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MEASURED PERFORMANCE
OF AN HF
LOG-PERIODIC ANTENNA

by

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NBS

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NATIONAL BUREAU OF STANDARDS
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FOREWORD

This report presents the results of measurements made on an HF log-periodic antenna located in Northern New York State.

The measurements were made by the Antenna Research Section of the Radio Systems Division, National Bureau of Standards, Boulder Laboratories, at the request of the Ground Electronics Engineering Installation Agency in co-operation with RADC. The work was carried out as project 85454, USAF Operational Antenna Measurements.

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Abstract

The performance of an operational log-periodic antenna was tested at frequencies of 12, 18, 24, 36, 48, and 60 Mc/s. At each frequency, values of impedance, gains, and radiation patterns were measured. In addition, radiation patterns were measured at 18 Mc/s with the axis of the antenna rotated to different bearing angles. This measurement was designed to estimate the influence of terrain and adjacent structures on the pattern response of the test antenna.

Values of voltage standing-wave ratio measured less than 1.32:1 at the different frequencies of operation. Measurements in the midfrequency range showed higher gains and narrower beamwidths in contrast to measurements at the lower and higher frequency limits of operation. Gains, slightly in excess of 6 decibels - relative to a dipole - and 66-degree-wide horizontally polarized beamwidths were measured from 18 to 48 Mc/s, as contrasted with 4.5 decibels and approximately 75-degree-wide beamwidths at the 12 and 60 Mc/s frequencies of operation.

The influence of adjacent structures and terrain had distorting effects on the radiation patterns, resulting in reduced gain in the forward direction.

The performance of the antenna, in general, conformed to the data available from the manufacturer. However, observed gains and beamwidth measurements were not constant over the full frequency range.

1. INTRODUCTION

The purpose of this report is to present and evaluate the characteristics of an HF operational log-periodic antenna, with respect to impedance, gain, beamwidth and front-to-back ratio over a 5-to-1 frequency range. The antenna, located in upstate New York, was tested over the period from November 9, 1959 to December 11, 1959.

2. ANTENNA AND SITE

The log-periodic antenna, which exhibits relatively constant characteristics that vary periodically as the logarithm of the frequency over an extremely wide band of frequencies, was first introduced by R.H. DuHamel and D.E. Isbell.[1] Although they present the theoretical aspects underlying the broadband characteristics, a limited discussion was included concerning the mechanics of the radiation properties of the antenna.

In a more recent paper, however, R.L. Bell, C.T. Elfving, and R.E. Franks[2] present the theory of operation, substantiated by measurements, describing the radiation properties of a type of log-periodic antenna similar to that tested. They show that the antenna supports a TEM transmission wave which launches the far-field radiation wave. The TEM wave terminates in an active region consisting of 5 elements within the antenna and centered around the $\lambda/2$-long resonant element. Due to the direction, magnitude, and phase relationship of the current and electric field distribution on the elements within this region, a radiation field is enhanced and propagated in the reverse direction of the transmission-line wave. The extremely wide bandwidth operation is due to the selected antenna design and geometry, whereby the electrical characteristics vary periodically with the logarithm of the frequency.

According to the available manufacturer's data, the antenna tested provides a substantially uniform impedance characteristic, a gain of approximately 6 decibels relative to a dipole, and a horizontally polarized half-power beamwidth of 65 degrees over a frequency bandwidth from 11.1 to 60 Mc/s.

The antenna consists of an arrangement of 13 tapered transverse elements mounted to two 41-foot-long steel booms. These elements are oriented to form an angle of 37 degrees. The array is located at a height of 75.5 feet above ground, and is mounted to a single rotatable structure, as shown in Figure 1. Construction details of one plane of the antenna are presented in Figure 2.

The nominal 150-ohm antenna impedance is matched to 50 ohms by employing tapered sections of coaxial line located within the lower boom section of the array. The rotatable, motor-driven, vertical shaft comprises the 50-ohm feed line, and connects the antenna to a rotating 3-1/8-inch coaxial joint located at the base of the array.

Because of its extreme broadband characteristic, the antenna is adaptable to communication systems where operational frequencies require repeated changing without the necessity of additional structures or arrays.

Figure 3 is a topographic view of the operational test site. It shows the location of the different antenna arrays, towers, and buildings in the vicinity of the antenna tested.

3. METHODS OF MEASUREMENT

At each test frequency, impedance, gains, and radiation patterns were measured, using commercially available test equipment.

The input impedance to the antenna was measured remotely through a 300-foot length of RG-9 coaxial cable. By introducing line-length corrections in each case, the impedance at the coaxial input connection to the antenna was determined.

The gain and radiation patterns were measured with the log-periodic antenna used as a receiving antenna, matched to 50 ohms for each test. A 300-foot-long coaxial cable connected the antenna to the receiver-recording equipment located in a nearby van. An equal length of cable was connected and matched to the reference dipole antenna, located at the same height as, and approximately 500 feet to one side of, the test antenna. Cable losses were measured for each antenna and found to be within 0.1 to 0.2 decibels. These were omitted in calculating the results.

When measuring the radiation pattern and gain of the antenna, it was oriented to a bearing angle of 100 degrees east of magnetic north. In this direction, the main beam of the antenna overlooked terrain clear of objectionable reflecting obstacles. Supplementing these 100-degree bearing tests, additional radiation patterns were measured at bearing angles of 160, 280, and 340 degrees. These tests were carried out at a frequency of 18.11 Mc/s and were designed to determine the influence of the nearby arrays, towers, and buildings on the performance of the test antenna.

Radiation patterns were measured by recording the signal from a crystal-controlled battery-powered target transmitter, and a trailing antenna mounted aboard an aircraft. The airplane flew in 360-degree circles at a range of from one to two miles from the site, at angles of departure ranging from 2 to 45 degrees. In its flight around the test site, the aircraft was tracked optically by an observer. The telescope, turntable and controls were mounted to the roof of the van. The direction to the aircraft, in terms of azimuth and elevation angles, was transmitted by syncro-generators to the automatic antenna pattern-recording equipment located inside the van.

Although the transmitted output power was maintained at a constant level throughout a day's tests, the field-intensity recordings had to be corrected for varying aircraft ranges from the site. In the process of conducting each test, the aircraft height and elevation angle were continuously noted and recorded. The operator aboard the aircraft observed the reading on a calibrated altimeter and periodically communicated the aircraft height. From these data, corrections up to 3 decibels in field intensity were made to compensate for variations in range, using the inverse-distance-squared relationship.

In some instances, the aircraft flew to within one mile of the test site. As a result, parallax up to 3 degrees existed between the location of the test antenna and the azimuthal-observation van. To maintain uniformity in measurements on all tests, parallax corrections were incorporated in arriving at the final results.

Antenna gain was measured by comparing the maximum response of the test antenna to the maximum response of the dipole. The dipole was periodically substituted for the test antenna while the aircraft was in the direction of the main beam. The difference in the two corrected field-intensity responses revealed the gain of the log-periodic antenna relative to the dipole.

The results of the measurements are presented in the form of curves and radiation pattern contours, at each frequency of operation. The results of the different bearing-angle pattern tests, conducted at 18.11 Mc/s, are presented in polar form only.

The measured pattern responses are within a two-degree azimuthal accuracy and the measured gains within one-decibel accuracy.

4. RESULTS

The performance characteristics of the antenna, relative to impedance, gain, and radiation pattern response, are herewith presented.

While values of impedance were measured with the antenna fixed in height, and influenced for the most part only by the ground below, the gain and pattern measurements were conducted under conditions of varying parameters. The latter phase of the measurements was subject to uncontrollable reflections caused by irregularities in the terrain and obstacles in the vicinity of the antenna at different angles of departure and azimuth. The results presented, therefore, characterize the antenna performance at this particular site and location.

Measured values of impedance (VSWR) at the different frequencies of operation are presented in Figure 4. Figure 5 presents values of gain relative to a dipole over a similar frequency range. It should be noted that the curves in each of the figures could have deviated from those shown if measurements had been conducted at smaller increments within the frequency range. However, for the purpose of presentation, it is assumed that the values vary with frequency as indicated.

Normalized vertical, azimuthal, and contour radiation pattern responses at the different frequencies of operation are presented in Figures 6 through 26.

The vertical pattern response curves presented in Figures 6, 9, 15, 18, 21 and 24 show the variation in field intensity at angles of departure from approximately 2 to 45 degrees. Because the antenna is at a fixed height of 75.5 feet above ground, the electrical height varies with frequency from 1.0λ at 12 Mc/s to 4.55λ at 60 Mc/s. Consequently, the number of lobe maxima increased from approximately two at 12 Mc/s to seven at 60 Mc/s over the range of departure angles. The curves are normalized with respect to the maximum response of the dipole. The gain, given in decibels, is the maximum response of the antenna in each case, as indicated. For comparison purposes, predicted vertical pattern responses, based on an H-plane beamwidth of 90 degrees, are presented with the measured responses.

Figures 7, 10, 16, 19, 22, and 25 present normalized azimuthal response patterns within the 3-decibel level of maximum radiation at the different frequencies of operation. These measurements were conducted with the axis of the antenna directed to the 100-degree azimuth. Figures 13 through 15 present the polar radiation patterns at 18.11 Mc/s, with the axis of the antenna directed to 160-, 280-, and 340-degree azimuths, respectively. To show the effects of neighboring obstacles, the patterns are plotted as an overlay on a topograpic view of the site.

Complete and detailed pattern characteristics at the different operating frequencies are presented by the normalized contour patterns shown in Figures 8, 11, 17, 20, 23, and 26. They represent intensity, structure, and occurrence of major- and minor-lobe radiation over 360 degrees in azimuth and angles of departure from 2 to 45 degrees. The field-intensity contour points and lines are presented at zero (maximum radiation), at half-power level, and at subsequent 5-decibel levels, down to -30 decibels.

Characteristics vs. frequency

Frequency	Gain (db)	Impedance	VSWR	Horizontal half-power beamwidth (degrees)	Front-to-back ratio (db)
12.975	4.5	$39\angle -6$	1.32	75	14
18.110	6.4	$56\angle 12$	1.26	67	19
23.86	6.1	$45\angle -5$	1.16	66	15
36.04	6.3	$53\angle 5$	1.13	66	18
47.7	5.7	$53\angle -5$	1.13	68	17
59.75	4.7	$48\angle -5$	1.08	73	13

5. DISCUSSION OF ANTENNA CHARACTERISTICS

5.1. Impedance and Gain

Measured values of impedance over the 5-to-1 frequency range are presented in Figure 4. These values compare favorably with the available published data and are within a 2-to-1 VSWR at the different frequencies tested. The response is uniform over the entire range, with a maximum of 1.32:1 occurring at 12.975 Mc/s and a minimum of 1.08:1 at 59.75 Mc/s.

Measured values of gain conformed to the published data in the midfrequency range, but measured somewhat less at the low and high frequency limits of operation. As shown in Figure 5, a maximum gain of 6.4 decibels was measured at 18.11 Mc/s and remained substantially constant throughout the range to 47.7 Mc/s. At 12.975 and 59.75 Mc/s, however, the gain depreciates to 4.5 and 4.7 decibels respectively, or approximately 2 decibels less than that measured at 18.11 Mc/s.

5.2. Radiation Patterns at 12.975 Mc/s

The performance of the antenna, operating at a frequency of 12.975 Mc/s, is characterized by the vertical, azimuthal, and radiation pattern contours presented in Figures 6 through 8. The shape of the vertical radiation pattern and the relative position of the lobes (Figure 6) conformed to that which was calculated, except that the second-lobe maximum was reduced in gain. At angles of departure from 35 to 45 degrees, the gain is expected to be reduced by as much as 6 decibels.

The azimuthal radiation pattern presented in Figure 7 shows irregularities, with a reduction of gain up to 2 decibels within the half-power beamwidth. These deformations are probably due to the presence of the discone and large steerable array in front and to the right side of the test antenna. The half-power beamwidth of 75 degrees is slightly greater than given in the published data, with radiation to the rear irregular and approximately 14 decibels down from that in the forward direction.

5.3. Radiation Patterns at 18.11 Mc/s

Optimum performance of the antenna was measured at an operating frequency of 18.11 Mc/s. Not only did the antenna yield maximum gain, but the response patterns were uniform in the forward direction with minimized side and rear radiation.

Within the range of departure angles, maximum radiation occurred at 8 and 30 degrees. Analogous to the results measured at the preceding frequency of operation, the gain at the second lobe maximum was reduced by approximately 5 decibels. It is believed that, at these lower frequencies, the reduction in gain at higher angles of departure is due to siting and to the limited, smooth terrain of the first Fresnel zone area in front of the antenna.

The azimuthal response pattern presented in Figure 10 was uniform over a wide range in the forward direction. Slight discontinuities occurred at azimuths of 25 and 160 degrees, and are believed to be due to the presence of the nearby discone and steerable arrays. The half-power beamwidth measured 67 degrees, and the front-to-back ratio measured 19 decibels.

Supplementing the 100-degree-bearing tests, radiation patterns were measured with the axis of the antenna directed to azimuths of 160, 280, and 340 degrees. The effects of nearby arrays, buildings and obstructions on the shape of the pattern were determined and are represented by the curves given in Figures 12 through 14.

The largest deformation in the shape of the pattern occurred at an antenna bearing of 160 degrees. Due to the deleterious effects of the large steerable array, the gain of the test antenna was reduced by 10 decibels in the forward direction, and prominent, irregular radiation occurred to the rear. For the most part, rear radiation was only 12 decibels down from that in the forward direction.

Figure 13 represents the radiation pattern of the antenna with its axis bearing to 280 degrees. Although undesirable radiation occurred to the rear, that in the forward direction was relatively uniform, with a slight asymmetry to one side. The gain measured 1.5 decibels below the maximum, and the average front-to-back ratio measured approximately 16 decibels.

Figure 14 presents the radiation pattern of the antenna bearing at 340 degrees. In this direction, the axis of the antenna pointed toward a large steerable array located approximately 1200 feet from the test antenna. Even at this distance, impeding effects were observed on the performance of the log-periodic antenna. These effects account for the deterioration of the pattern in the forward direction, and for reduced gain. The slight skewing of the beam to the right is believed due to scattering of energy by the steel microwave towers and guy lines located in the foreground. Front-to-back ratio in this case measured 14 decibels.

It should be noted that the radiation patterns measured at the 160-, 280-, and 340-degree azimuths were recorded at an average angle of departure of 8.5 degrees, while that at the 100-degree-bearing angle was recorded at 6.5 degrees. Even though a 2-degree difference exists in departure angles between the tests, each may be considered as the representative maximum response of the antenna. (See Figure 9.)

5.4. Radiation Patterns at 23.86 Mc/s

At this frequency of operation, considerable deviation in the position and the shape of the vertical pattern lobe structure existed between the predicted and measured responses. As represented by the curves in Figure 15, the first- and second-lobe maxima occurred at angles of departure approximately 4 degrees less than predicted.

The discrepancy in the shape and position of the first- and second-lobe maxima is believed to be due to the effects of the sloping first Fresnel zone area in front of the antenna and the scattering of energy from the discone antenna located in the left foreground of the test antenna. These deleterious effects on the shape of the pattern were prominent up to 30 degrees, but did not seem to influence the performance of the antenna at the higher angles.

Minor-lobe radiation to the side and rear was enhanced, as indicated by the azimuthal response presented in Figure 16.

The radiation pattern showed irregularities up to 2 decibels in the forward direction. Radiation to the right, rear and left was from 12 to 15 decibels below the maximum. These undesirable radiations were caused by the presence of the nearby steerable array, discone and microwave towers. Discounting the deformations in the pattern - at one point slightly in excess of 3 decibels - the half-power beamwidth measured 66 degrees.

5.5. Radiation Patterns at 36.04 Mc/s

Except for a slight deviation in the shape of the first-lobe maximum, the measured radiation pattern in the vertical plane, presented in Figure 18, compared favorably with that which was calculated. At the different angles of departure, the lobe maximum occurred within 2 degrees of the predicted, with the magnitude of gain deteriorating to less than 2 decibels at the higher angles of departure.

The azimuthal pattern, measured at an angle of departure of 2.5 degrees, given in Figure 19, is relatively uniform in the forward direction, with no protruding lobes to the side and rear. The half-power beamwidth measured 66 degrees. For the most part, back radiation was below the 18-decibel level - except for a single 13-decibel down spike occurring at 275 degrees.

5.6. Radiation Patterns at 47.7 Mc/s

The radiation patterns measured at this frequency of operation agreed favorably with those predicted. The vertical pattern response, presented in Figure 21, shows the lobe maxima occurring within one degree of that predicted. It was displaced only slightly in position as the angle of departure increased. The gain, however, remained within 2 decibels over the entire range.

Figure 22 presents the azimuthal pattern response at the second-lobe maximum at an angle of departure of 11 degrees. The half-power beamwidth measured 68 degrees with deformations slightly in excess of 3 decibels - occurring at azimuths of 73 and 135 degrees. The steerable arrays influenced the pattern to a lesser degree than at the lower frequencies of operation. The presence of the microwave towers showed no appreciable effects on the pattern response. Front-to-back ratio measured 17 decibels.

5.7. Radiation Patterns at 59.75 Mc/s

The vertical pattern response, presented in Figure 24, compared favorably with that predicted at low angles of departure. However, at 25 degrees and higher, the gain of the antenna was slightly reduced. Aside from this, the pattern responses were uniform and the maxima occurred within 2 degrees of the predicted radiation patterns over the entire range.

The nearby steerable arrays, trees, and sloping terrain influenced the shape of the pattern (Figure 25), and enhanced undesirable radiation to the side and rear.

Analogous to results measured at the lowest frequency of operation, the half-power beamwidth measured 73 degrees and the front-to-back ratio measured 13 decibels. Both the larger beamwidths and the higher secondary-lobe levels account for the lower values of gain than that measured in the midfrequency range of operation.

6. CONCLUSIONS

In the frequency range, from 18.11 to 47.7 Mc/s, the gain of the antenna measured 6 decibels relative to a half-wave dipole located at the same height above ground. At 12.975 and 59.75 Mc/s, however, the gain measured approximately 2.0 decibels less than anticipated.

The half-power beamwidth measured 66 degrees in the 18.11 to 47.7 Mc/s frequency range and increased to 73 degrees at 12.975 and 59.75 Mc/s.

Front-to-rear radiation decreased from approximately 18 decibels in the midfrequencies to 13 decibels at the lowest and highest frequencies of operation.

The effects of terrain and the presence of nearby obstacles in the vicinity of the test antenna distorted the radiation pattern of the antenna and reduced the gain for certain orientations of the antenna.

The voltage standing-wave ratio measured less than 1:32 to 1 over the entire frequency range of operation.

7. ACKNOWLEDGMENTS

Appreciation is extended to J.E. Chukoski and R.J. Heim for their contribution in making the measurements and scaling the recordings.

8. REFERENCES

1. R.H. DuHamel and D.E. Isbell, Broadband logarithmically periodic antenna structures, IRE Convention Record, Part I., 1957, pp 119-128.

2. R.L. Bell, C.T. Elfving and R.E. Franks, Near-field measurements on a logarithmically periodic antenna, Tech. Memo. No. EDL - M231, December 21, 1959, Sylvania Electric Products, Inc., Electronic Defense Laboratory.

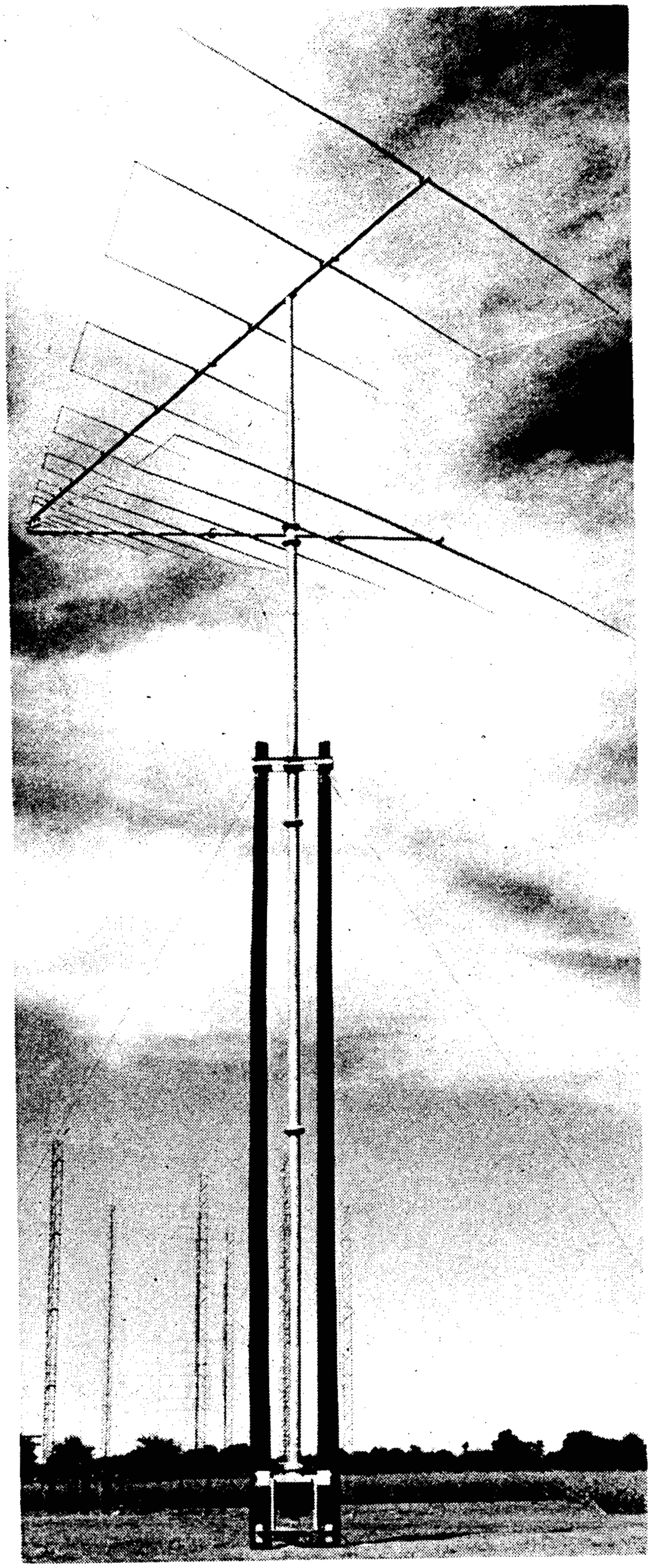


Fig. 1: PICTORIAL VIEW OF THE LOG-PERIODIC ANTENNA

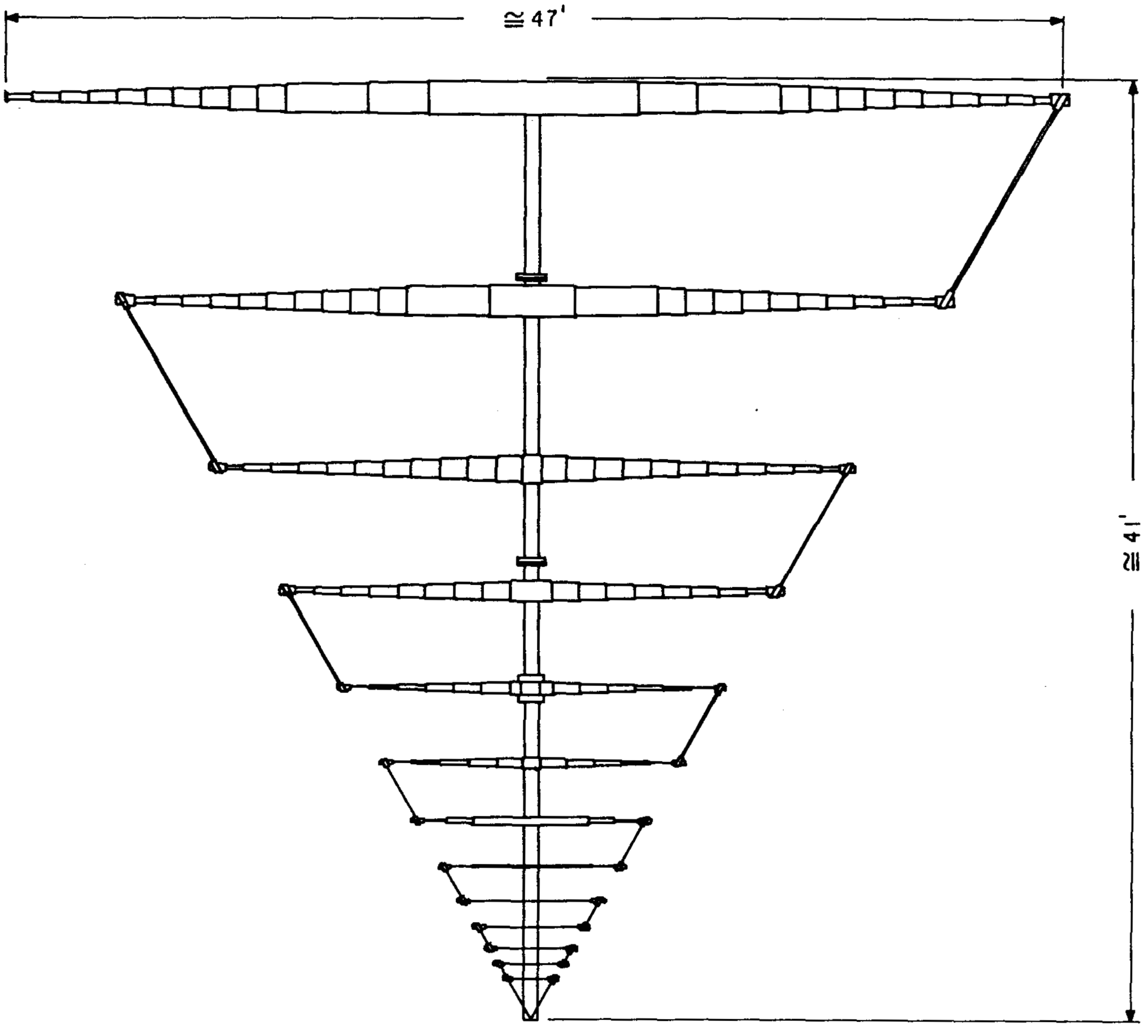


Fig. 2: CONSTRUCTION DETAILS OF ONE PLANE OF THE ANTENNA

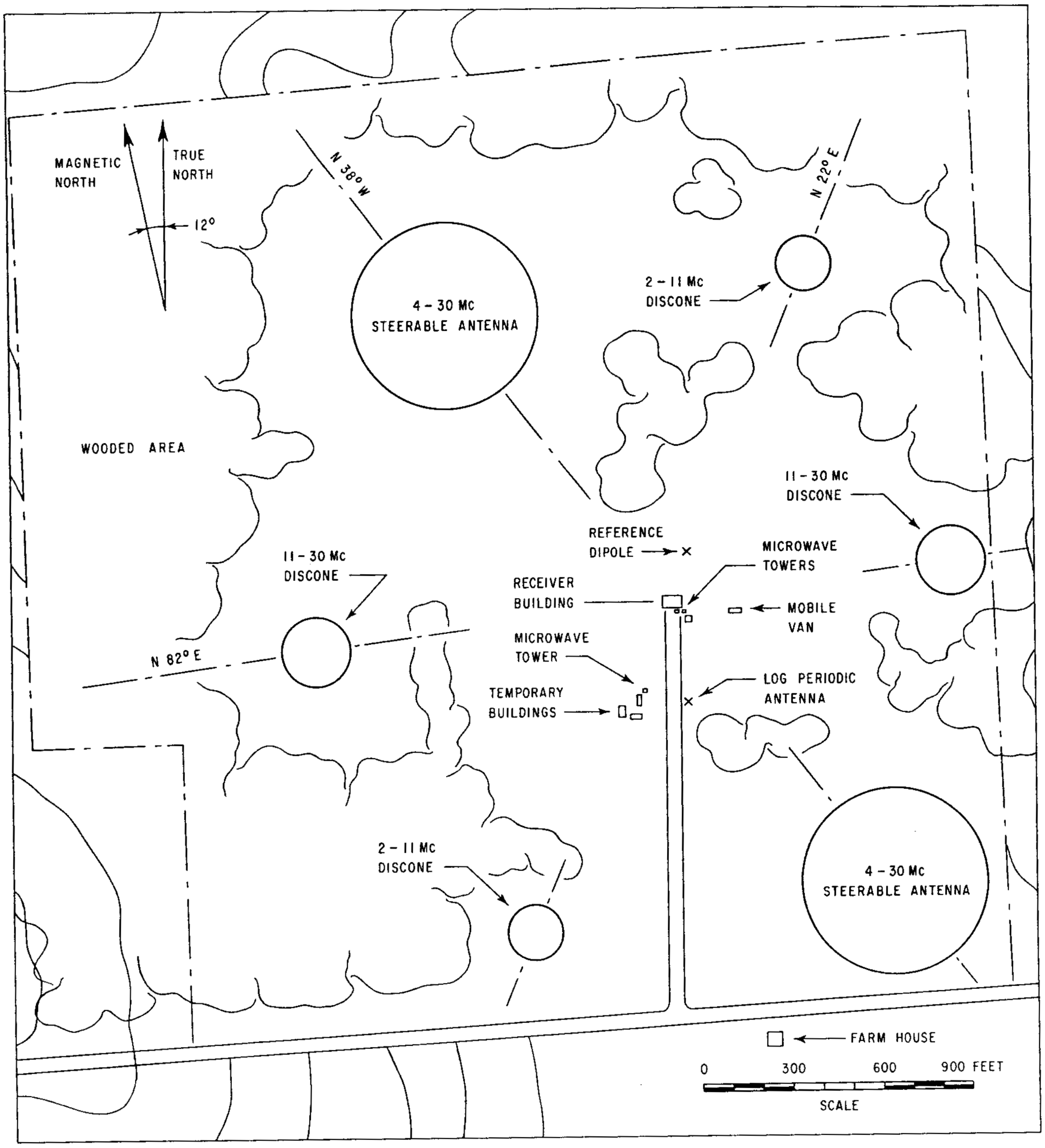


Fig. 3: TOPOGRAPHIC VIEW OF THE OPERATIONAL TEST SITE

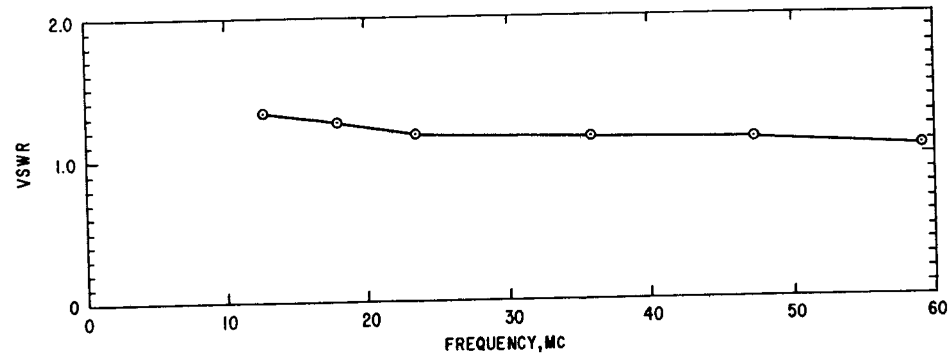


Fig. 4: MEASURED VALUES OF VSWR AT THE DIFFERENT FREQUENCIES OF OPERATION

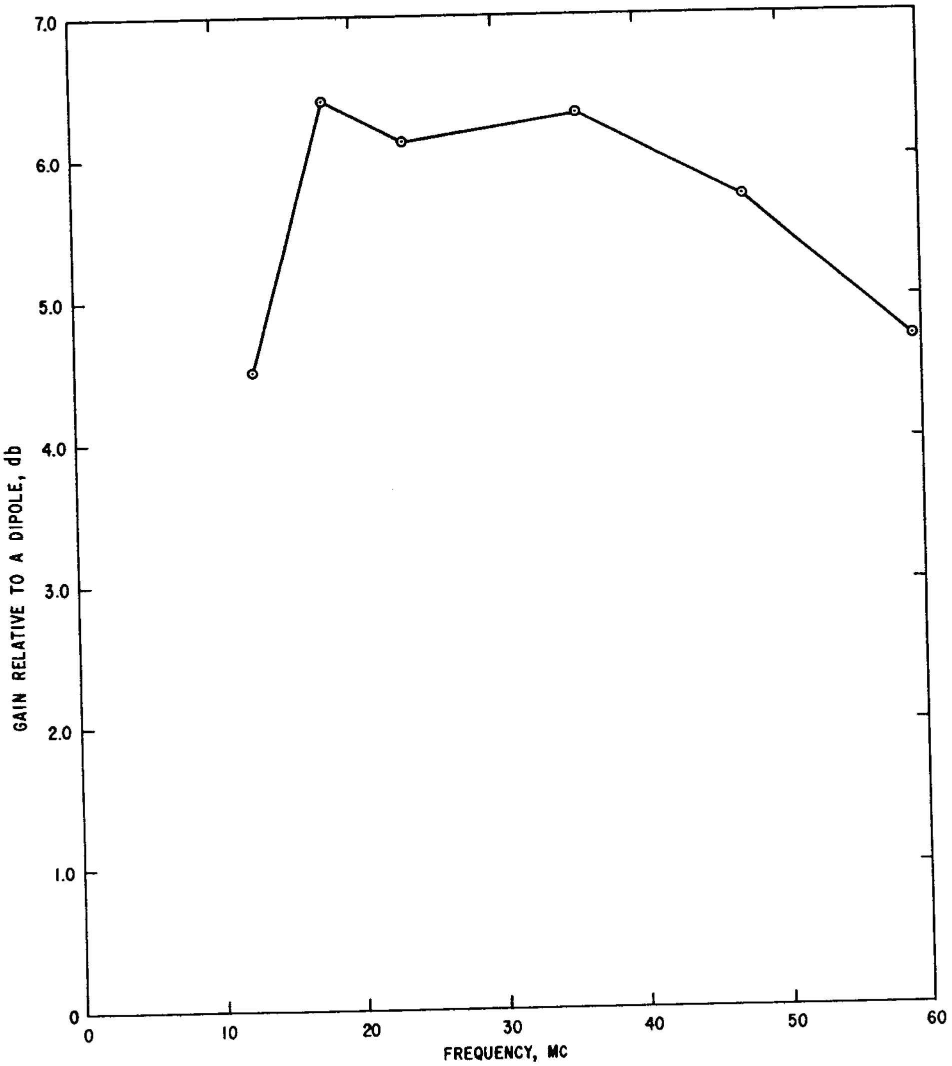
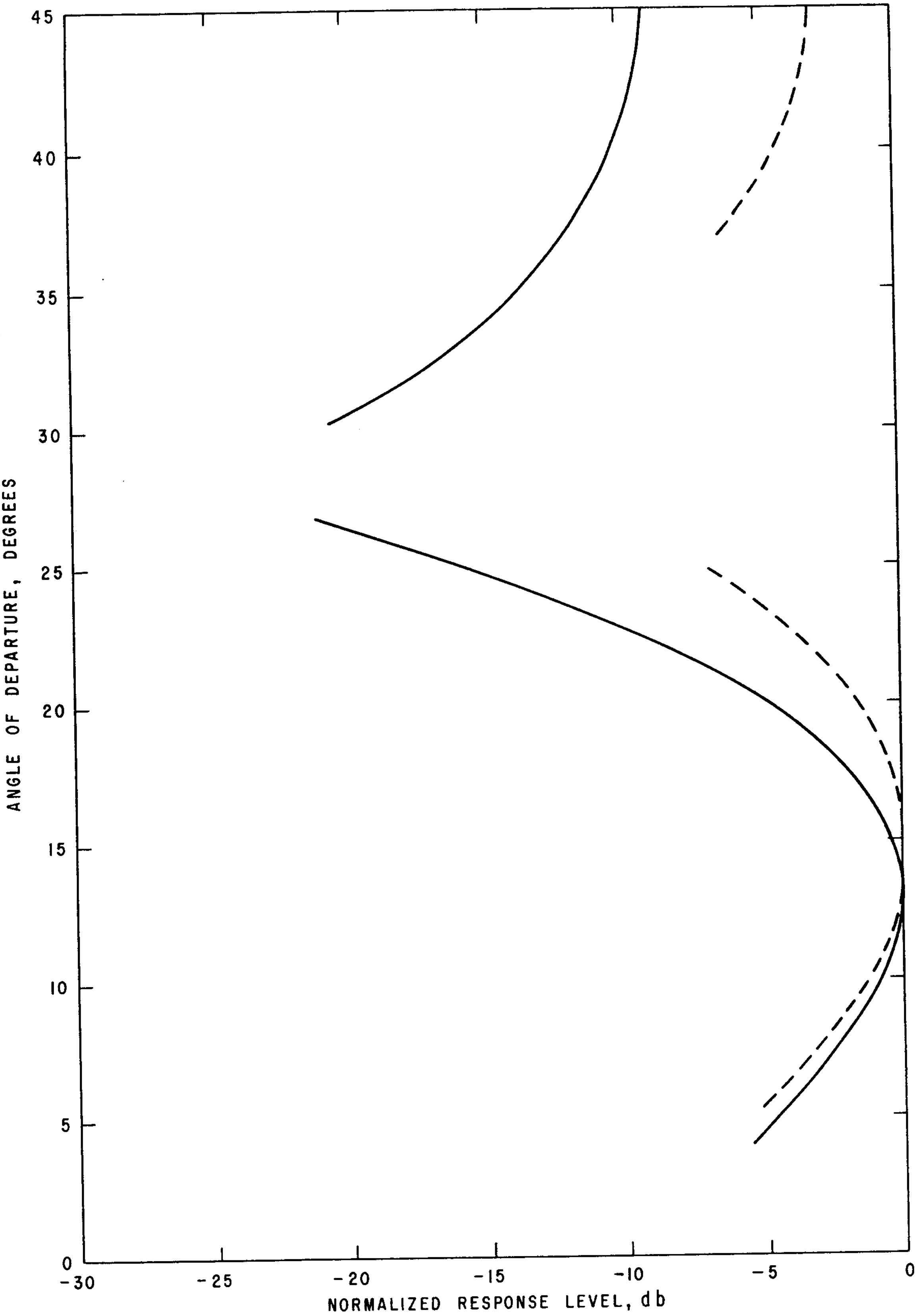


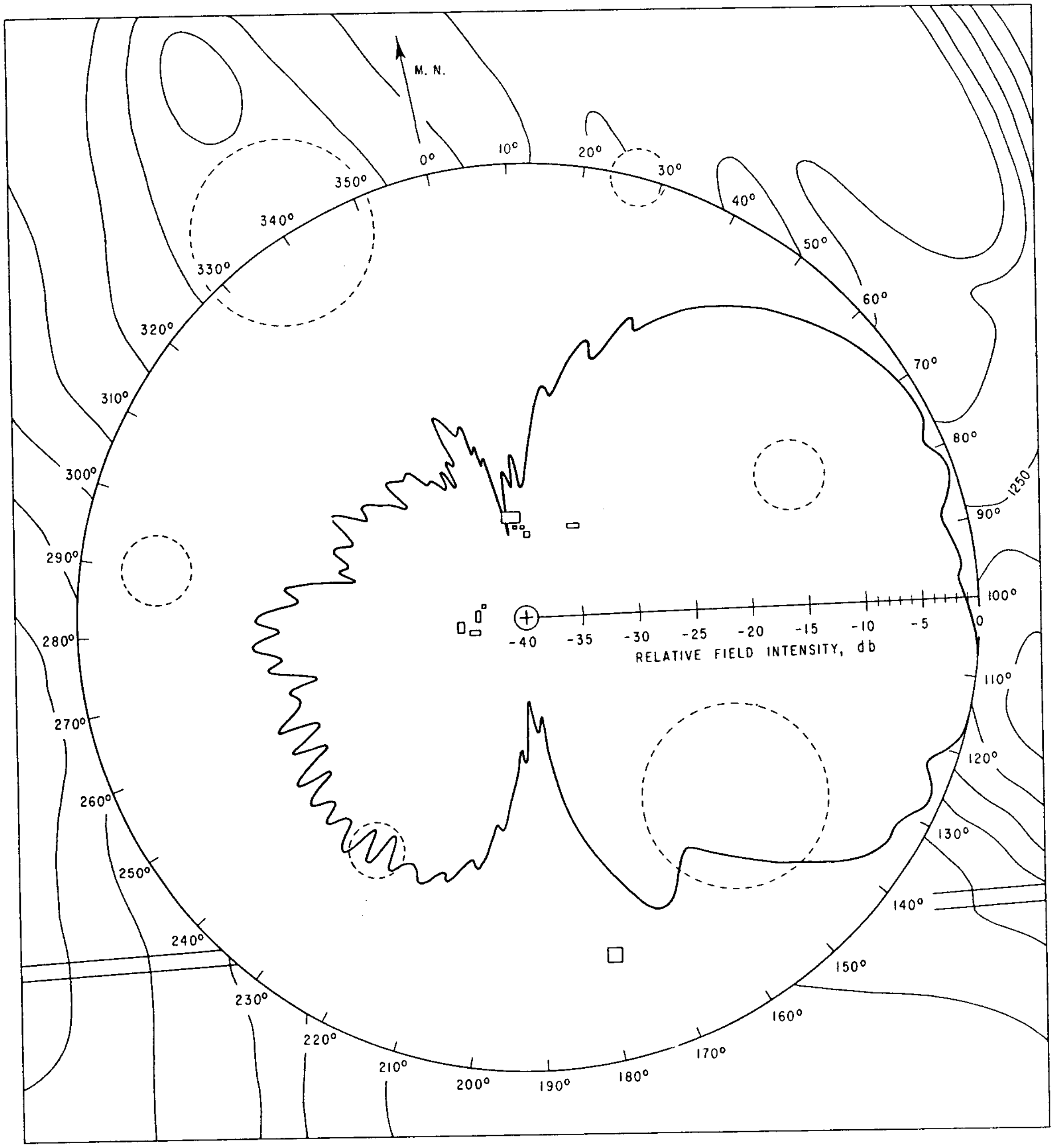
Fig. 5: MEASURED VALUES OF GAIN AT THE DIFFERENT FREQUENCIES OF OPERATION



NORMALIZED VERTICAL RADIATION PATTERN AT 12.975 Mc/s

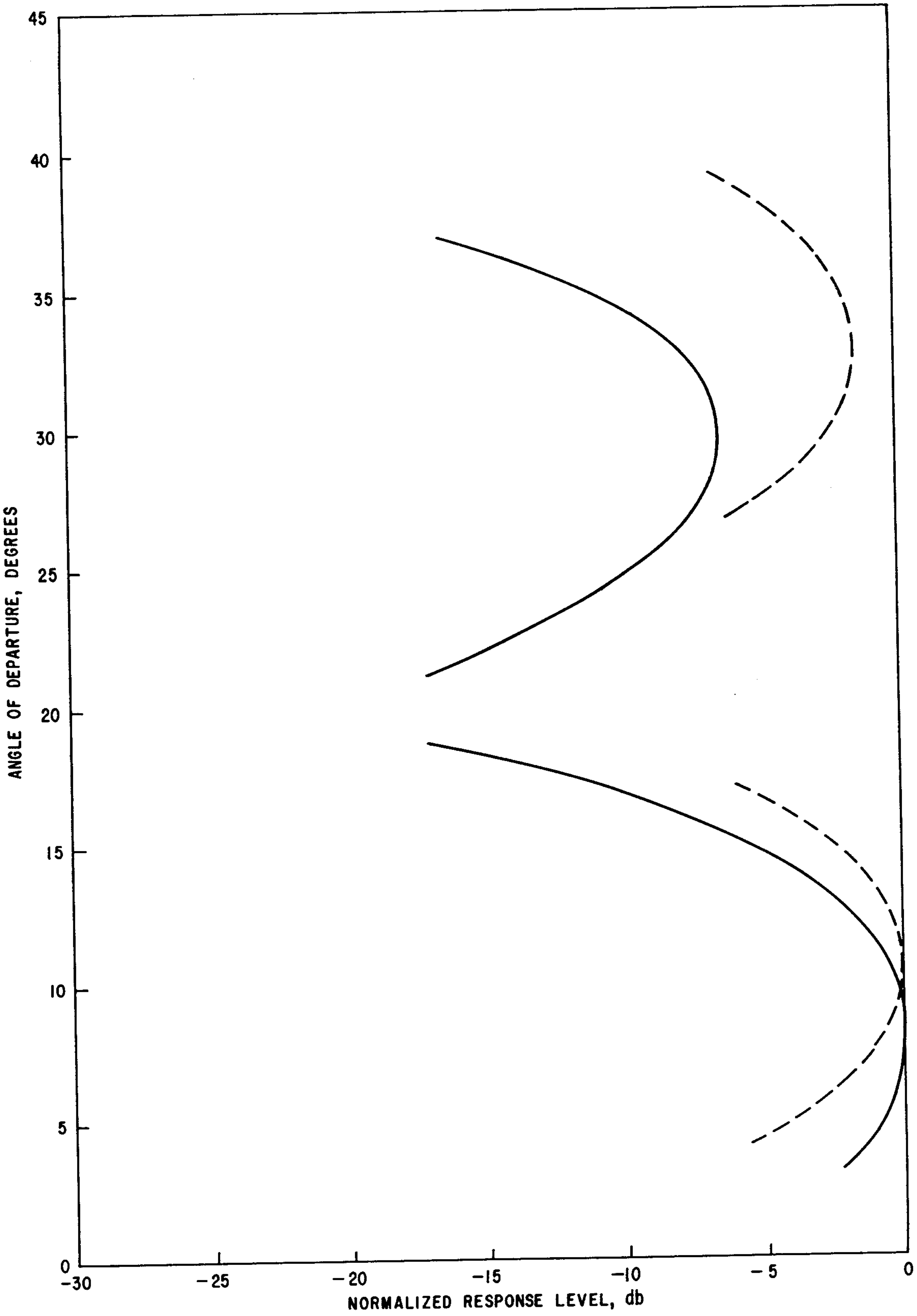
Fig. 6: Electrical height of antenna, 1.0λ
Gain relative to a dipole, 4.5 db

——— Measured
- - - - Calculated



NORMALIZED AZIMUTHAL RADIATION PATTERN AT 12.975 Mc/s

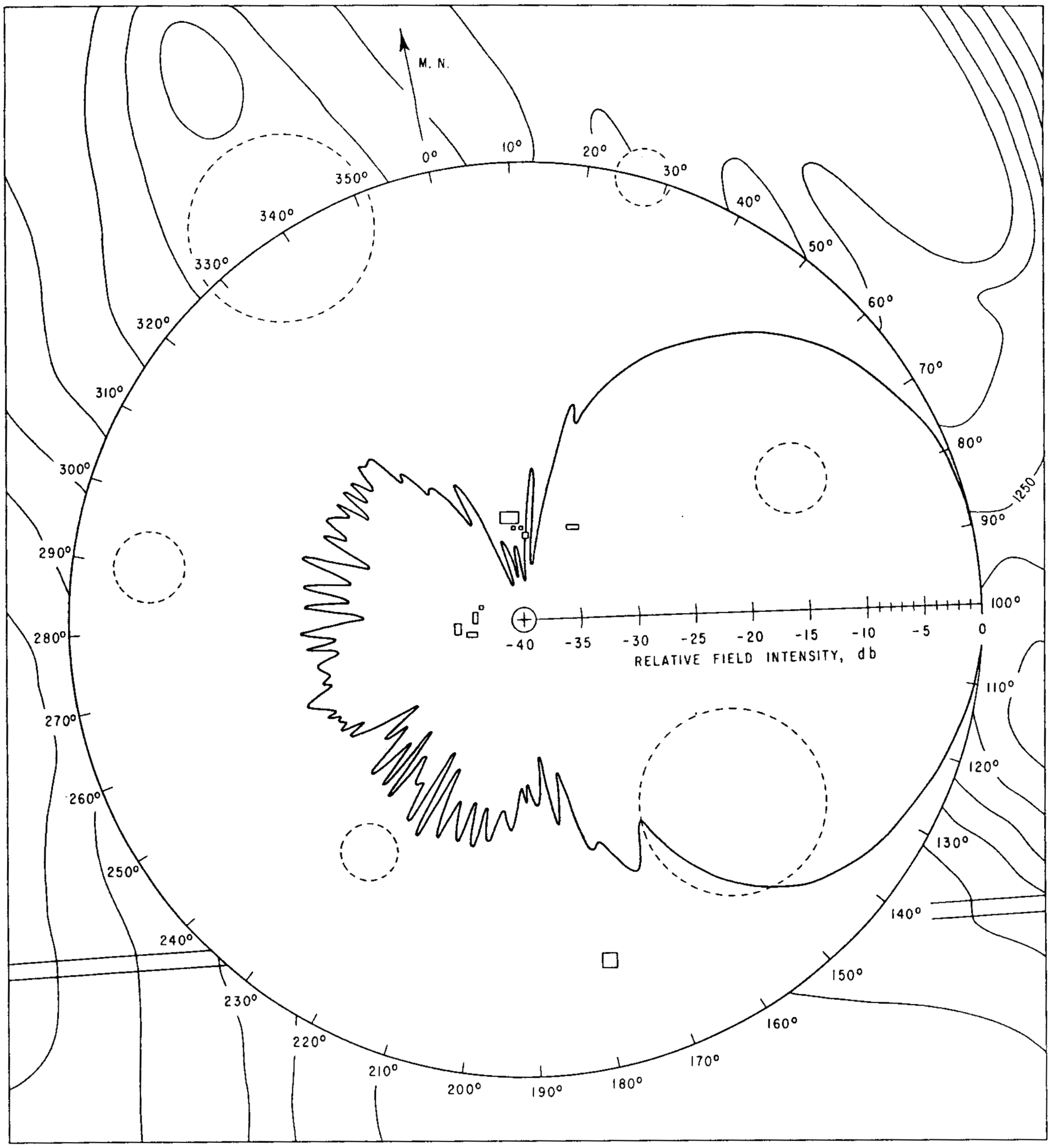
Fig. 7: Angle of departure, 12.5 degrees
Half-power beamwidth, 75 degrees
Gain relative to a dipole, 4.5 db
Front-to-rear radiation, 14 db



NORMALIZED VERTICAL RADIATION PATTERN AT 18.110 Mc/s

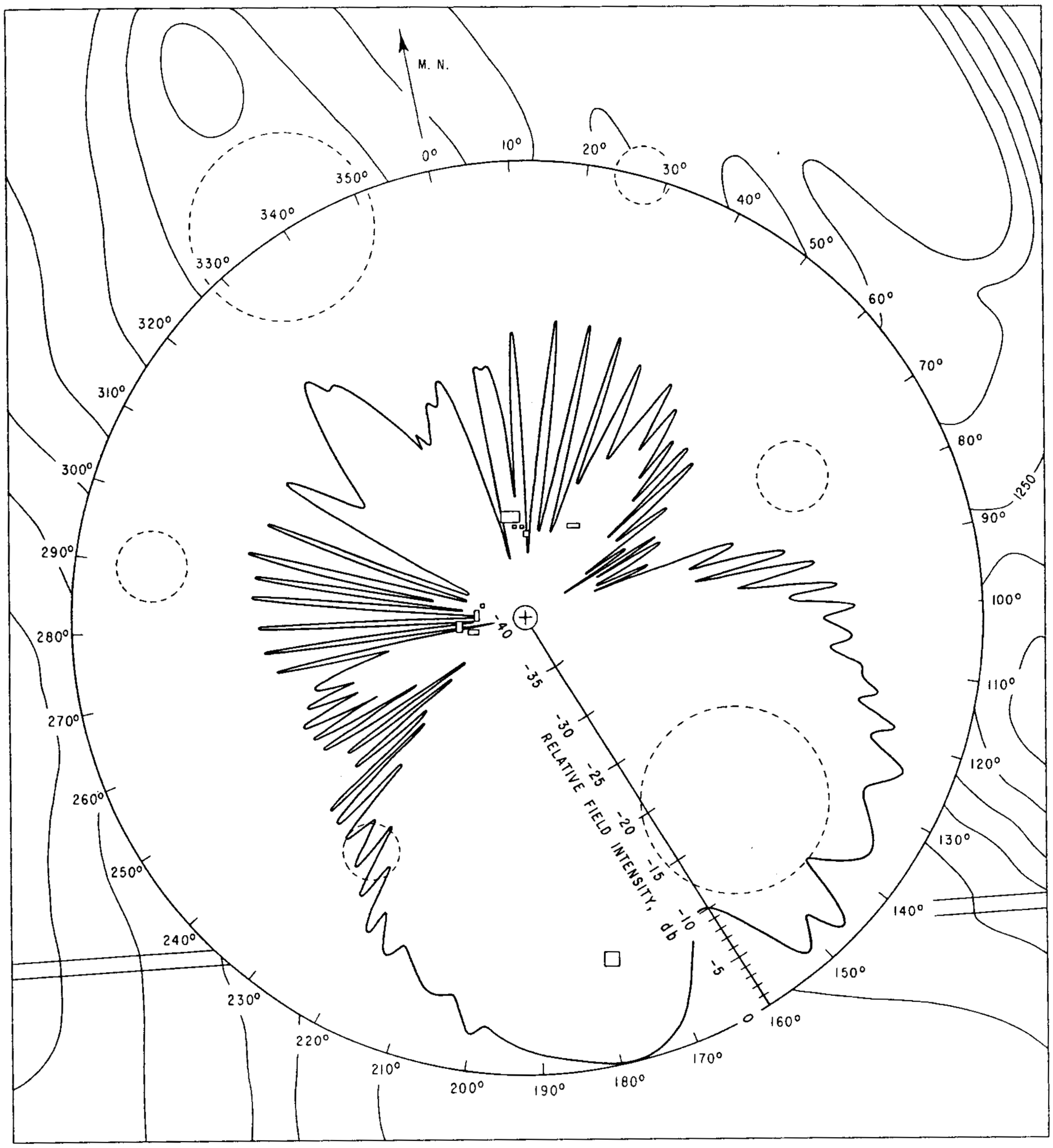
Fig. 9: Electrical height of antenna, 1.38λ
Gain relative to a dipole, 6.4 db

——— Measured
- - - - Calculated



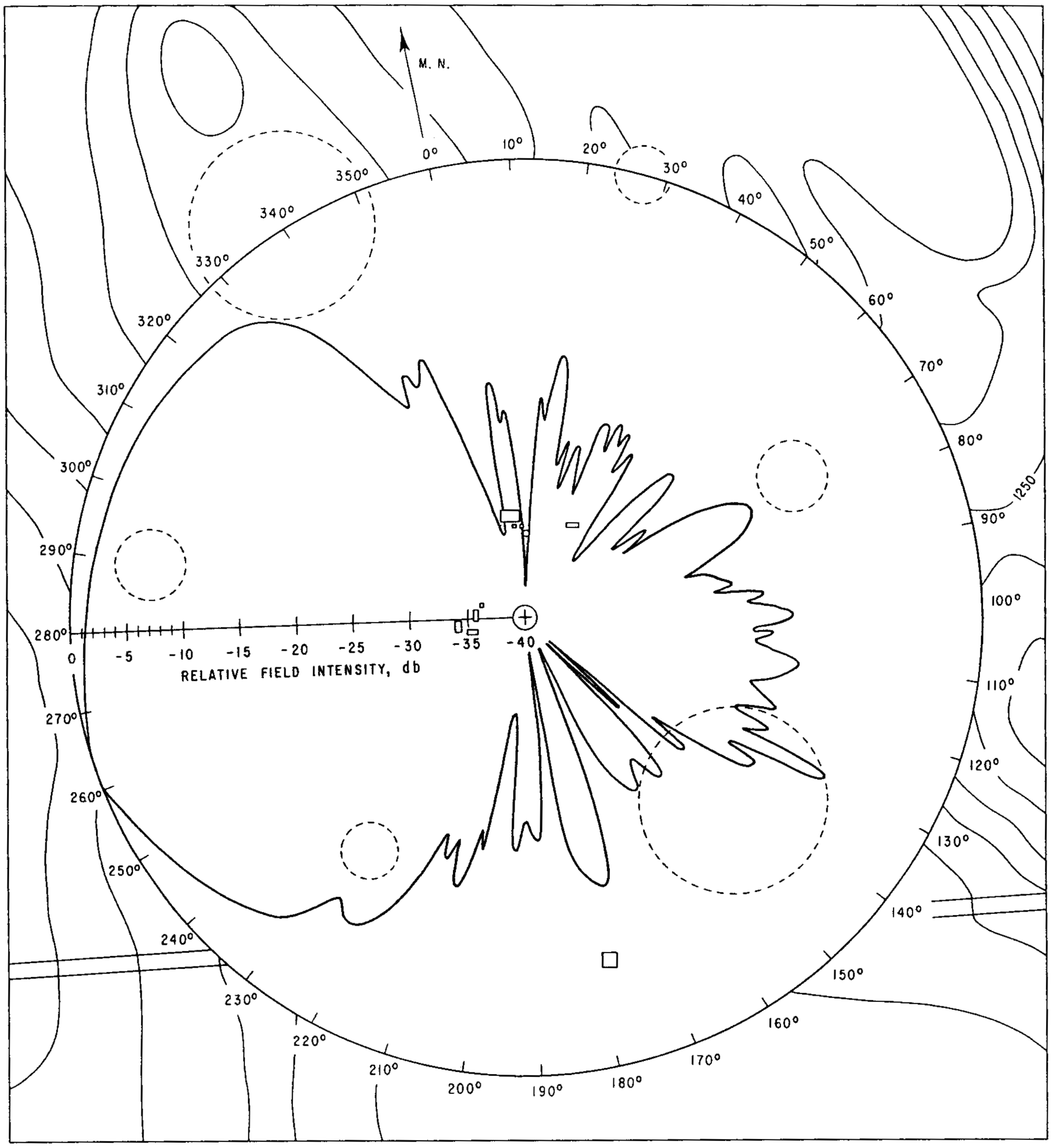
NORMALIZED AZIMUTHAL RADIATION PATTERN AT 18.110 Mc/s

Fig. 10:
Angle of departure, 6 degrees
Half-power beamwidth, 67 degrees
Gain relative to a dipole, 6.4 db
Front-to-rear radiation, 19 db



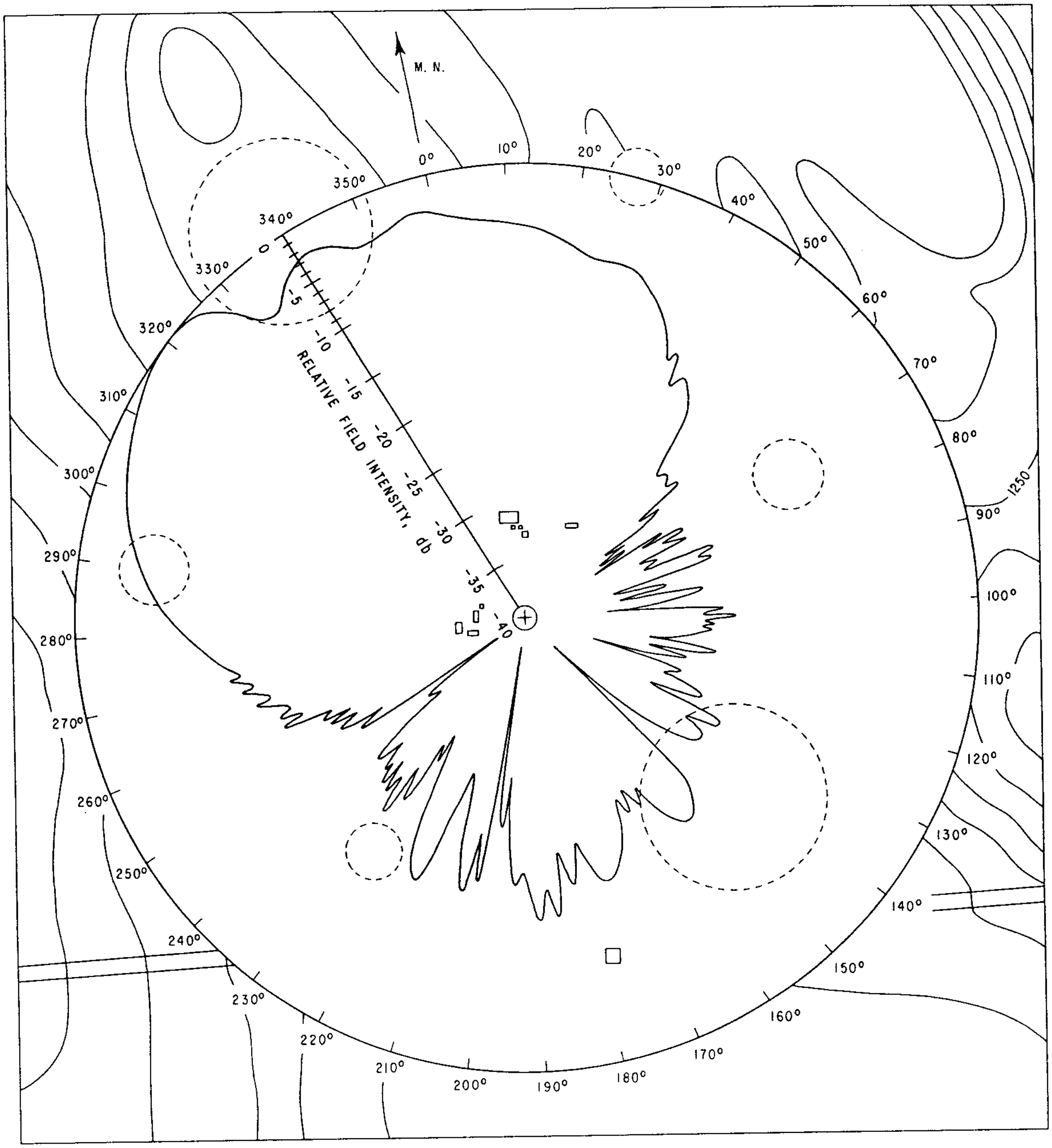
NORMALIZED AZIMUTHAL RADIATION PATTERN AT 18.110 Mc/s

Fig. 12: Axis of main beam bearing to 160 degrees
Angle of departure, 8.5 degrees
Front-to-rear radiation, 12 db



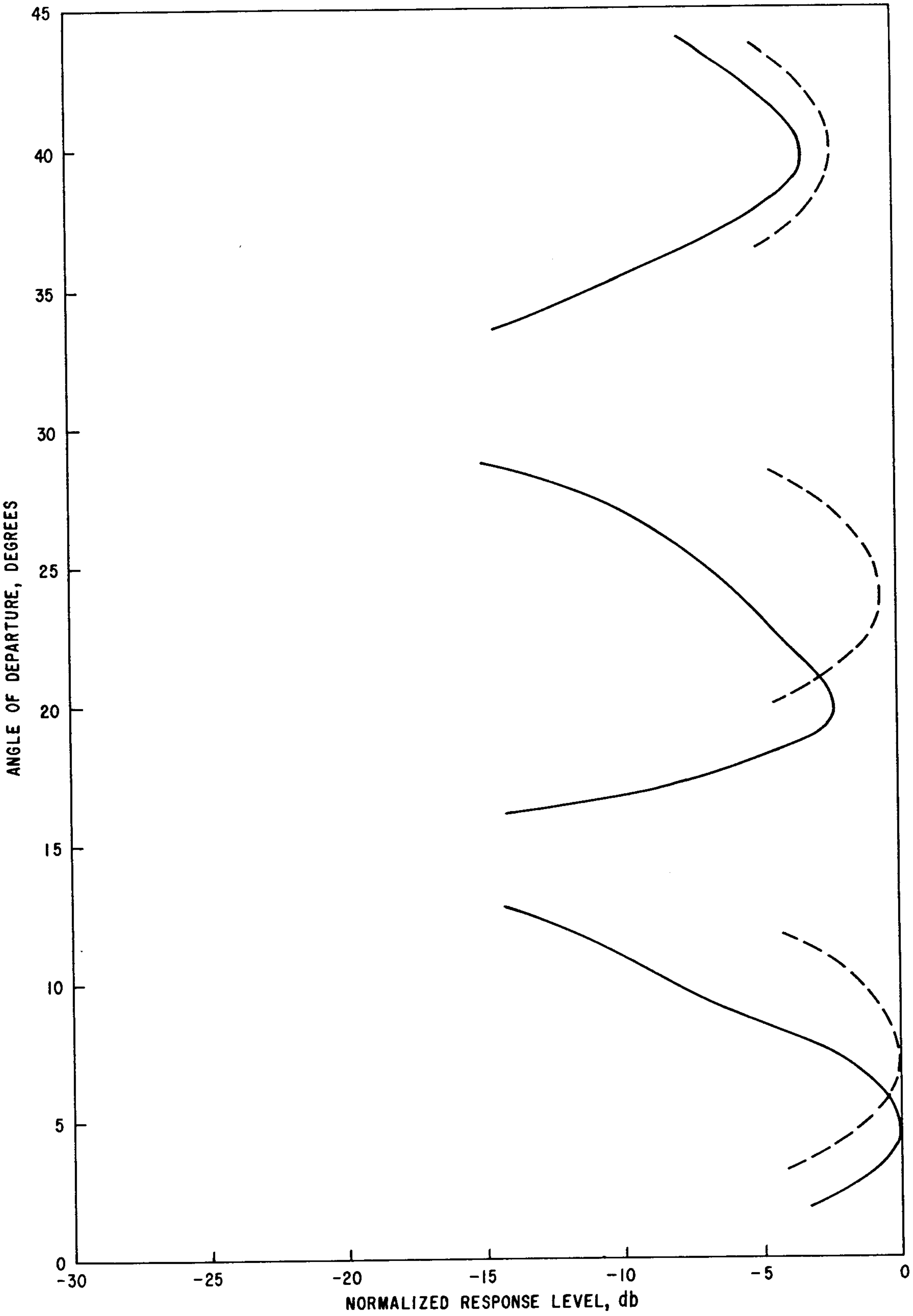
NORMALIZED AZIMUTHAL RADIATION PATTERN AT 18.110 Mc/s

Fig. 13: Axis of main beam bearing to 280 degrees
Angle of departure, 8.5 degrees
Front-to-rear radiation, 11 db



NORMALIZED AZIMUTHAL RADIATION PATTERN AT 18.110 Mc/s

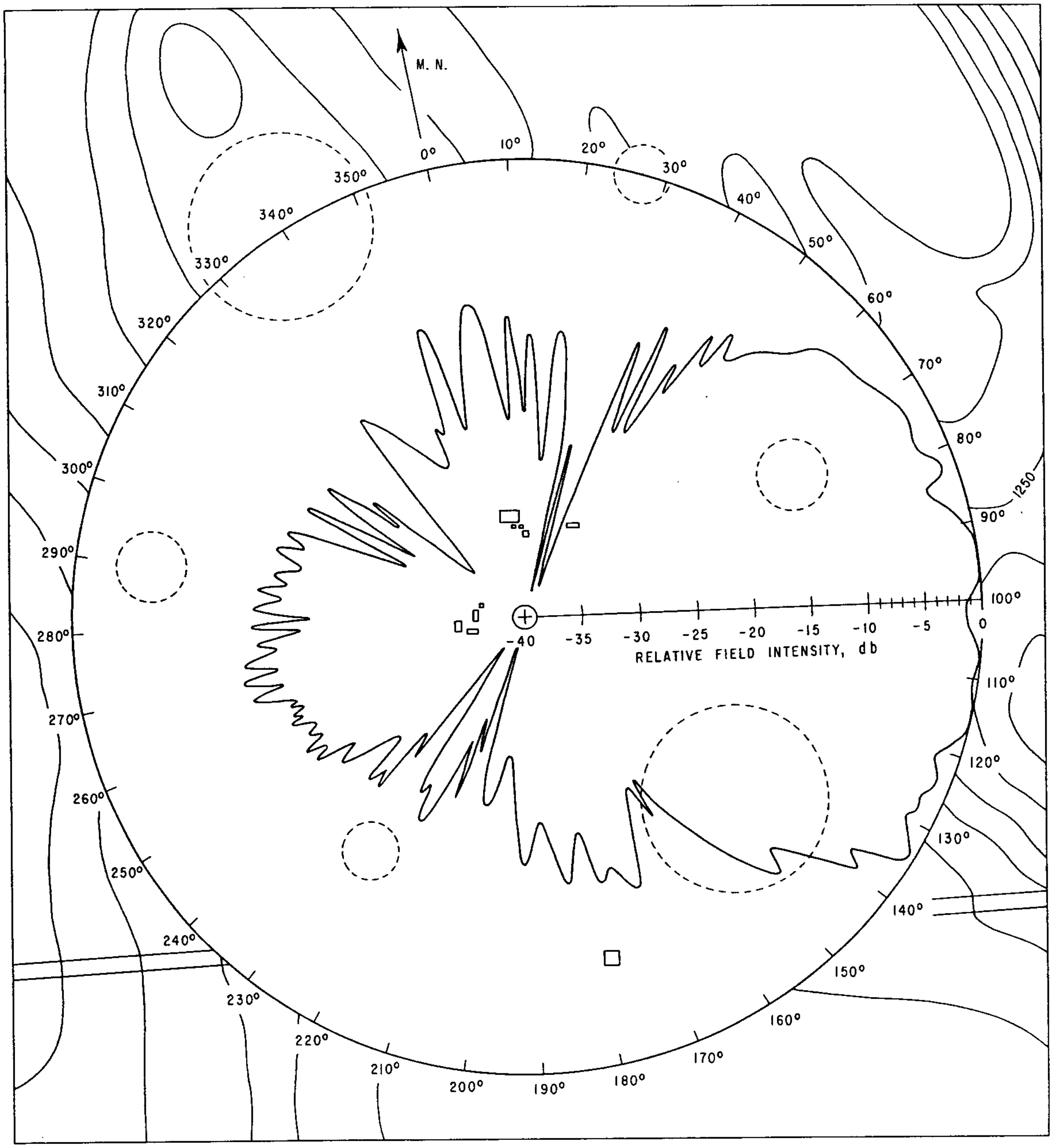
Fig. 14: Axis of main beam bearing to 340 degrees
Angle of departure, 8.5 degrees
Front-to-rear radiation, 14 db



NORMALIZED VERTICAL RADIATION PATTERN AT 23.860 Mc/s

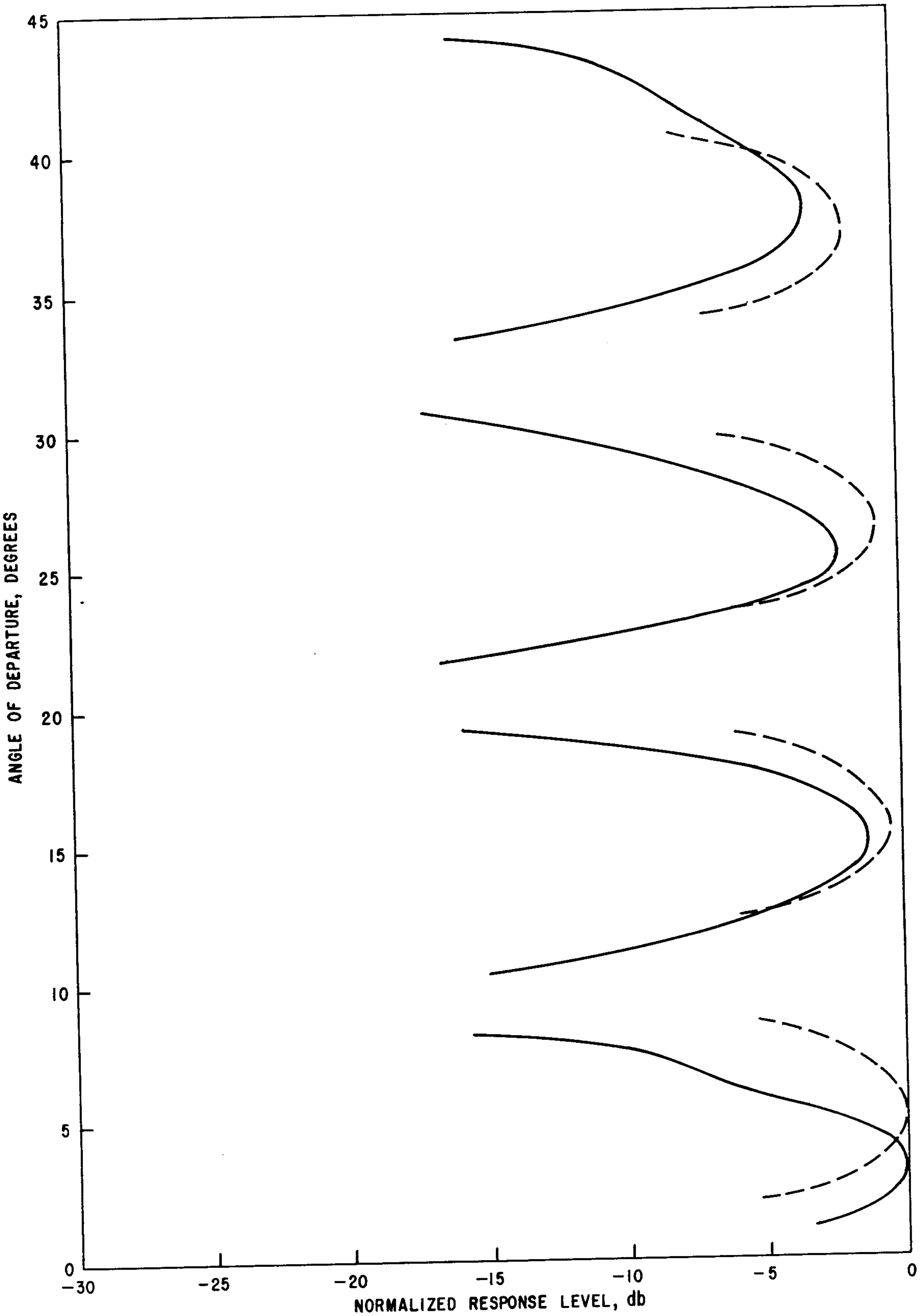
Fig. 15: Electrical height of antenna, 1.82λ
Gain relative to a dipole, 6.1 db

——— Measured
- - - - Calculated



NORMALIZED AZIMUTHAL RADIATION PATTERN AT 23.860 Mc/s

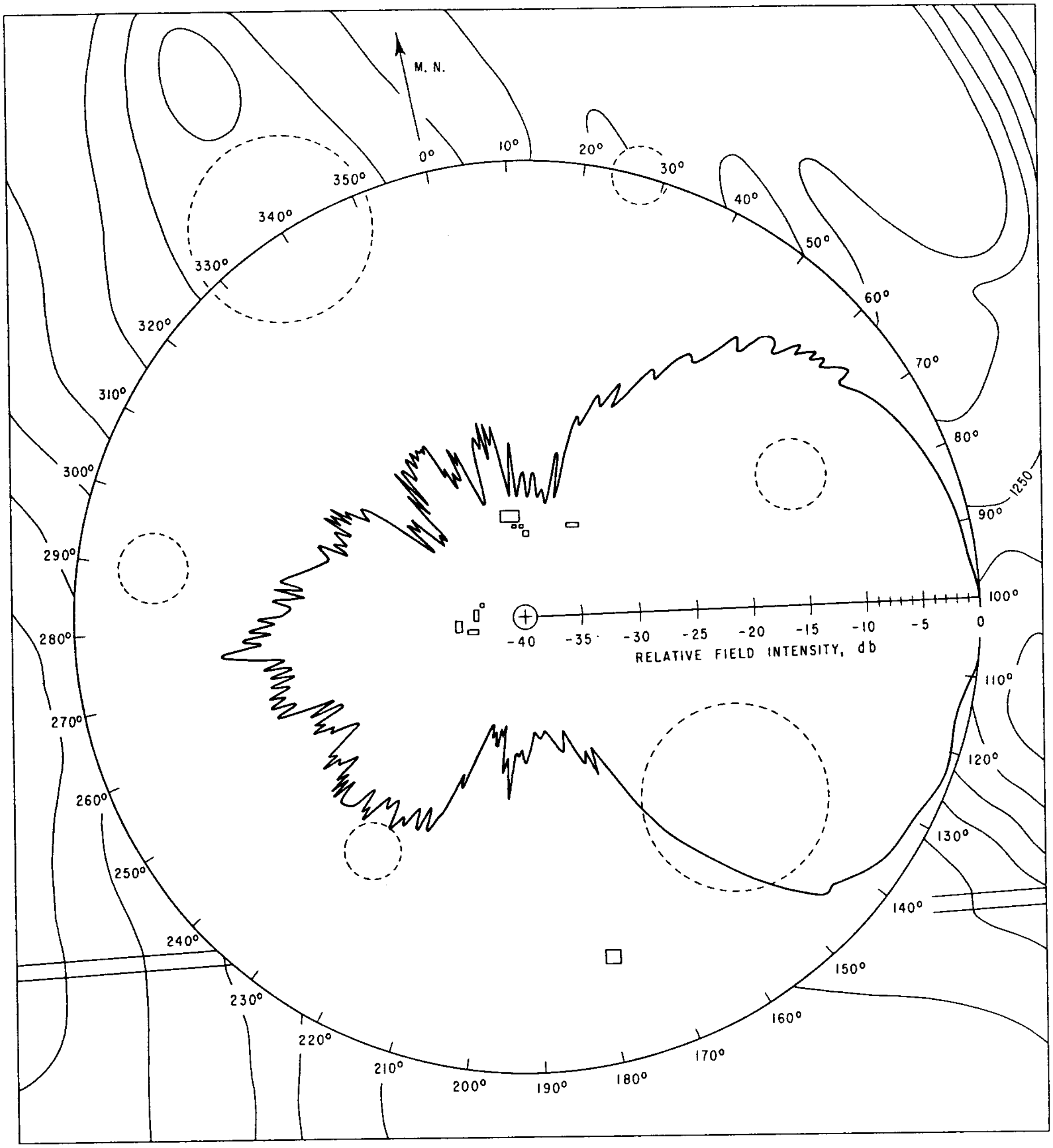
Fig. 16: Angle of departure, 6.0 degrees
Half-power beamwidth, 66 degrees
Gain relative to a dipole, 6.1 db
Front-to-rear radiation, 15 db



NORMALIZED VERTICAL RADIATION PATTERN AT 36.040 Mc/s

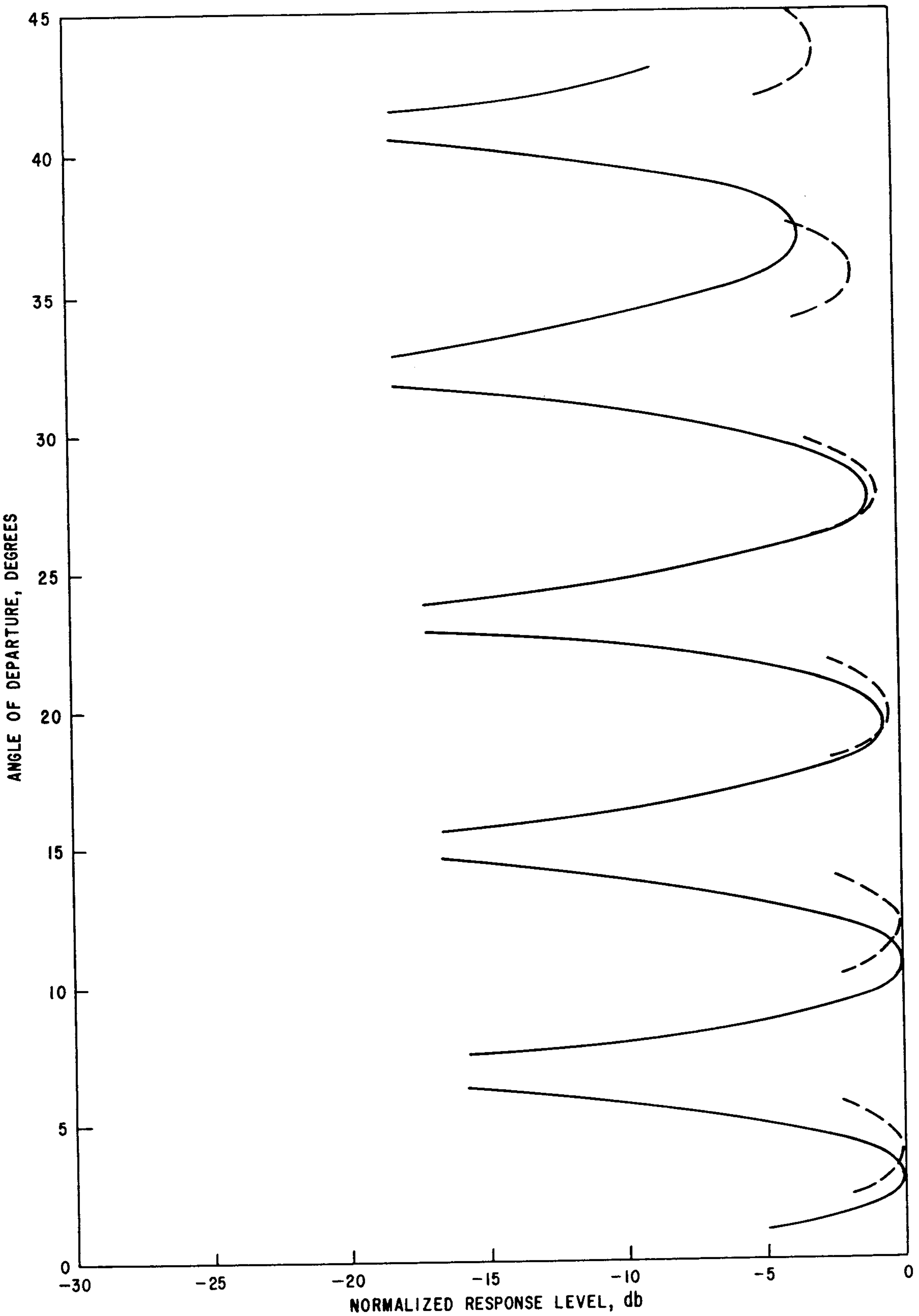
Fig. 18: Electrical height of antenna, 2.74λ
Gain relative to a dipole, 6.3 db

——— Measured
- - - - Calculated



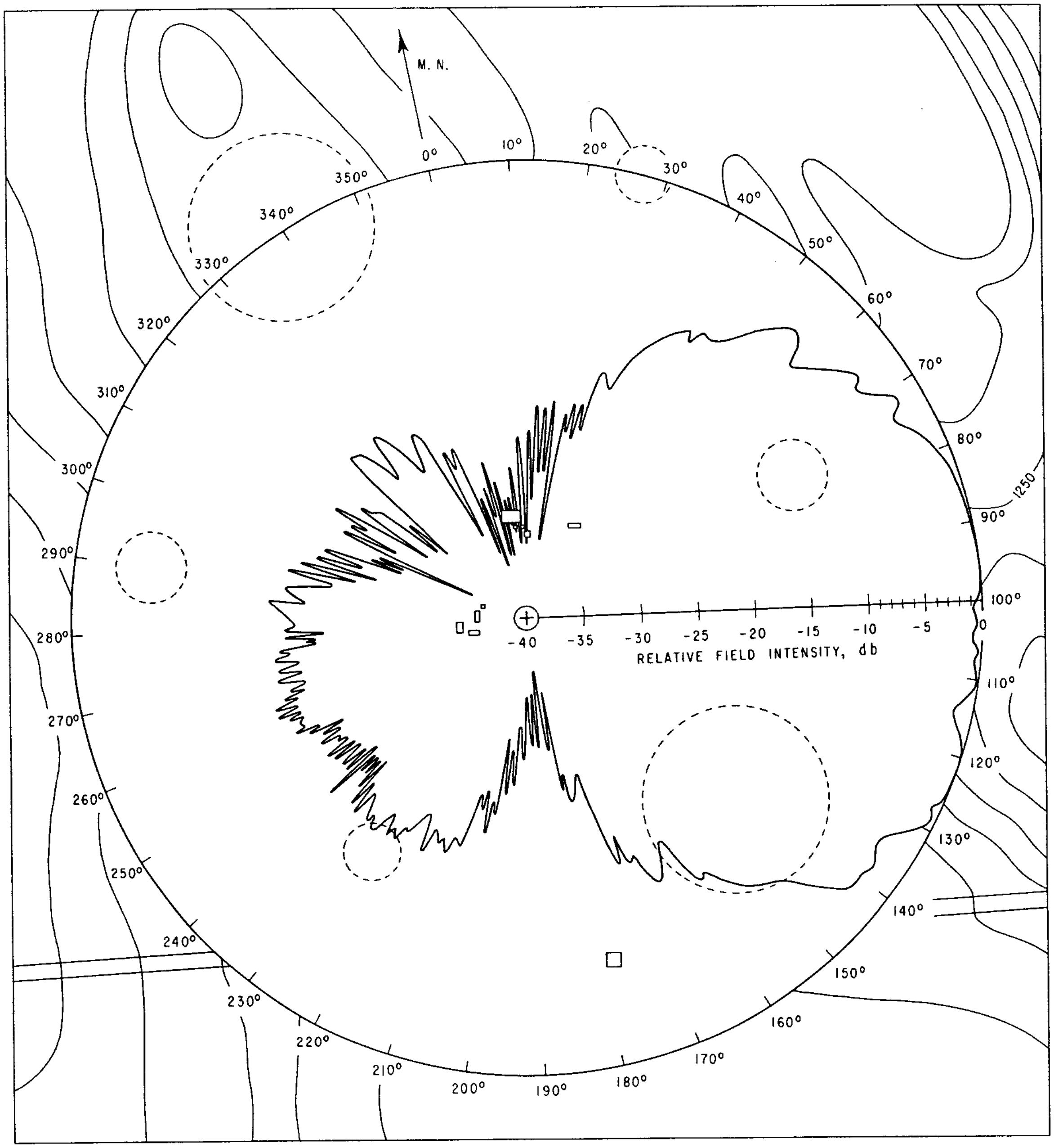
NORMALIZED AZIMUTHAL RADIATION PATTERN AT 36.040 Mc/s

Fig. 19: Angle of departure, 2.5 degrees
Half-power beamwidth, 66 degrees
Gain relative to a dipole, 6.3 db



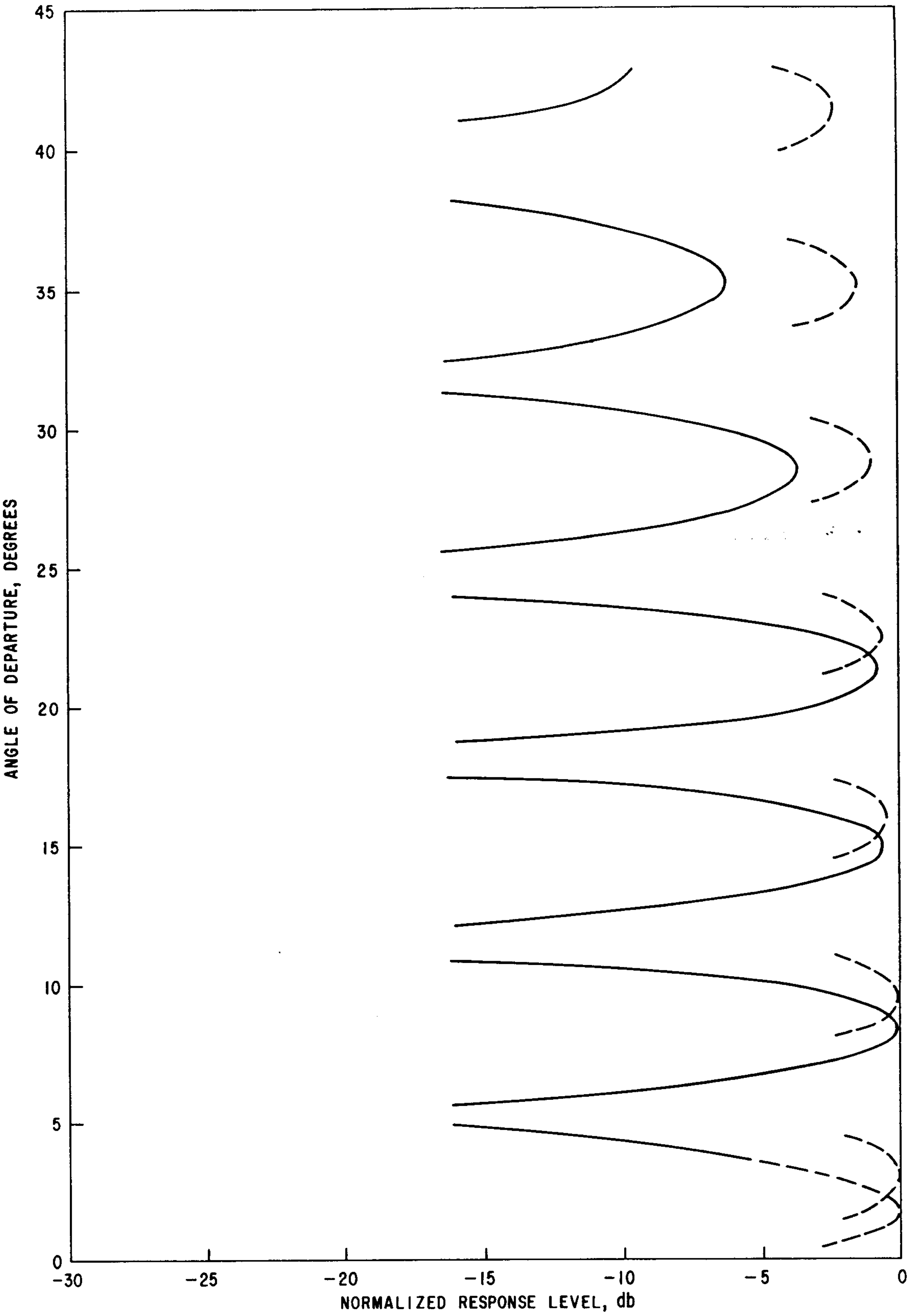
NORMALIZED VERTICAL RADIATION PATTERN AT 47.700 Mc/s

Fig. 21: Electrical height of antenna, 3.64λ ——— Measured
Gain relative to a dipole, 5.7 db - - - -Calculated



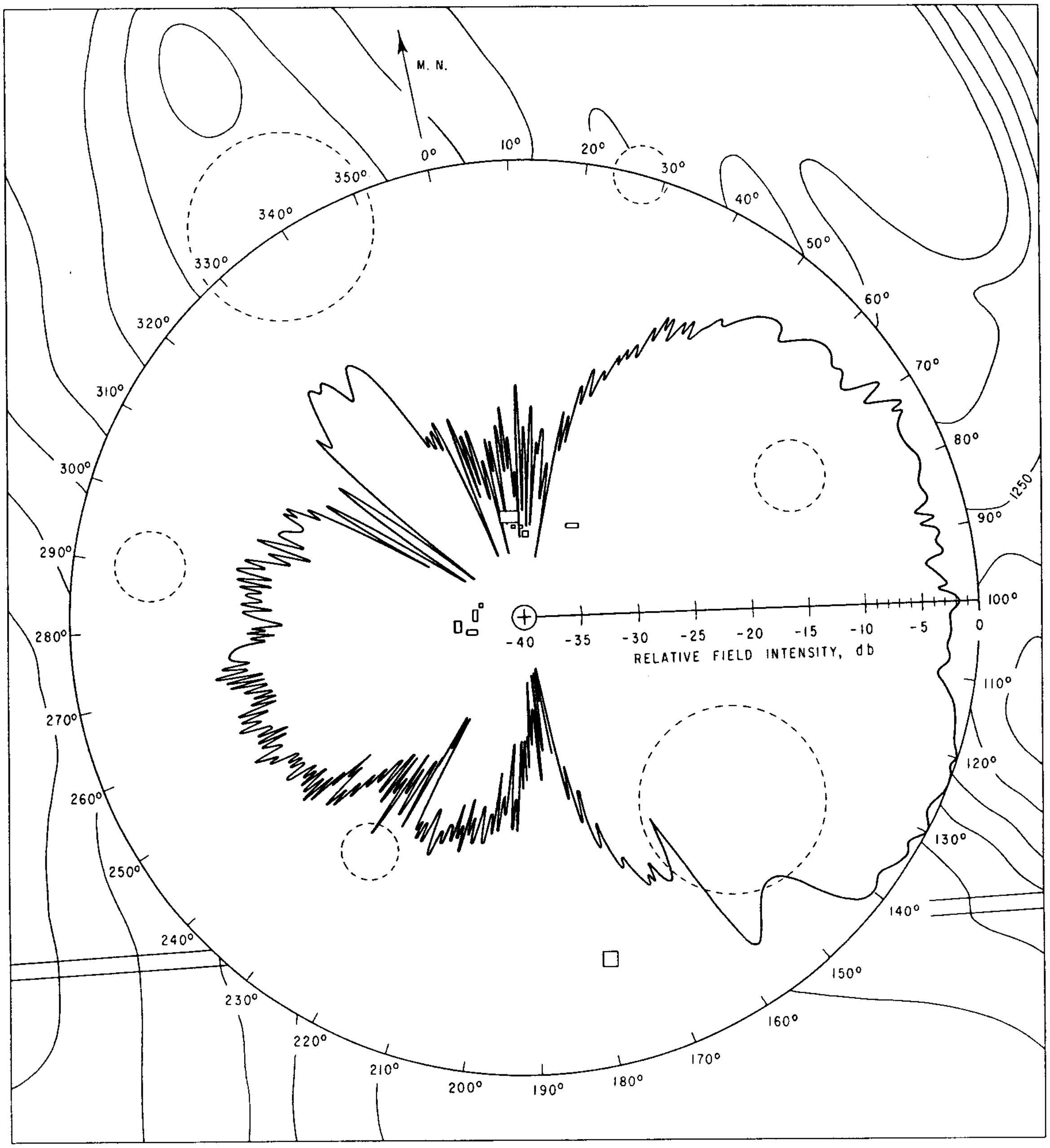
NORMALIZED AZIMUTHAL RADIATION PATTERN AT 47.700 Mc/s

Fig. 22: Angle of departure, 11 degrees (2nd lobe max.)
Half-power beamwidth, 68 degrees
Gain relative to a dipole, 5.7 db
Front-to-rear radiation, 17 db



NORMALIZED VERTICAL RADIATION PATTERN AT 59.750 Mc/s

Fig. 24: Electrical height of antenna, 4.55λ ——— Measured
Gain relative to a dipole, 4.7 db - - - - Calculated



NORMALIZED AZIMUTHAL RADIATION PATTERN AT 59.750 Mc/s

Fig. 25: Angle of departure, 8 degrees (2nd lobe max.)
Half-power beamwidth, 73 degrees
Gain relative to a dipole, 4.7 db
Front-to-rear radiation, 13 db