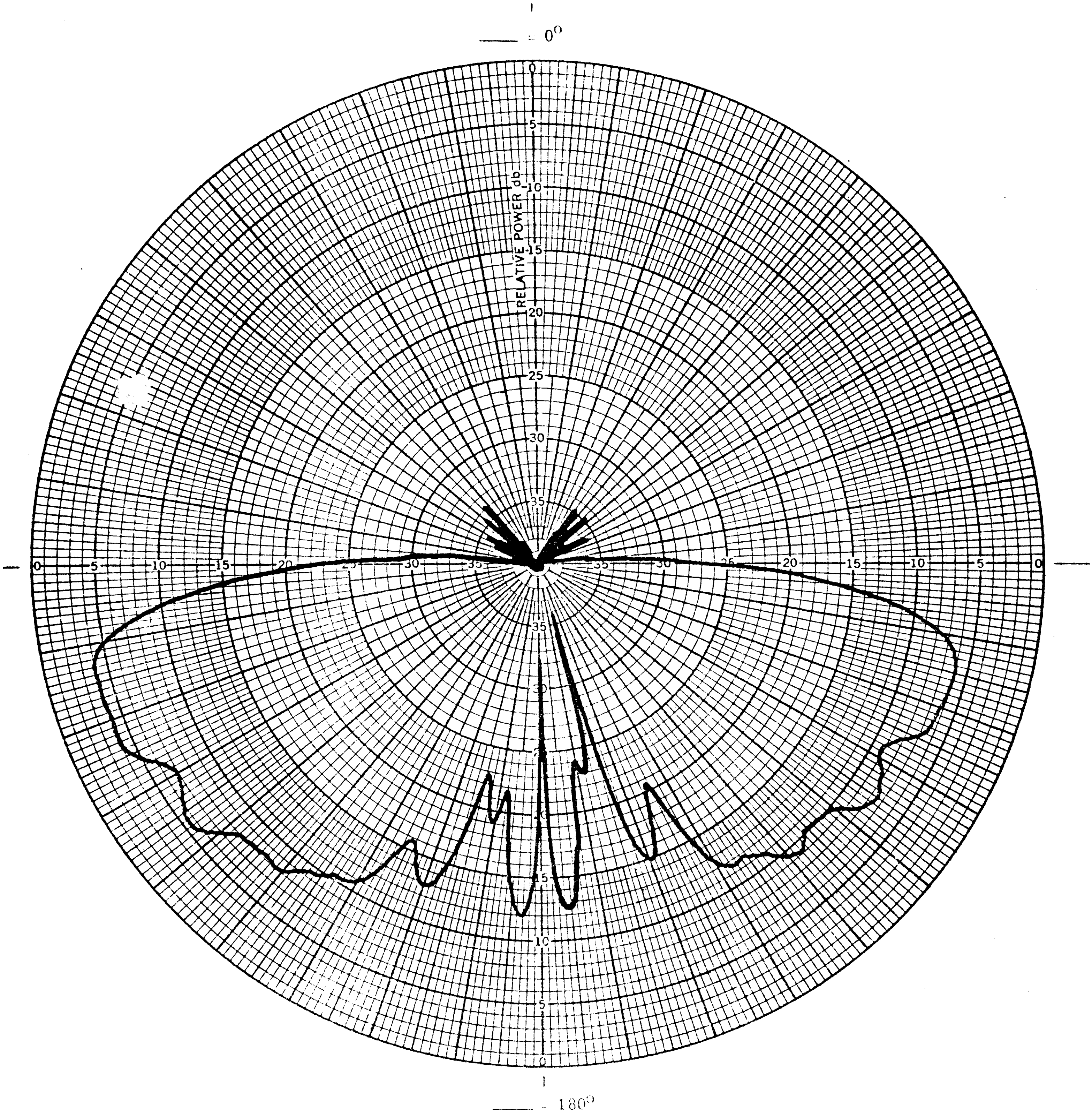


Figure 12: H-plane pattern, 15.5 GHz, horizontal polarization, $\phi = 0^{\circ}$.

V

CONCLUSIONS AND RECOMMENDATIONS

Two dual band microwave aircraft antennas to be used in the testing and evaluation of microwave landing systems have been designed, developed, fabricated, tested and delivered to the sponsor. Each antenna is operable in the C and K_u radio frequency bands. One of the dual band antennas is vertically polarized and the second is horizontally polarized. The antennas may be employed on either fixed wing or rotary wing aircraft.

Each of the antennas is a relatively narrow band device, e.g., the C band antennas operate from 5.0 - 5.28 GHz and the K_u band antennas operate from 15.4 - 15.675 GHz with VSWR's less than 2:1. The interband isolation is greater than 40dB and the volume coverage for the four antennas is essentially the same and coverage includes most of the lower hemisphere. The weight of the antennas is less than 5 pounds. The radomes covering the antennas will protrude 6 inches from the airframe and their mounting plates are 8 inches in diameter.

In the event modifications on the antennas were required, it would be advisable to re-design the radome covering to permit quick access to the antenna elements; it is now cemented in place. Further, it would be desirable to re-design the C band input to facilitate removal of the low pass filter and connector. These elements are now fixed in place with lock-tite in their threads. It may be possible to make some improvement in the elevation coverage of the horizontally polarized K_u band antenna by replacing the slotted coax with a tridipole similar to that employed with the C band antenna. This would make it possible for the center of radiation to be closer to the ground plane.

VI

ACKNOWLEDGEMENT

The author wishes to express his appreciation to Mr. Anthony Ploski of the Electronics Command for his support of this program and to Professor Ralph E. Hiatt for his many helpful suggestions with regard to design concepts. The conscientious and painstaking help of Mr. Chester Grabowski in the fabrication and testing of the antennas was an important ingredient in the successful completion of this work. My thanks also go to Mrs. M. King for the typing of the final manuscript.

APPENDIX A

TEST PLAN

The following data should be obtained from both the horizontally and vertically polarized antenna systems:

1. VSWR characteristics
2. Radiation patterns
3. Interband isolation
4. Power rating.

These tests should be conducted with the antenna under test mounted on a three-foot diameter flat ground plane.

1.0 VSWR

1.1 The VSWR of each antenna shall be measured employing the test setup shown in Figure A-1.

1.2 The VSWR is to be measured and recorded at the following frequencies:

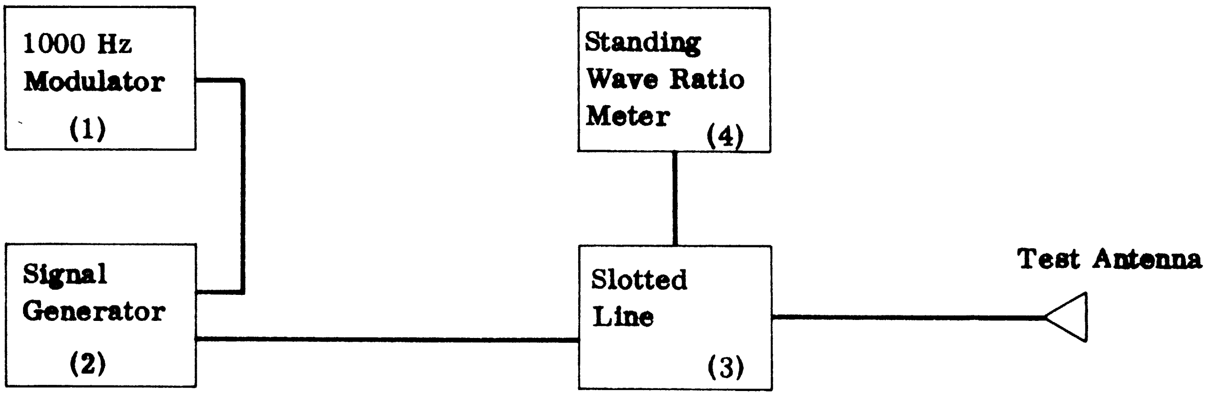
1.2.1 C-Band Antennas

4.95, 5.0, 5.05, 5.1, 5.15, 5.2, 5.25 and 5.3 GHz

1.2.2 K_u-Band Antennas

15.35, 15.4, 15.45, 15.5, 15.55, 15.6, 15.65 and 15.7 GHz

1.3 The VSWR should be less than 2:1 over the frequency bands given in paragraph 1.2.



Test Equipment

Frequency Band	1	2	3	4
C-band	Antlab Modulator	Hewlett-Packard 618B	Hewlett-Packard 806B	Hewlett-Packard 415
K_u-band	Antlab Modulator	Hewlett-Packard 628A	Hewlett-Packard 810B	Hewlett-Packard 415

Figure A-1: VSWR setup.

2.0 Radiation Patterns

2.1 Radiation patterns of each antenna should be measured employing the test setup shown in Figure A-2.

2.2 Radiation patterns are to be measured and recorded at the following frequencies:

2.2.1 C-Band Antennas

5.0, 5.15, and 5.25 GHz

2.2.2 K_u-Band Antennas

15.4, 15.5, and 15.7 GHz

2.3 The spherical coordinate system of Figure A-3 shall be used for the purposes of defining the radiation pattern geometries.

2.4 Elevation plane patterns of each dual band antenna (θ variable over 360^o) should be recorded at θ increments of 0, 45, 90, and 135 degrees at each of the appropriate frequencies of paragraph 2.2, employing the appropriate polarization of the antenna under test.

2.4.1 See paragraph 2.6.7 for pattern requirements.

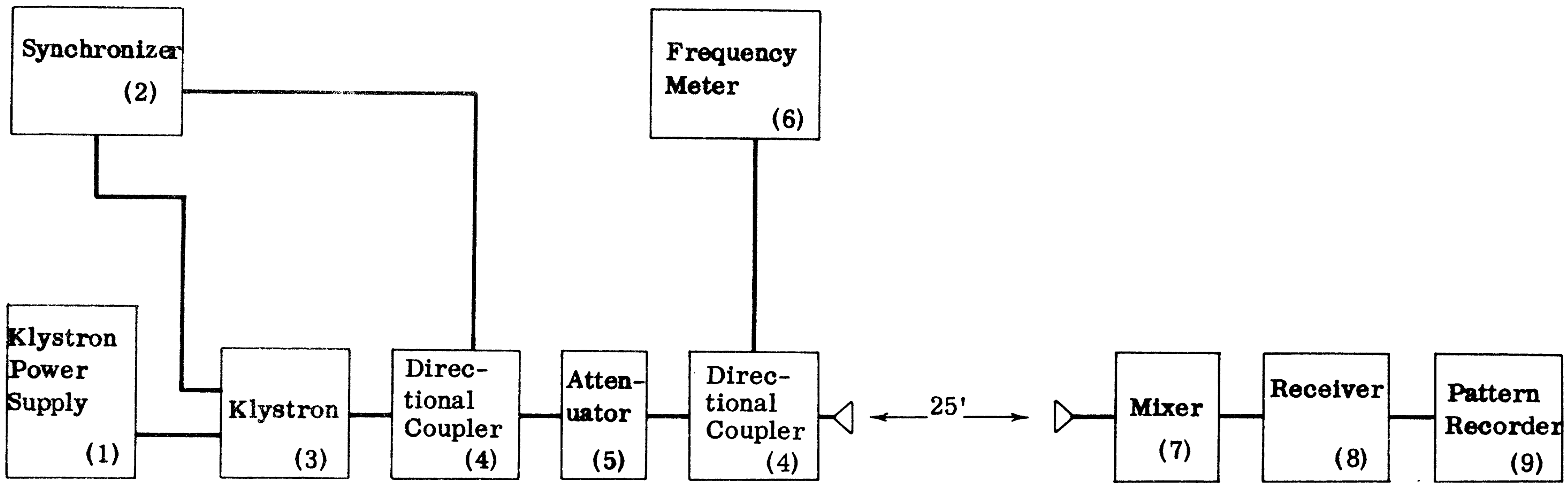
2.5 Azimuthal plane patterns (ϕ variable) shall be recorded at θ equal 0 degrees for each of the frequencies of paragraph 2.2.

2.5.1 The azimuthal pattern should be uniform within 3dB.

2.6 Antenna Gain Measurements.

For these measurements no changes are to be made in the transmitter or receiver gain controls except as noted in pargraphs 2.6.1 - 2.6.4. The test setup of Figure A-2 should be used for these tests.

2.6.1 Record the elevation pattern for one of the dual band antennas (θ variable through 360^o) at ϕ = 0 degrees.



Test Equipment

Frequency Band	1	2	3	4	5	6	7	8	9
C-band	FXR Z815B	Curry, McLaughlin and Len MOS-1	Sperry 2K43	Narda 3024	H-P+ G382A	H-P G532A	Sage Broadband	Microtel WR 200	S.A.++ 1520
K_u-band	FXR Z815B	Curry, McLaughlin and Len MOS-1	Varian X-12	H-P P752C	H-P P382A	H-P P532A	Microtel WM 200-6	Microtel WR 200	S.A. 1520

Figure A-2: Antenna pattern setup.

+ Hewlett-Packard
++ Scientific-Atlanta

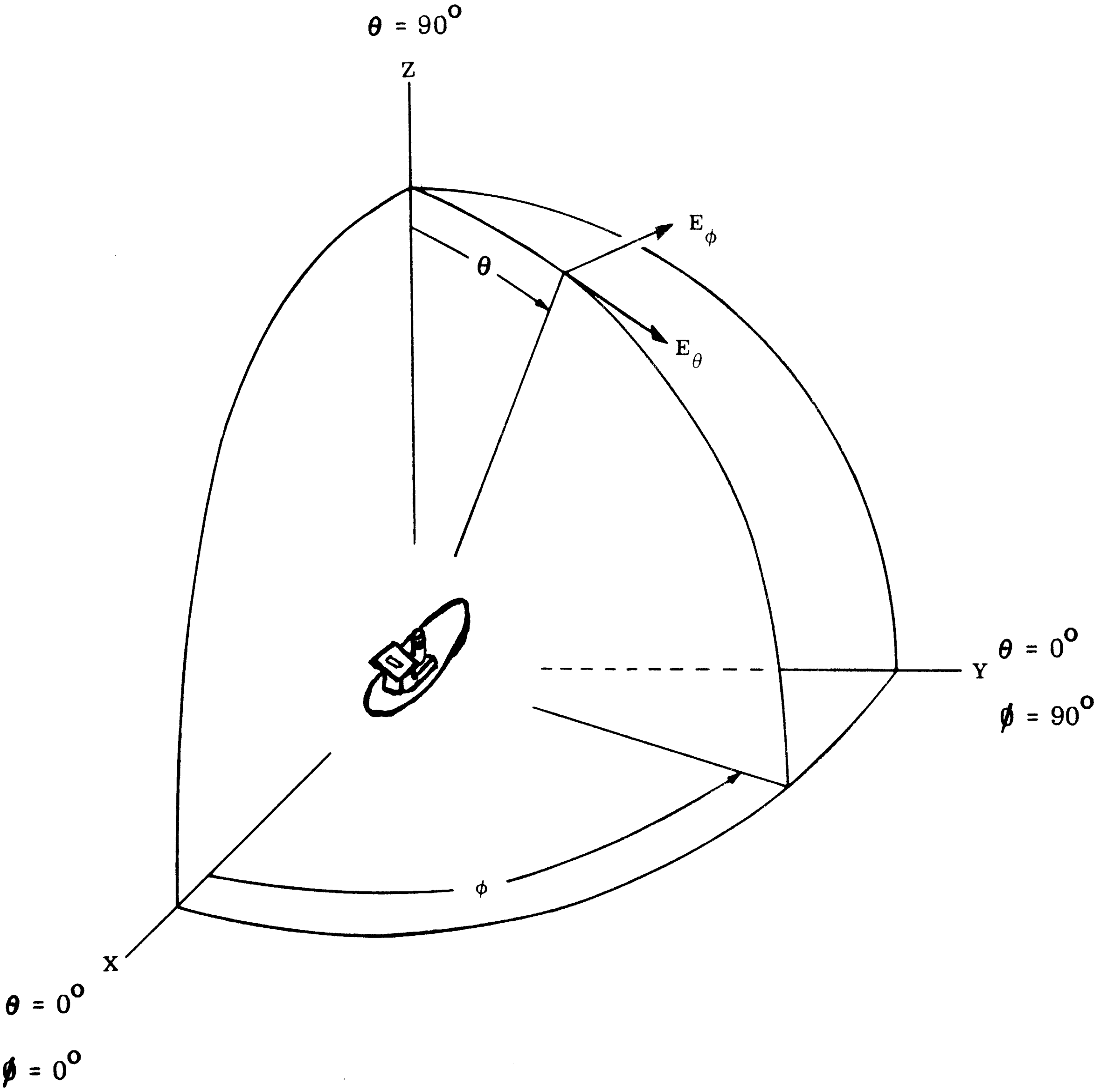


Figure A-3: Spherical coordinate system.

2.6.2 Replace the dual band antenna with a gain standard horn (NRL design, see NRL report 4144) of the appropriate frequency and polarization.

2.6.3 Set the attenuation of Figure A-2 to 18.8dB[+] for C-band tests and 24.5dB[+] for K_u-band tests.

2.6.4 Record the main beam of the pattern of the gain standard horn on the chart of 2.6.1.

2.6.5 The gain of the dual band antenna with respect to an isotropic source is the difference noted between the patterns of 2.6.1 and the pattern maximum of 2.6.4. The pattern maximum of 2.6.4 represents 0dB with respect to an isotropic source.

2.6.6 Repeat 2.6.1 - 2.6.5 for each antenna at each of the frequencies noted in 2.2.

2.6.7 The above should show that the elevation patterns have a gain of 0dB with respect to isotropic within the region of $-60^{\circ} \leq \theta \leq 0^{\circ}$.

3.0 Interband Isolation

For these tests the setup of Figure A-2 shall be used.

3.1 Set the attenuator of Figure A-2 to -20dB. Record the elevation pattern (θ variable through 360°) at ϕ = 0 degrees (using the K_u band transmitter, K_u band dual band antenna and receiver setup) for both dual band antennas.

3.2 Set the attenuation of Figure A-2 to 0dB. Record on the chart of 3.1 the elevation pattern (θ variable through 360°) at ϕ = 0 degrees using the K_u band transmitter, the C-band dual band antenna and K_u band receiver setup for each dual band antenna.

[+] Values to be adjusted if other type gain standards are used.

3.3 Repeat 3.1 using the C band transmitter, C band dual band antenna and receiver setup.

3.4 Repeat 3.2 using the C band transmitter, K_u band dual band antenna and C band receiving equipment.

3.5 The interband isolation should be 40dB and is equal to the difference between the data of 3.1 and 3.2 plus 20dB, i.e., data of 3.1 - data of 3.2 + 20 = interband isolation.

3.6 Repeat the 3.1 - 3.5 for each of the frequencies of paragraph 2.2.

4.0 Power Rating+

The power rating test shall be made using the test setup of Figure A-1 with the signal generators replaced with the appropriate power oscillator.

4.1 Connect the appropriate dual band antenna to the setup of Figure A-1.

4.2 Adjust the CW power output of the power oscillator to 25 watts.

4.3 Observe and record the VSWR.

4.4 The VSWR shall be less than 2:1 and remain steady for a period of five minutes.

4.5 Repeat paragraphs 4.1 - 4.4 for each of the frequencies of paragraph 2.2.

+ Test to be performed by the Sponsor.

APPENDIX B

PATTERN DATA

Typical gain measurements for the dual band vertically and horizontally polarized antennas are shown in Figures B-1 through B-4. Figures B-5 through B-8 are typical interband isolation measurements for the dual band antennas. Elevation pattern data recorded at ϕ increments of 0^o, 45^o, 90^o and 135^o for the dual band vertically polarized C band antennas are shown in Figures B-9 through B-20 and the K_u band antennas in Figures B-21 through B-32. Similar elevation data for the dual band horizontally polarized C band antenna are shown in Figures B-33 through B-44 and the K_u band antennas in Figures B-45 through B-56.

Information on the azimuth radiation characteristics of the antennas is given in the next twelve patterns. These patterns have been drawn by hand and each is based on eight values obtained from the several elevation patterns. The patterns are for the zero degree elevation plane and the eight points plotted represent the relative field intensity at 0^o, 180^o, $\pm 45^o$, $\pm 90^o$ and $\pm 135^o$. From azimuth data obtained on the preliminary antennas, it was concluded that the patterns were essentially omnidirectional. Figures B-57 through B-59 are for the C band vertically polarized antenna and Figures B-60 through B-62 are for the horizontally polarized C band antenna. Patterns for the vertically and horizontally polarized D_u band antennas are given in Figures B-63 through B-65 and B-66 through B-68 respectively.

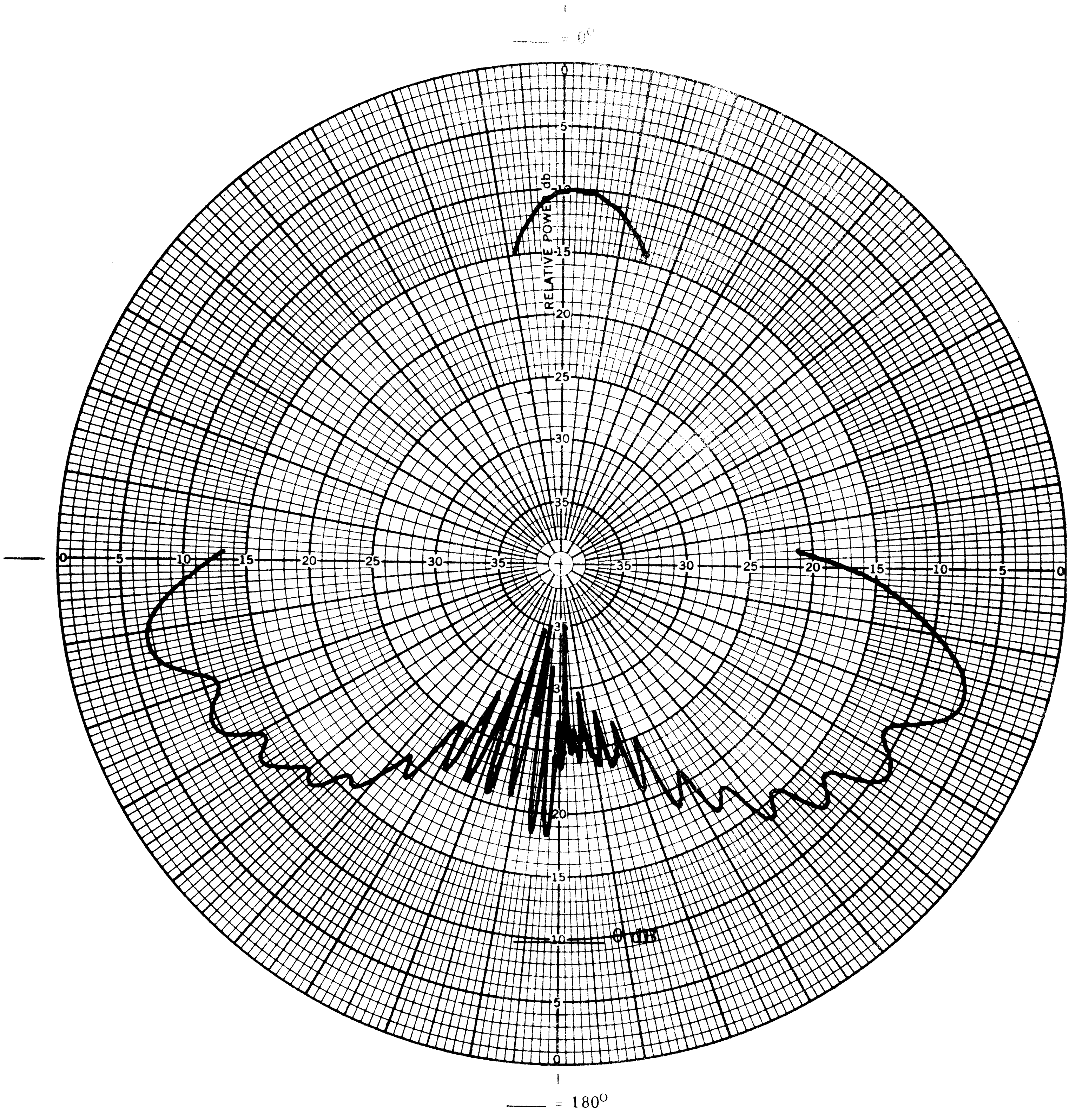


Figure B-1: Gain measurement, E-plane pattern, 5.15 GHz, vertical polarization.

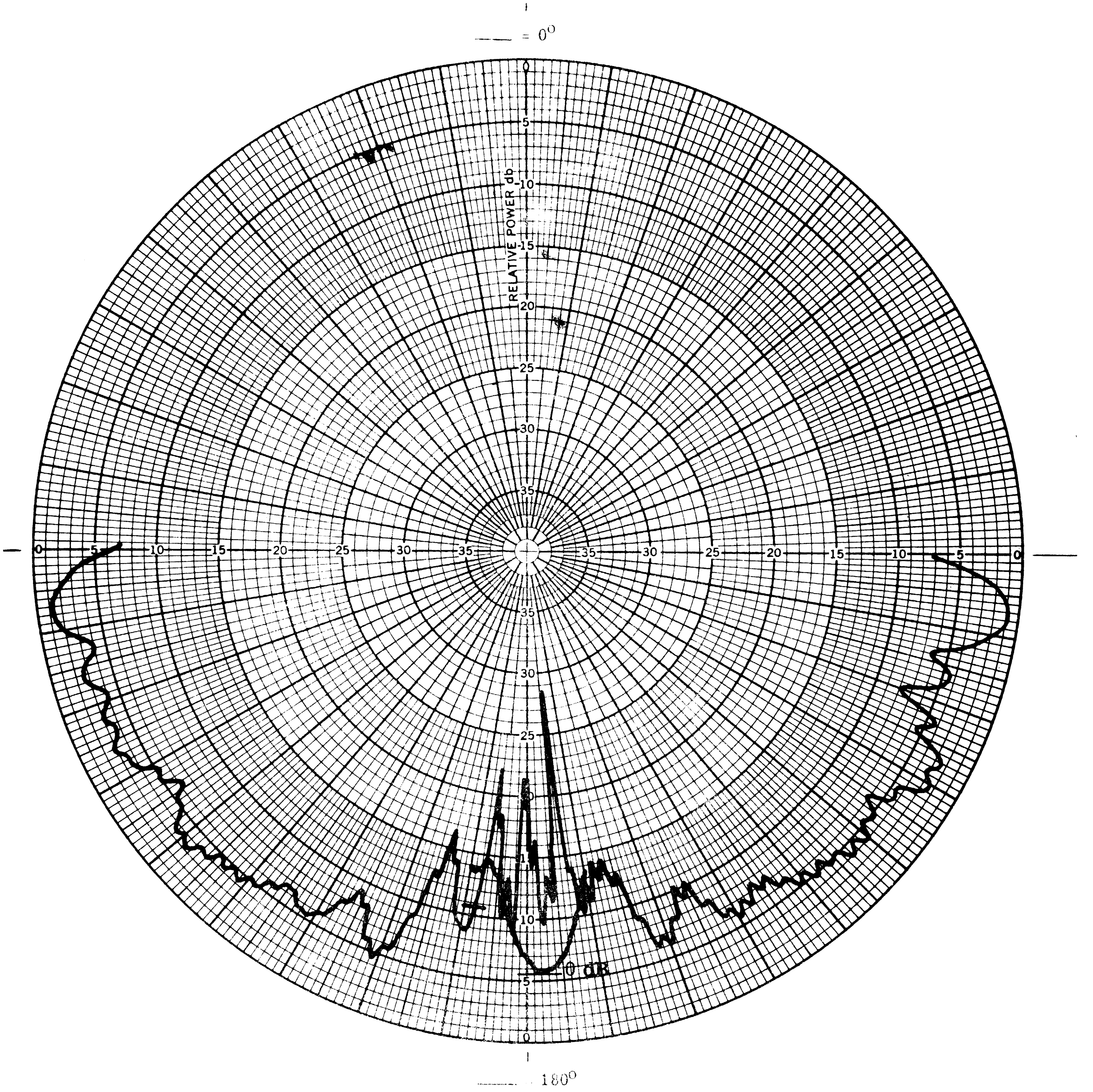


Figure B-2: Gain measurement, E-plane pattern, 15.5 GHz, vertical polarization.

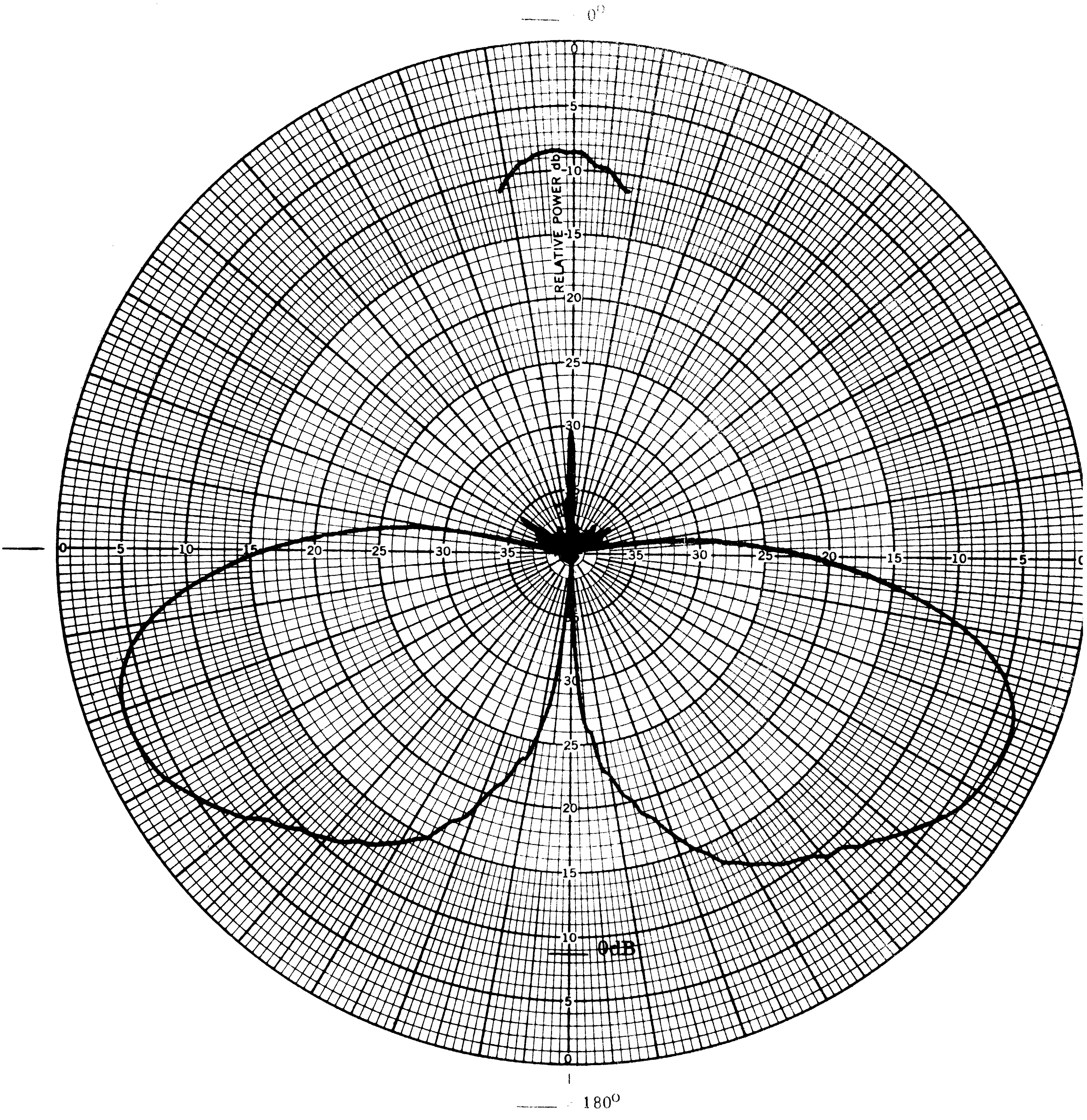


Figure B-3: Gain measurement, H-plane pattern, 5.15 GHz, horizontal polarization.

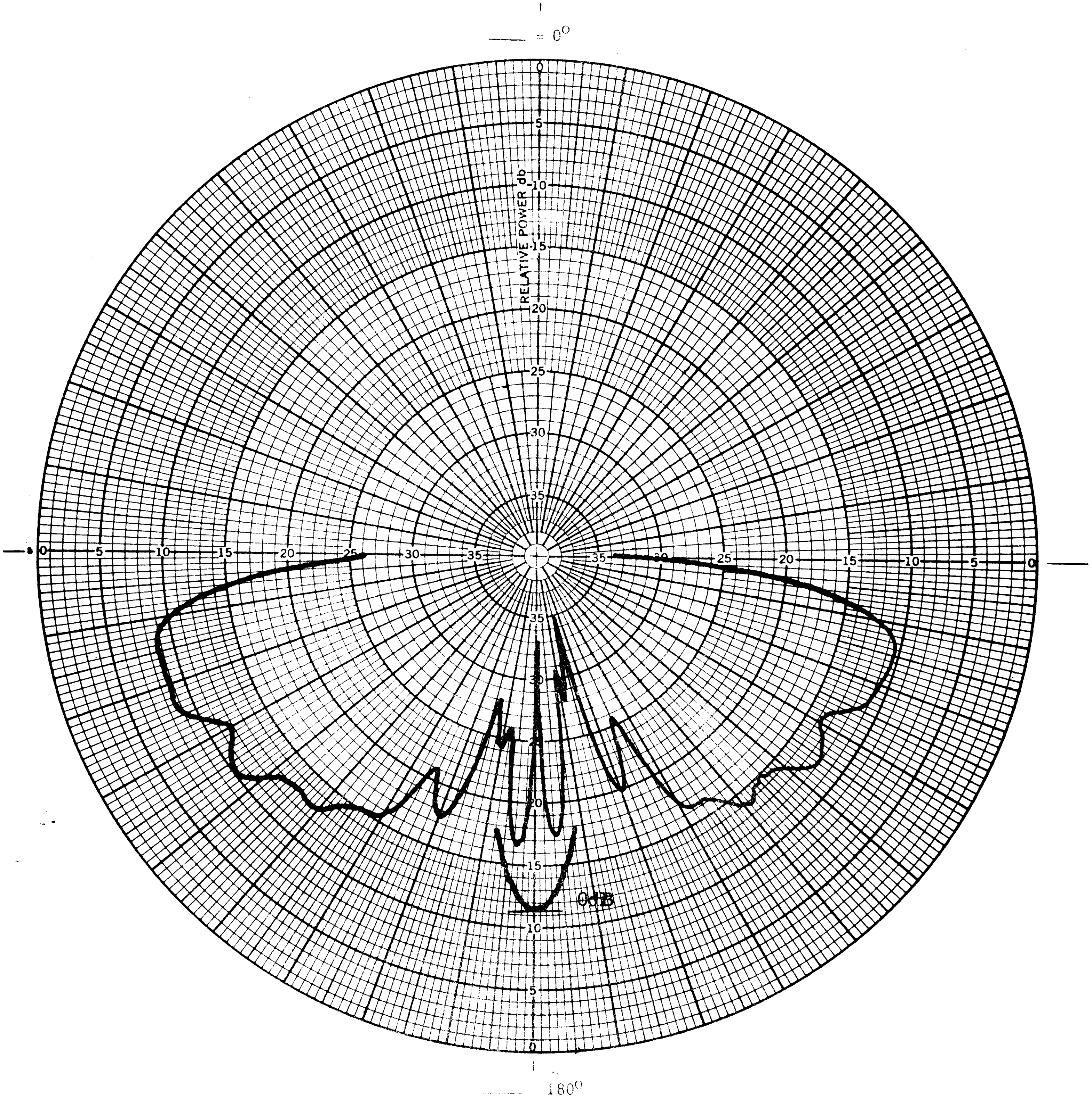


Figure B-4: Gain measurement, H-plane pattern, 15.5 GHz, horizontal polarization.

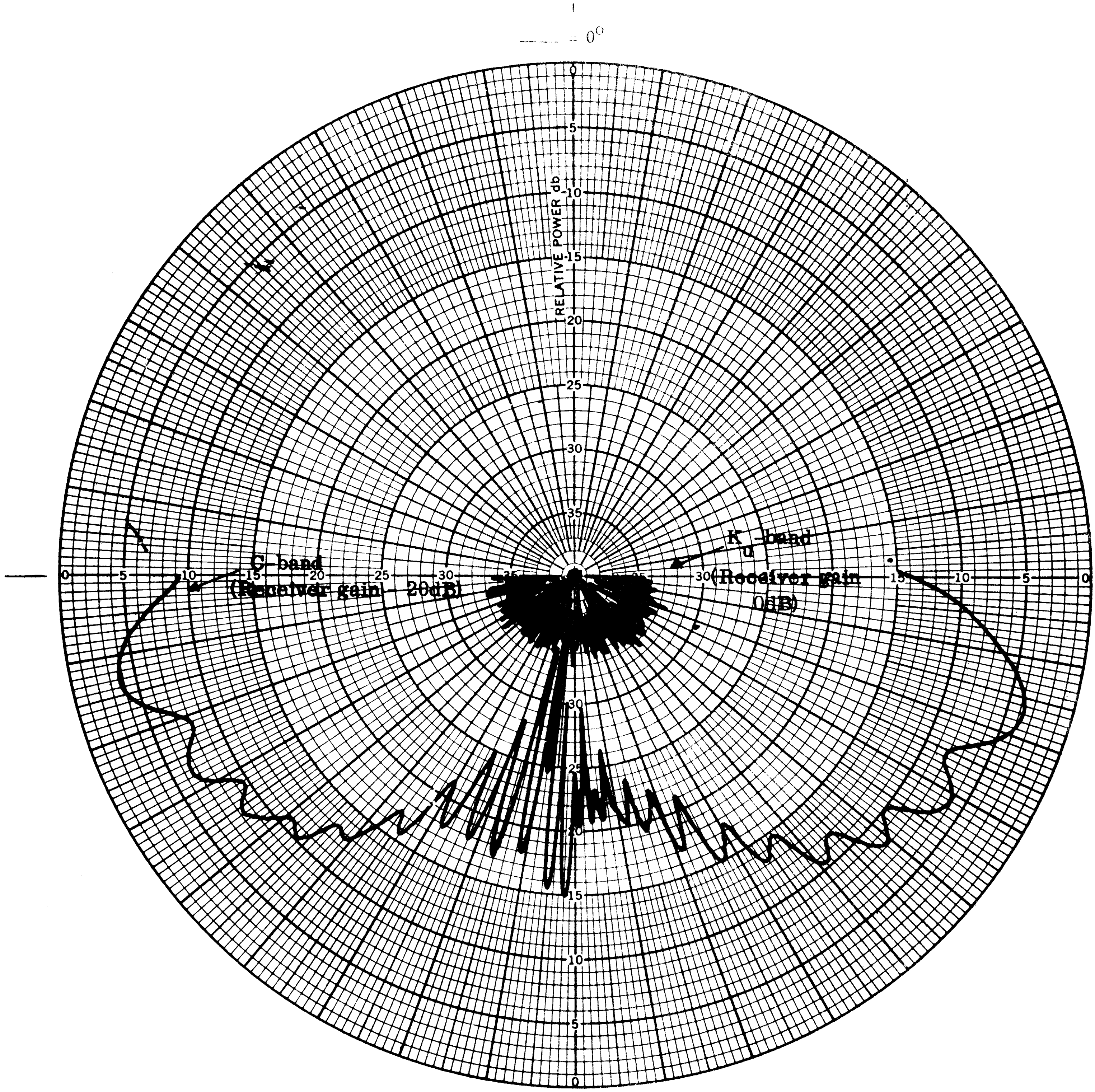


Figure B-5: Interband isolation measurement, 5.15 GHz transmitted; vertical polarization.

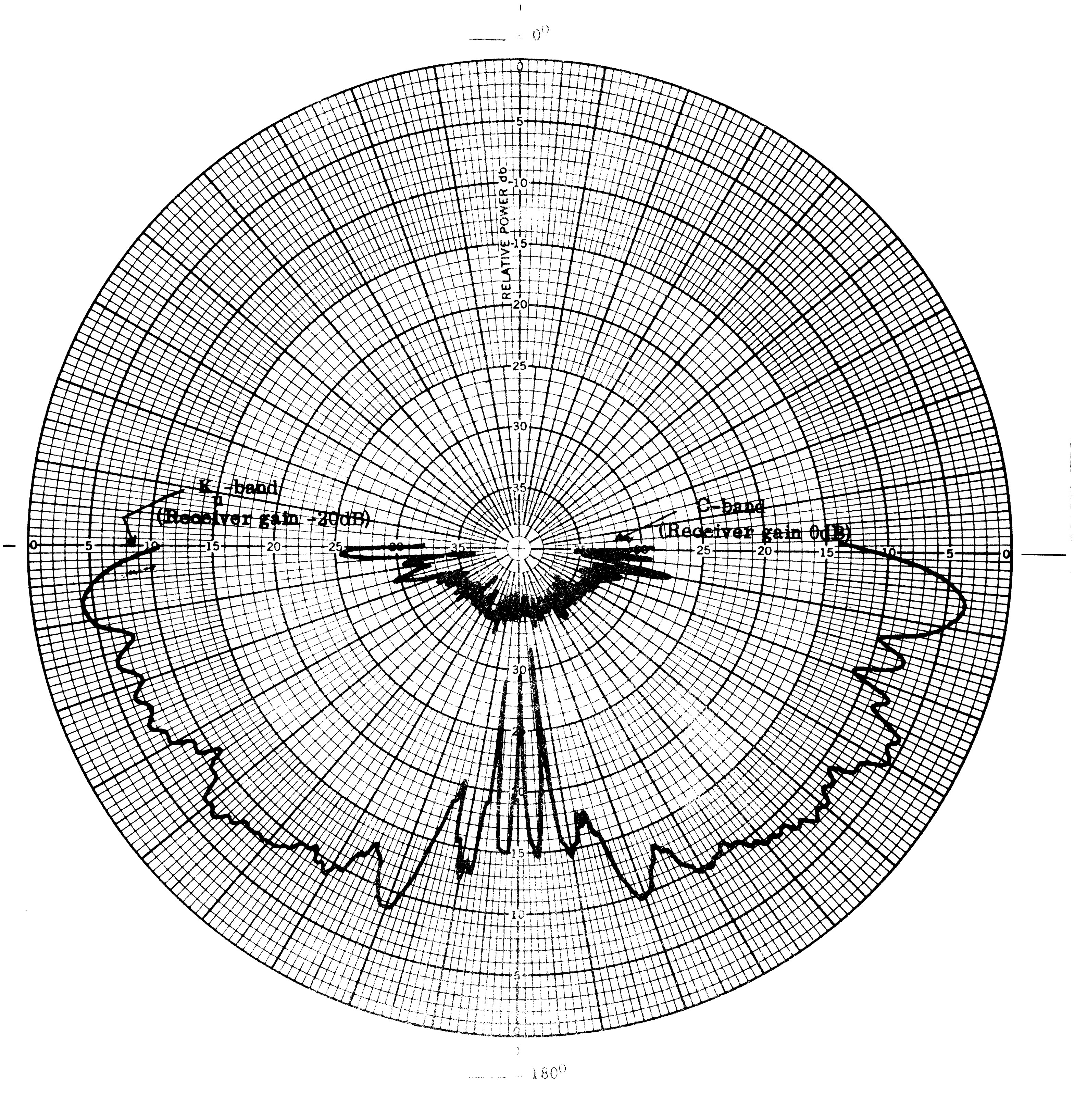


Figure B-6: Interband isolation measurement, 15.5 GHz transmitted; vertical polarization.

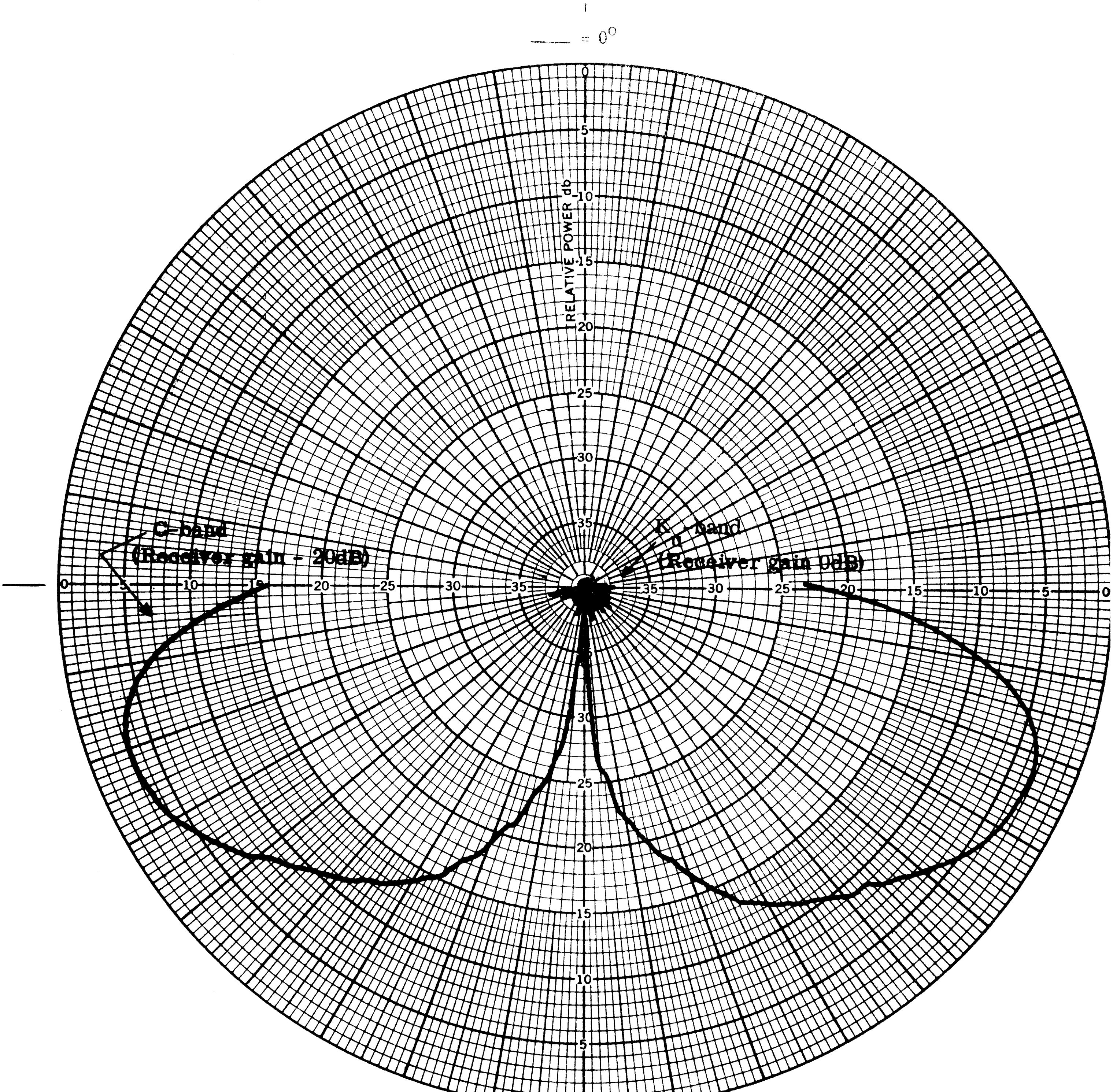


Figure B-7: Interband isolation measurement, 5.15 GHz transmitted; horizontal polarization.

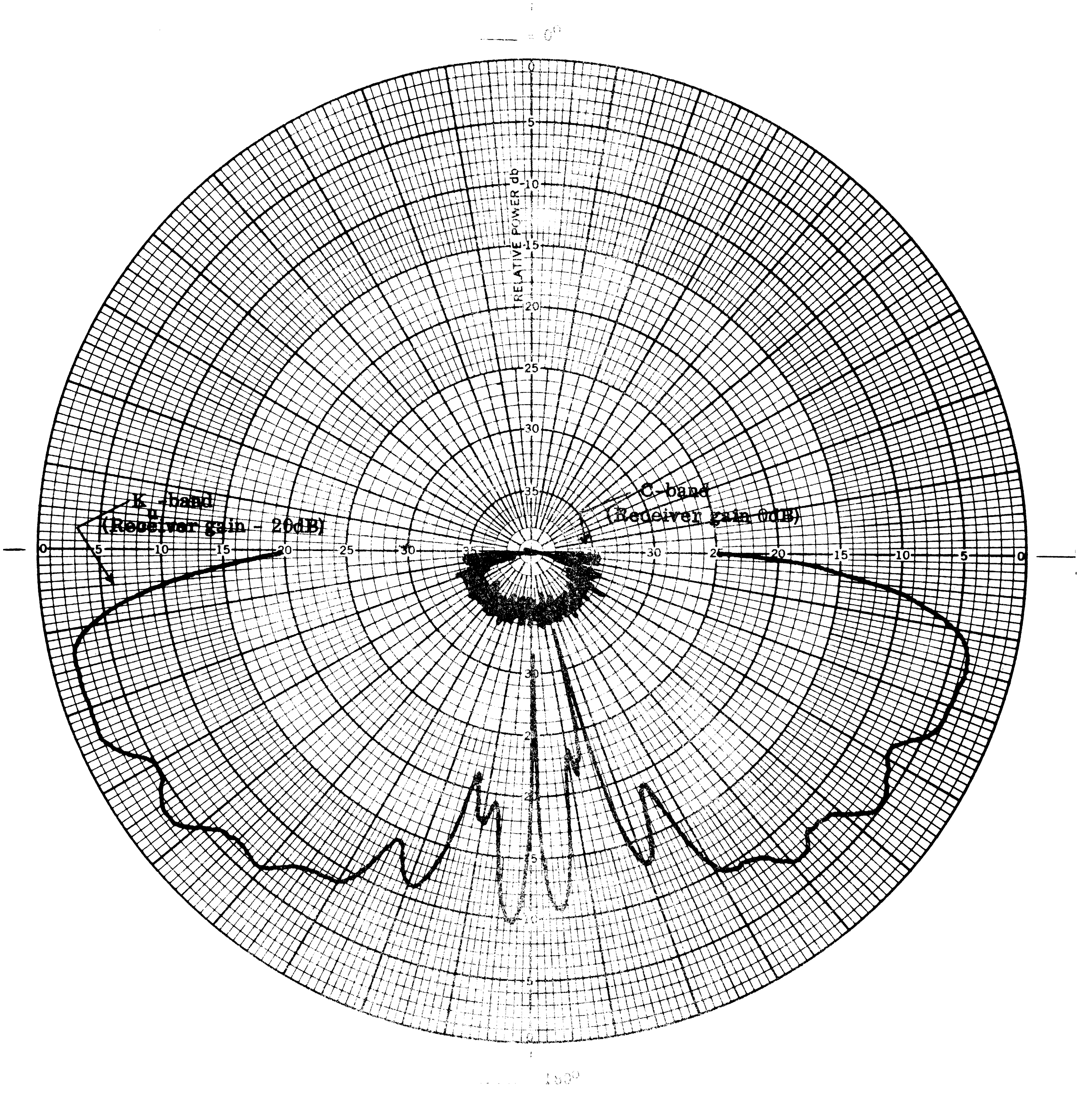


Figure B-8: **Interband isolation measurement, 15·5 GHz transmitted; horizontal polarization.**

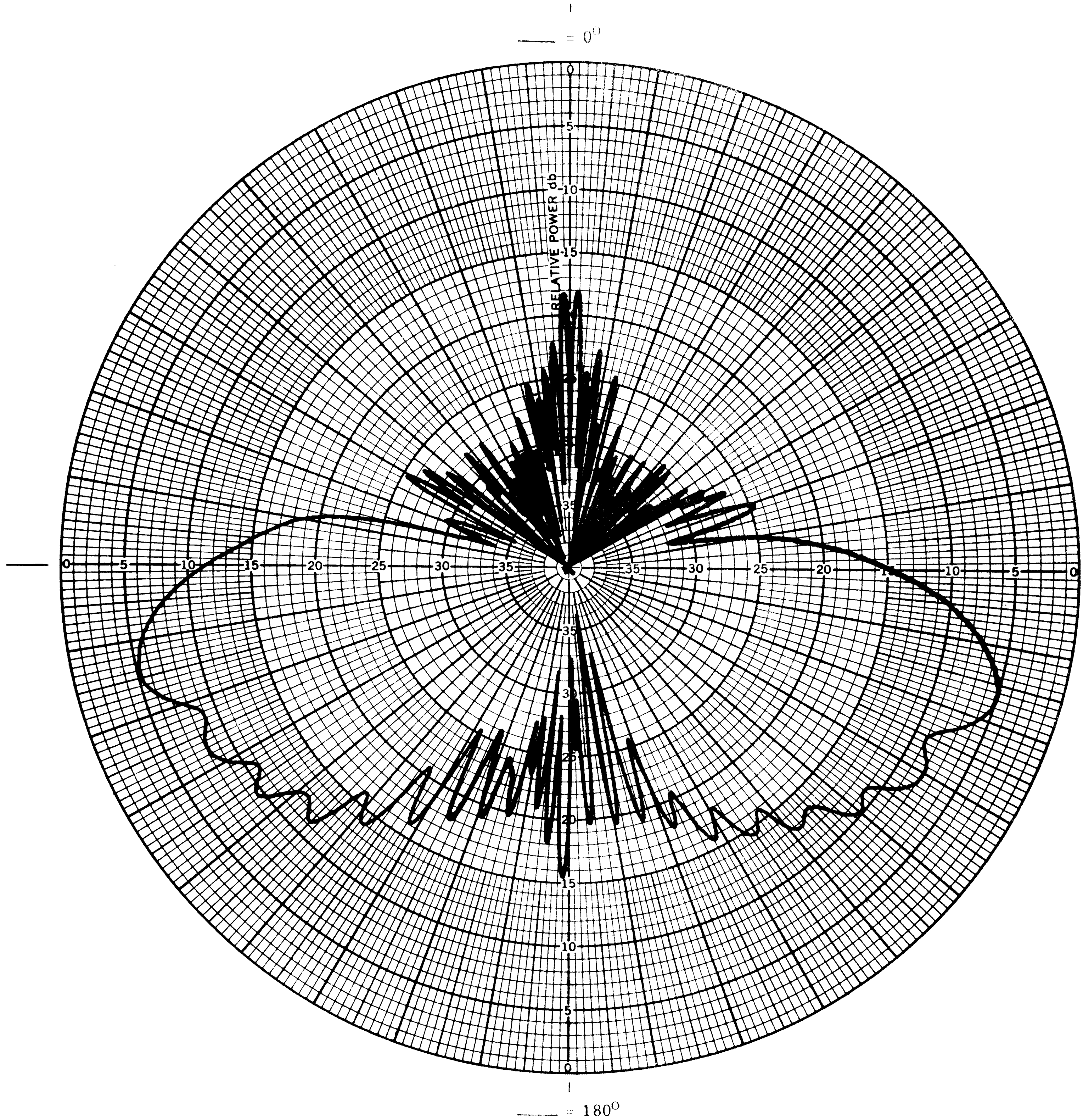


Figure B-9: E-plane pattern, 5.0 GHz, vertical polarization, $\phi = 0^{\circ}$.

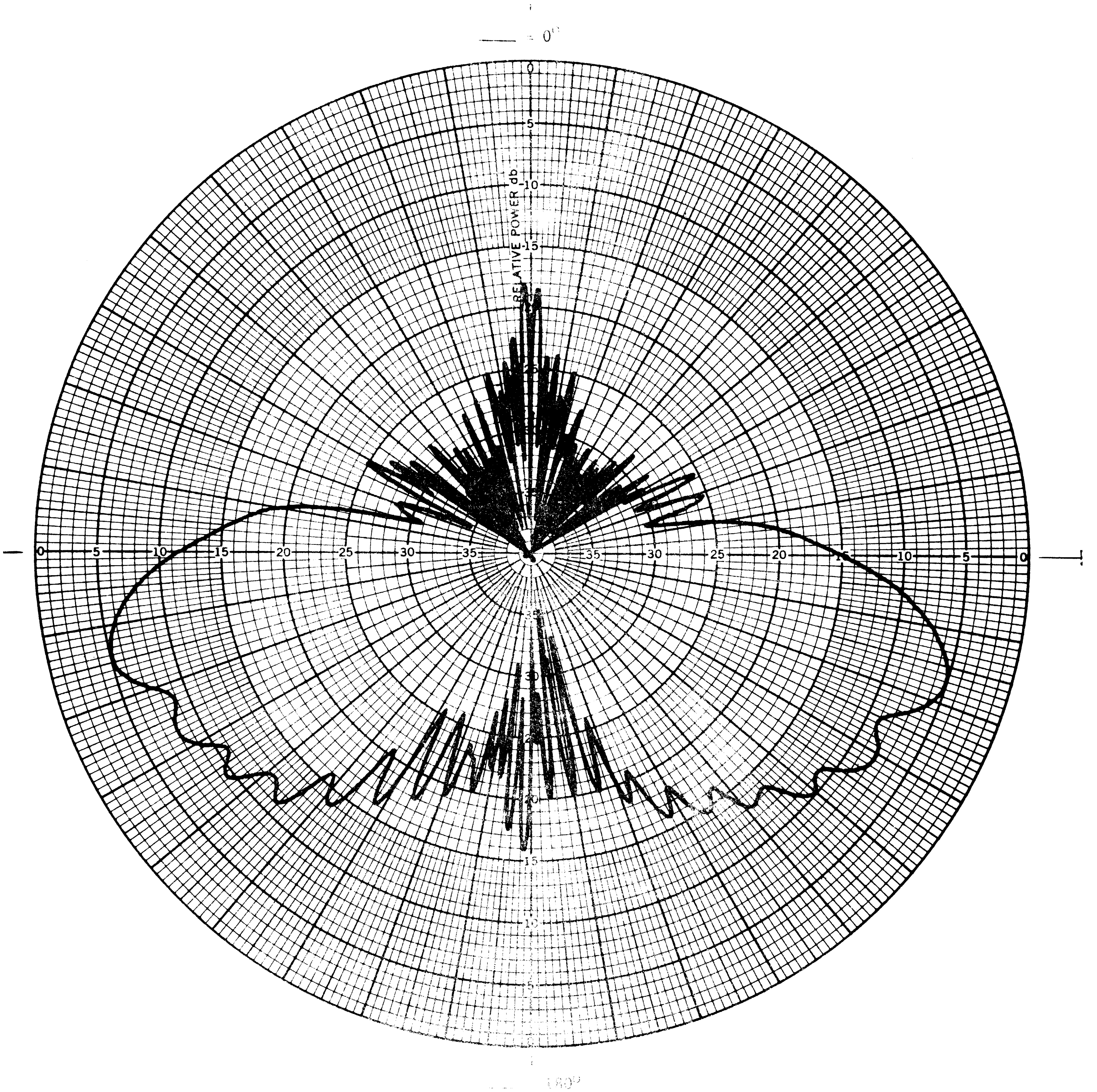


Figure B-10: E-plane pattern, 5.0 GHz, vertical polarization, $\phi = 45^{0}$.

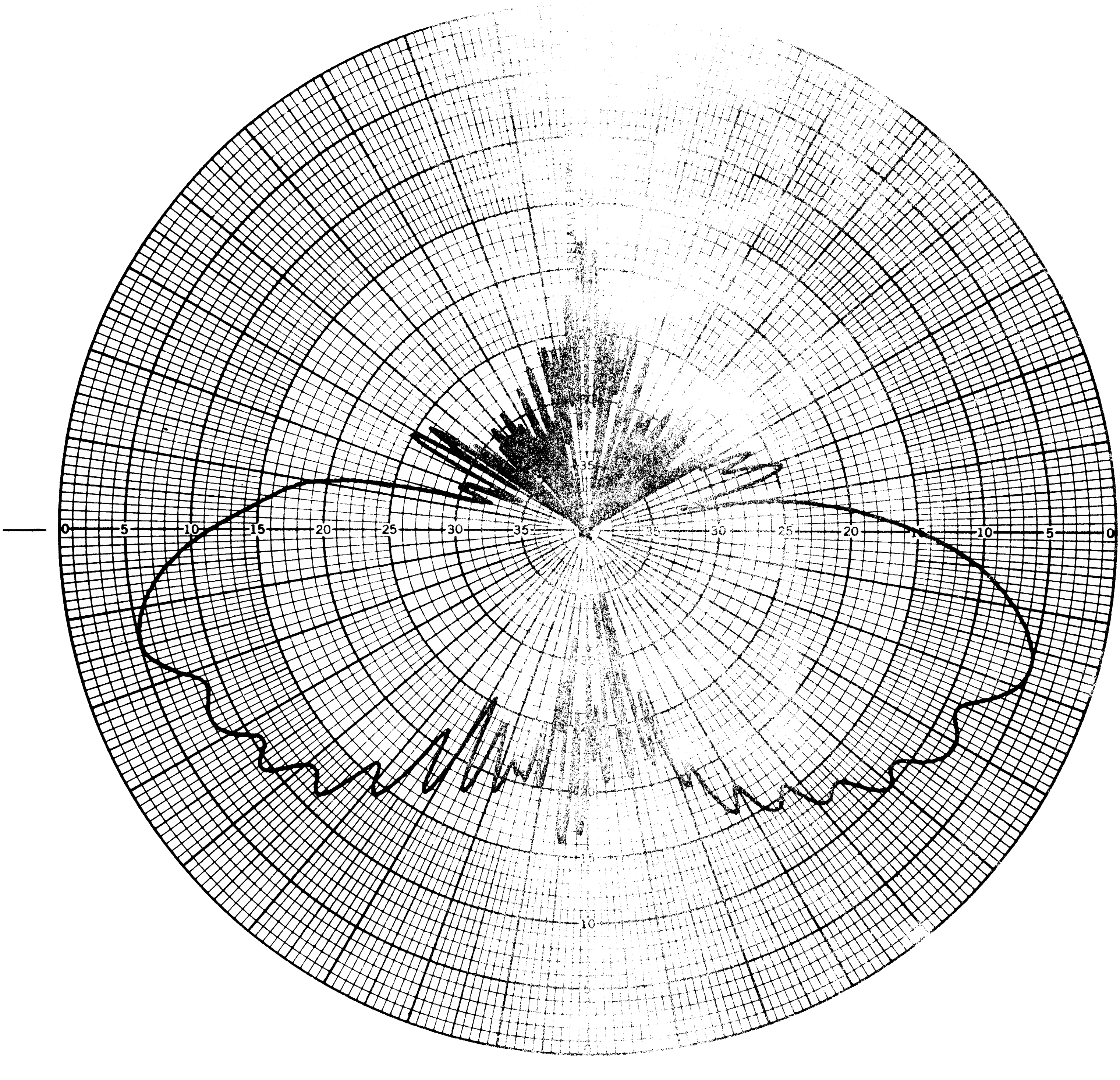


Figure B-11: E-plane [illegible] GHz,
vertical [illegible]

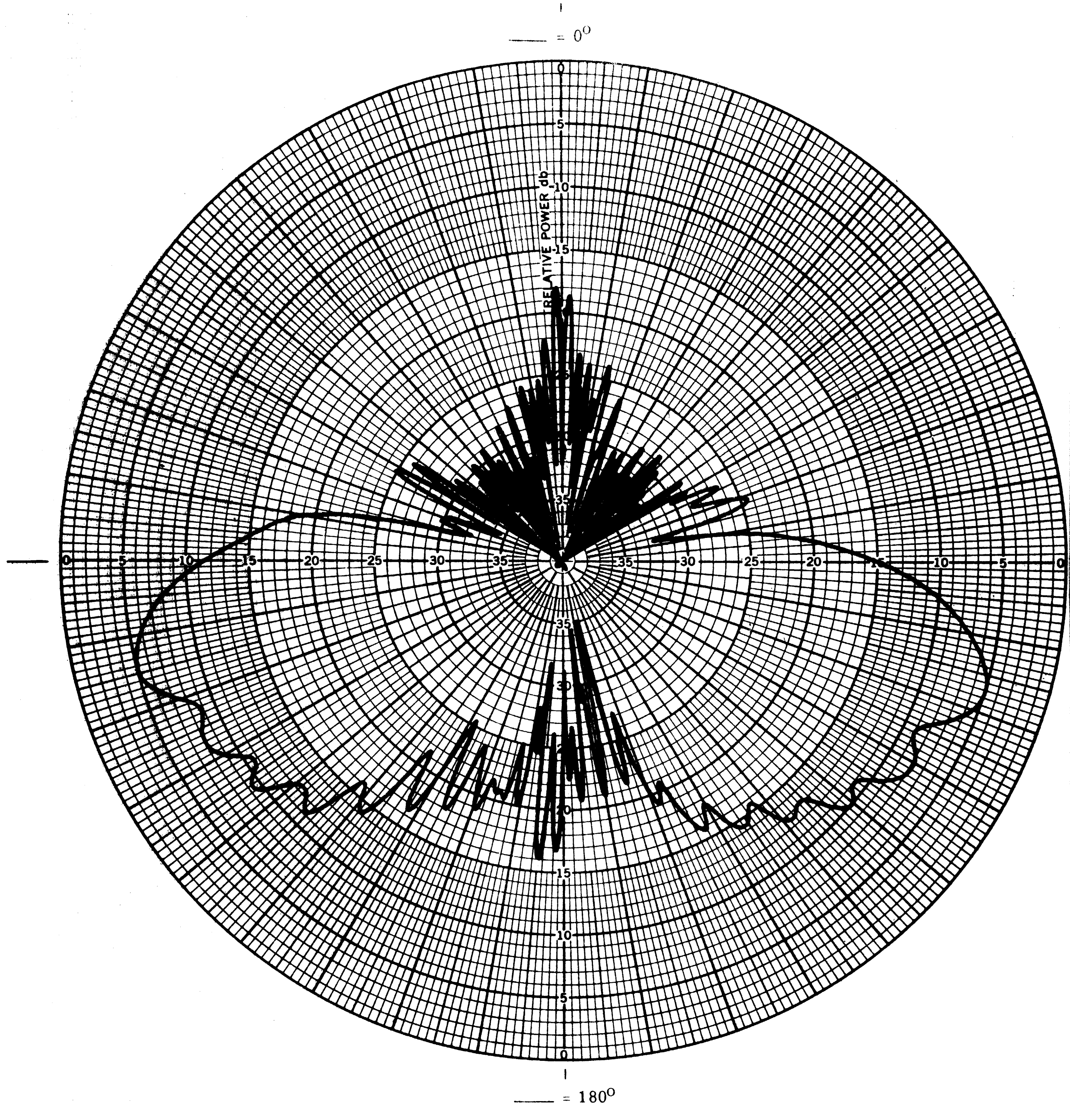


Figure B-11: E-plane pattern, 5.0 GHz, vertical polarization, $\phi = 90^{o}$.

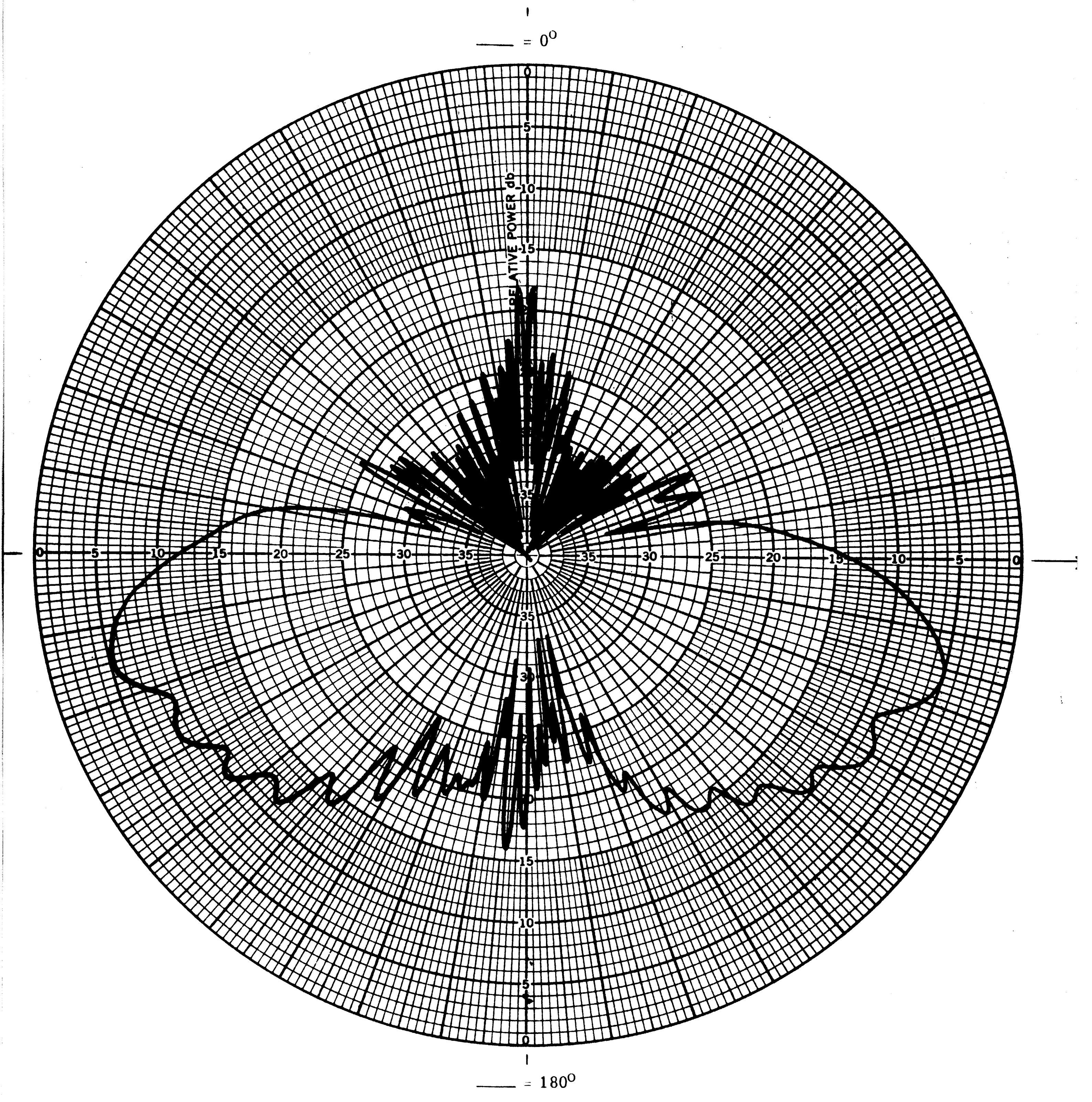


Figure B-12: E-plane pattern, 5.0 GHz, vertical polarization, ϕ = 135°.

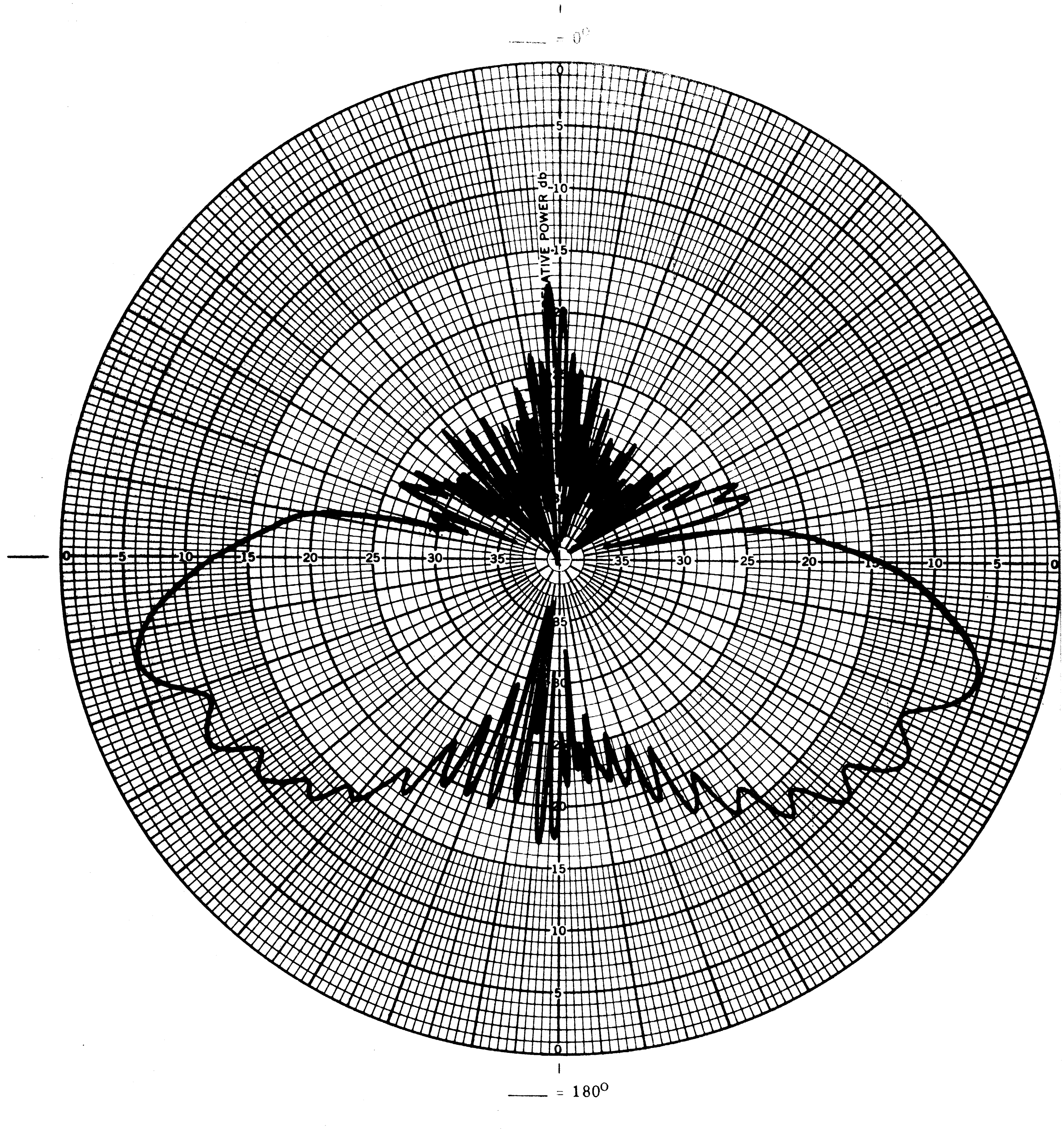


Figure B-13: E-plane pattern, 5.15 GHz, vertical polarization, $\phi = 0^{\circ}$.

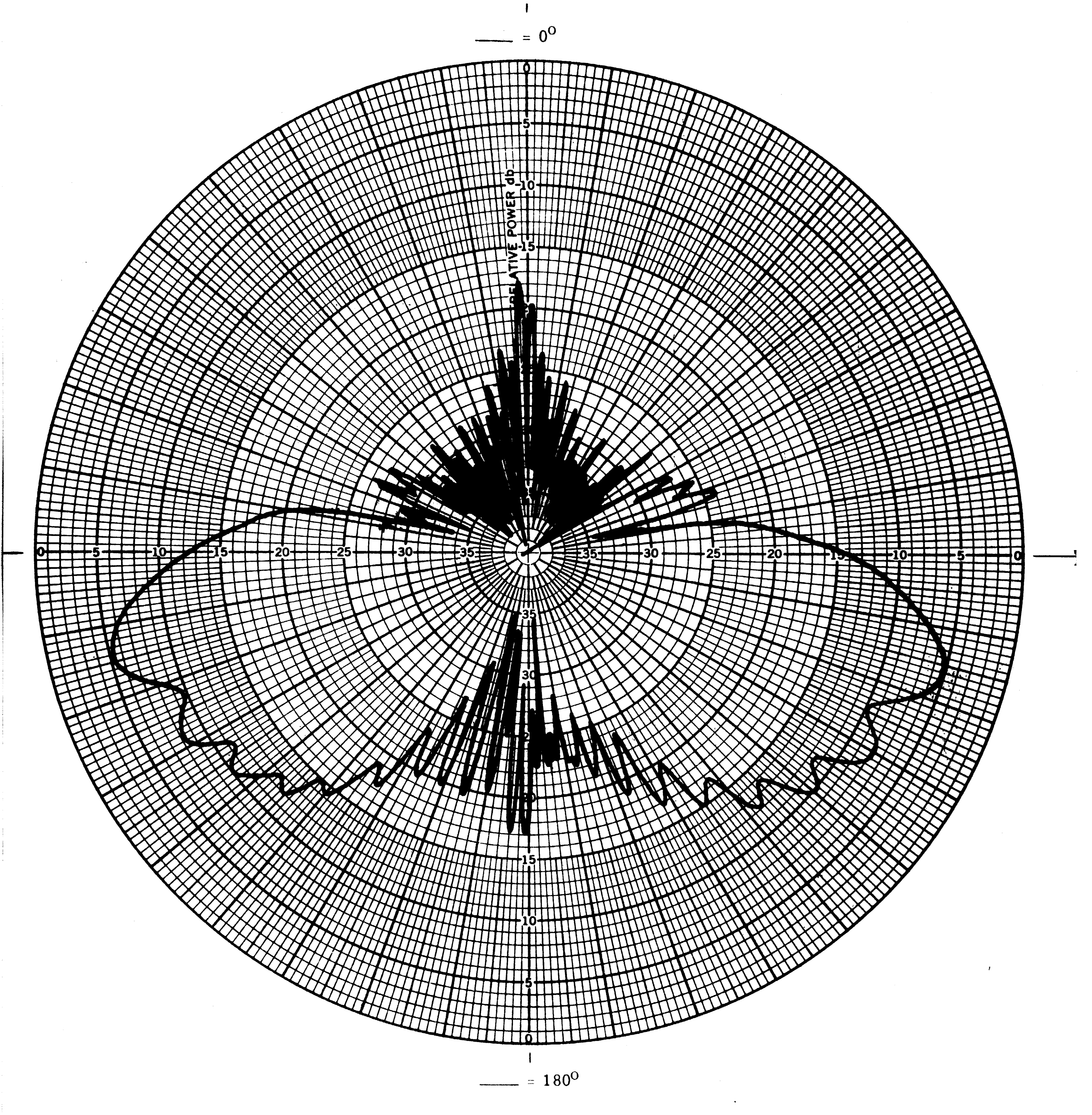


Figure B-14: E-plane pattern, 5.15 GHz, vertical polarization, ϕ = 45°.

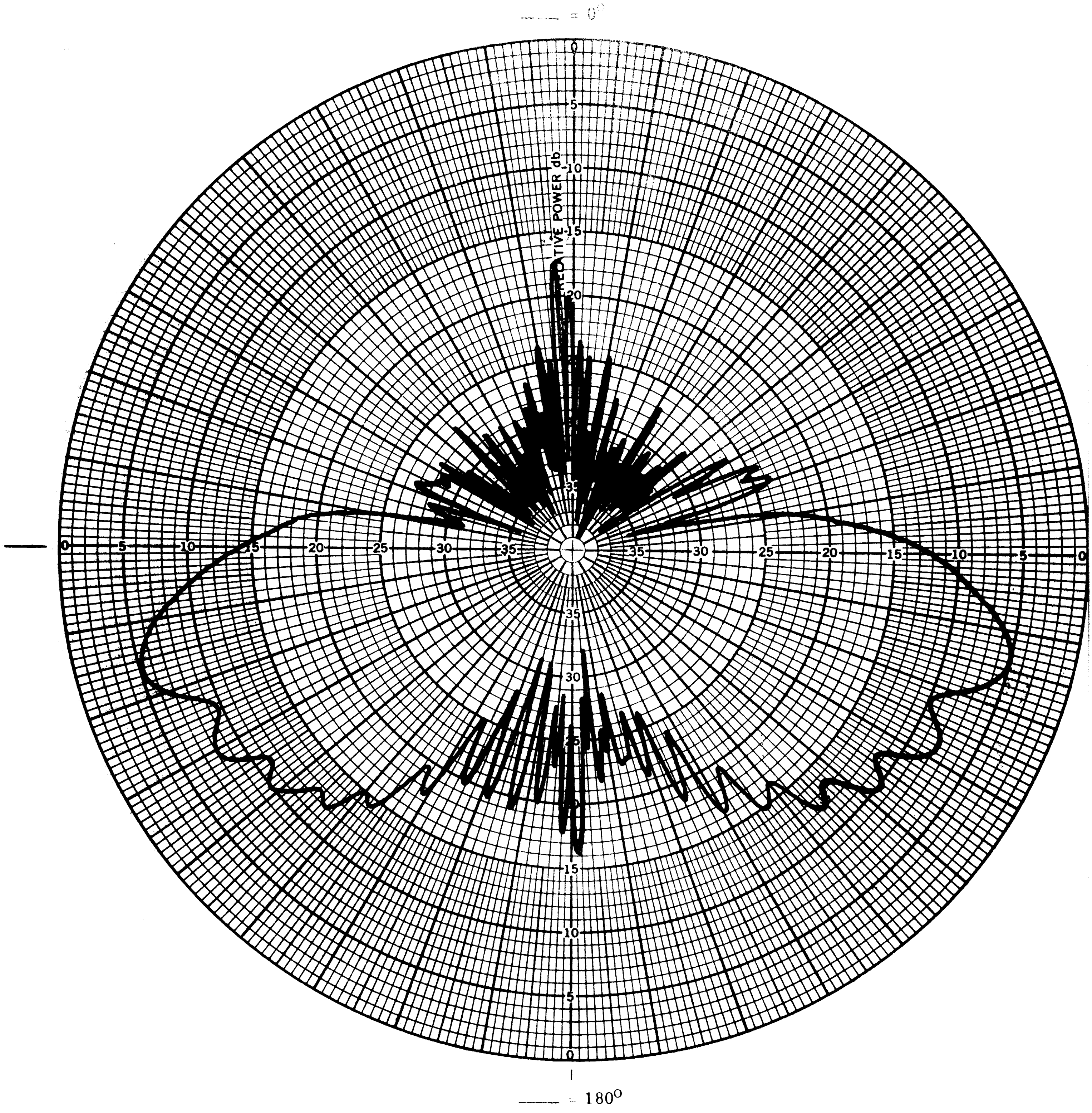


Figure B-15: E-plane pattern, 5.15 GHz, vertical polarization, $\phi = 90^{o}$.

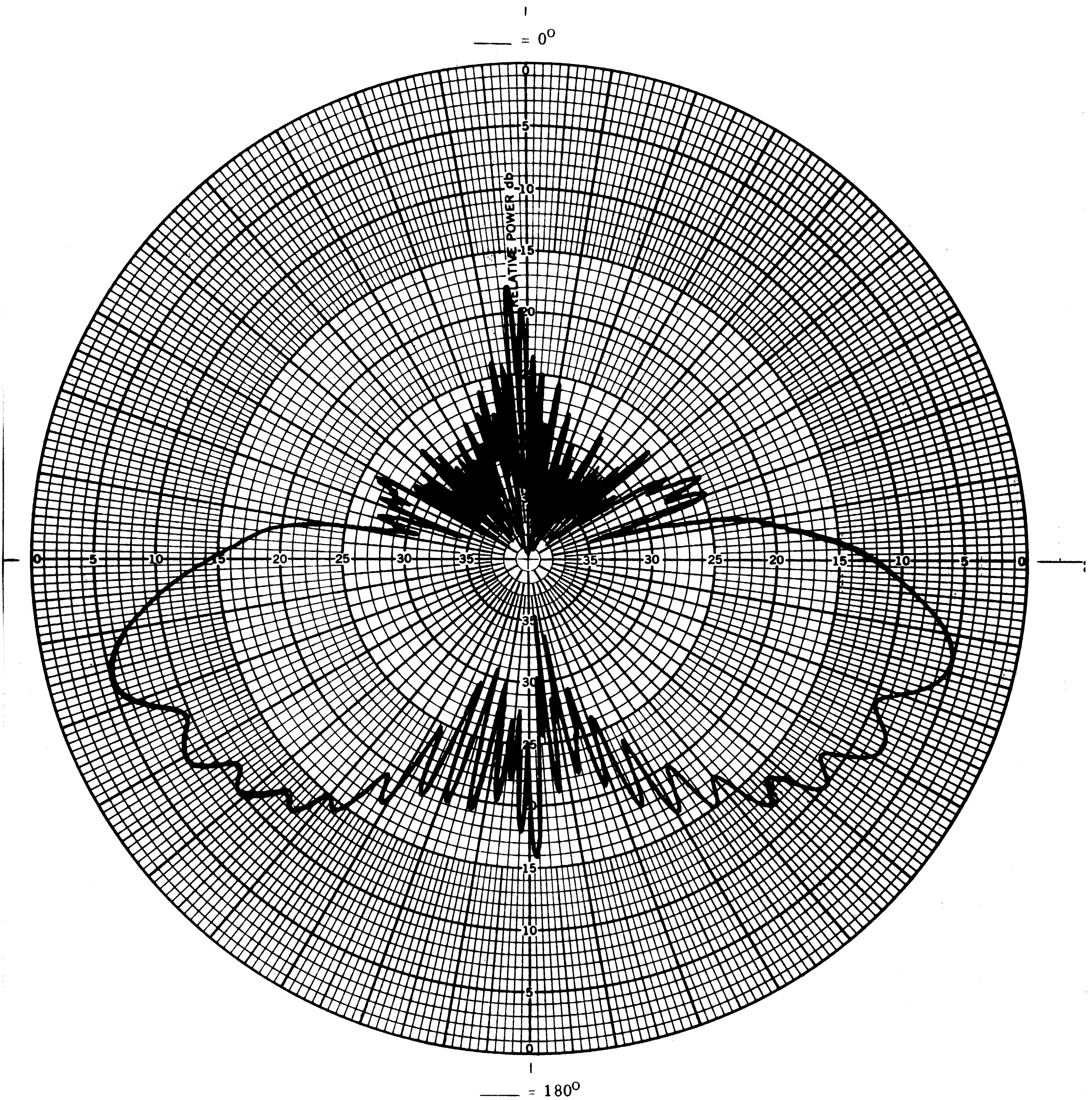


Figure B-16: E-plane pattern, 5.15 GHz, vertical polarization, $\phi = 135^{\circ}$.

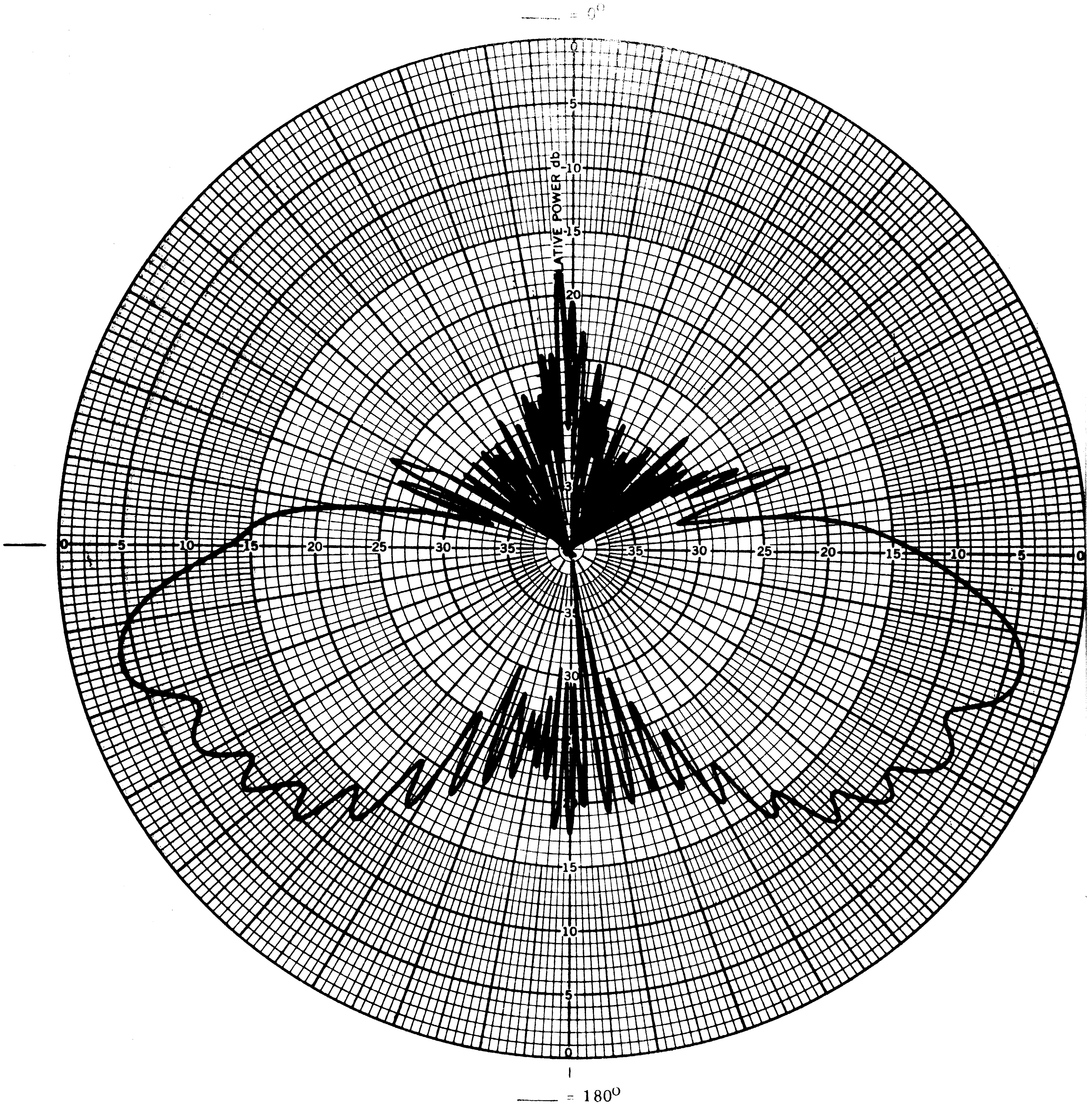


Figure B-17: E-plane pattern, 5.25 GHz, vertical polarization, $\phi = 0^{\circ}$.

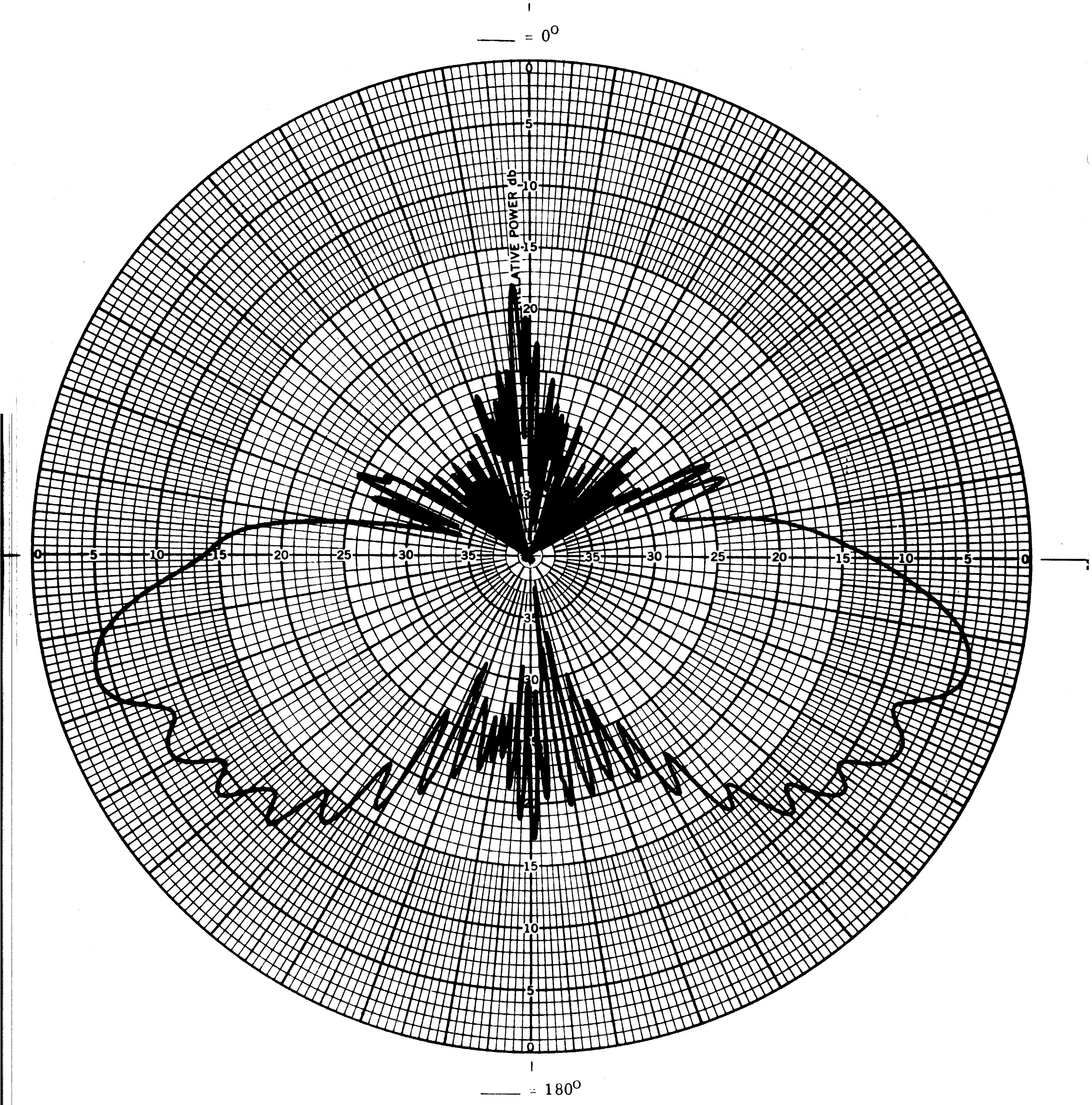


Figure B-18: E-plane pattern, 5.25 GHz, vertical polarization, ϕ = 45°.

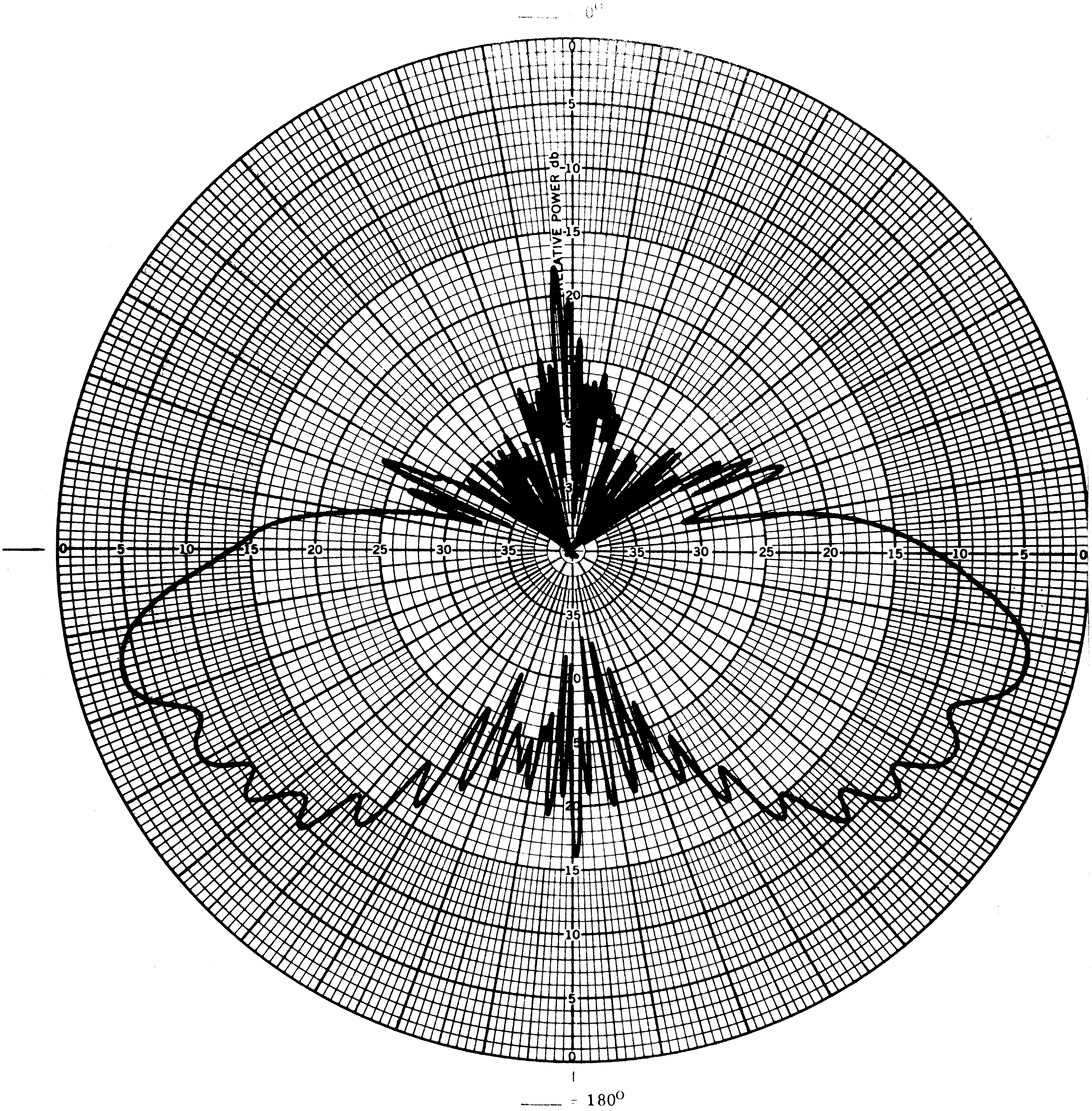


Figure B-19: E-plane pattern, 5.25 GHz, vertical polarization, $\phi = 90^{\circ}$.

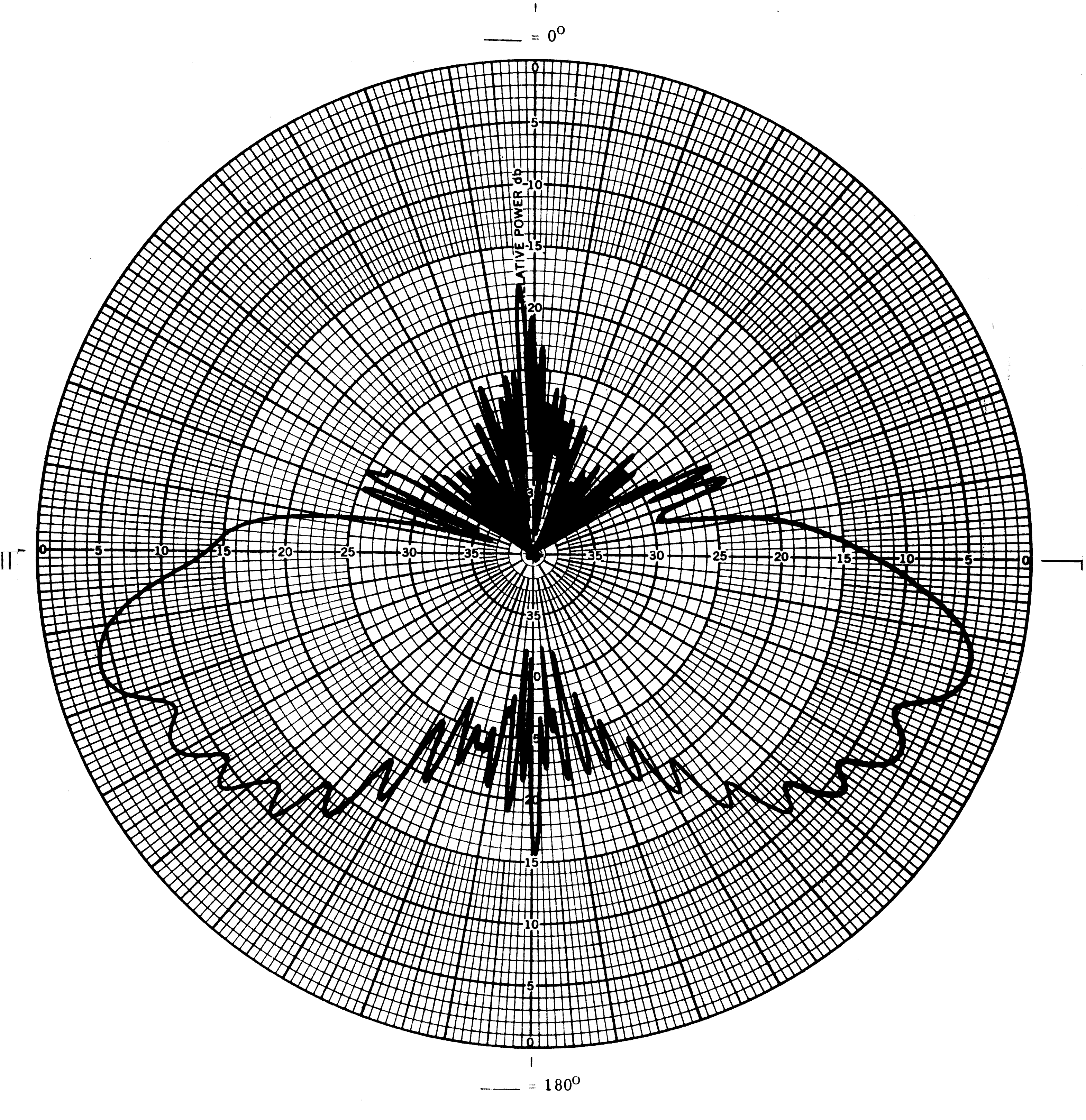


Figure B-20: E-plane pattern, 5.25 GHz, vertical polarization, $\phi = 135^{\circ}$.

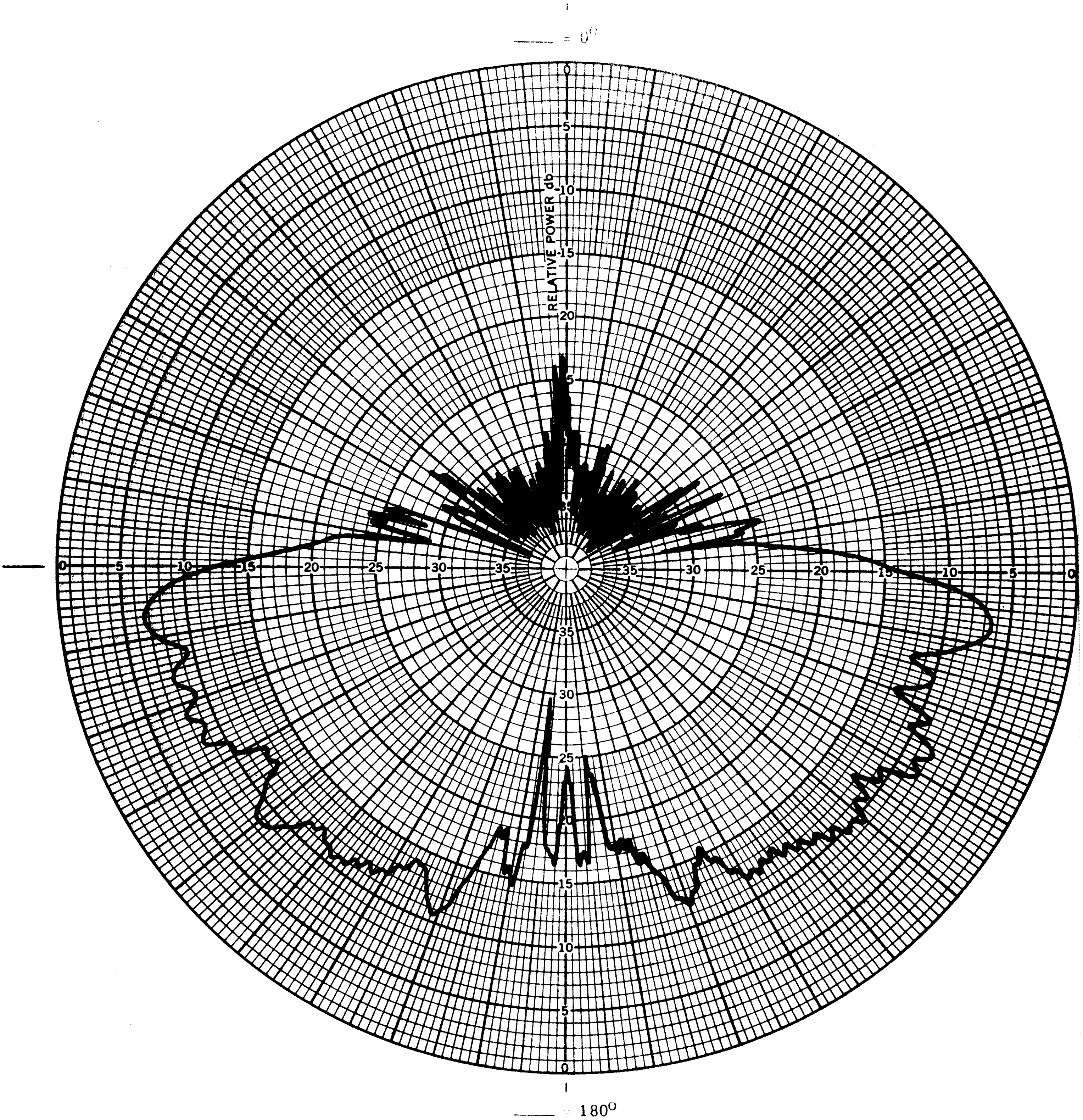


Figure B-21: E-plane pattern, 15.4 GHz, vertical polarization, $\phi = 0^{o}$.

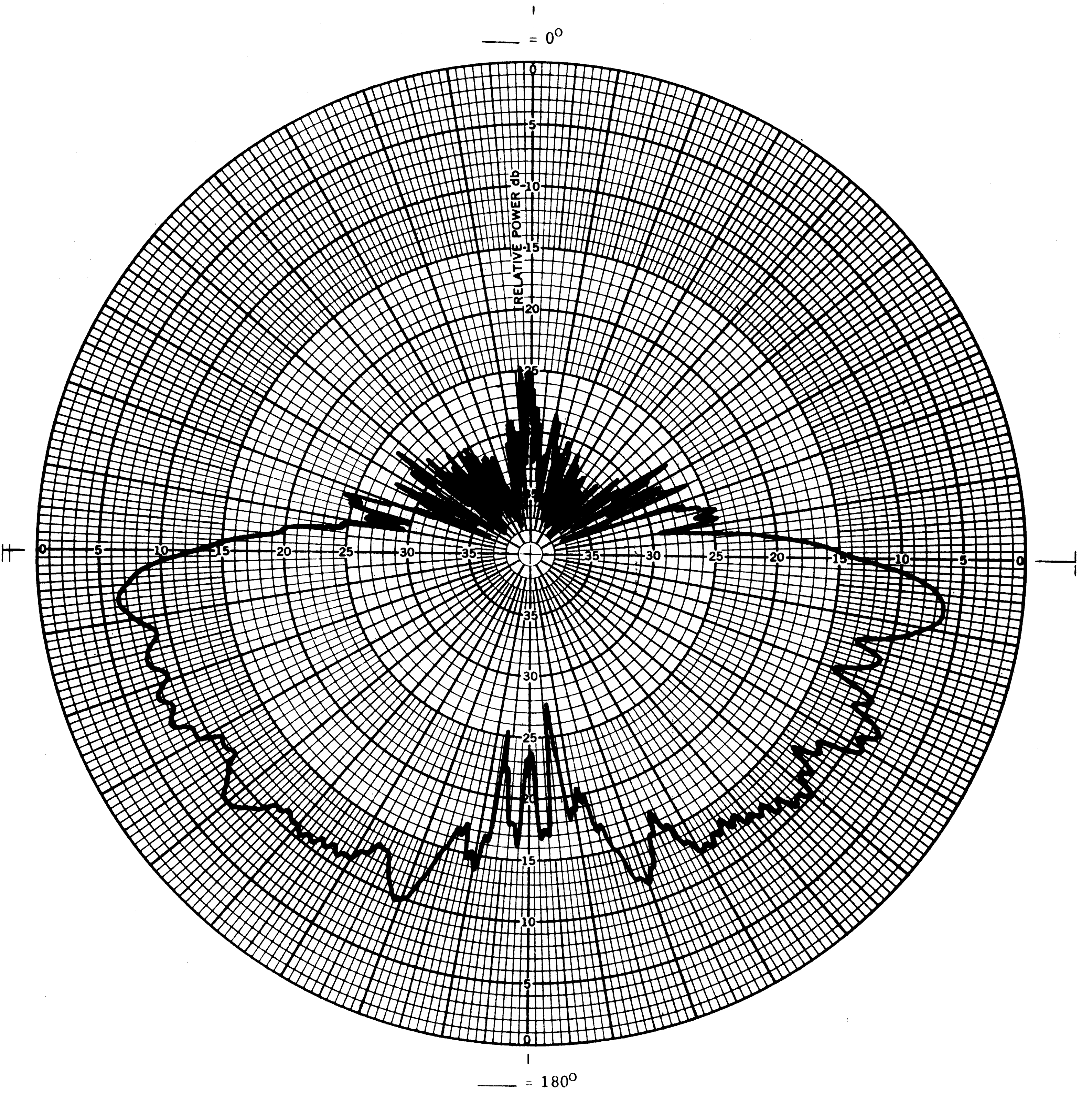


Figure B-22: E-plane pattern, 15.4 GHz, vertical polarization, $\phi = 45^{o}$.

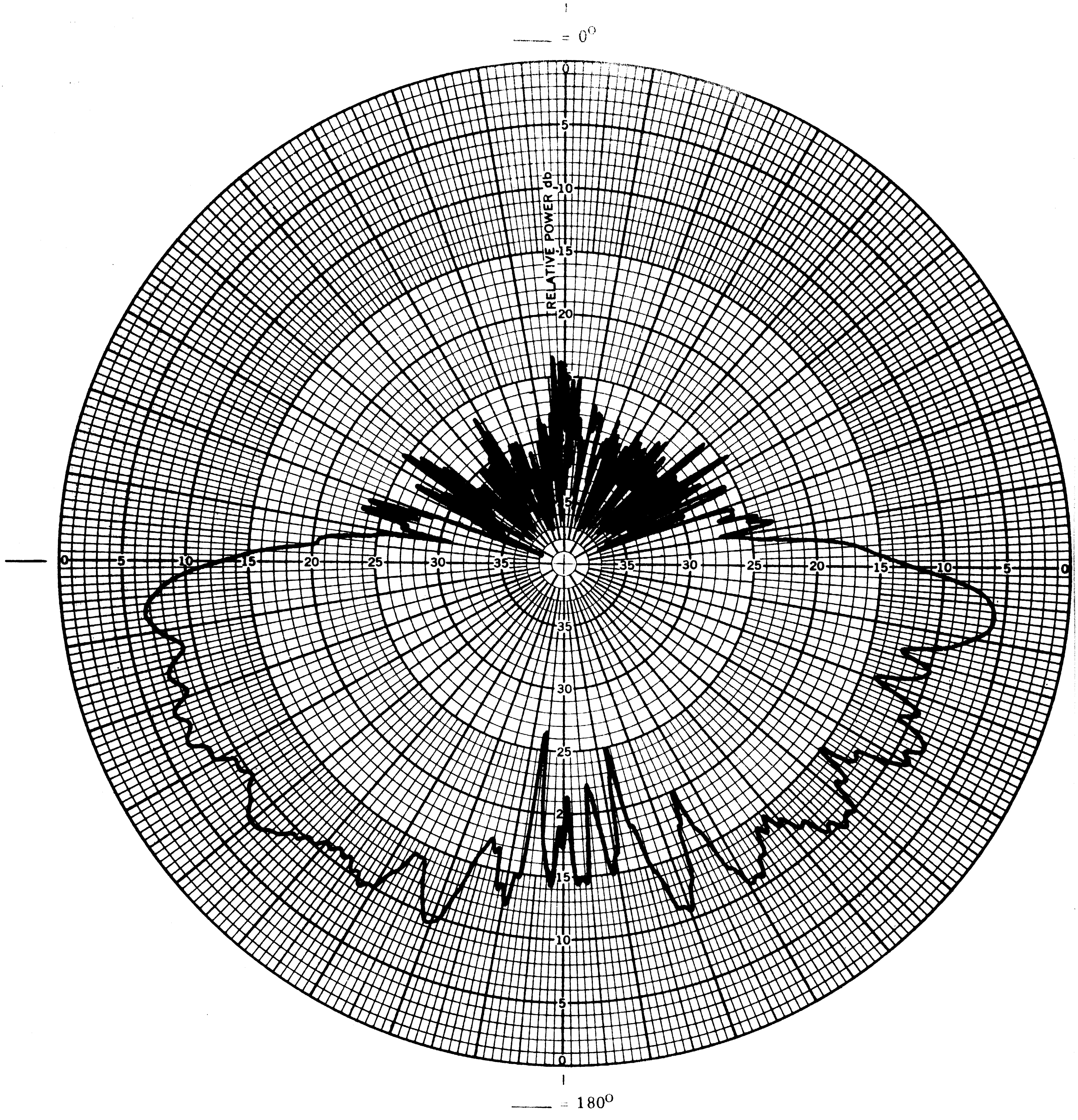


Figure B-23: E-plane pattern, 15.4 GHz, vertical polarization, $\phi = 90^{\circ}$.

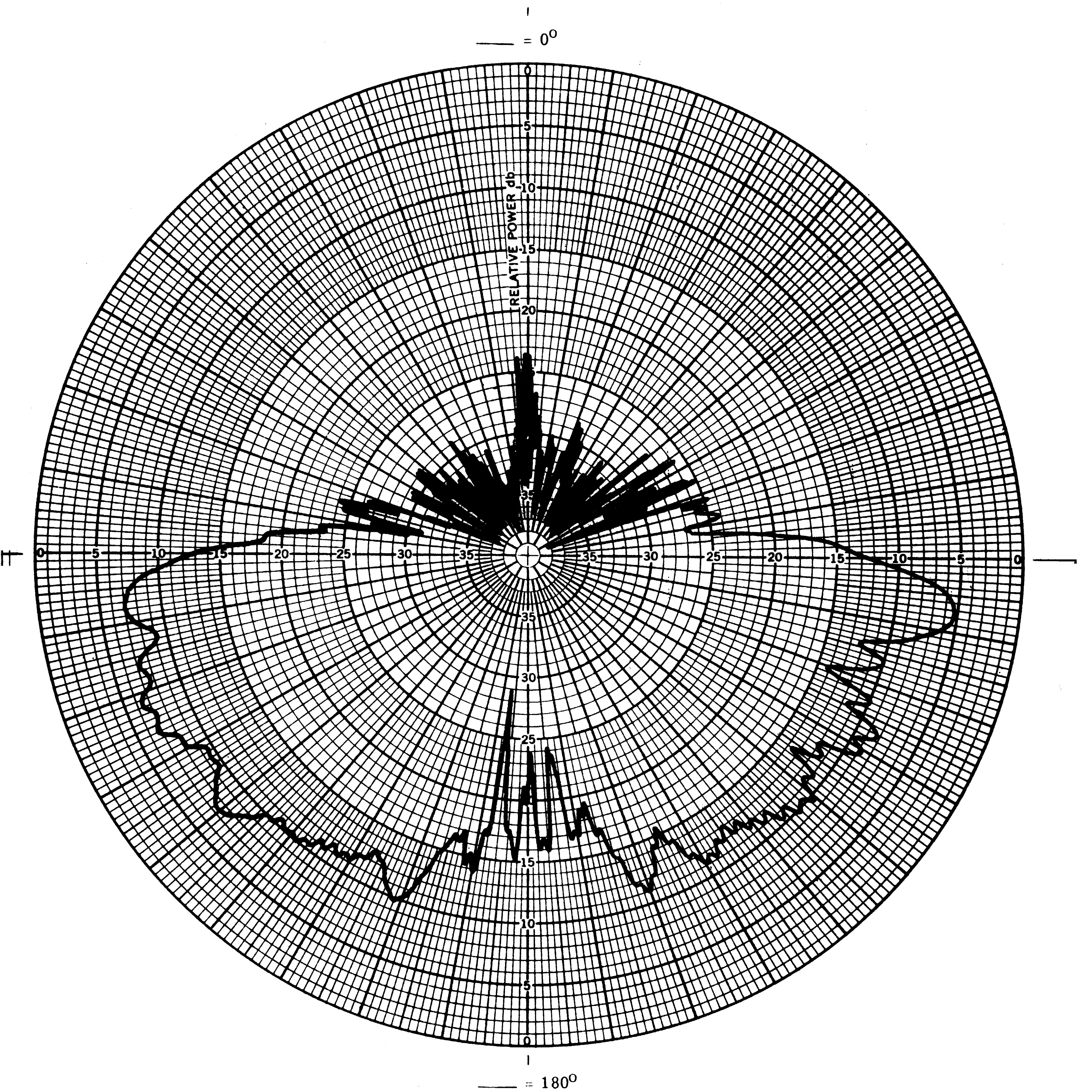


Figure B-24: E-plane pattern, 15.4 GHz, vertical polarization, $\phi = 135^{\circ}$.

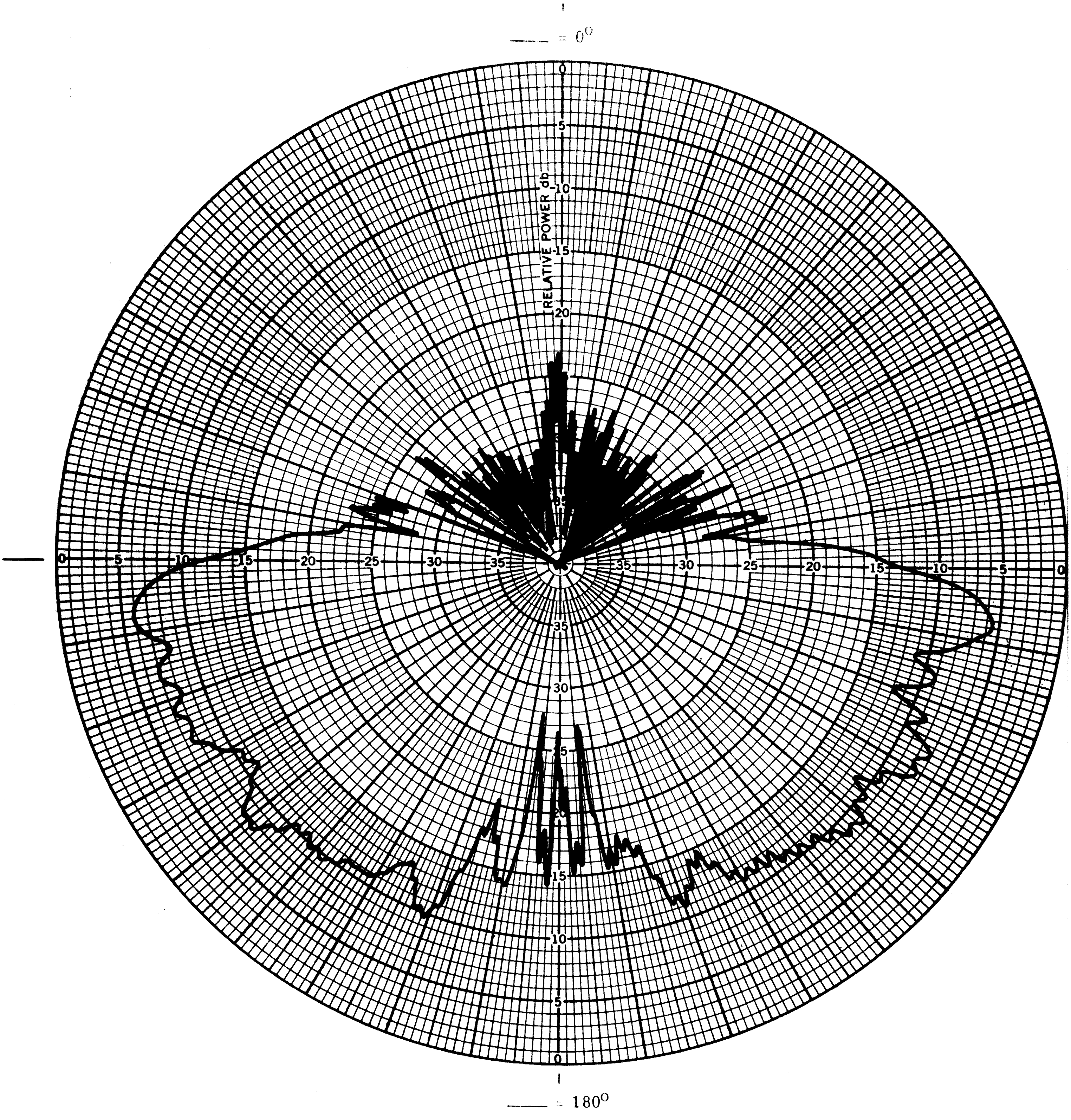


Figure B-25: E-plane pattern, 15.5 GHz, vertical polarization, $\phi = 0^{\circ}$.

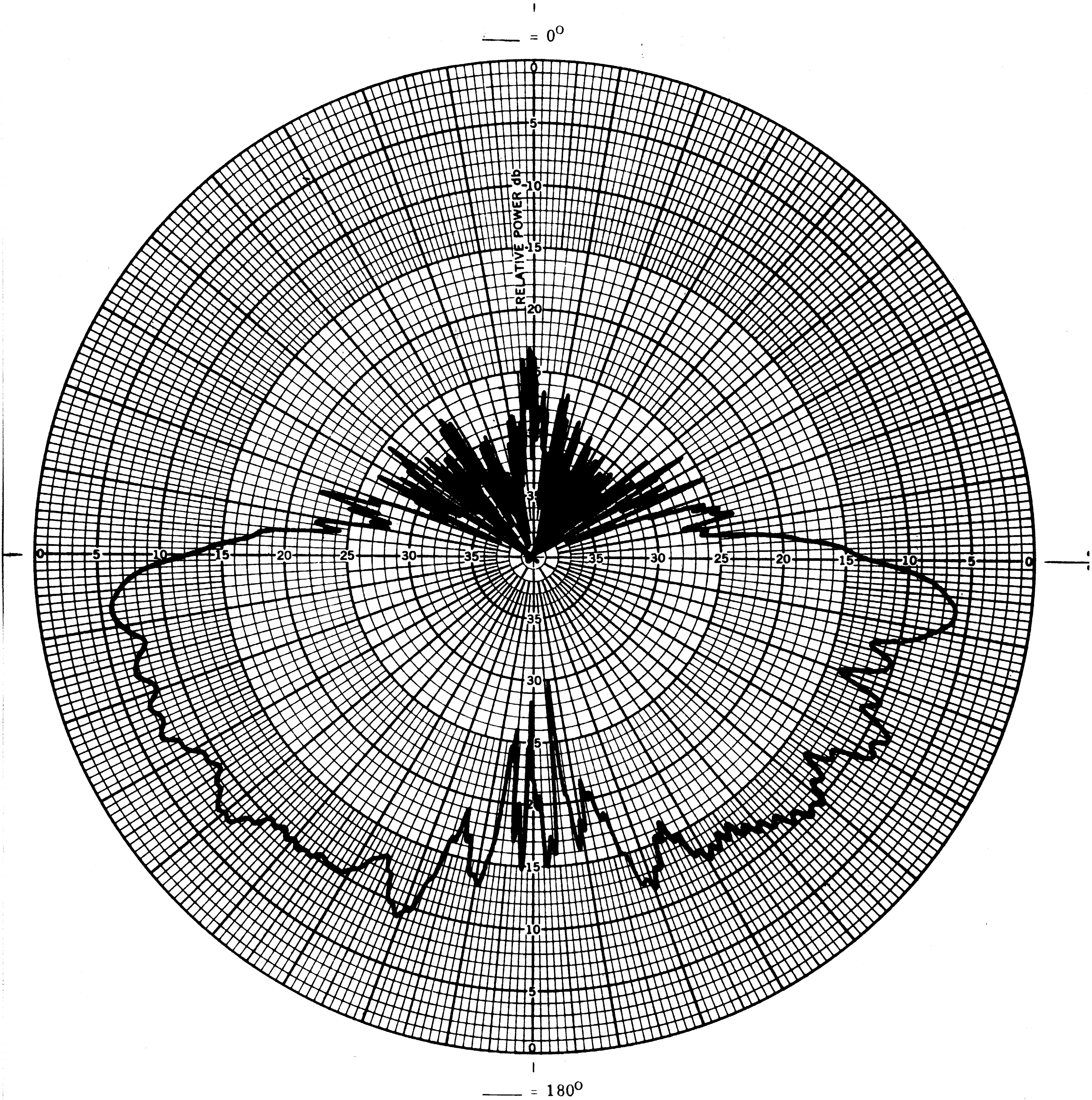


Figure B-26: E-plane pattern, 15.5 GHz, vertical polarization, ∅ = 45°.

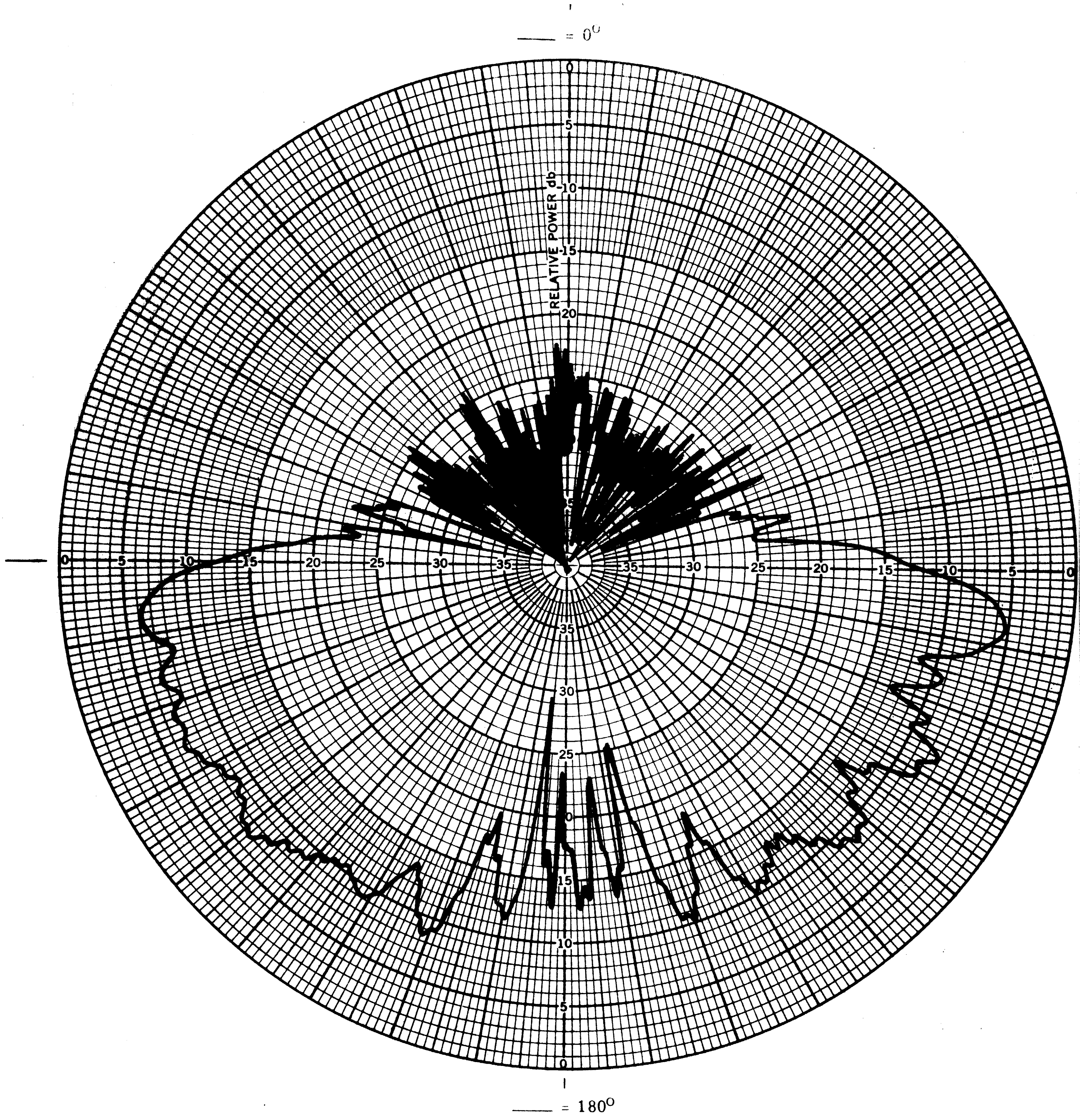


Figure B-27: E-plane pattern, 15.5 GHz, vertical polarization, $\phi = 90^{\circ}$.

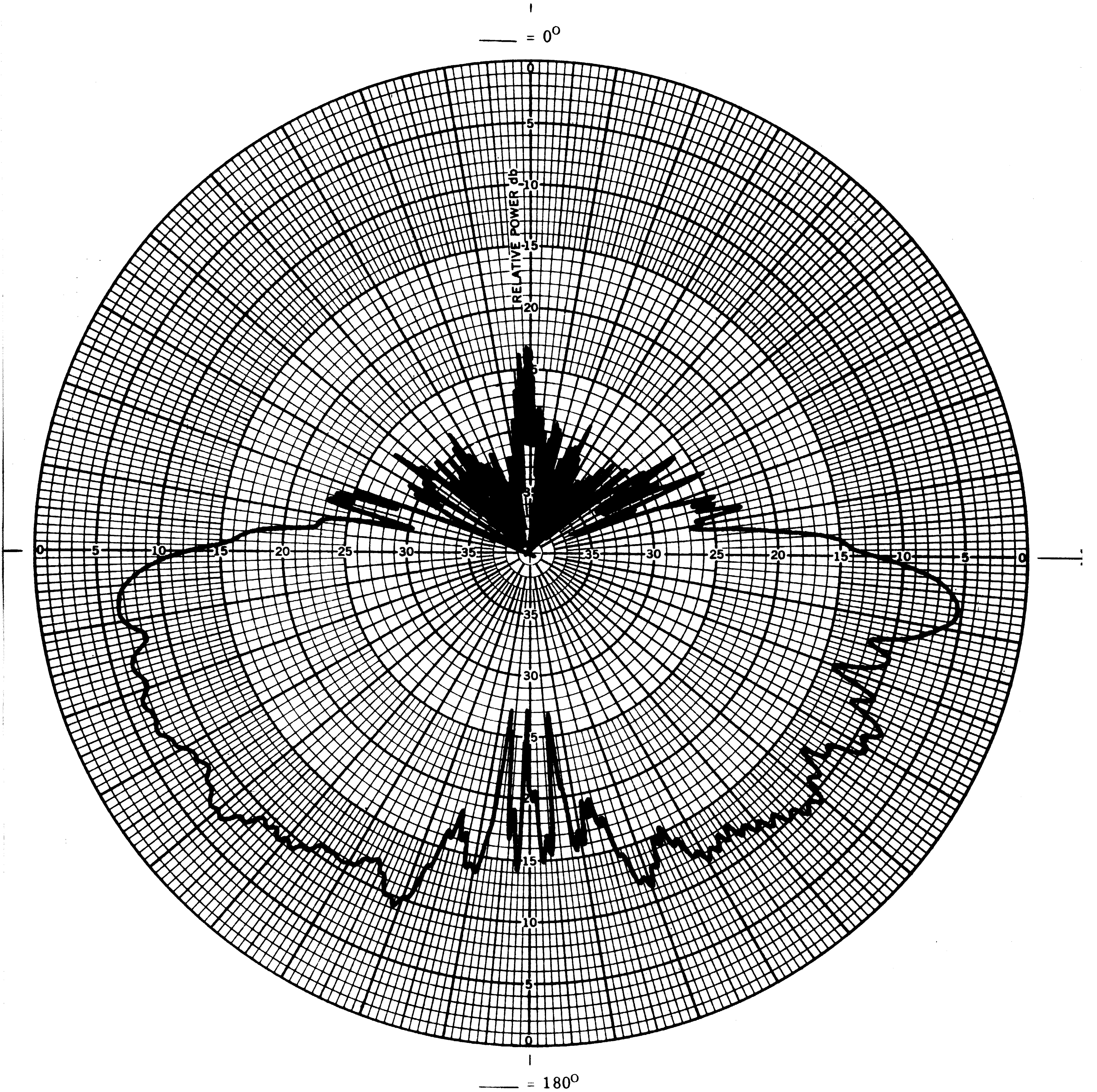


Figure B-28: E-plane pattern, 15.5 GHz, vertical polarization, $\phi = 135^{o}$.

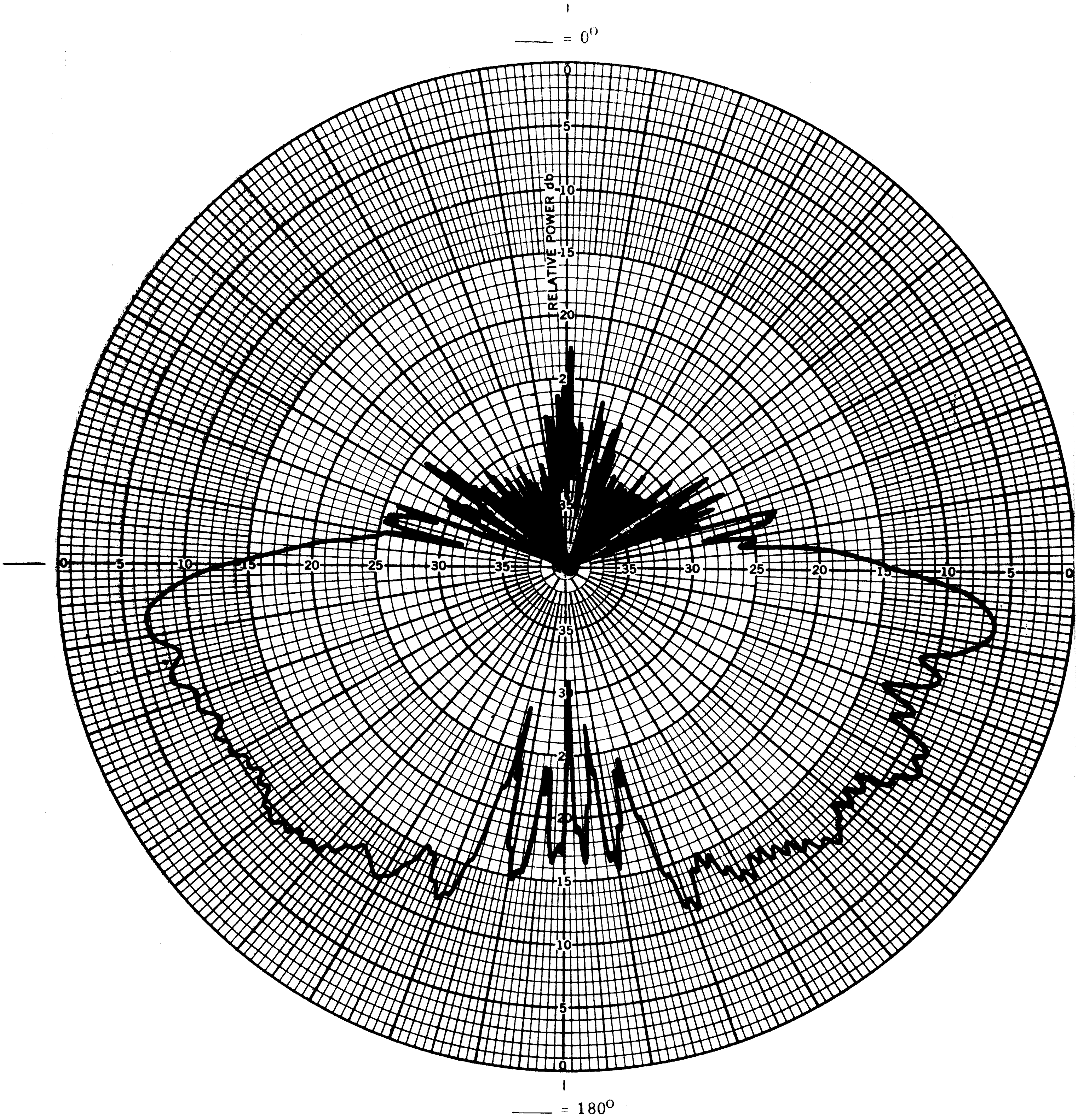


Figure B-29: E-plane pattern, 15.7 GHz, vertical polarization, $\phi = 0^{o}$.

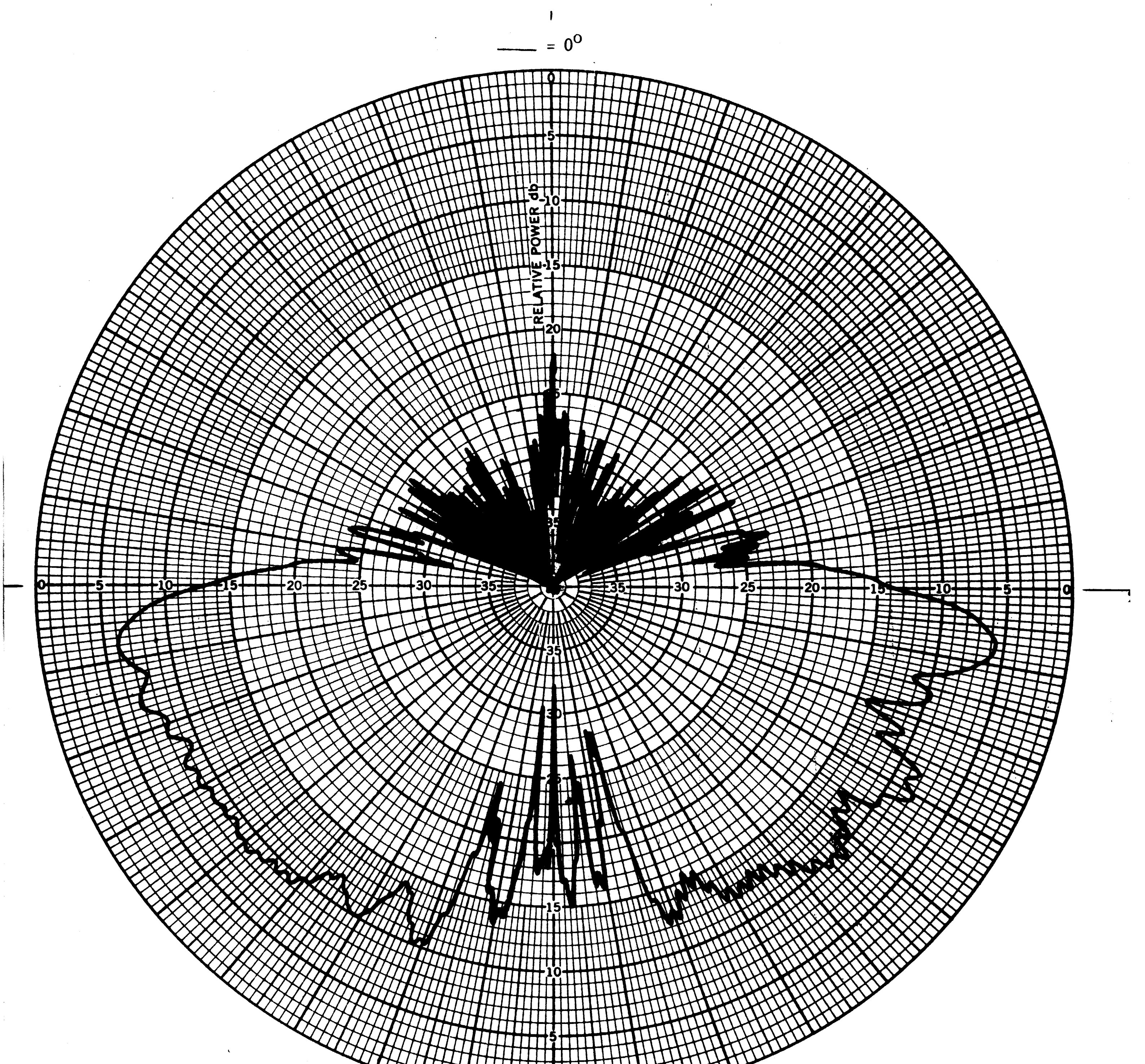


Figure B-30: E-plane pattern, 15.7 GHz, vertical polarization, $\phi = 45^{\circ}$.

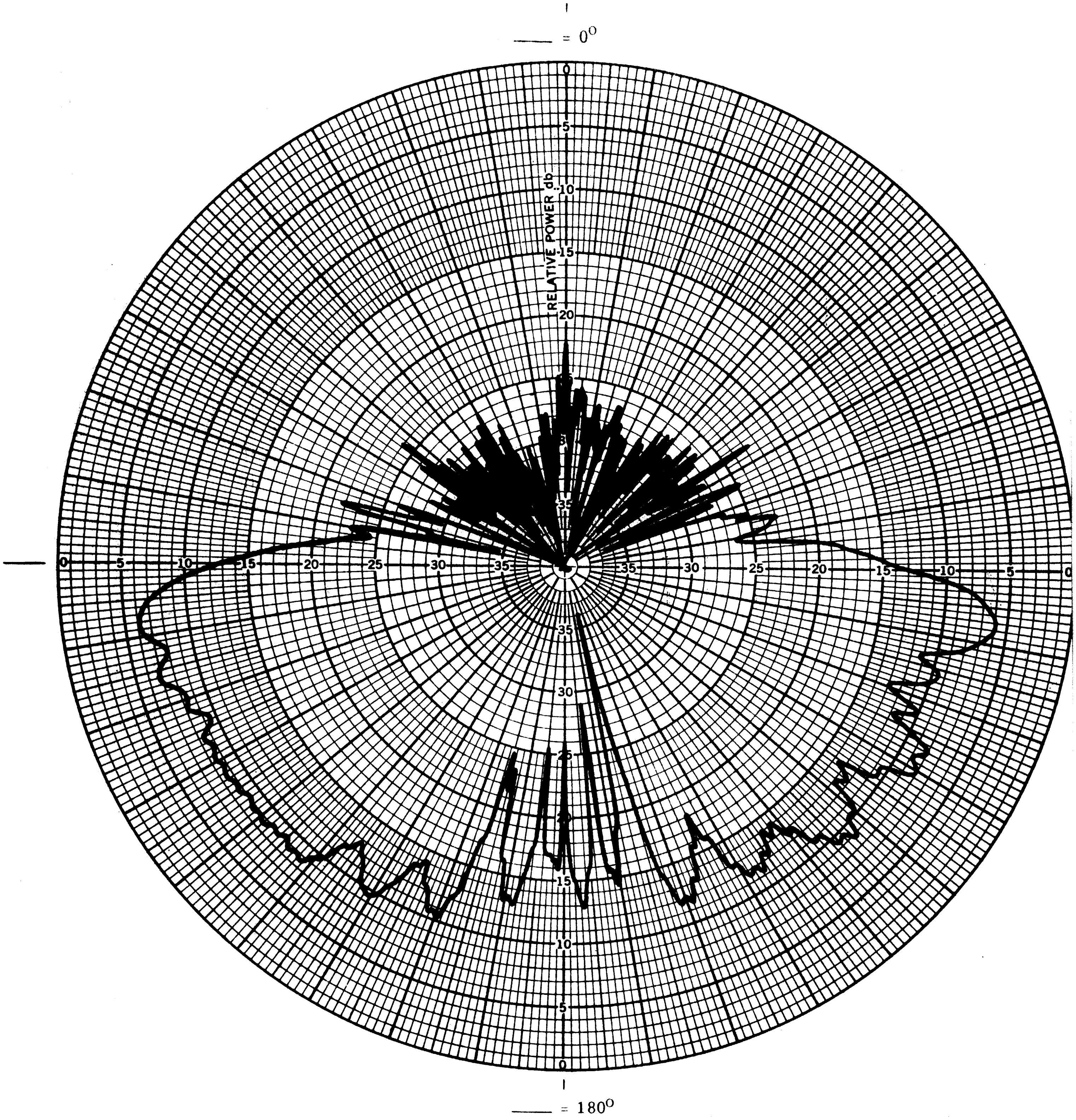


Figure B-31: E-plane pattern, 15.7 GHz, vertical polarization, $\phi = 90^{o}$.

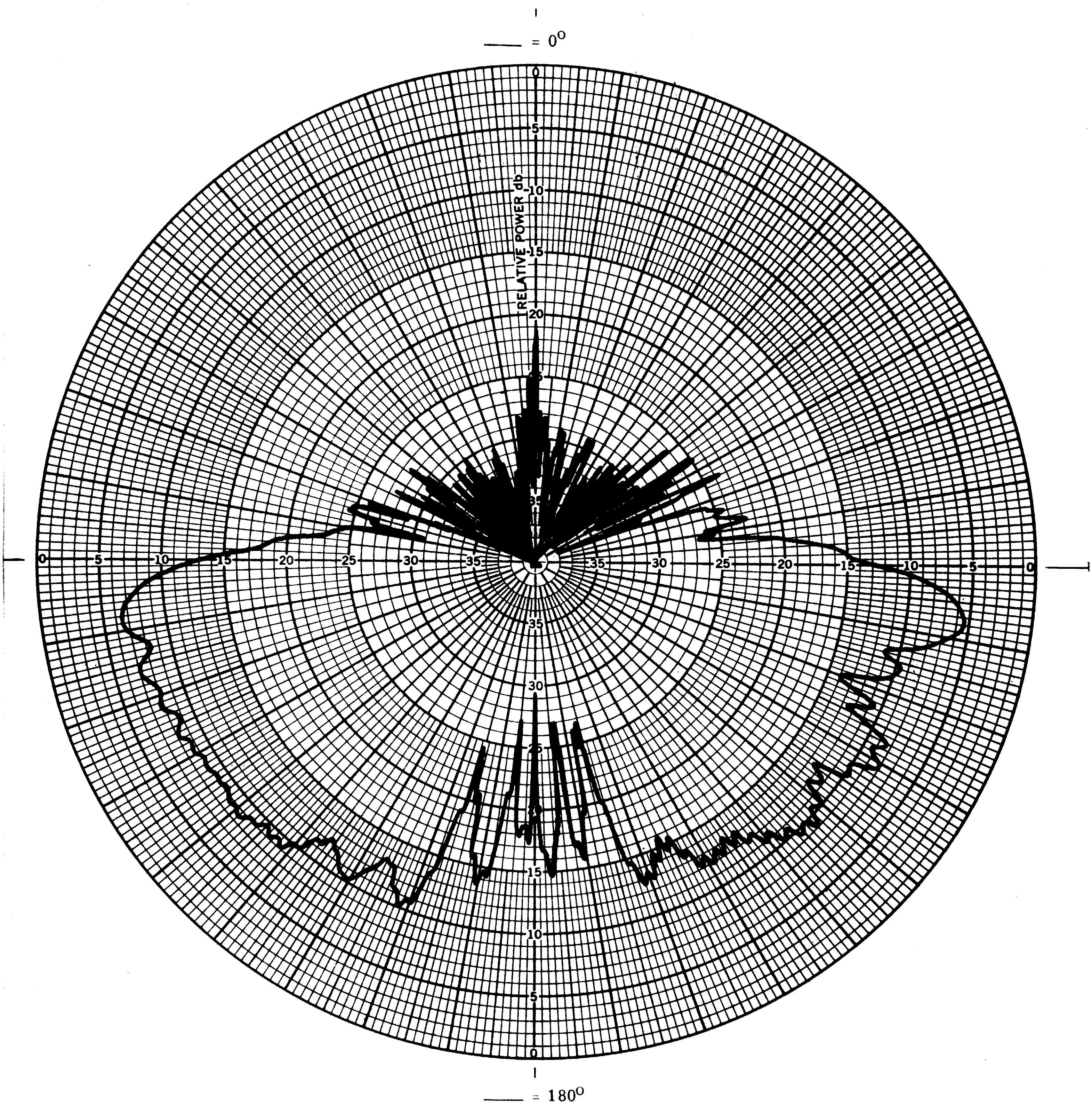
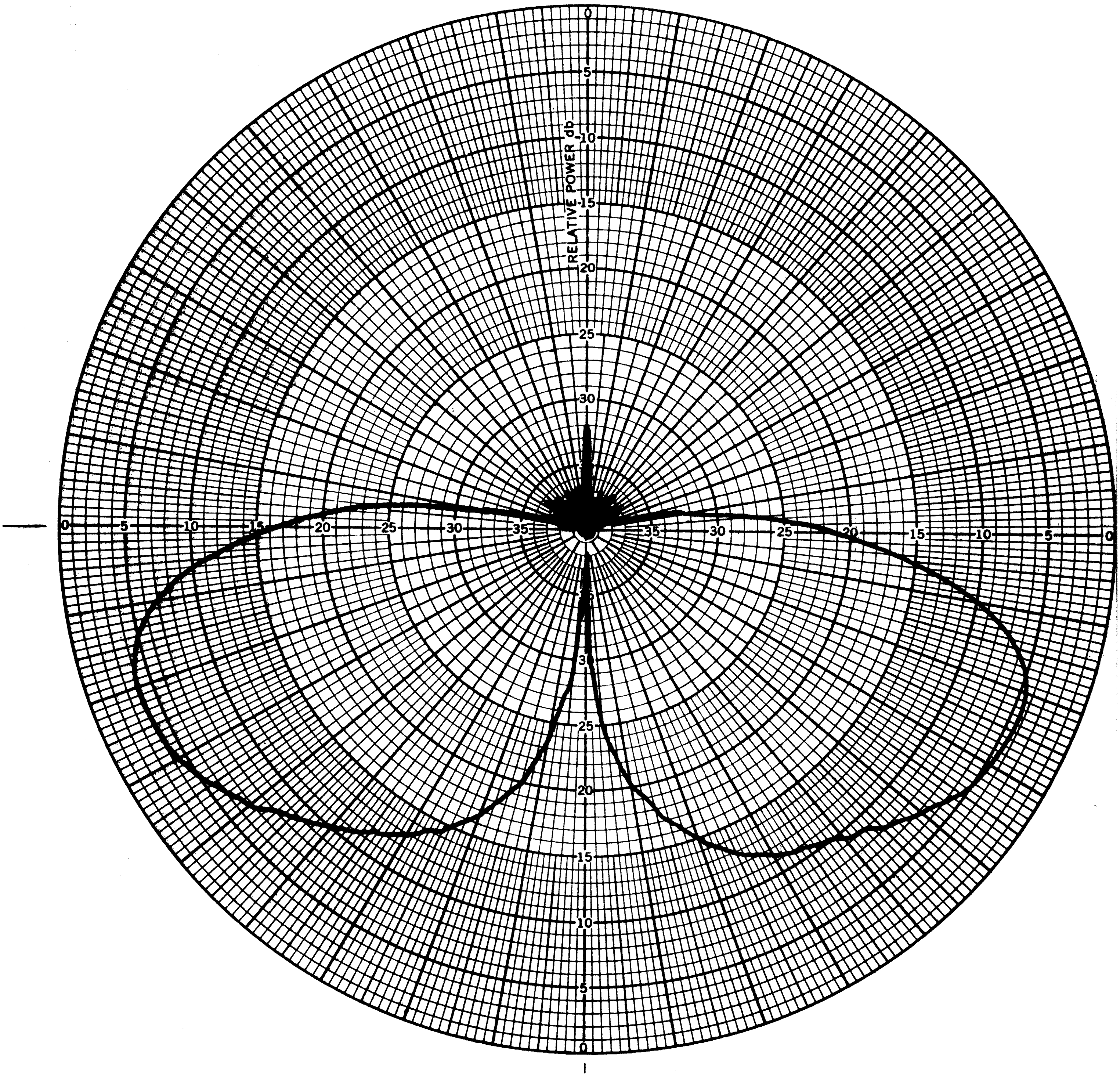


Figure B-32: E-plane pattern, 15.7 GHz, vertical polarization, $\phi = 135^{\circ}$.

——— = 0°



——— = 180°

Figure B-33: **H-plane pattern, 5.0 GHz, horizontal polarization, ϕ = 0°.**

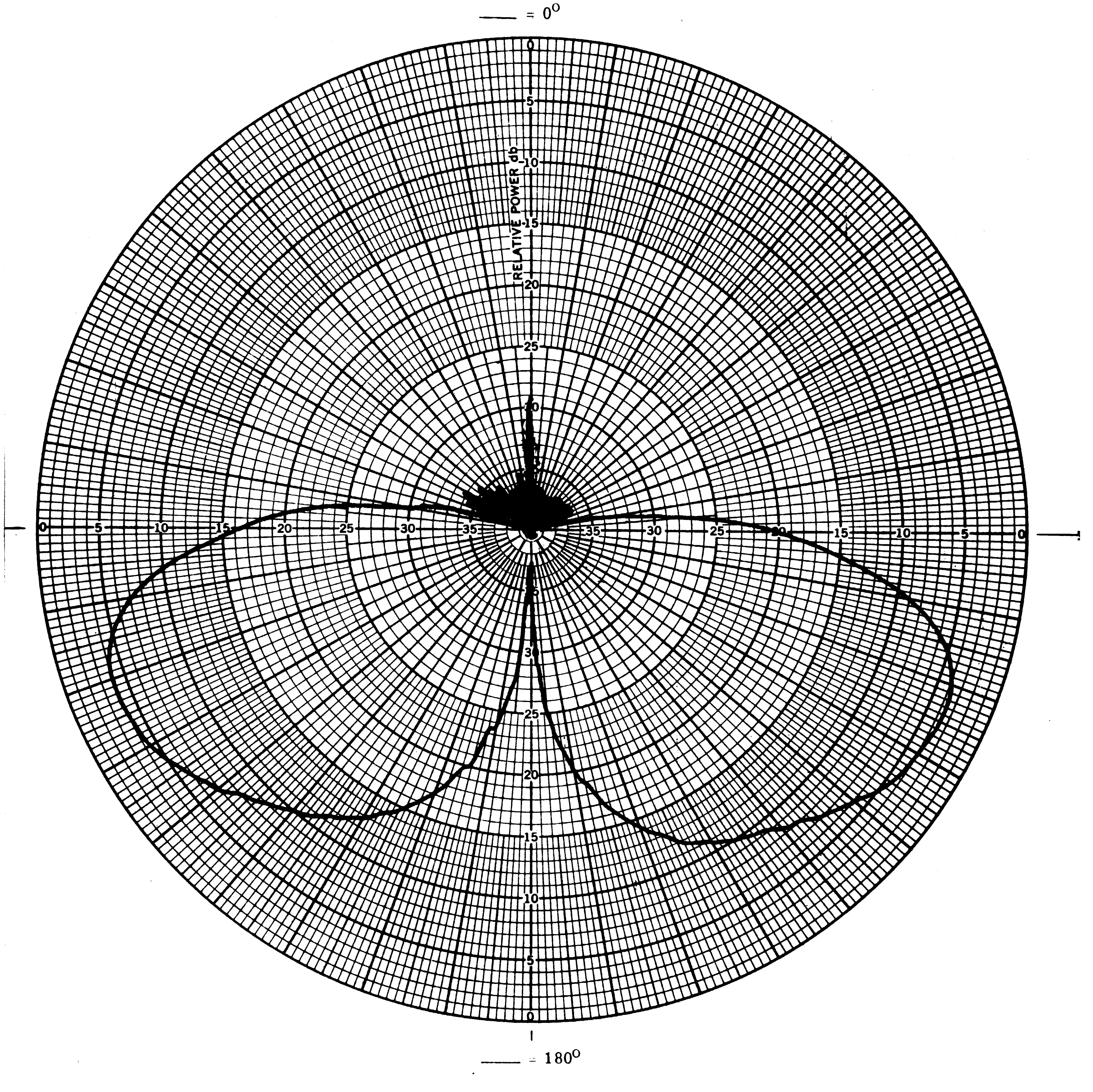


Figure B-34: H-plane pattern, 5.0 GHz,
horizontal polarization, $\phi = 45^{\circ}$.

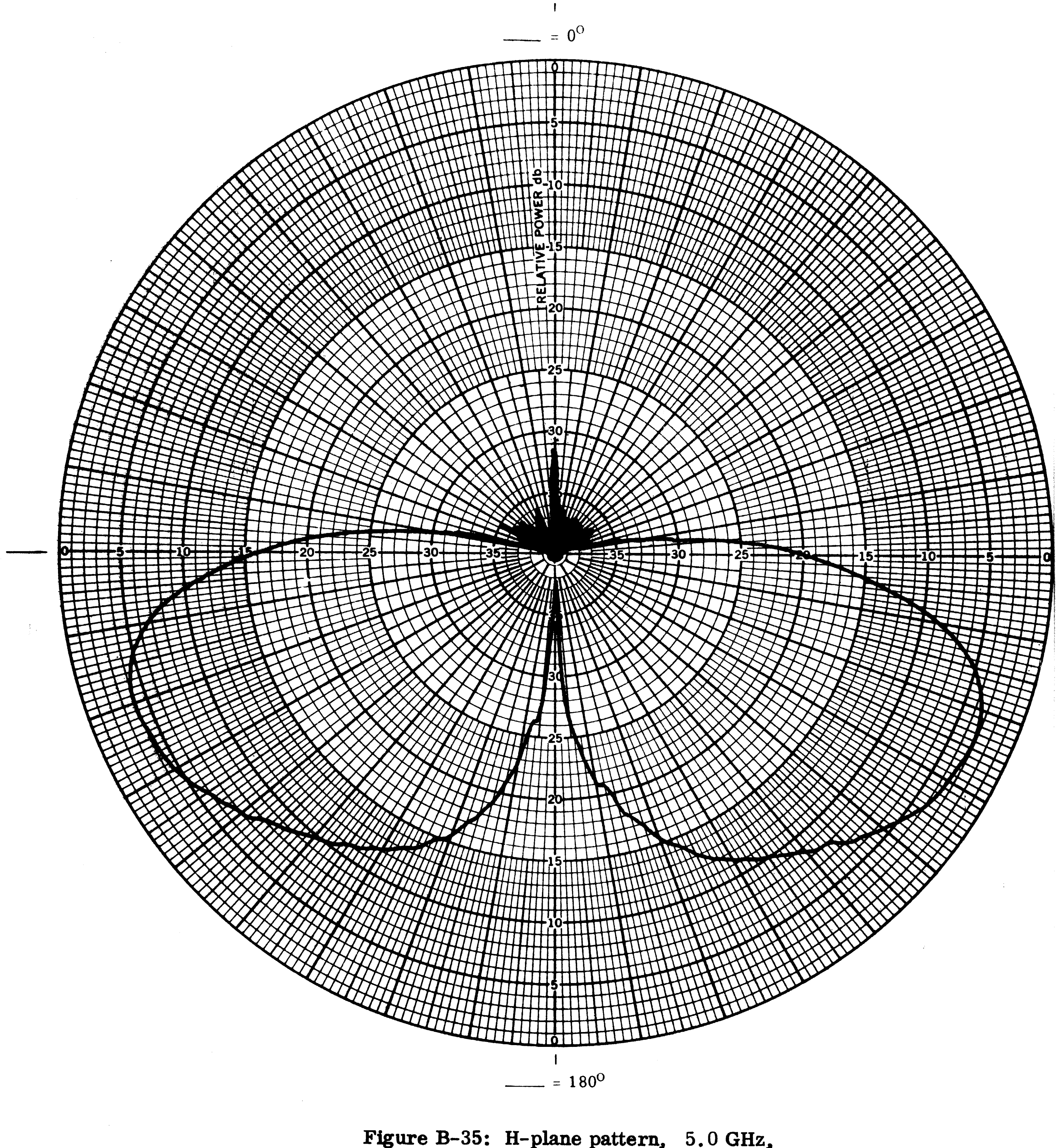


Figure B-35: H-plane pattern, 5.0 GHz, horizontal polarization, ϕ = 90°.

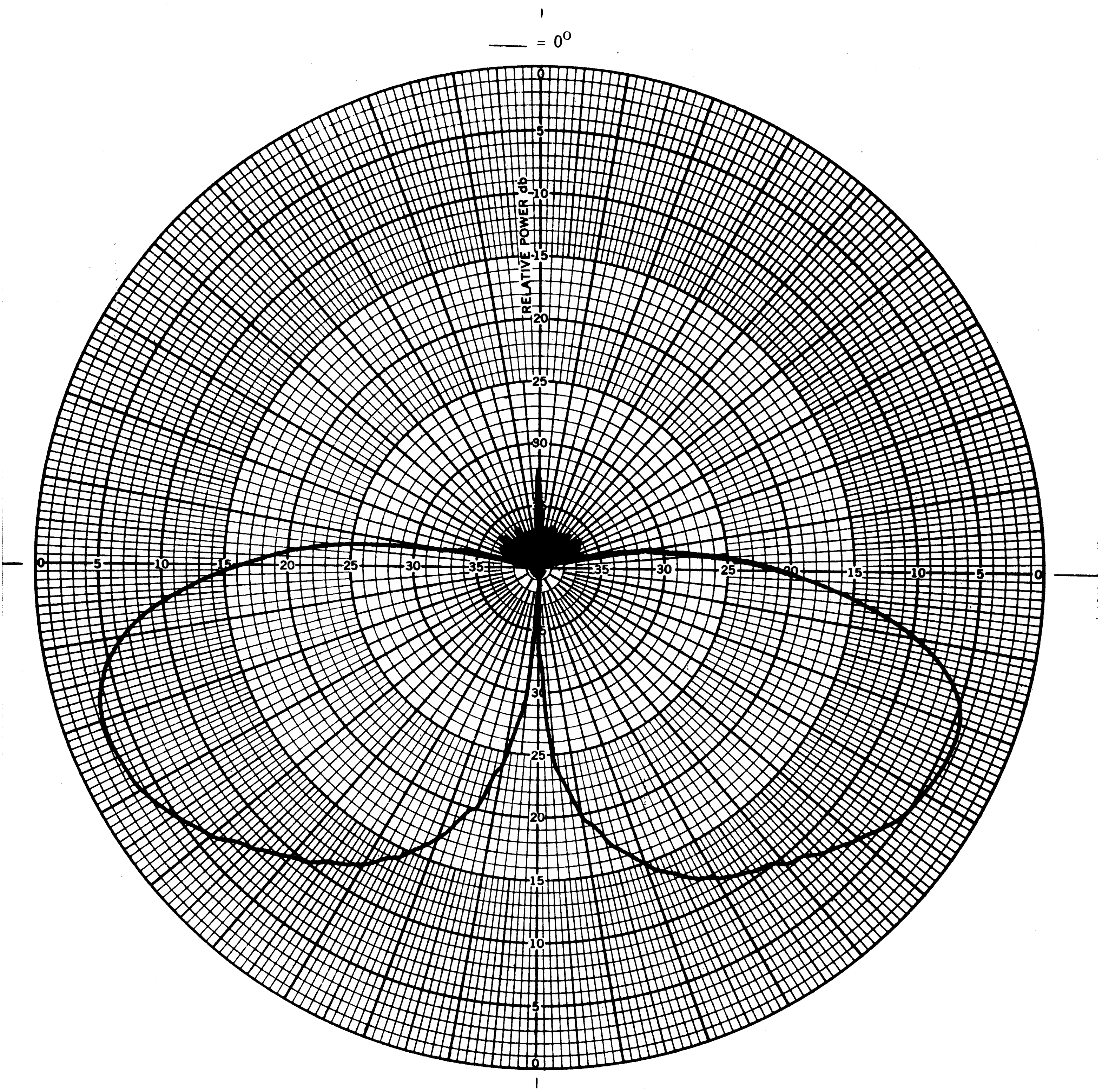
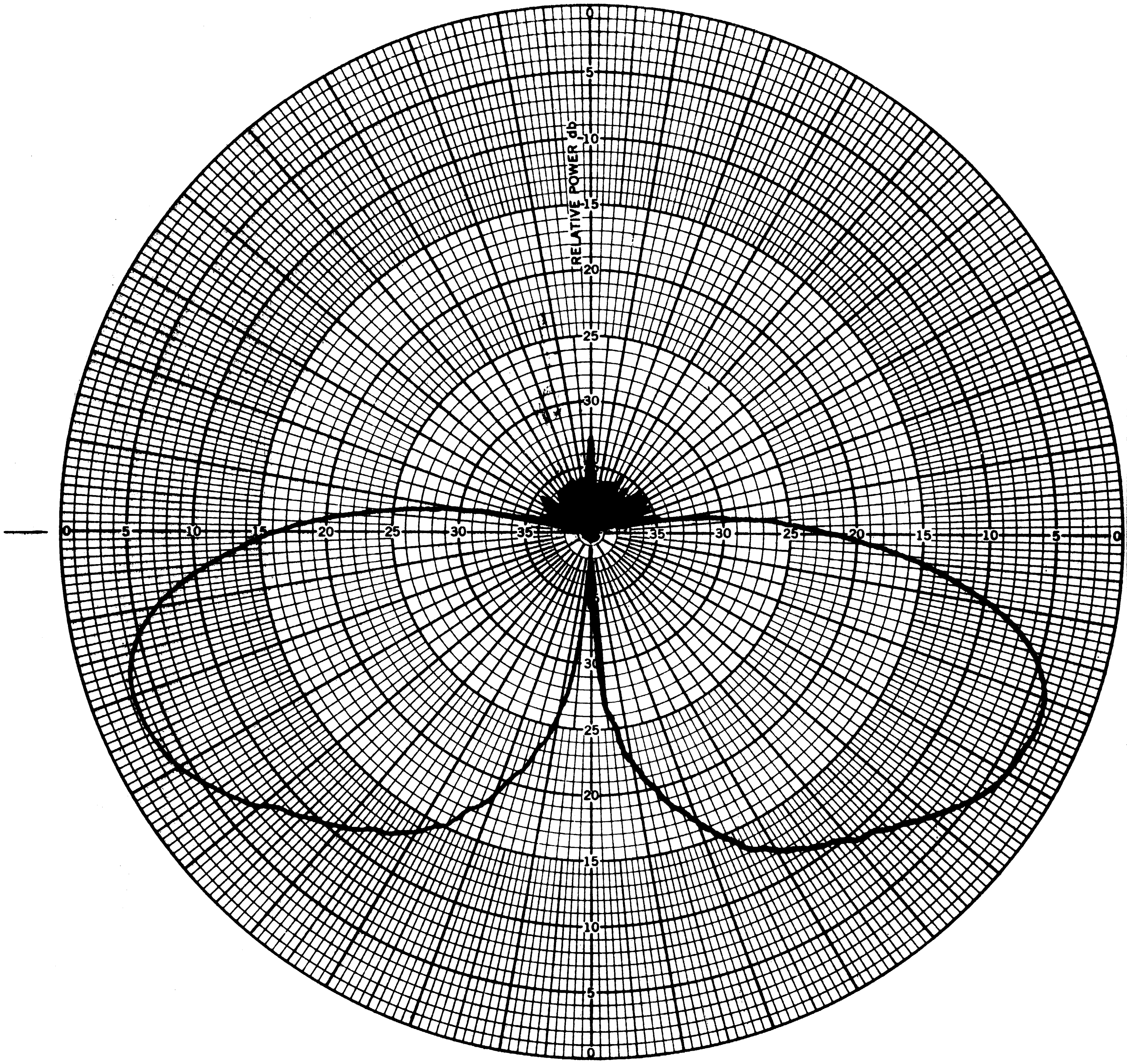


Figure B-36: H-plane pattern, 5.0 GHz, horizontal polarization, ϕ = 135°.

———— = 0°



———— = 180°

Figure B-37: **H-plane pattern,** 5.15 GHz, **horizontal polarization,** $\phi = 0^{\circ}$.

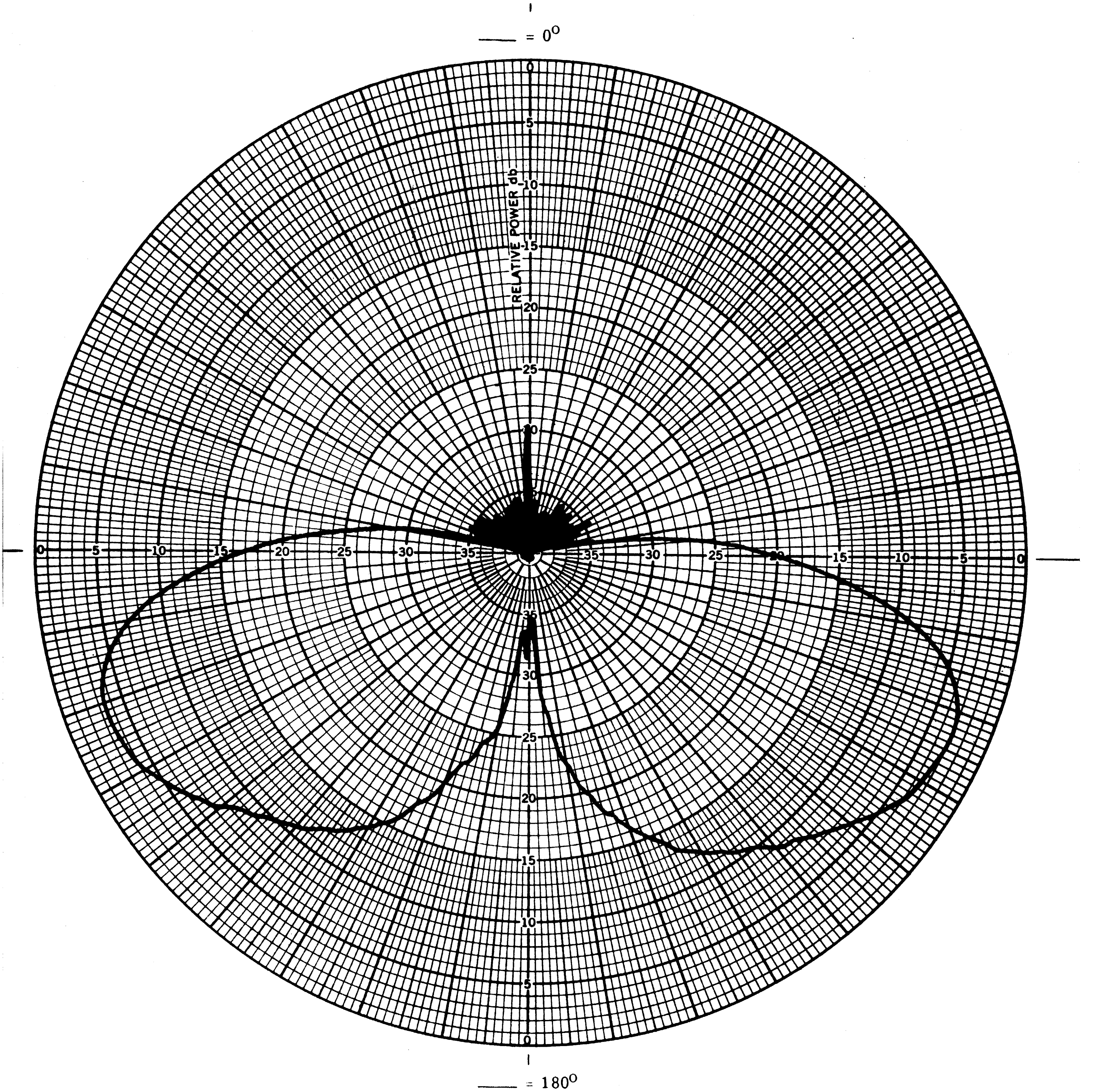


Figure B-38: H-plane pattern, 5.15 GHz, horizontal polarization, $\phi = 45^{\circ}$.

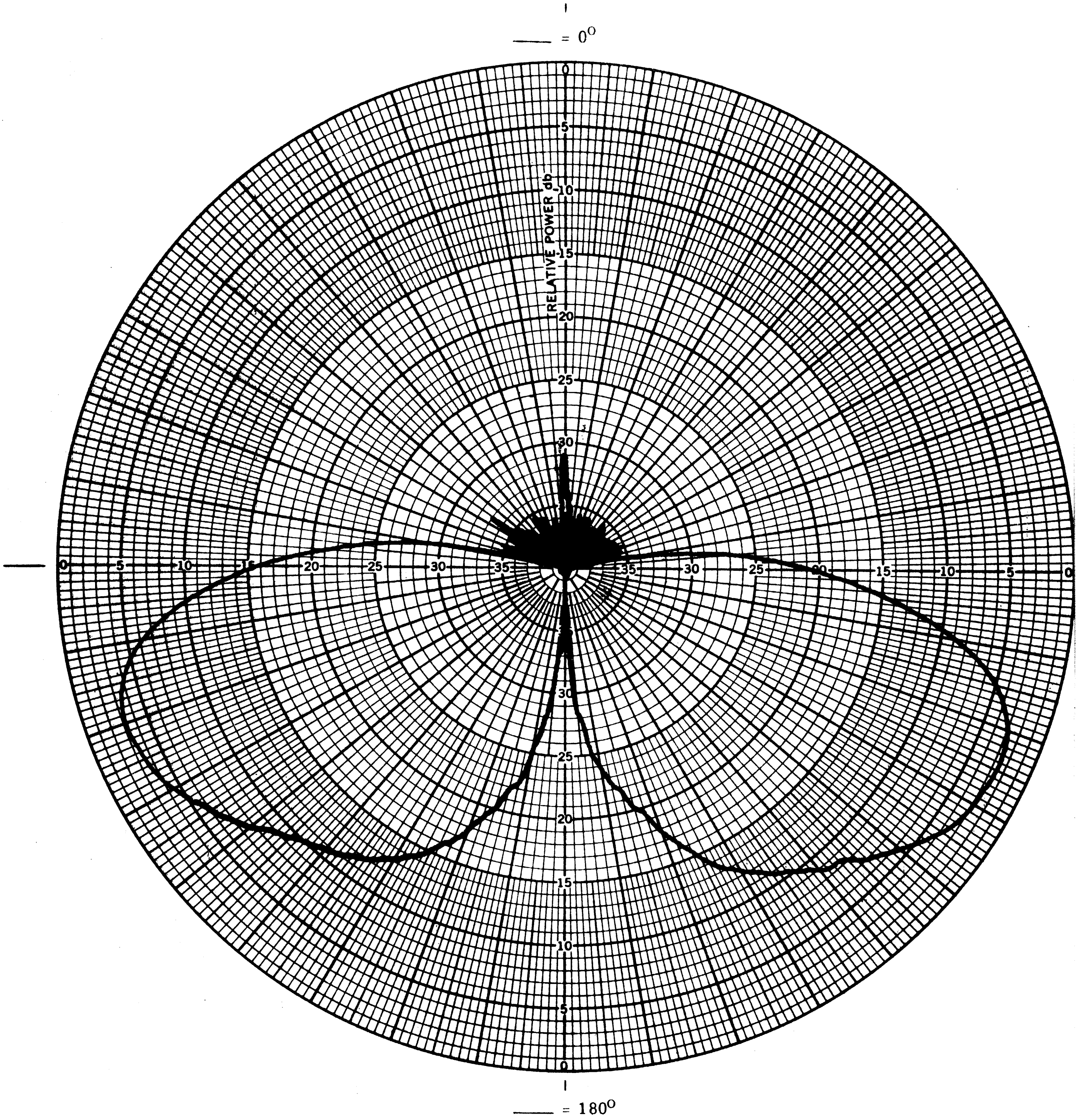


Figure B-39: H-plane pattern, 5.15 GHz, horizontal polarization, $\phi = 90^{\circ}$.

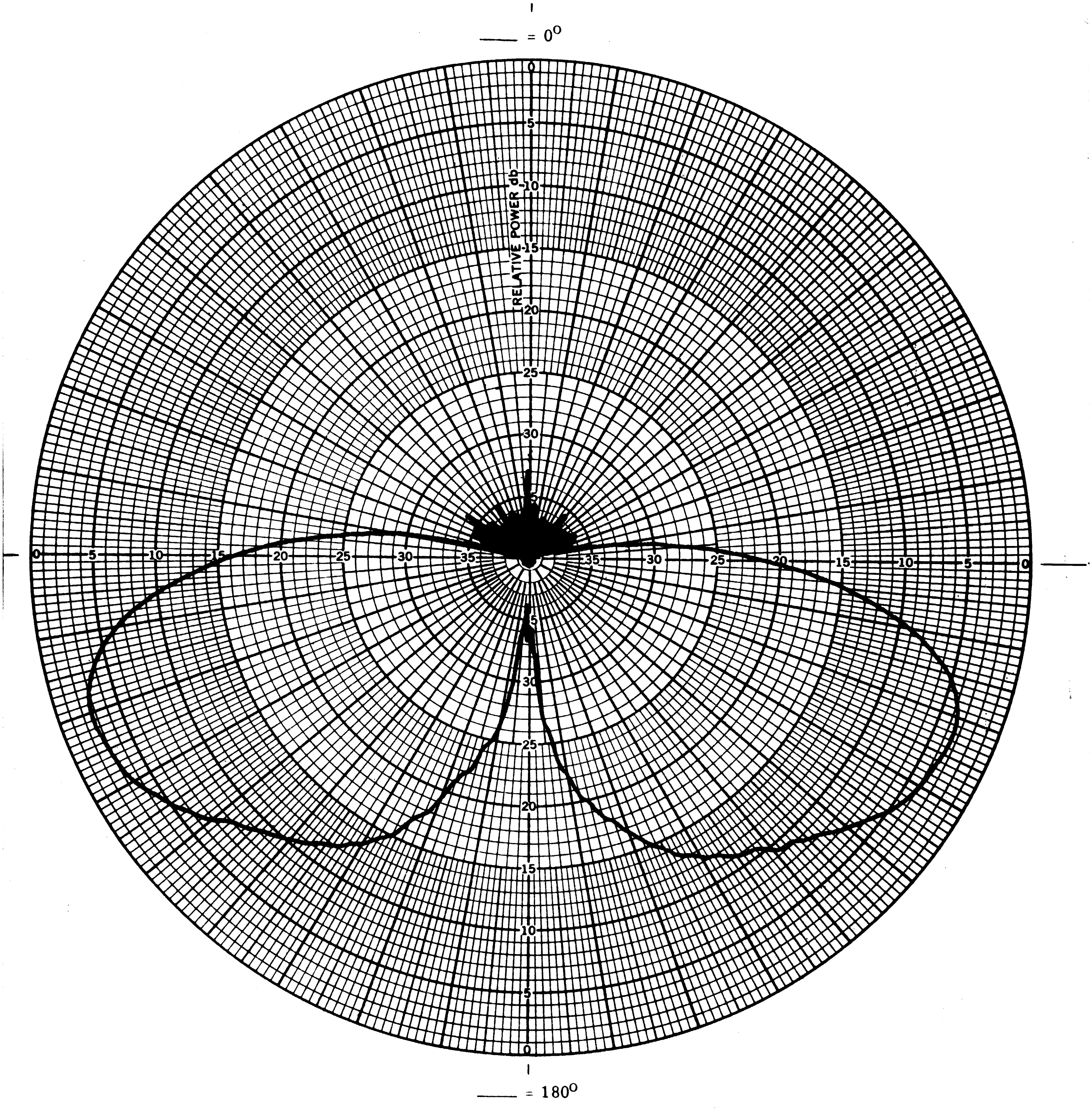


Figure B-40: H-plane pattern, 5.15 GHz, horizontal polarization, ϕ = 135°.

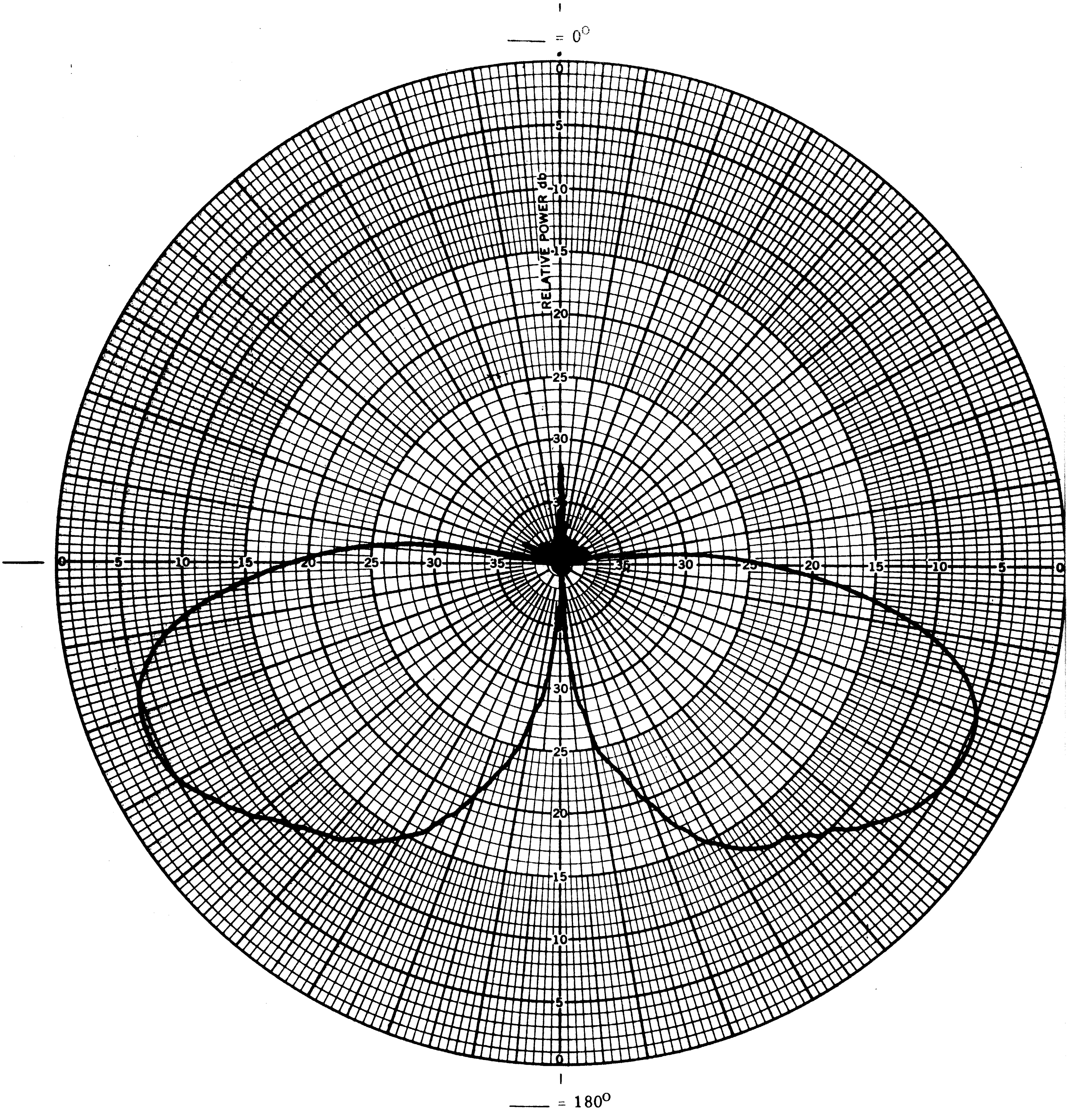
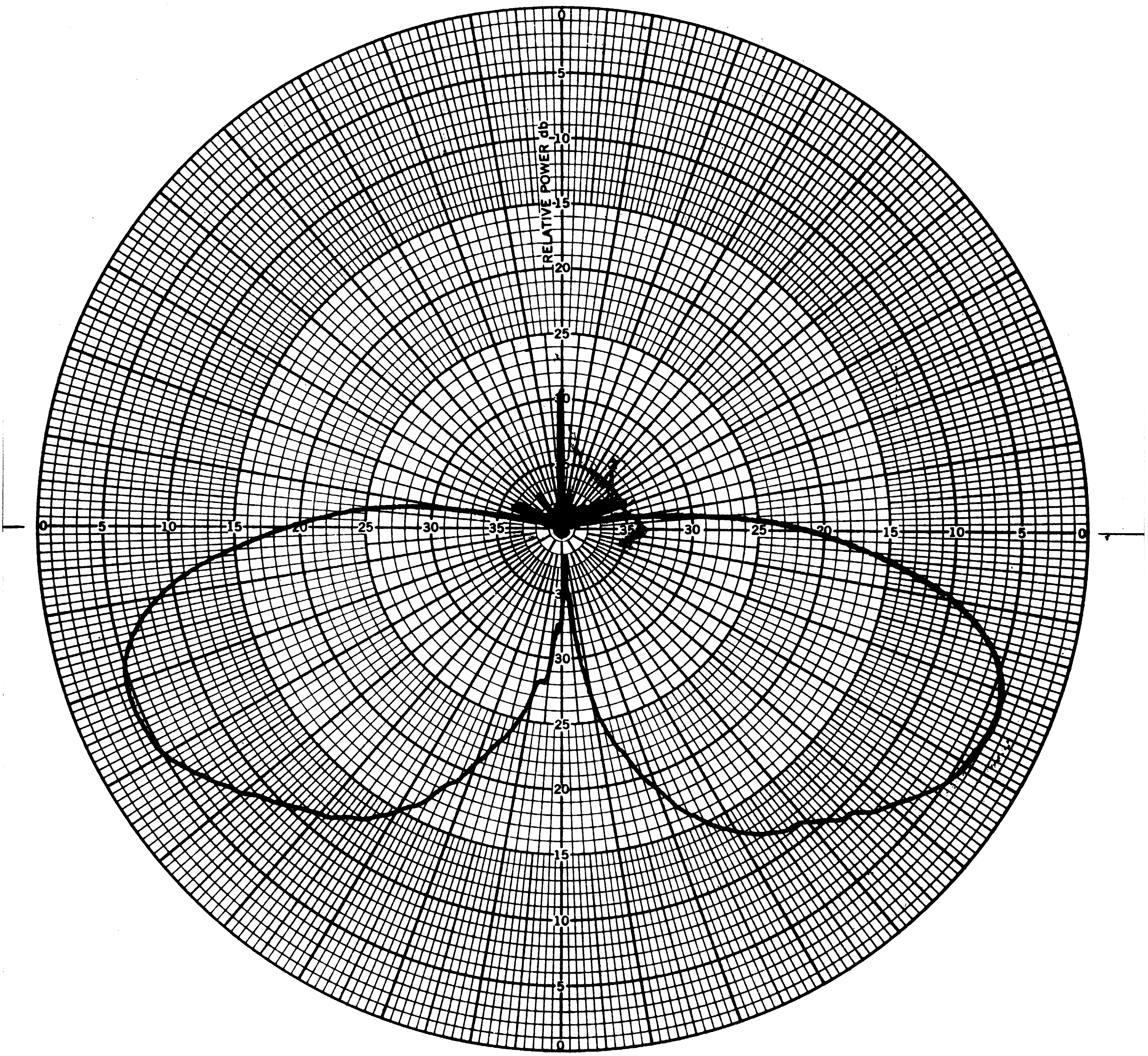


Figure B-41: **H-plane pattern,** 5.25 GHz**,**
horizontal polarization, $\phi = 0^{\circ}$.

—— = 0°



—— = 180°

Figure B-42: H-plane pattern, 5.25 GHz, horizontal polarization, ϕ = 45°.

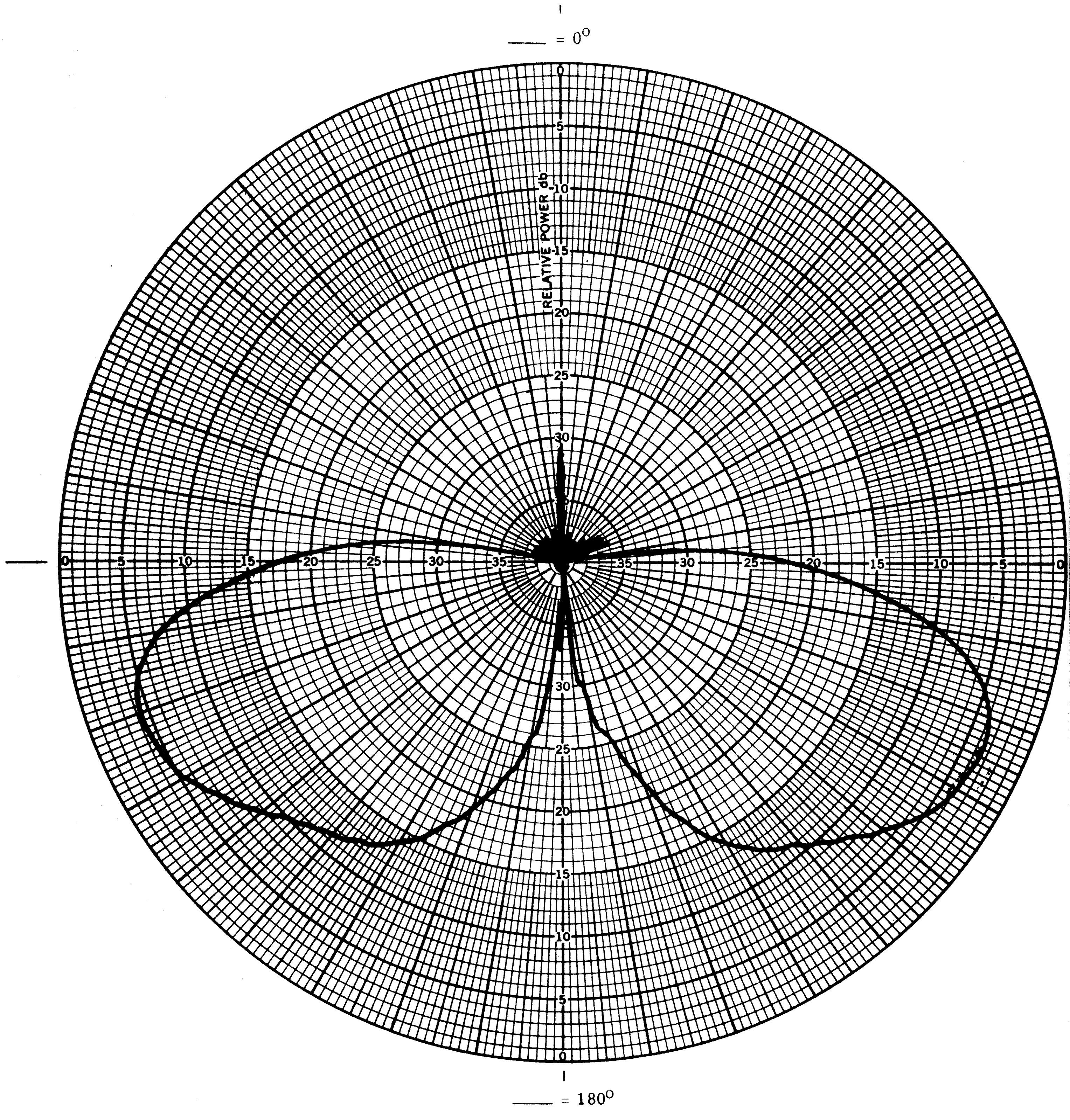


Figure B-43: H-plane pattern, 5.25 GHz, horizontal polarization, $\phi = 90^{\circ}$.

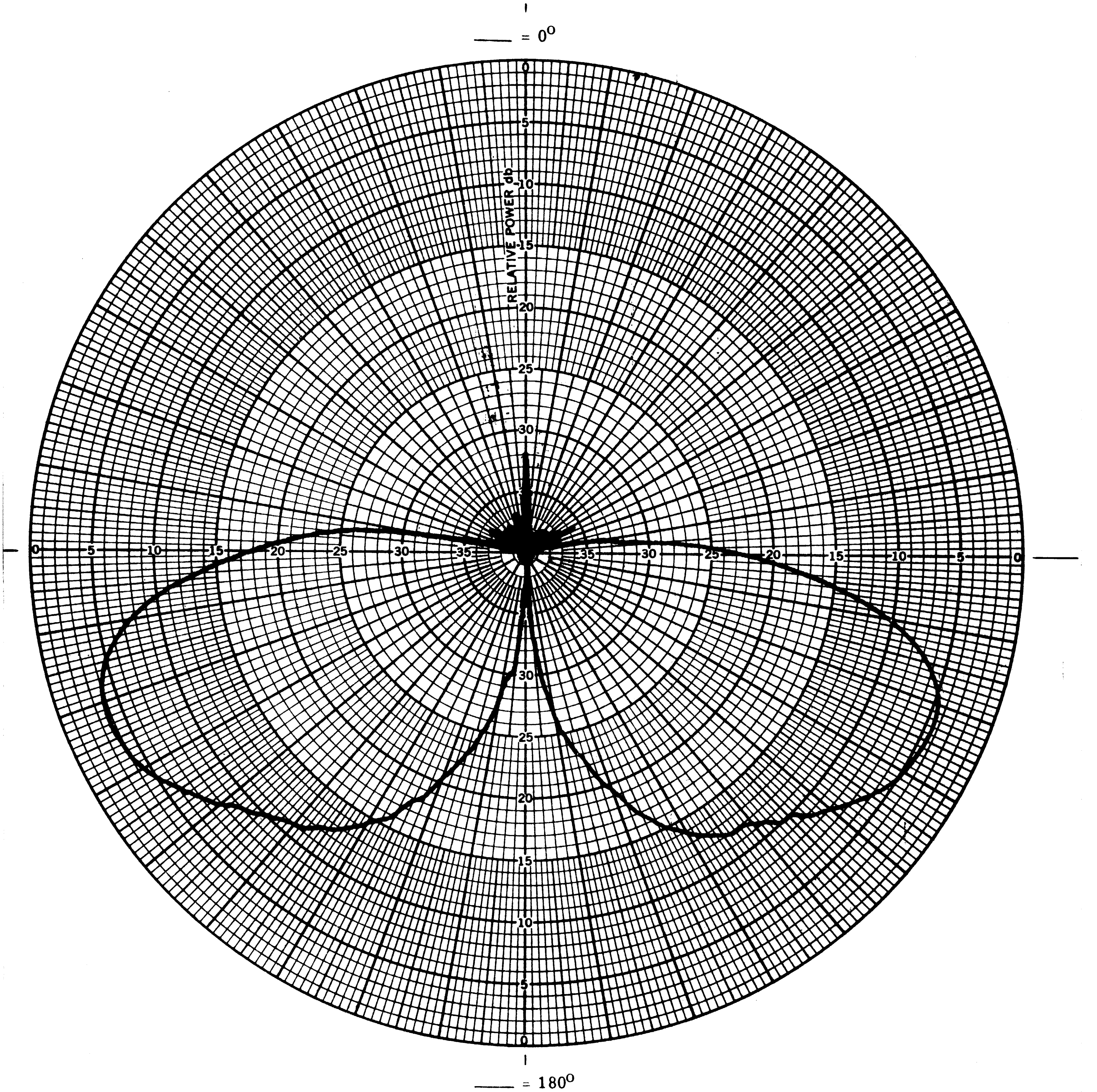


Figure B-44: H-plane pattern, 5.25 GHz, horizontal polarization, $\phi = 135^{\circ}$.

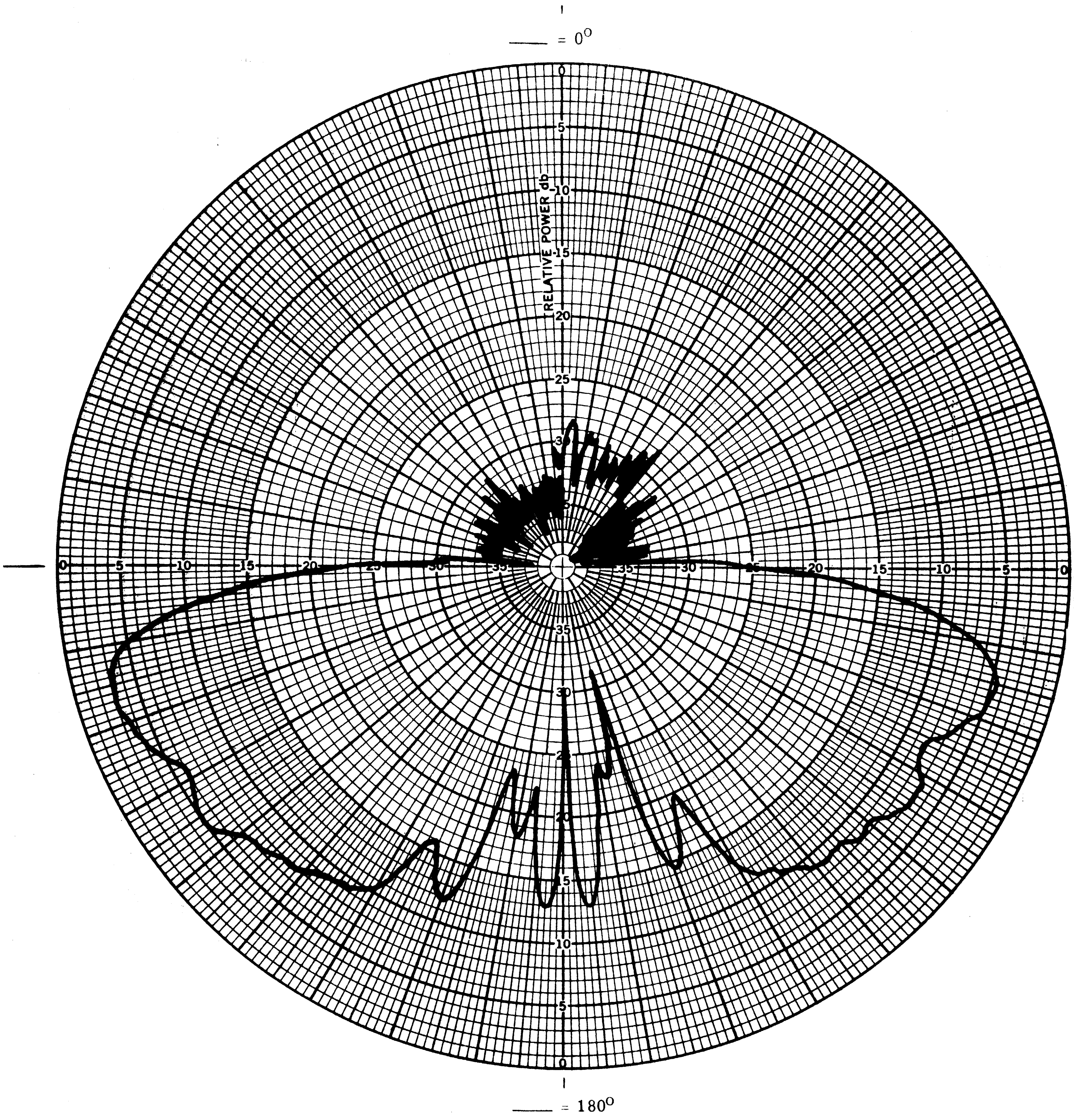


Figure B-45: H-plane pattern, 15.4 GHz, horizontal polarization, $\phi = 0^{\circ}$.

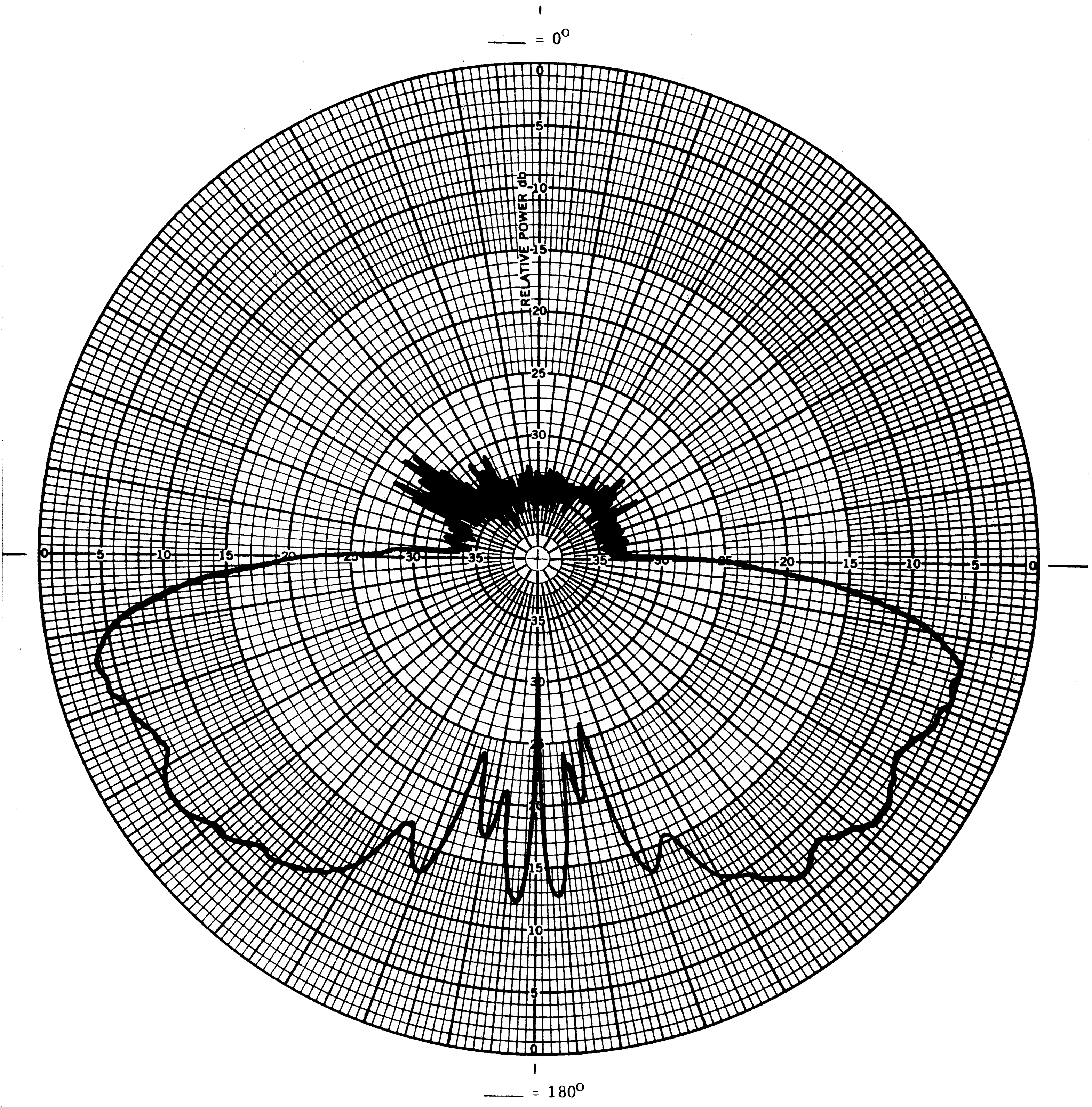


Figure B-46: H-plane pattern, 15.4 GHz, horizontal polarization, $\phi = 45^{\circ}$.

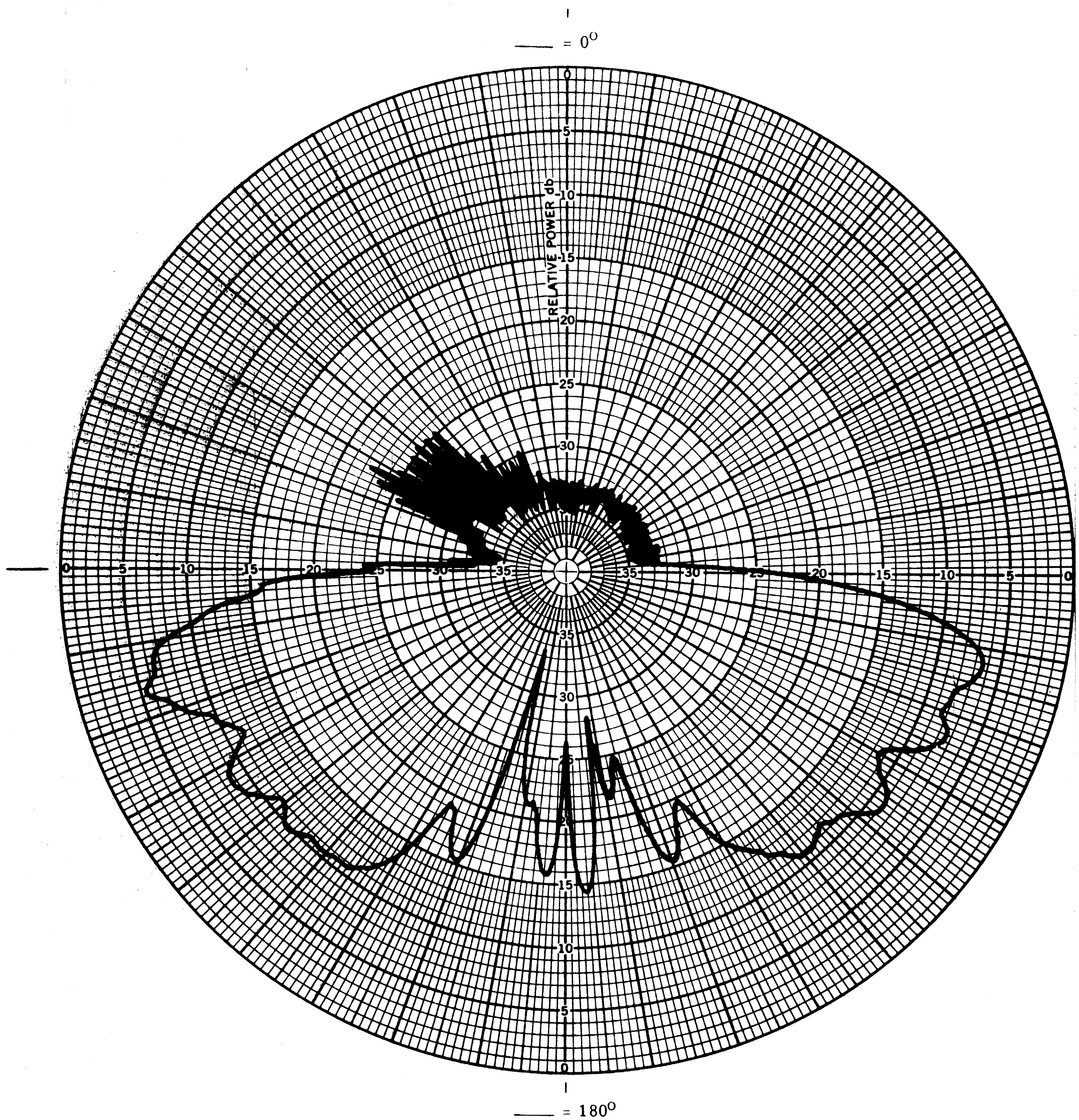


Figure B-47: H-plane pattern, 15.4 GHz, horizontal polarization, $\phi = 90^{\circ}$.

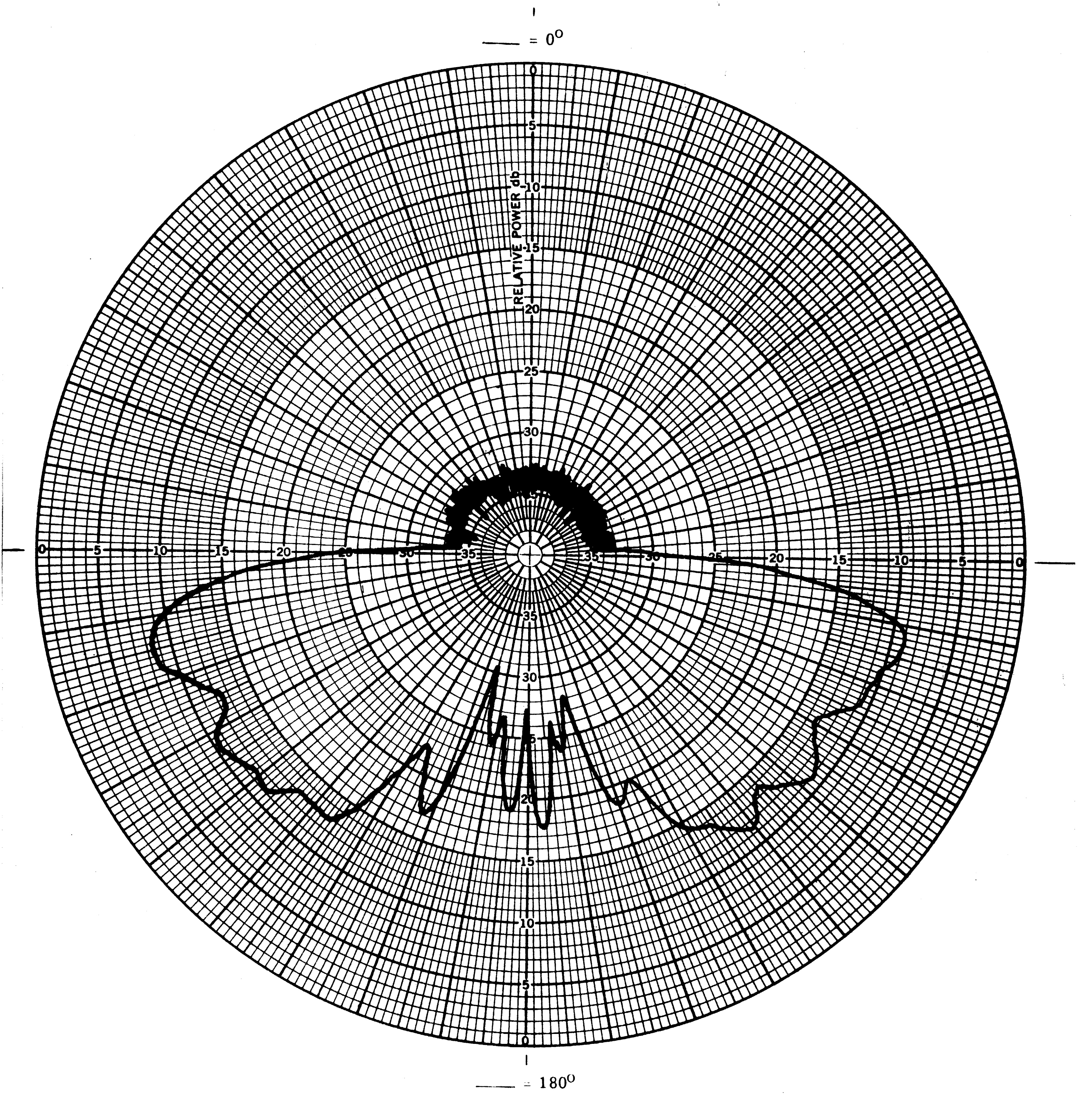
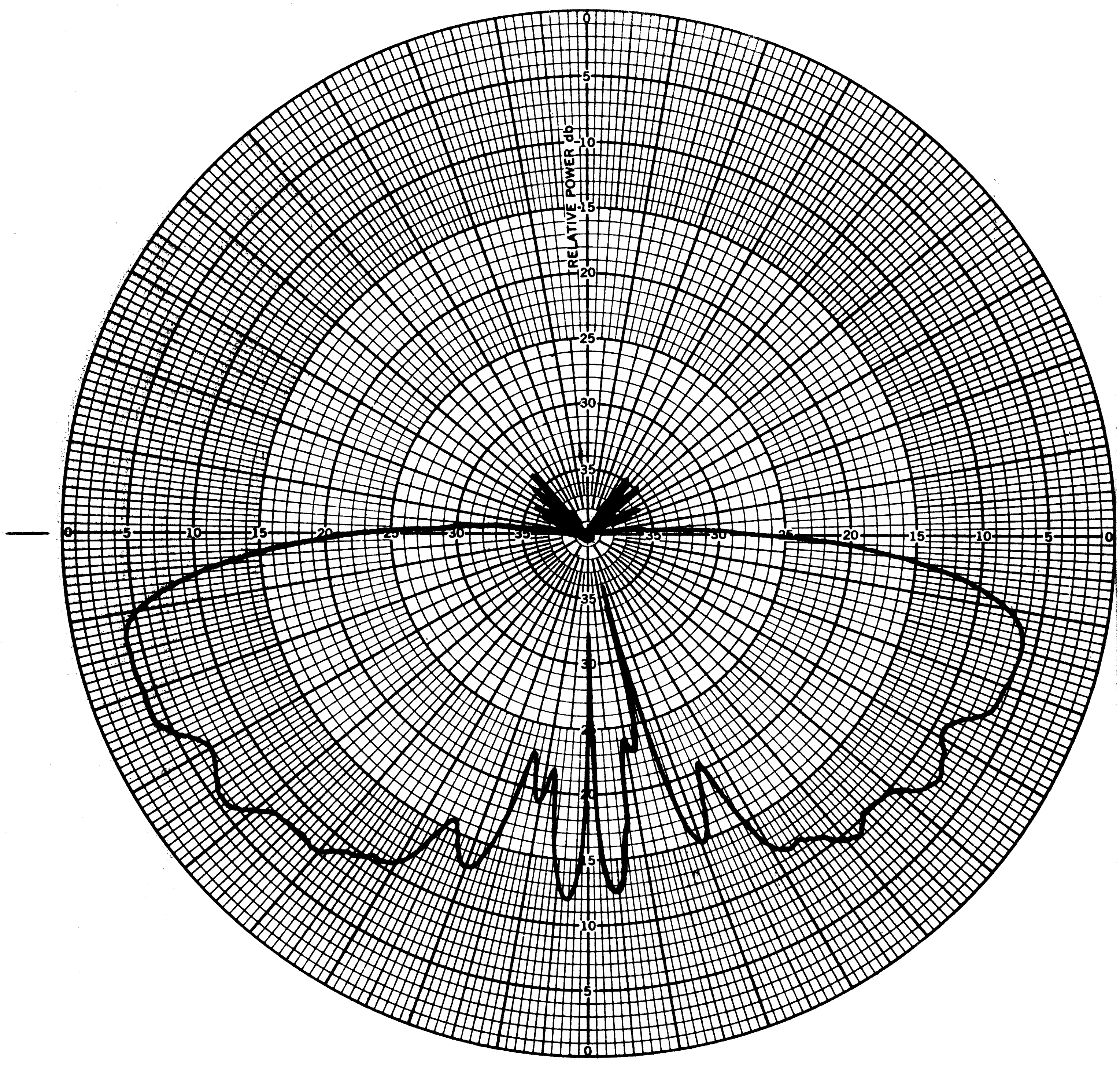


Figure B-48: H-plane pattern, 15.4 GHz, horizontal polarization, ϕ = 135°.

= 0°



= 180°

Figure B-49: H-plane pattern, 15.5 GHz, horizontal polarization, $\phi = 0^{\circ}$.

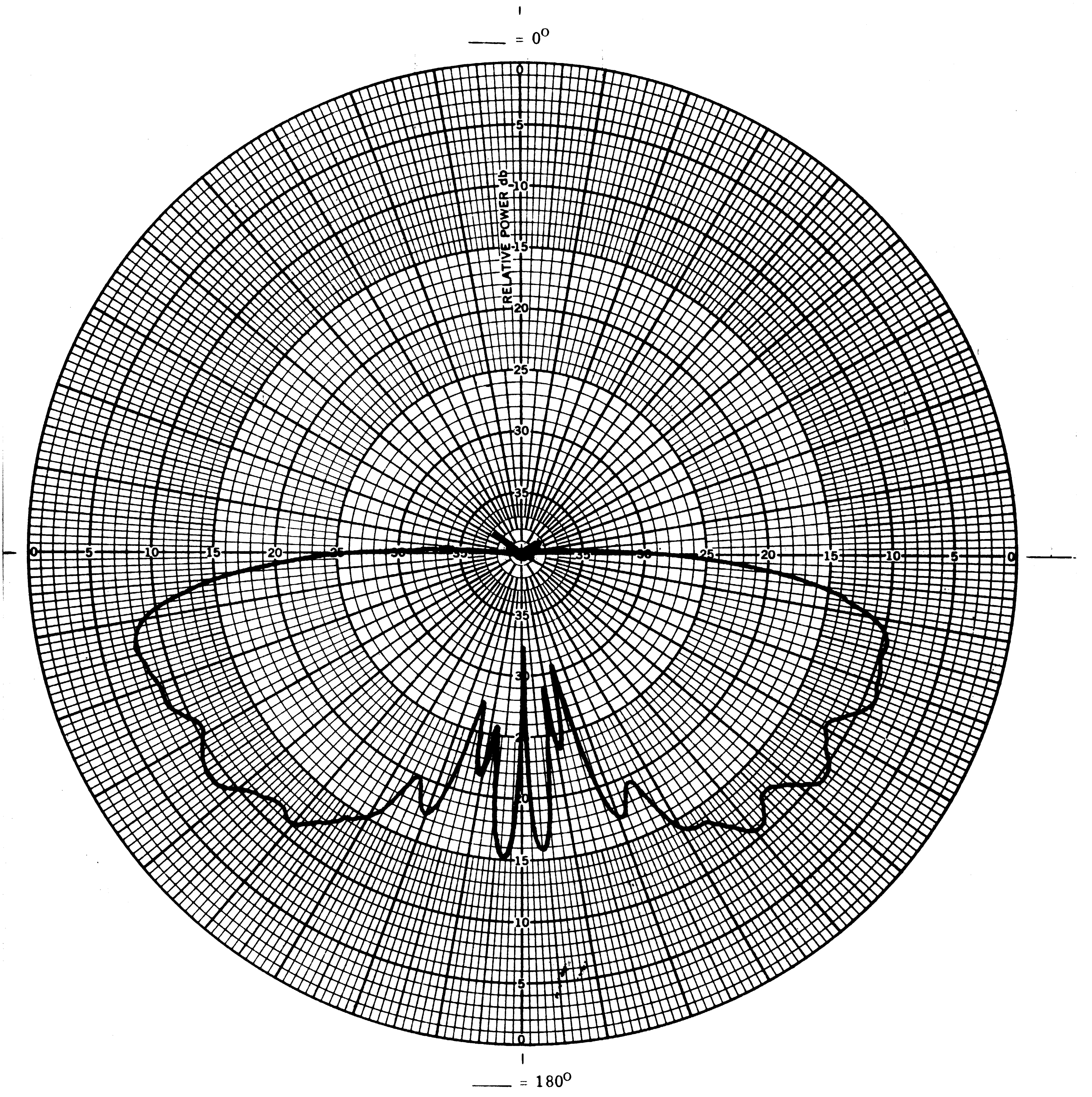


Figure B-50: H-plane pattern, 15.5 GHz, horizontal polarization, ϕ = 45°.

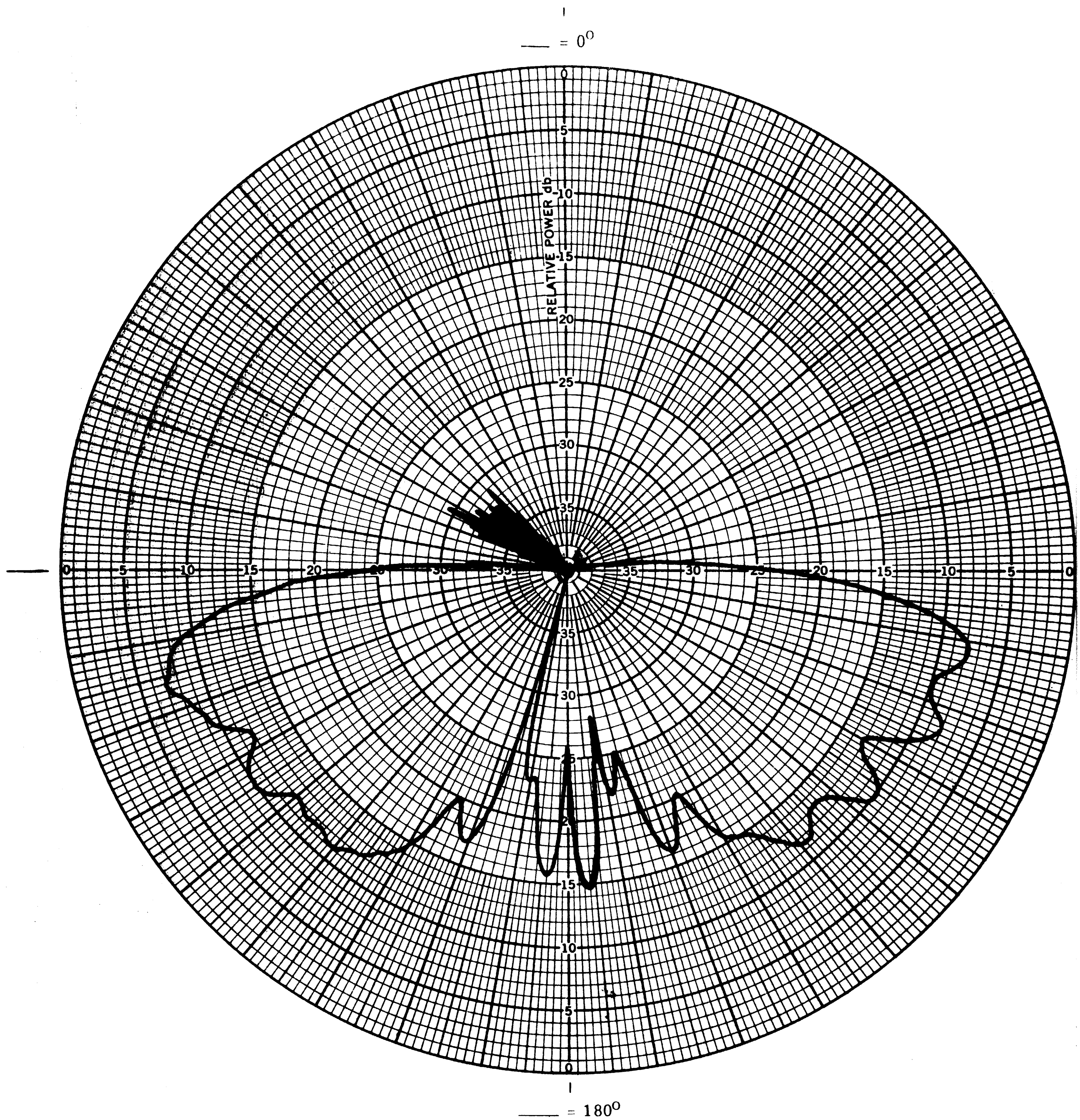


Figure B-51: H-plane pattern, 15.5 GHz, horizontal polarization, ϕ = 90°.

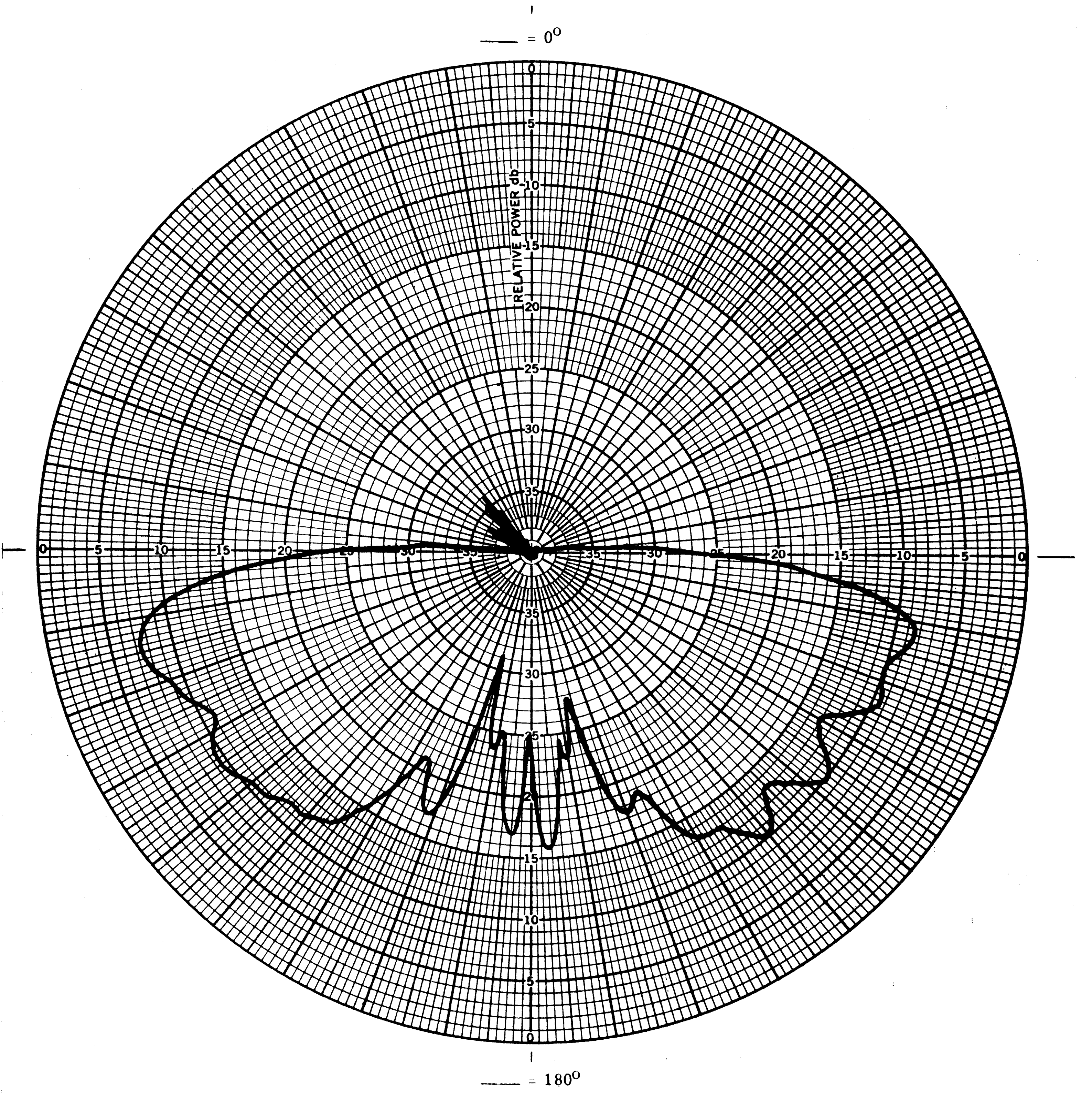


Figure B-52: H-plane pattern, 15.5 GHz, horizontal polarization, ϕ = 135°.

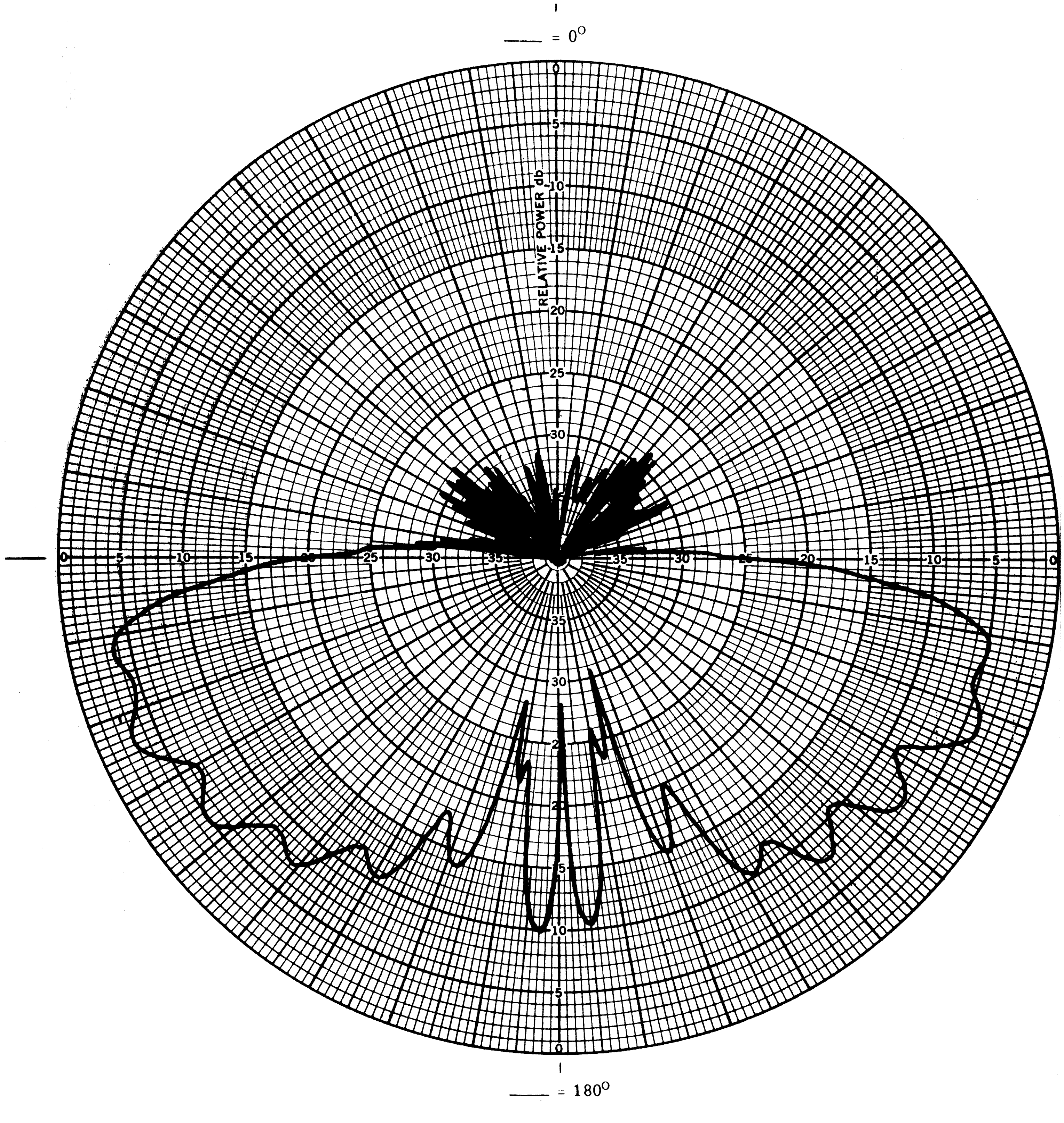


Figure B-53: H-plane pattern, 15.7 GHz, horizontal polarization, $\phi = 0^{\circ}$.

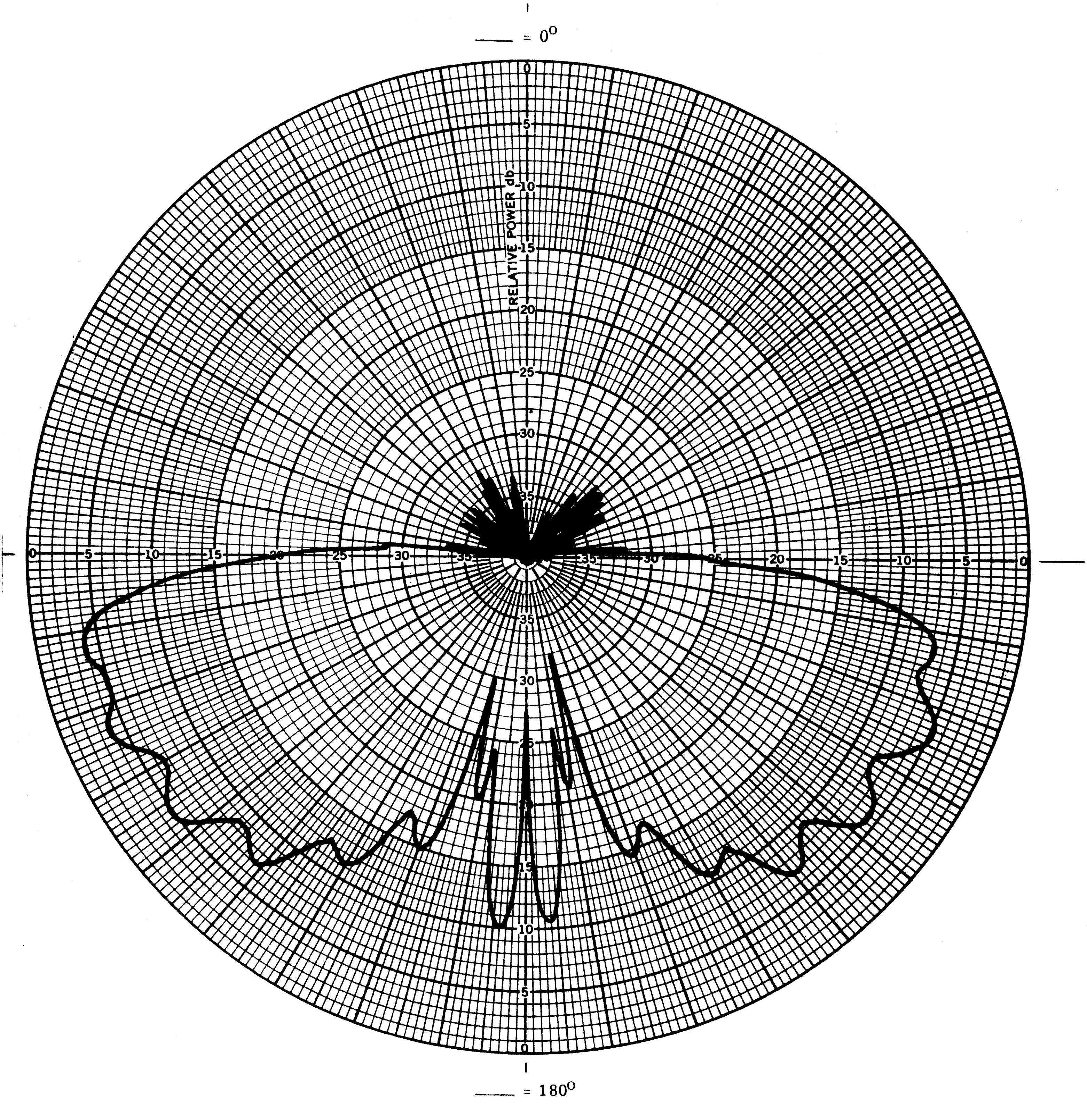


Figure B-54: H-plane pattern, 15.7 GHz, horizontal polarization, ϕ = 45°.

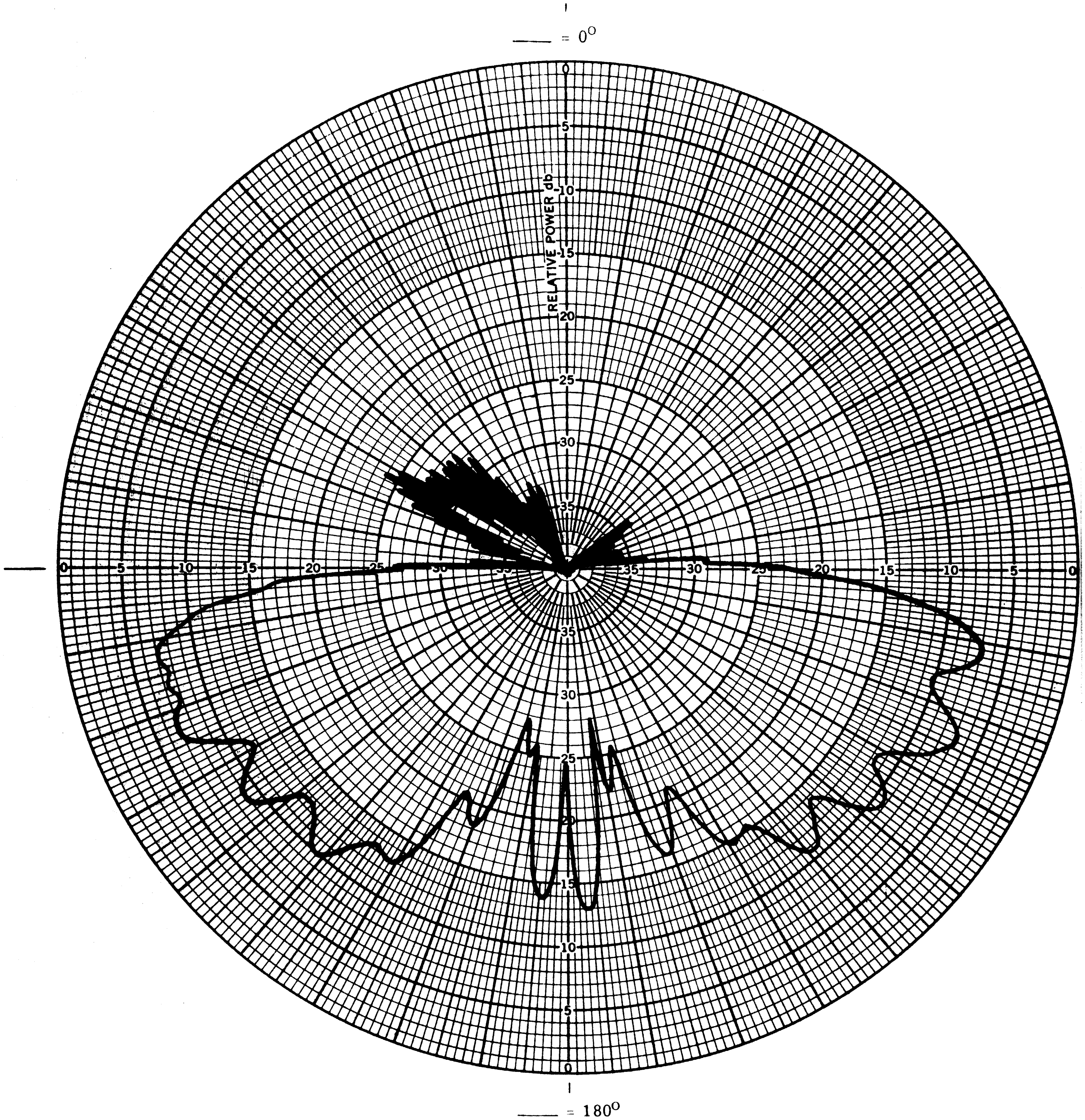
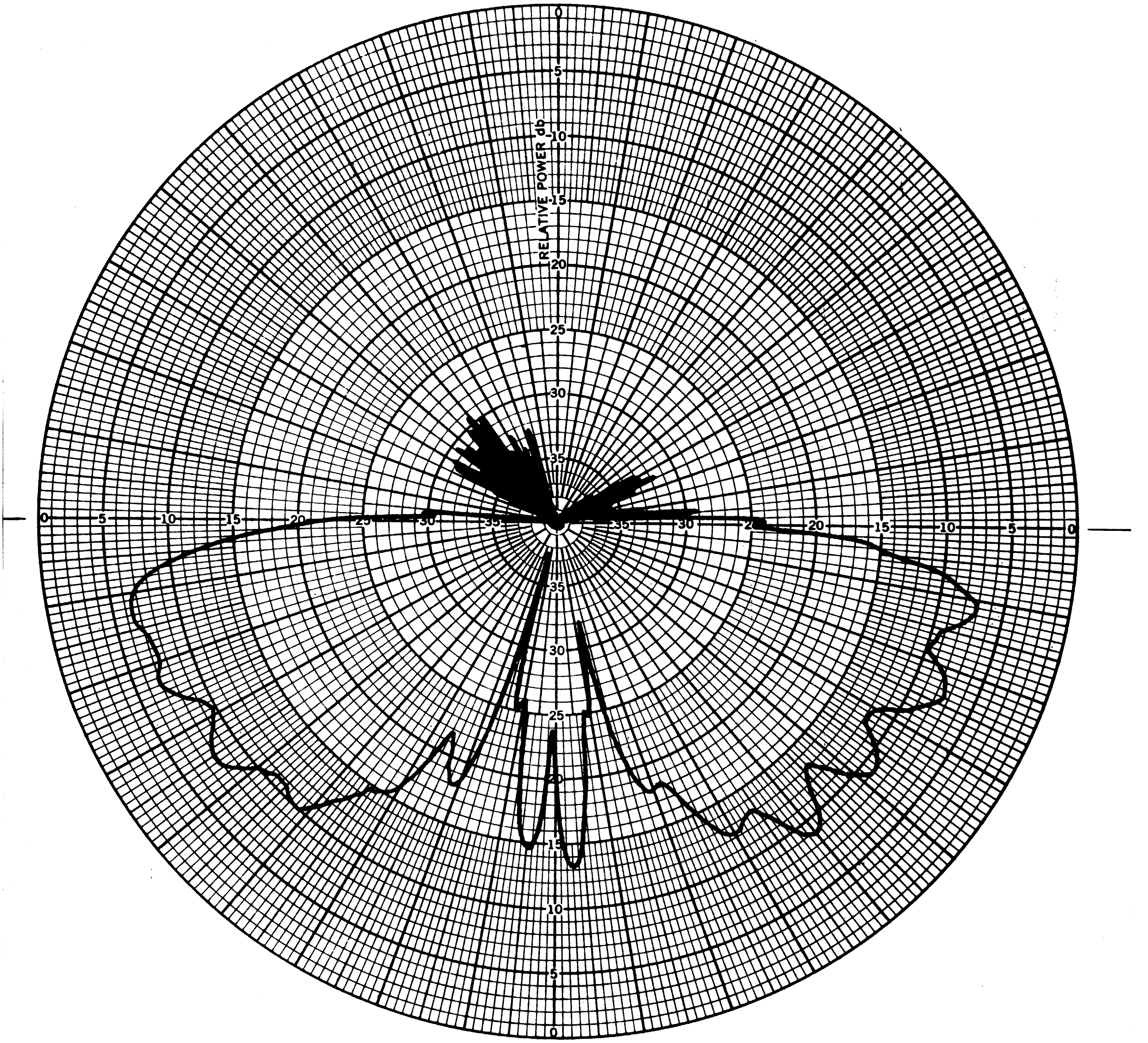


Figure B-55: **H-plane pattern, 15.7 GHz, horizontal polarization, $\phi = 90^{\circ}$.**

$\_\_\_ = 0^o$



$\_\_\_ = 180^o$

Figure B-56: H-plane pattern, 15.7 GHz, horizontal polarization, $\phi = 135^o$.

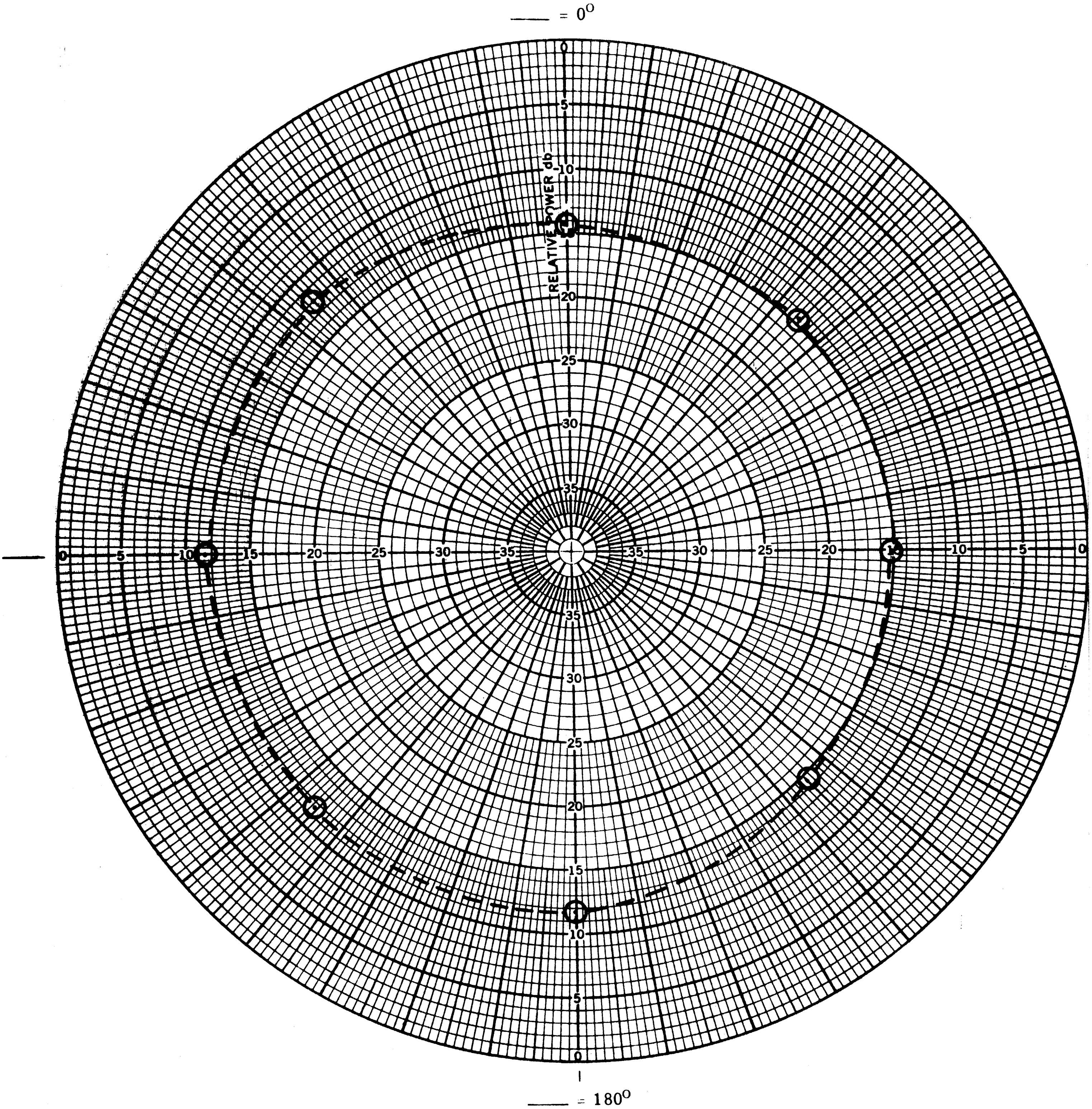


Figure B-57: H-plane pattern, 5 GHz, vertical polarization, $\theta = 0^{\circ}$.

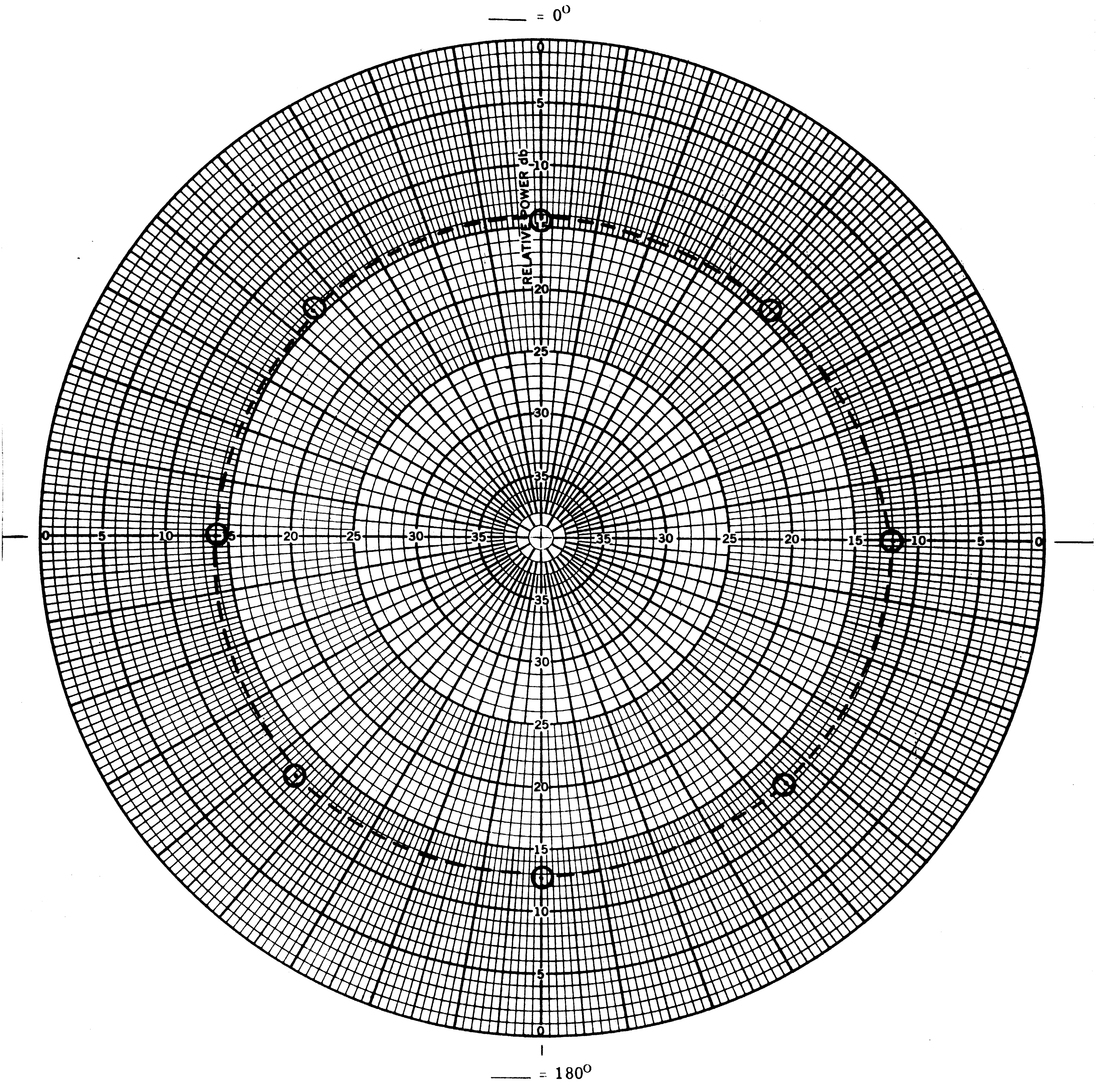


Figure B-58: H-plane pattern, 5.15 GHz, vertical polarization, $\theta = 0^{o}$.

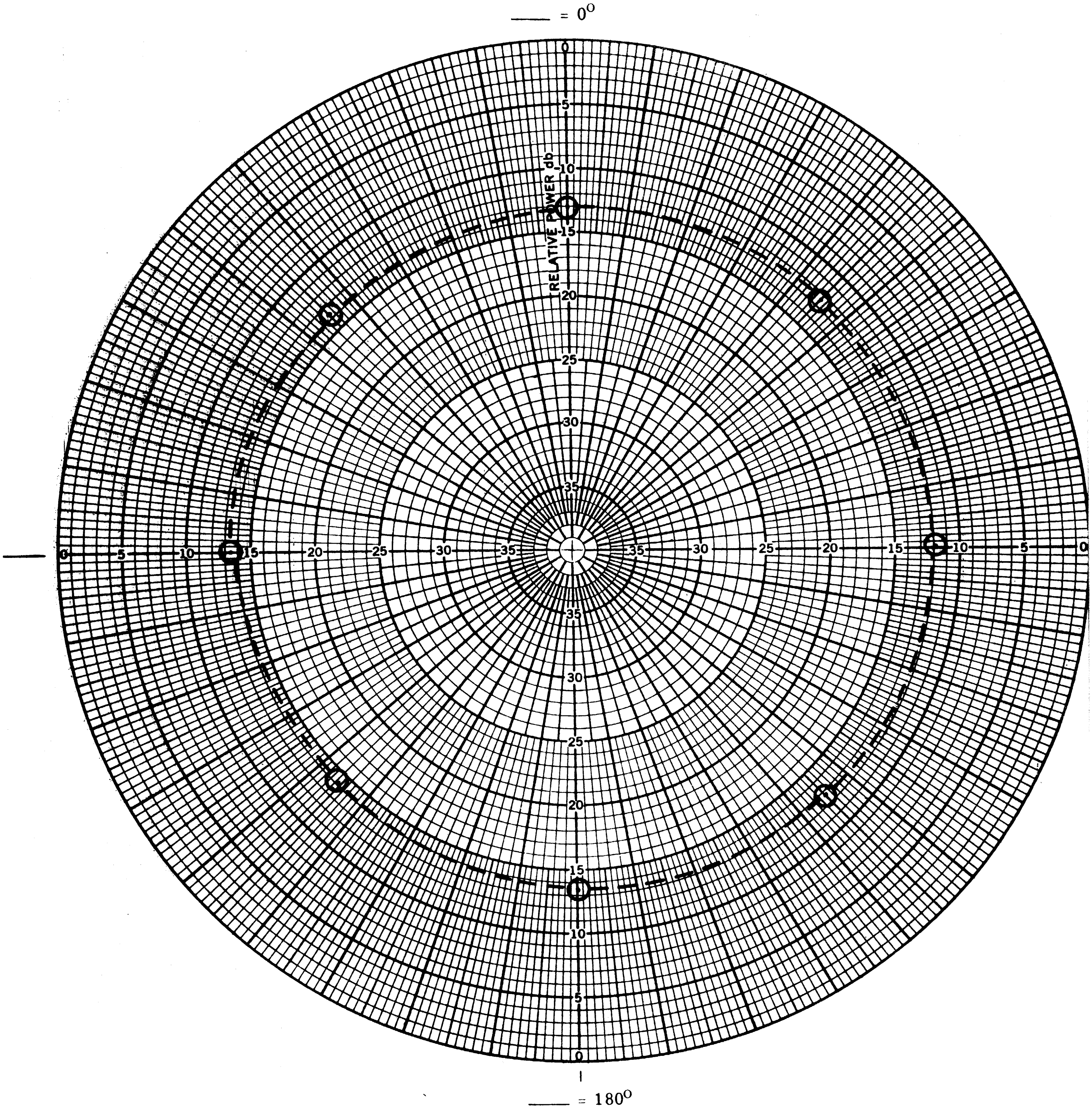


Figure B-59: H-plane pattern, 5.25 GHz, vertical polarization, $\theta = 0^{\circ}$.

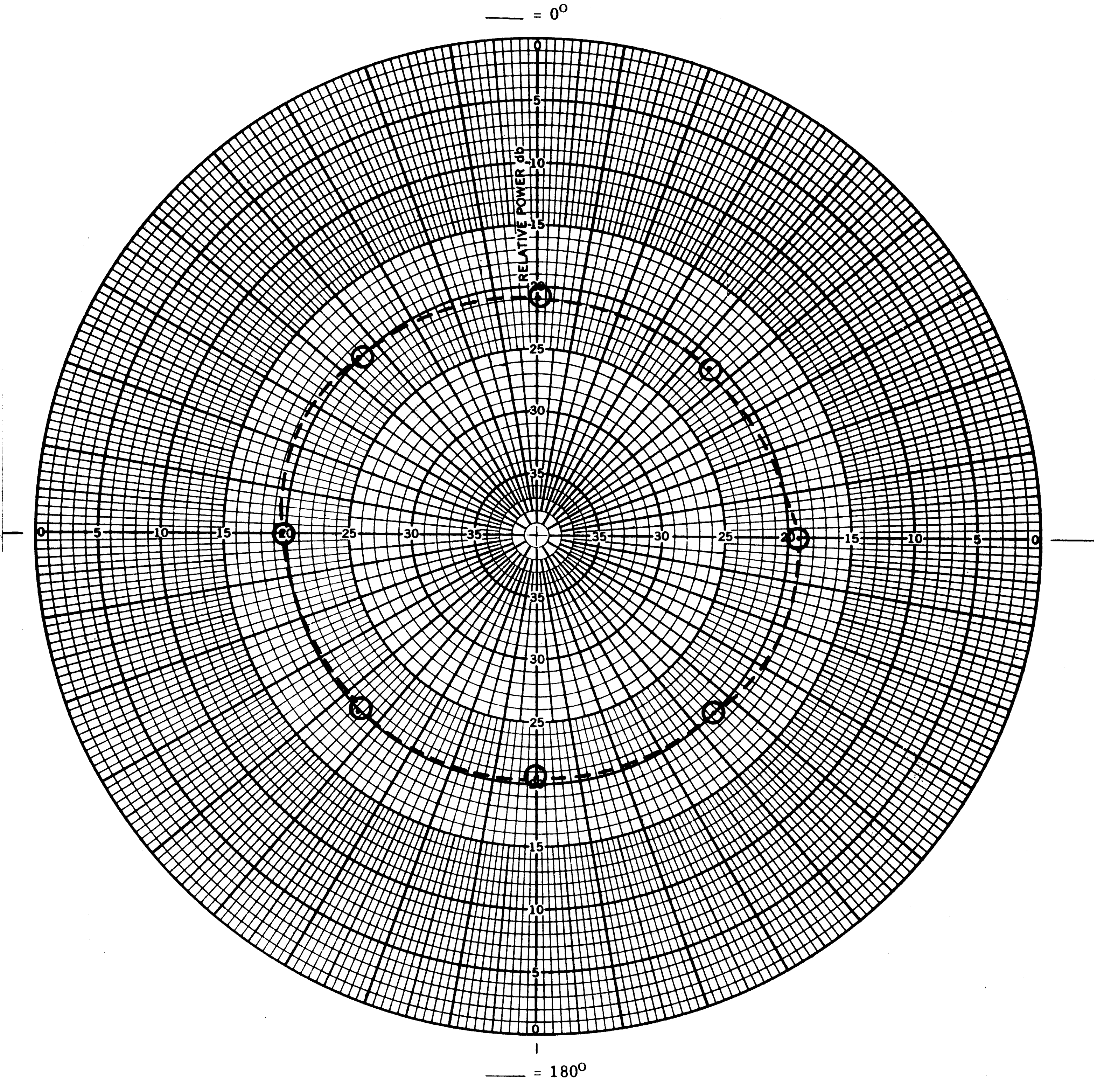


Figure B-60: E-plane pattern, 5.25 GHz,
horizontal polarization, $\theta = 0^{o}$.

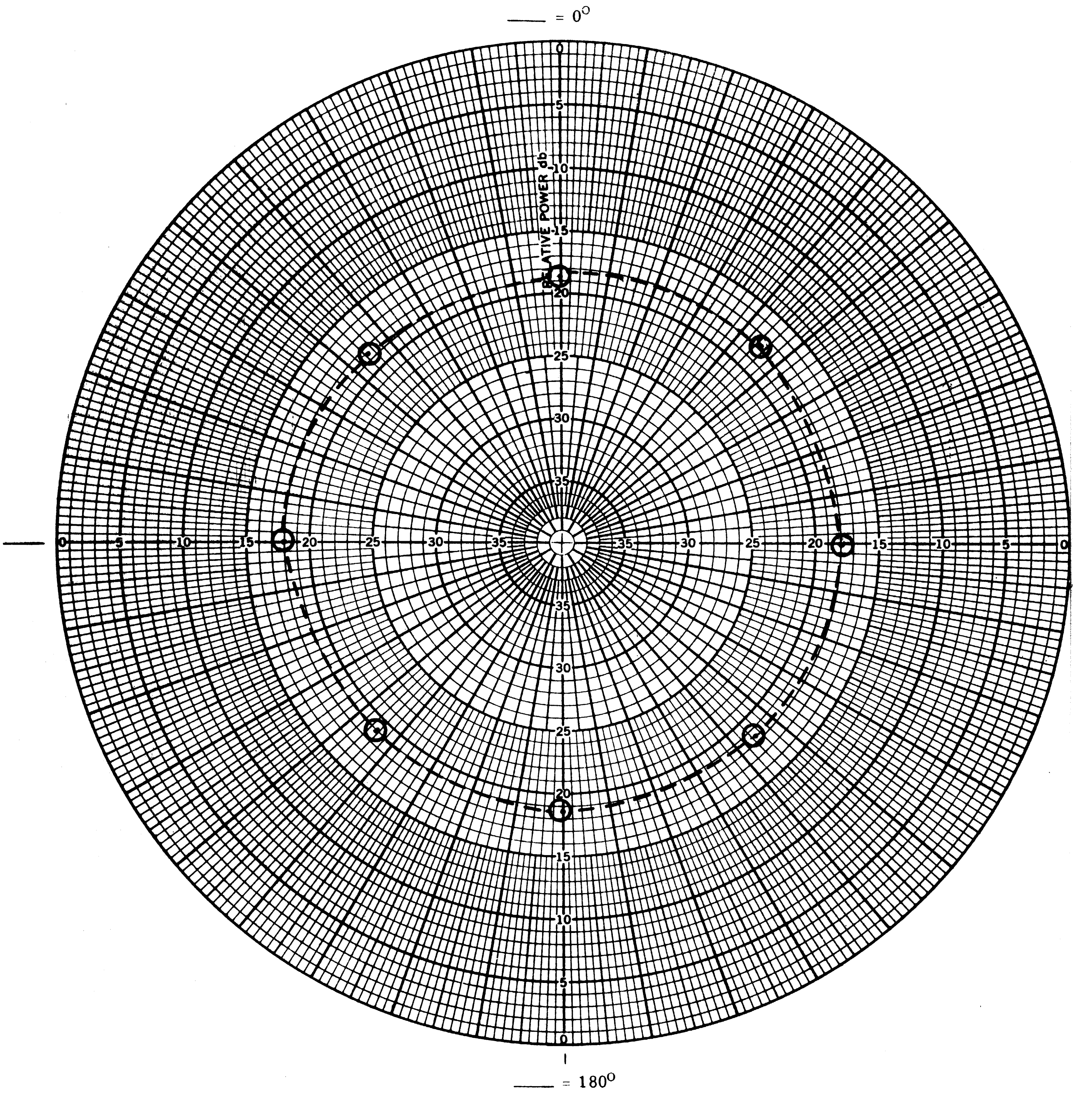
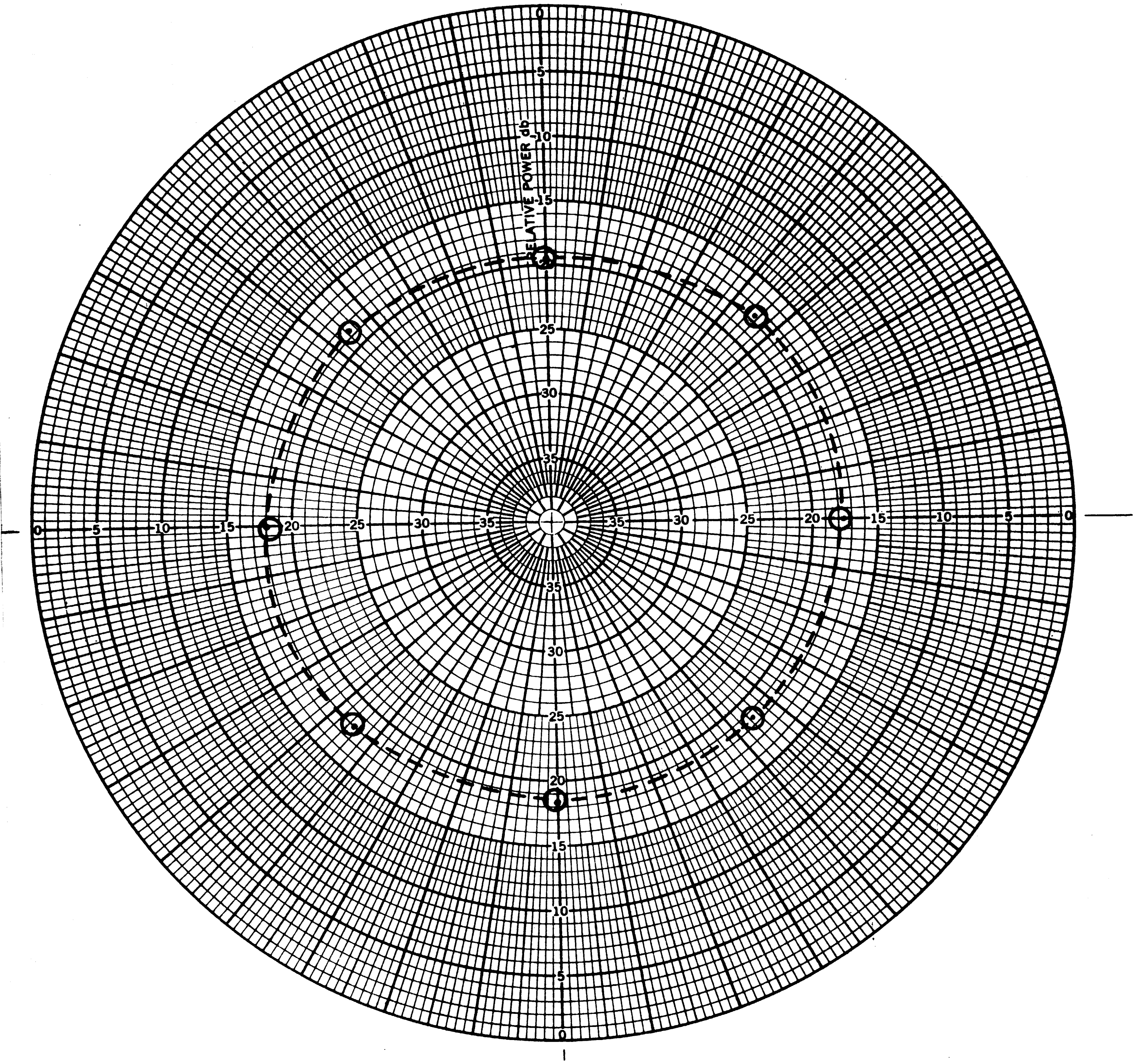


Figure B-61: E-plane pattern, 5. 15 GHz, horizontal polarization, $\theta = 0^o$.

———— = 0°



———— = 180°

Figure B-62: E-plane pattern, 5.0 GHz, horizontal polarization, $\theta = 0^{\circ}$.

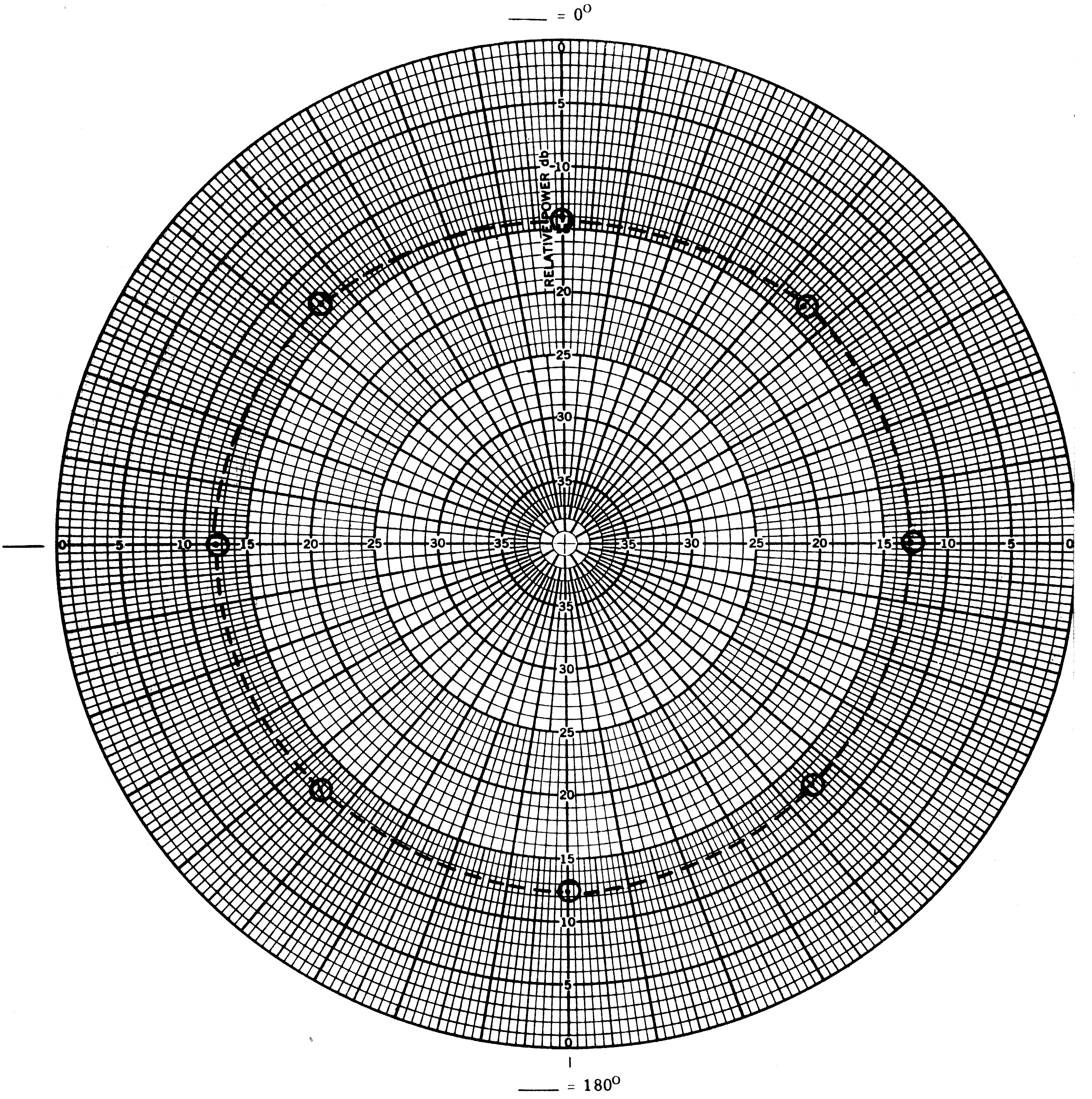
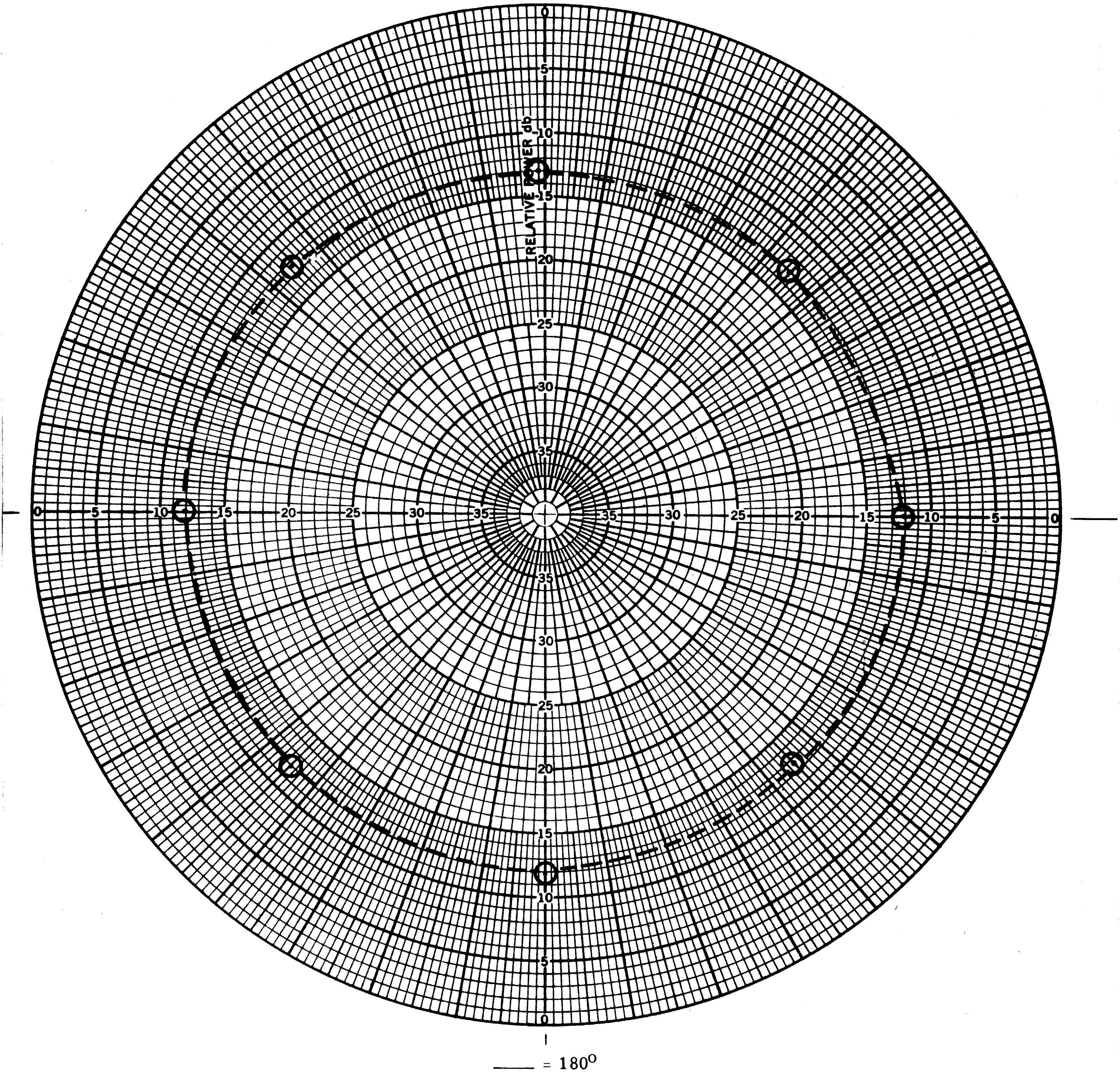


Figure B-63: H-plane pattern, 15.4 GHz, vertical polarization, $\theta = 0^{o}$.

— = 0°



— = 180°

Figure B-64: H-plane pattern, 15.5 GHz, vertical polarization, $\theta = 0^{o}$

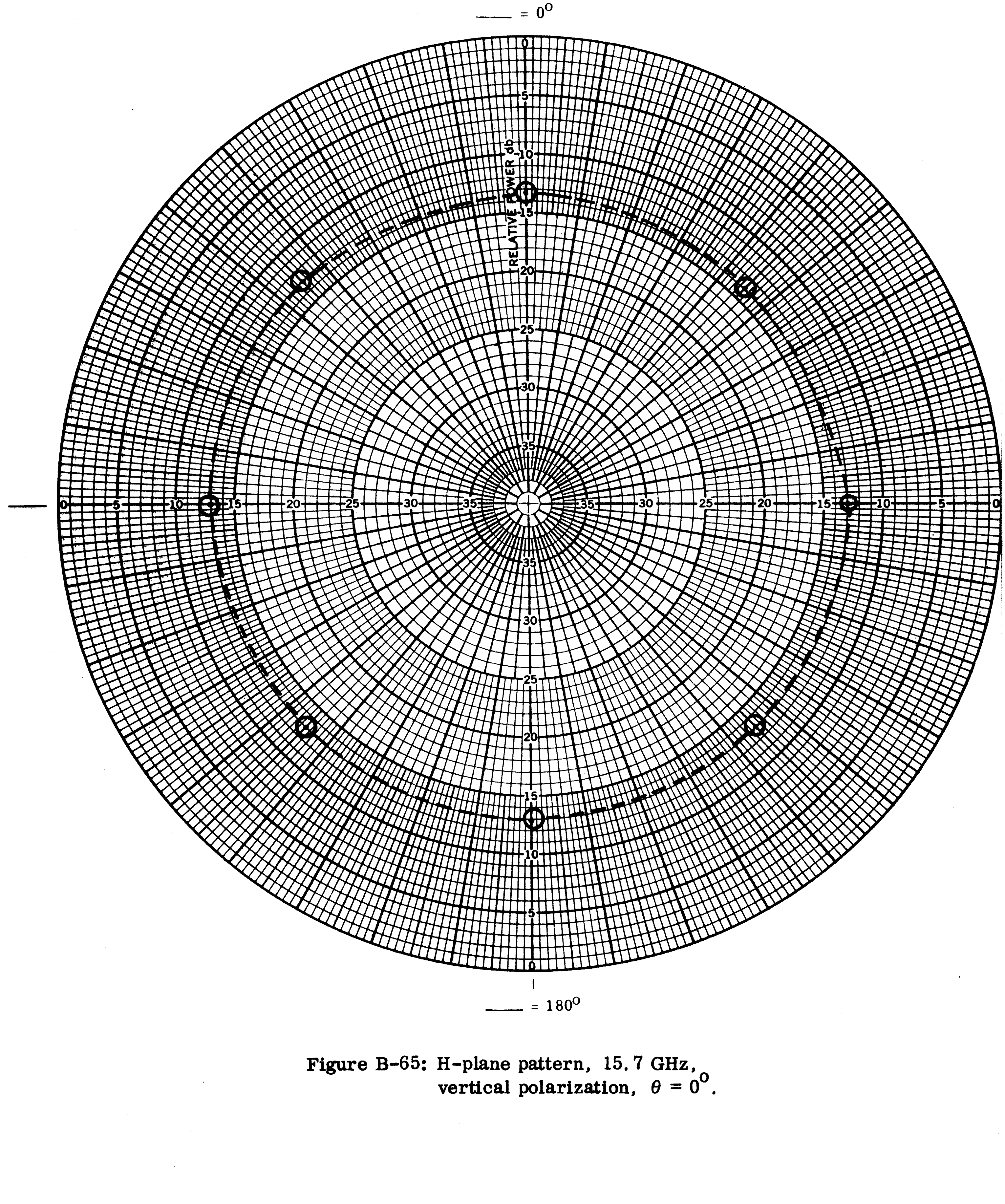


Figure B-65: H-plane pattern, 15.7 GHz, vertical polarization, $\theta = 0^{\circ}$.

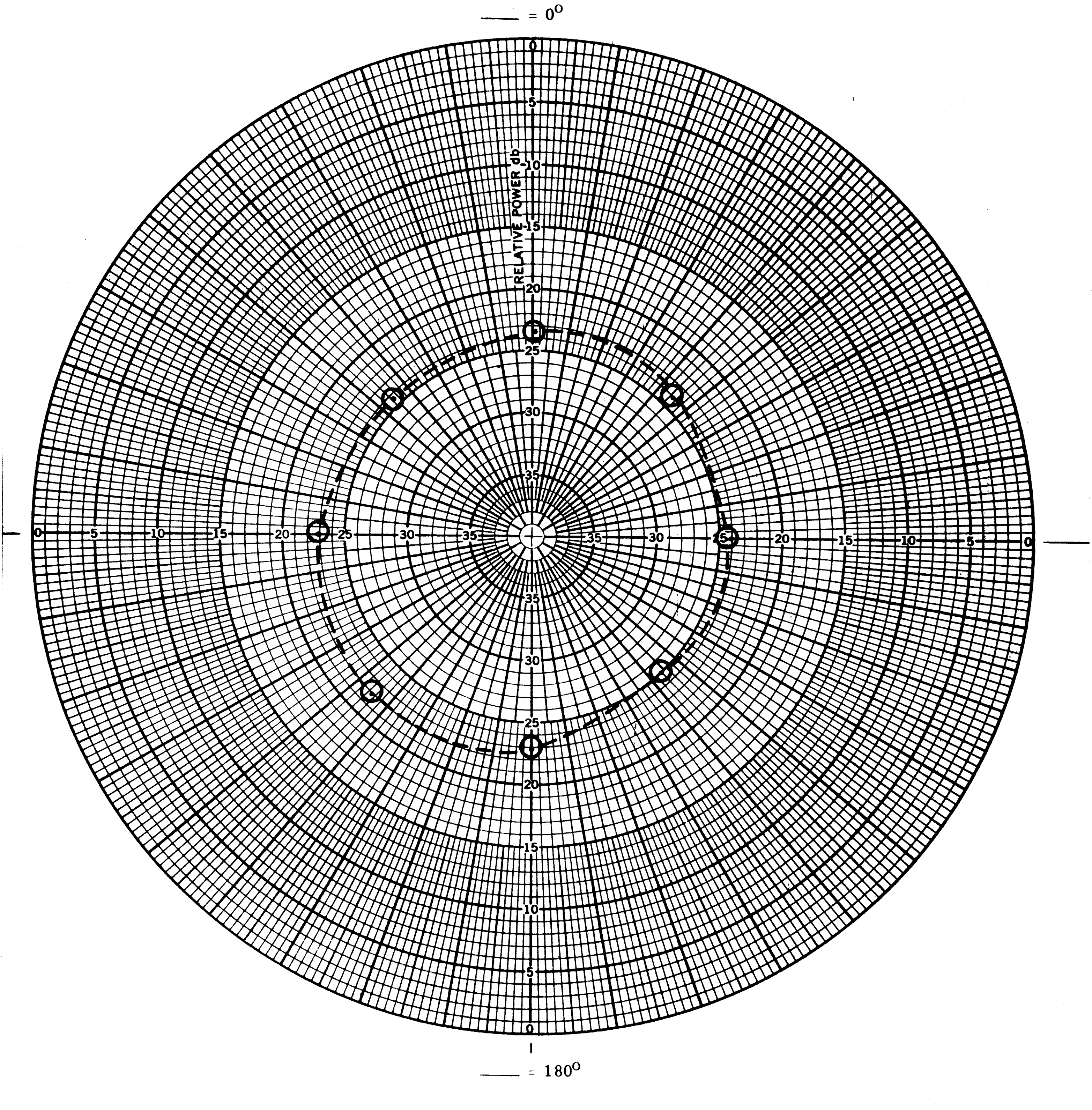
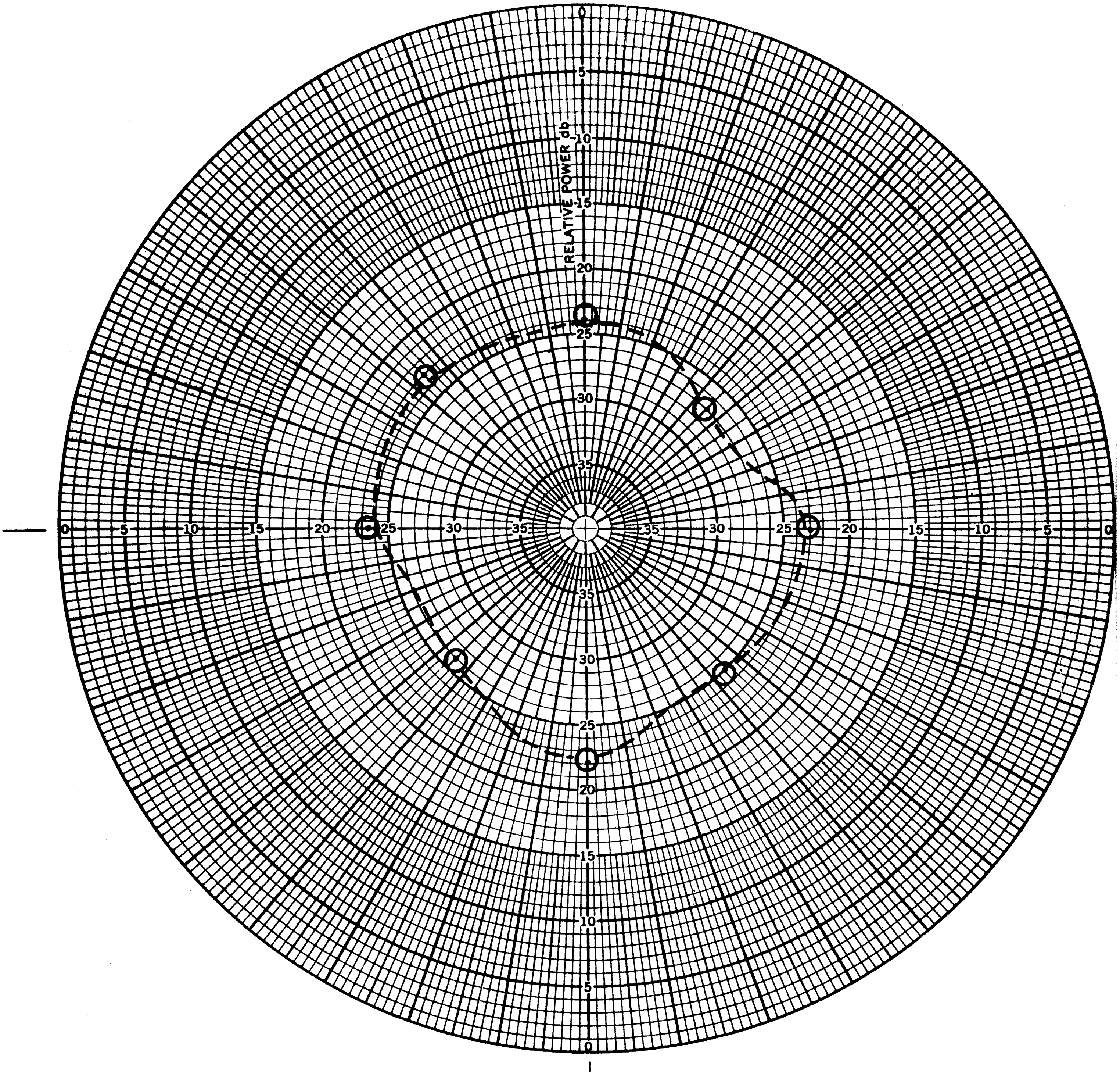


Figure B-66: E-plane pattern, 15.4 GHz, horizontal polarization, $\theta = 0^{o}$.

——— = 0°



——— = 180°

Figure B-67: E-plane pattern, 15.5 GHz, horizontal polarization, $\theta = 0^{\circ}$

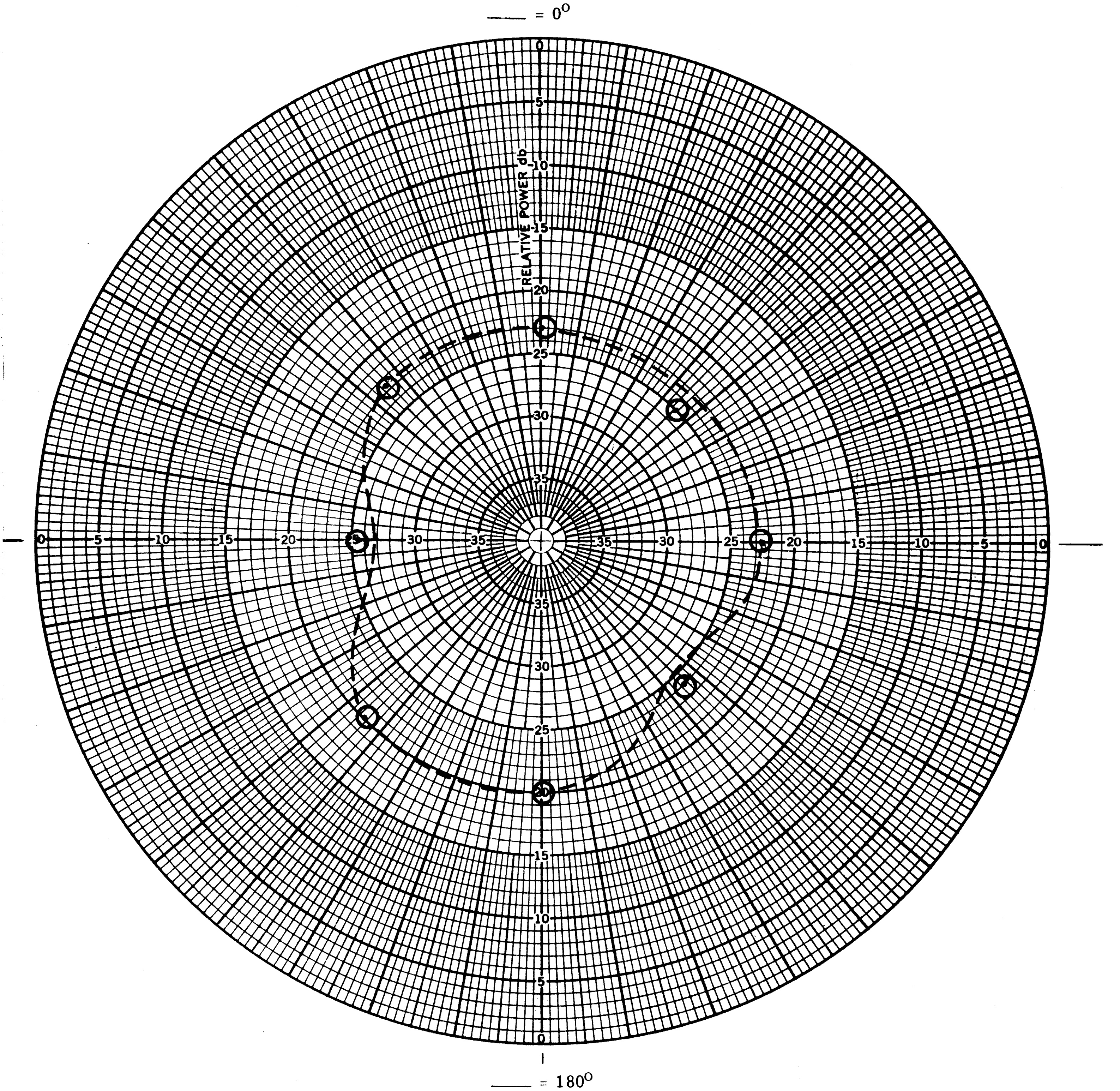


Figure B-68: E-plane pattern, 15.7 GHz, horizontal polarization, $\theta = 0^{o}$.

APPENDIX C

ANTENNA DESIGN SKETCHES

Information that may be helpful in repairing or duplicating the antennas is provided in this section. The waveguide input and transition section used for both antennas is shown in Figure C-1. Dimensions for the vertically polarized antenna are given in Figure C-2. Those for the horizontally polarized antenna feed are given in Figure C-3. Dimensions for the horizontally polarized K_u band and C band antennas are given in Figures C-4 and C-5 respectively. The feed system used for the horizontally polarized feed is shown in Figure C-6.

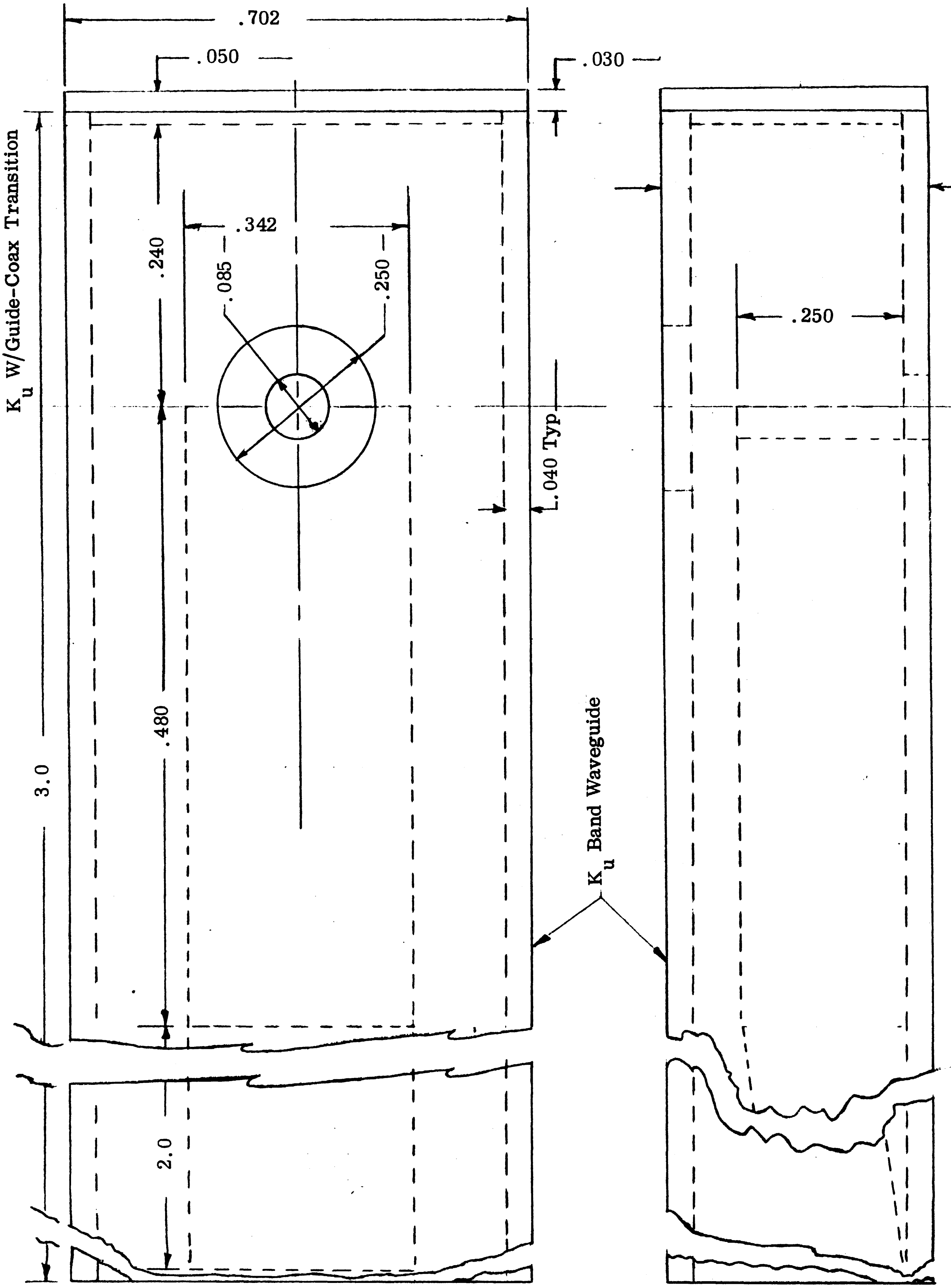


Fig. C-1: Dual Band Antenna Input

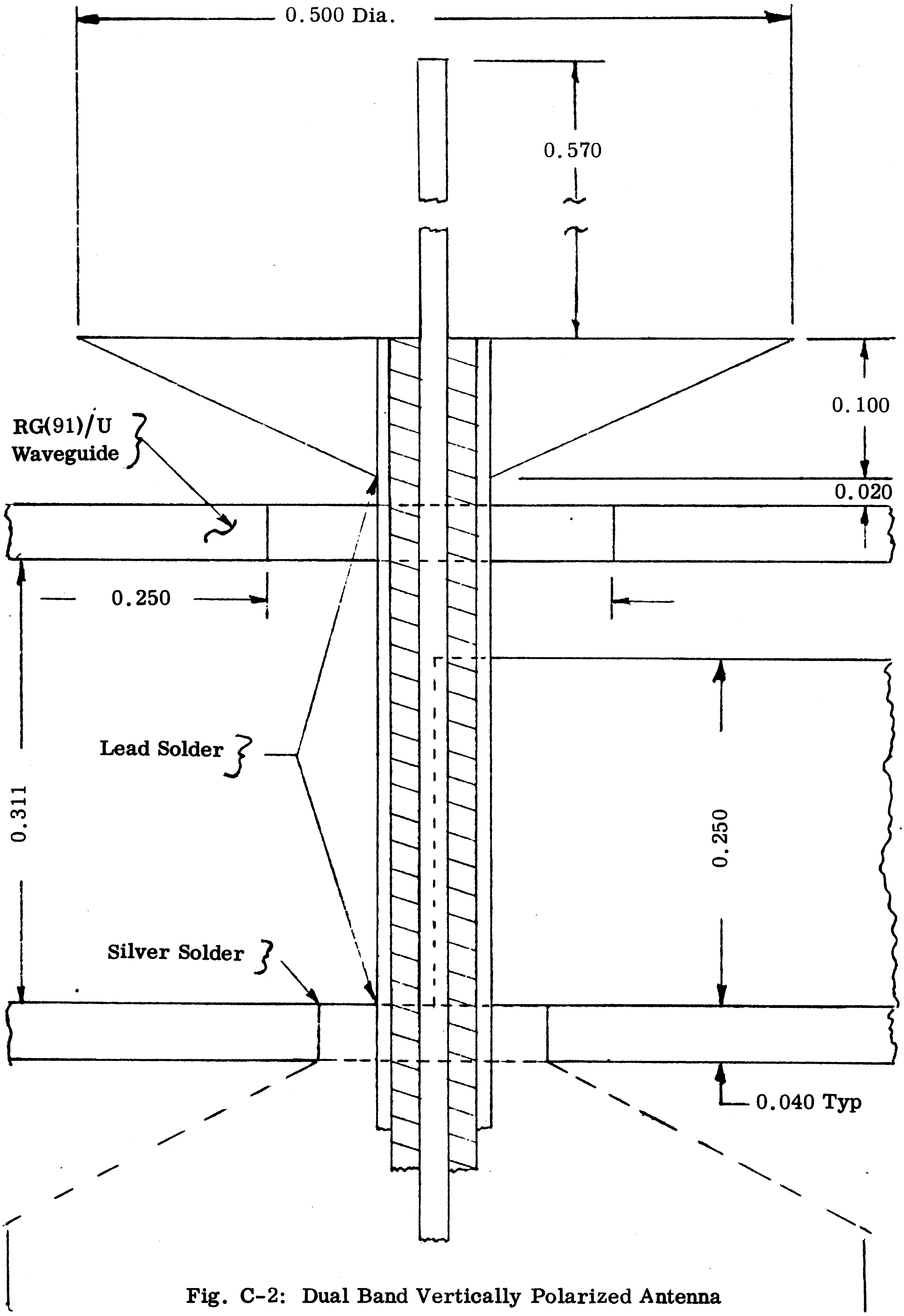


Fig. C-2: Dual Band Vertically Polarized Antenna

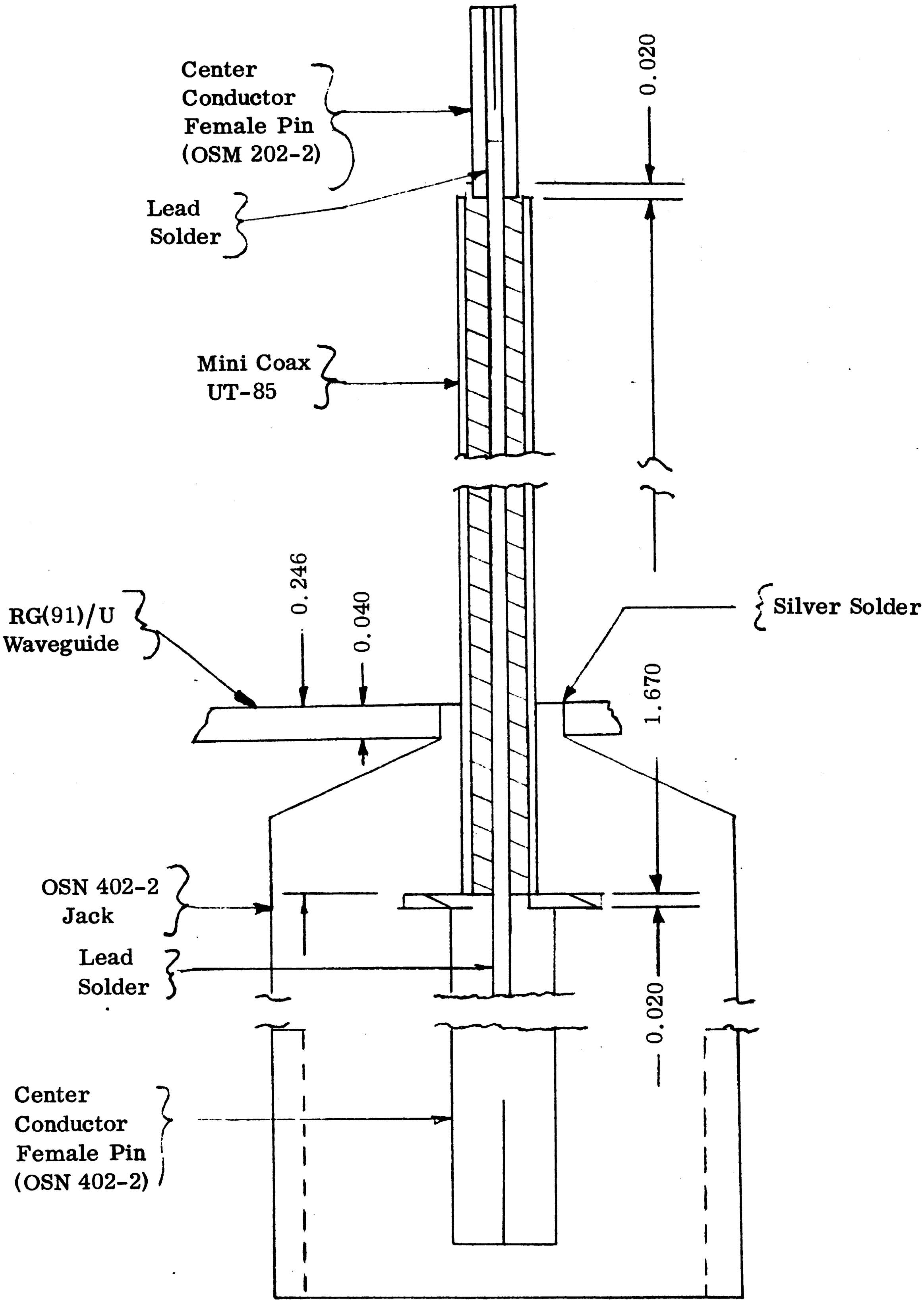


Fig. C-3: Dual Band Horizontally Polarized Antenna Feed

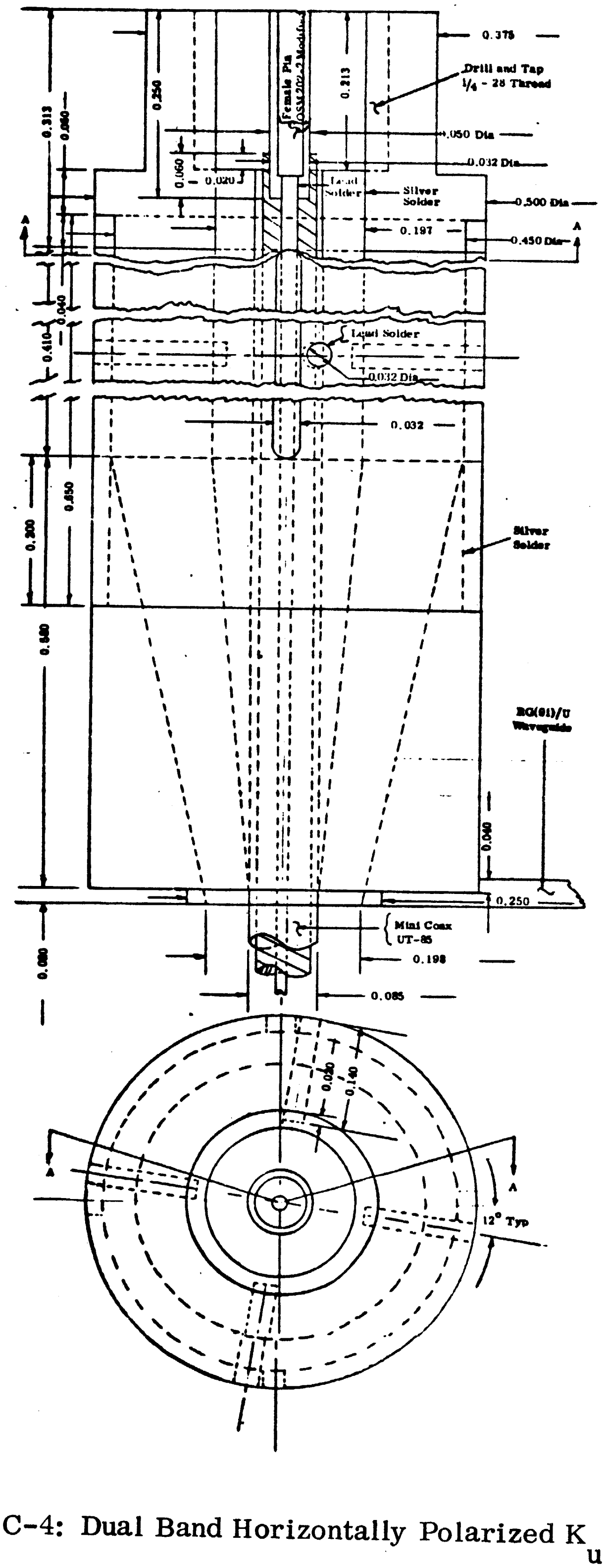


Fig. C-4: Dual Band Horizontally Polarized K_u Band Antenna.

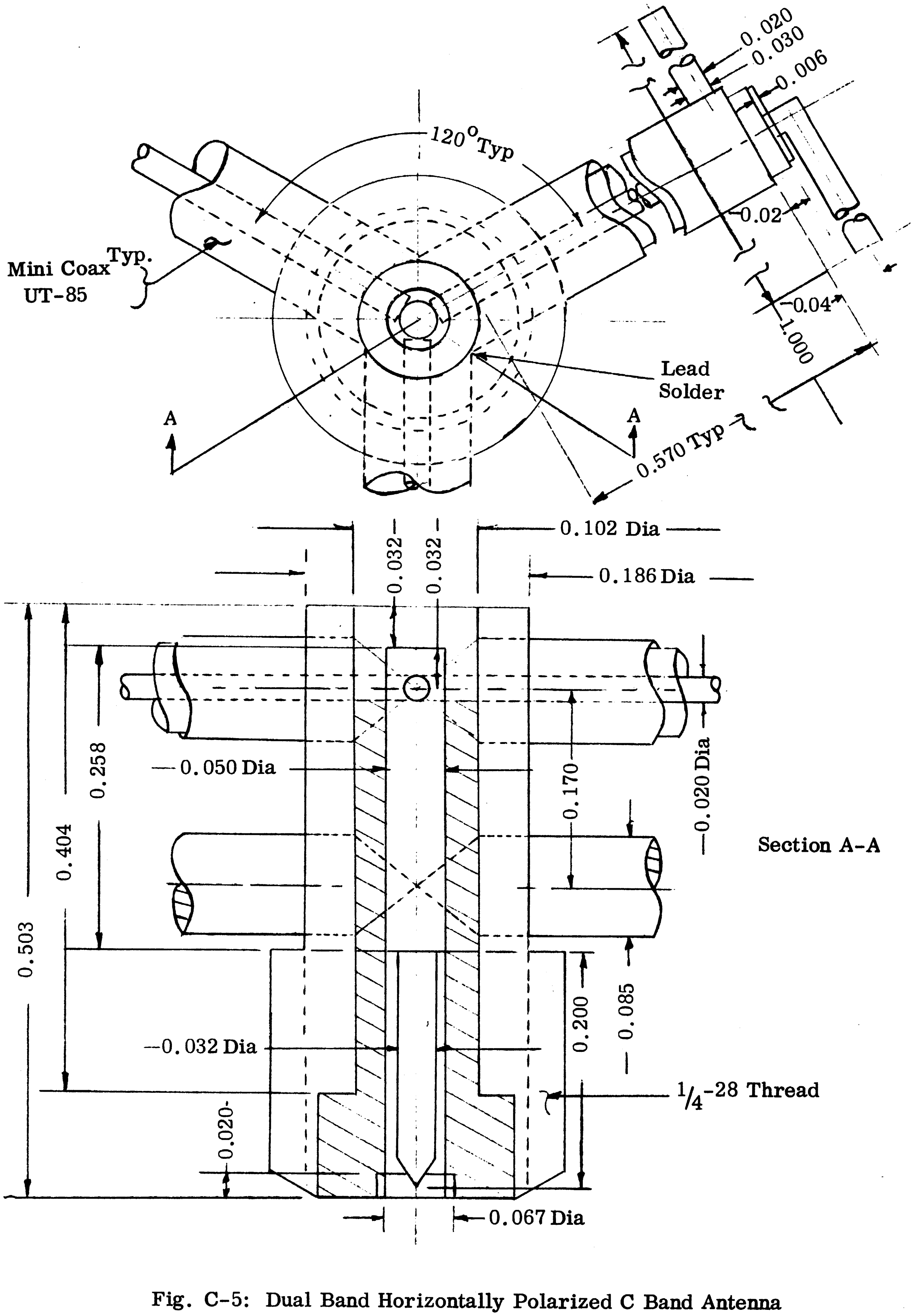


Fig. C-5: Dual Band Horizontally Polarized C Band Antenna

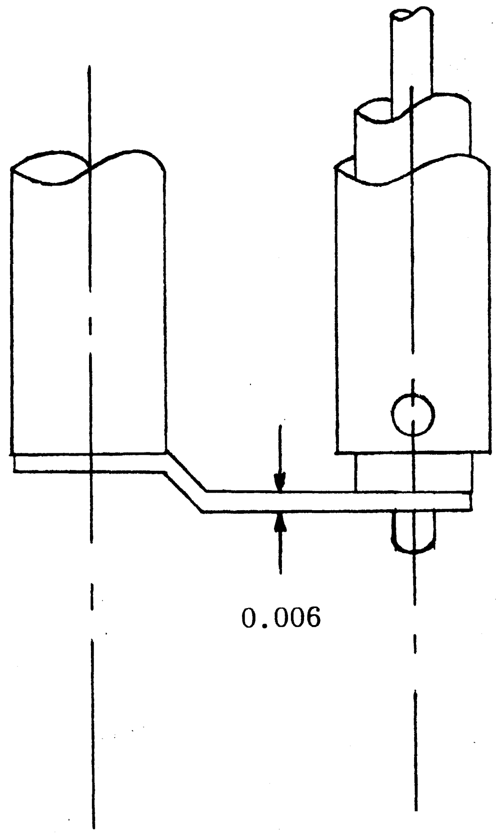


Fig. C-6: Dual Band Horizontally Polarized
C Band Antenna Feed