Telecommunications

Courseware Sample

28113-F0

TELECOMMUNICATIONS

COURSEWARE SAMPLE

by
the Staff
of
Lab-Volt (Quebec) Ltd

Printed in Canada
September 2000

Table of Contents

Introduction

The Model 8090 Microwave Technology Training System is part of the Lab-Volt family of award-winning telecommunications training systems. It is a complete, integrated package of hardware and courseware that allows students to perform experiments in microwave principles and practices. All power supplies, instrumentation, high-quality microwave components, and accessories required to perform the experiments are included.

The Model 8090 Microwave Technology Training System consist of:

- A Gunn diode oscillator running at 10.5 GHz in continuous wave (CW) mode or modulated by a 1 kHz squarewave.

- A crystal detector, thermistor, and slotted line used with the Gunn Oscillator Power Supply, Power Meter, and SWR Meter (standing wave ratio) to detect microwave signals and power and to take SWR measurements. The Gunn Oscillator Power Supply provides power to the SWR and power meters through connectors that align when the meters are stacked on top of the power supply.

- Antenna Azimuth Indicator for accurate plotting of antenna field patterns

- Inductive and capacitive irises used to measure reactive impedance

- Three lenses, a metal plate, and a dielectric plate for microwave optics experiments.

Courseware Outline

INTRODUCTION TO MICROWAVE TECHNOLOGY

Sample Exercise

from

Introduction to

Microwave Technology

Exercise 14

Antennas and Propagation

OBJECTIVE

When you have completed this exercise, you will be familiar with, and be able to measure, the gain and directivity of an antenna. You will also be able to plot the radiation pattern of an antenna.

DISCUSSION

So far, we have only been considering guiding energy through waveguides. In this exercise, we will consider launching microwave power into **free space**. Antennas are the transition devices between waveguides or transmission lines and free space. They can be used either to receive free-space waves or radiate guided waves. Figure 14-1 shows the pa9535Horn Antenna used in this exercise and its schematic representation used in this exercise.

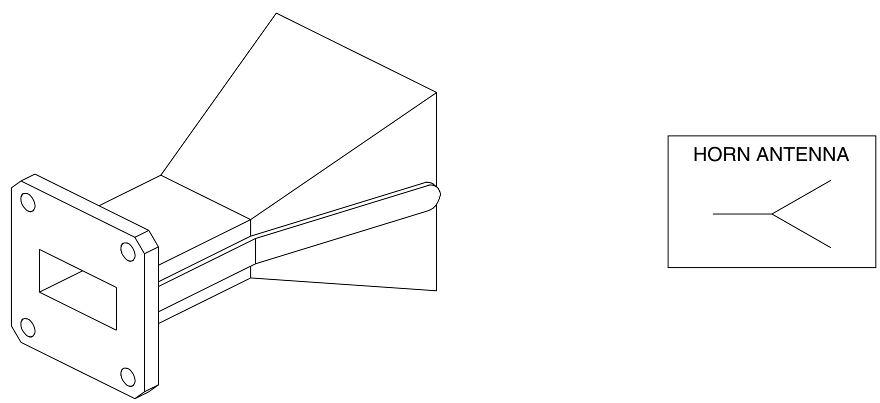

Figure 14-1. pa9535Horn Antenna and its schematic representation.

The power received by an antenna decreases as the antenna is moved away from the transmitting antenna. The received signal power is inversely proportional to the square of the distance that separates the transmitting and receiving antennas. This power loss, due to the separation between the antennas, is called the free-space propagation loss PL. The mathematical expression for determining the free-space propagation loss is given in Equation 14-1:

$$PL\ (dB) = 10\ \log \left(\frac{4\pi r}{\lambda}\right)^2 = 20\ \log \frac{4\pi r}{\lambda} \qquad (14\text{-}1)$$

where r represents the distance between the antennas (in meters) and
λ represents the wavelength in free space (in meters)

The wavelength in free-space is related to the frequency of the transmitted signal by the relation $\lambda = c/f$ where c is the speed of light, that is, 3×10^8 m/s.

The free-space propagation loss is defined as the loss between the **isotropic radiators** in free space, expressed as a power ratio. It is usually expressed in dB, as in Equation 14-1. An isotropic radiator is a hypothetical antenna having equal radiation intensity in all directions. The concept of an isotropic radiator is very useful in antenna studies as it gives a convenient reference for expressing the directive properties of actual antennas. Note that the definition of free-space propagation loss is directly related to the concept of an isotropic radiator, bringing out the fact that it is independent of the directive properties of antennas.

For a given operating frequency, Equation 14-1 shows that PL depends only on the distance between the antennas. This relationship can be determined experimentally by transmitting a signal from one antenna and measuring the power received at another antenna for different separations. However, since the antennas used generally have directive properties, the same orientation must be kept between them when the experiment is performed. If the different antenna separations are known, the attenuation of the received signal power obtained at a greater distance relative to that obtained at a near distance can easily be calculated with the use of Equation 14-2.

$$A\ (\text{dB}) = 20 \log \frac{r_2}{r_1} \qquad (14\text{-}2)$$

where A is the attenuation in dB
r_2 is the greater distance between the antennas
r_1 is the smaller distance between the antennas

Equation 14-2 clearly shows that if the distance is double ($r_2 = 2r_1$), 6 dB less power will be received, which means that the received power has been reduced to one-fourth of the transmitted power. This is just another way of expressing the inverse-square law response of the power with distance.

In general, a given antenna can be used to transmit or receive a signal. When an antenna is used to receive a signal, the power that it receives will depend on its orientation with respect to the transmitting antenna. In certain orientations, the receiving antenna is able to receive a stronger signal than in other orientations. Similarly, if the same antenna is used to transmit a signal, the radiated power is stronger in some directions than in others. As it turns out, for the same antenna, the direction of maximum power transmission coincides with the direction of maximum power reception. Obviously, when transmitting a signal from one antenna to another, it is preferable to have the two antennas aligned so that the transmitting antenna is transmitting most of the signal towards the receiving antenna, and so that the receiving antenna is aligned for the best reception of the signal.

A radiation pattern is a three-dimensional graphical representation of the far-field radiation properties of an antenna as a function of space coordinates. The far-field region is a region far enough away for the radiation pattern to be independent of the distance from the antenna. A radiation pattern represents the energy distribution transmitted by the antenna. Although the term radiation pattern is used, it applies just as well to receiving antennas. The reception pattern of an antenna is identical to its radiation pattern, except that it indicates the relative signal level of received power as a function of direction.

Although the radiation pattern of an antenna is a three-dimensional function, for reasons of presentation, one or two radiation patterns plotted in polar coordinates are generally used to characterize the directional properties of an antenna. Although a radiation pattern plotted in polar coordinates represents the power distribution of energy in only one plane of rotation around the antenna, it often gives a sufficient indication of the radiation characteristics of the antenna if the plane is correctly chosen. To characterize an antenna more completely, two radiation patterns, usually called the E-plane pattern, is defined as the plane parallel to the electric field in the direction of maximum radiated power. The other pattern, called the H-plane pattern, is defined in the same way except that it is parallel to the magnetic field.

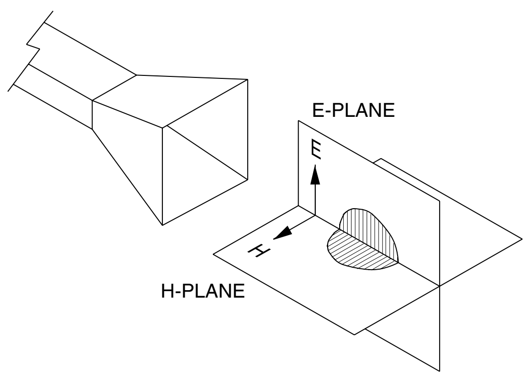

Figure 14-2. Definition of E- and H-planes.

To plot a radiation pattern in the H-plane, the antenna must be rotated in such a way that its direction of maximum radiated is situated in the H-plane.

Generally, radiation patterns are measured by rotating an antenna while measuring the level of received power as a function of the orientation of the antenna. To obtain a valid radiation pattern, the measurement environment must be free from all obstacles. Walls, buildings, and even the ground can act as reflectors and cause errors in the measurement of the radiation pattern.

To characterize numerically the directional properties of antennas, the concept of **directive gain** is most often used. For a given point in space, the gain of an antenna is the ratio of the power produced by the antenna at the given point to the power that would be produced by an isotropic radiator radiating the same total power. Figure 14-3 illustrates this definition. The same total power is radiated by the two antennas but antenna A produced 20 dB more power in its direction of maximum radiation than antenna O. Antenna A is said to be a 20-dB gain antenna.

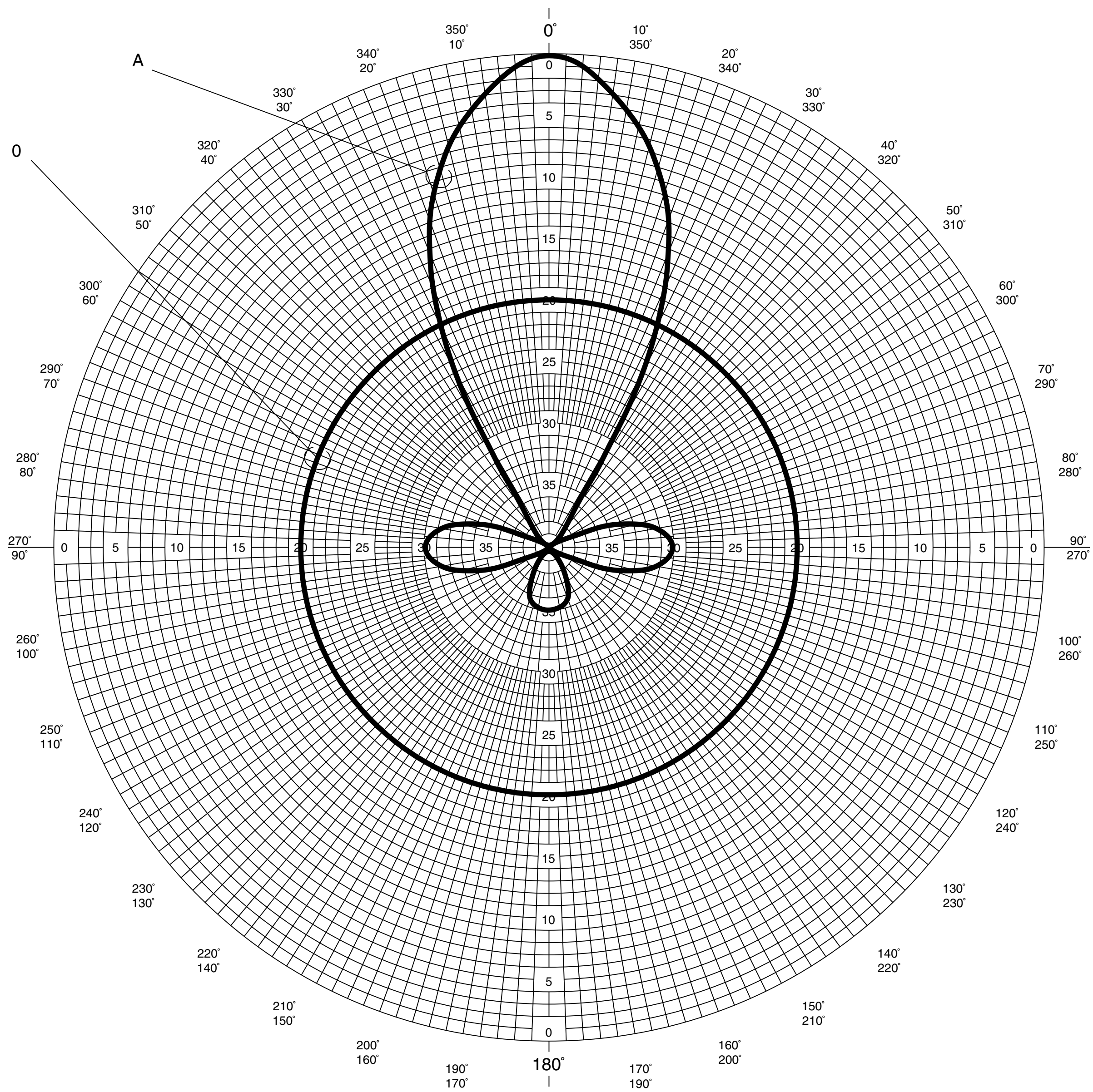

Figure 14-3. Radiation patterns (in dB) of a directional antenna A and an isotropic antenna O.

When antenna gain is specified with no mention of direction, the direction of maximum radiation is always assumed.

There are different methods for measuring the gain of an antenna. The simplest method consists of comparing the power received by a reference antenna $P_{Ref.}$ to the power received by the antenna being tested P_{Test}. The gain of the unknown antenna is given by the following equation:

$$G_{Test} = \frac{P_{Test}}{P_{Ref.}} G_{Ref.}$$

or, if all measurements are in dB relative to an arbitrary reference:

$$G_{Test}(dB) = P_{Test}(dB) + G_{Ref.}(dB) - P_{Ref.}(dB)$$

It should be noted that if absolute power measurements are made, dBm can replace the dB in the above equation. For example, if the power received by the antenna under test is −15 dBm, and the power received by the reference antenna, whose gain is 10 dB, is −12 dBm, the gain of the antenna under test will be 7 dB.

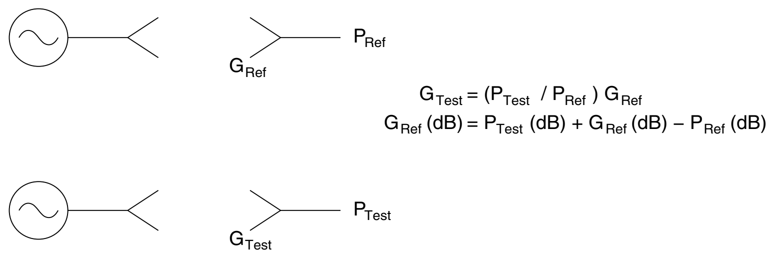

Figure 14-4. Illustration of antenna gain measurement with reference antenna.

Another method allows the gain of two identical antennas to be evaluated. Once the transmitted and received powers P_T and P_R, respectively, have been measured, the gain can be calculated with Equation 14-3.

$$G = \frac{4\pi r}{\lambda} \sqrt{\frac{P_R}{P_T}} \qquad (14\text{-}3)$$

where λ is the signal wavelength in free space. (It should be in the same units as r, the antenna separation.)

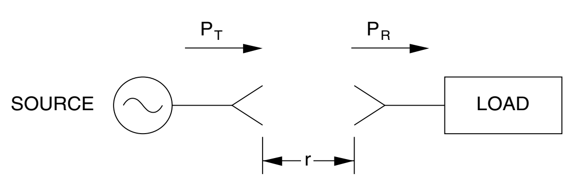

Figure 14-5. Illustration of identical-antenna gain measurement technique.

Procedure Summary

In this exercise, you will be using the pa9502SWR Meter to make relative power measurements as it is more sensitive than the pa9503Power Meter. Absolute power measurements cannot be made with the pa9502SWR Meter, but relative powers can be determined using the dB scale.

In the first part of this exercise, you will determine the relationship between the power of the received signal and the distance between two horn antennas. You will transmit a signal from one horn and use the pa9502SWR Meter to measure the strength of the signal received by the other horn for various antenna separations. Relative signal powers will be determined by subtracting the reference received signal level from the received signal level (in dB). You will plot these results against the horn separation and use this curve to determine the relationship between the two variables.

Then, you will determine the gain of two identical horn antennas using the identical-antenna gain-measurement technique. First, you will put the pa9532Variable Attenuator between the pa9510Gunn Oscillator and the pa9522Crystal Detector connected to the pa9502SWR Meter, and adjust the pa9532Variable Attenuator to set the transmitted power reference level. You will then insert the transmitting and receiving horns in the setup and the pa9502SWR Meter reading will now represent the received signal level. Subtracting the transmitted power reference level from the received signal level will give the ratio of the received power to the transmitted power in dB. From this ratio and Equation 14-3, the gain of each horn will be determined.

Finally, in the last part of the exercise, you will plot the radiation pattern of a horn antenna and of a long triangular lens. The pa9592Antenna Azimuth Indicator will be used to vary the orientation of the receiving antenna under study. You will set a reference level on the pa9502SWR Meter with the receiving antenna aligned with the transmitting antenna. This value will be used to determine the relative power of the received signal as the receiving antenna is turned through 360°. Each relative power will be plotted to produce the radiation pattern.

> **Note:** *Since you will be transmitting microwaves through free space, it is suggested that you work in an open area clear from any obstacles that might reflect the transmitted signal. Reflected signals will change the results of the exercise. Also, set up the pa9501Gunn Oscillator Power Supply and the pa9502SWR Meter behind the pa9510Gunn Oscillator, and avoid working between the transmitting and receiving antennas so that you do not interfere with the propagating signal.*

EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart, in Appendix F of this manual, to obtain the list of equipment required to perform this exercise.

PROCEDURE

☐ 1. Make sure that all power switches are in the O (off) position and set up the modules as shown in Figure 14-6.

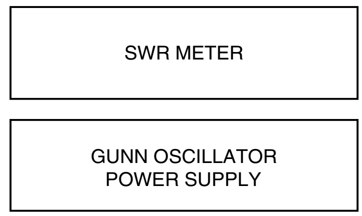

Figure 14-6. Module arrangement.

☐ 2. Set up the components as shown in Figure 14-7. Use the long support rods and the pa9592Antenna Azimuth Indicator.

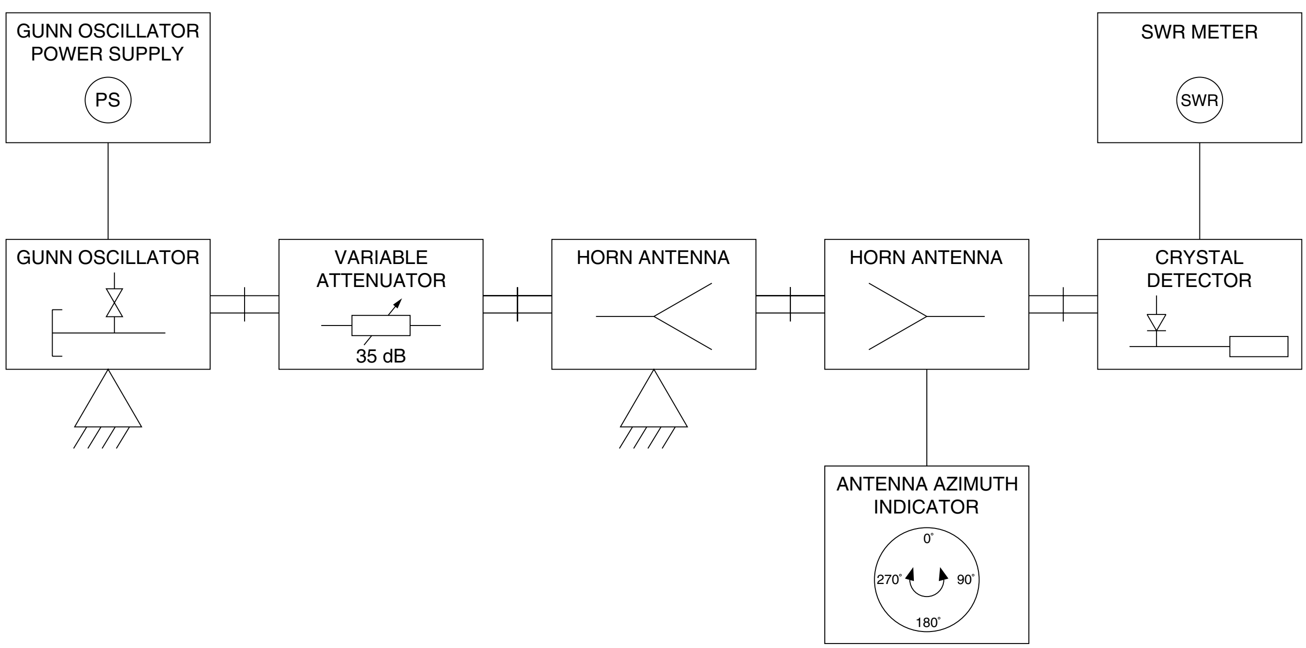

Figure 14-7. Setup used to measure propagation loss.

☐ 3. Place the receiving antenna next to the transmitting antenna. Adjust the height of the supporting rods so that the center of each antenna is about 30 cm above the working surface. Referring to Figure 14-8, move the antennas a distance r = 60 cm apart. Adjust the horns so that they are at the same height and directly facing each other.

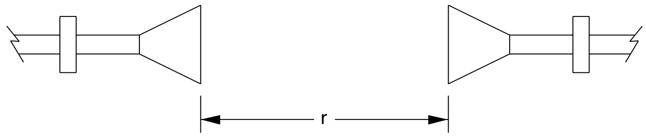

Figure 14-8. Distance r between the antennas.

Note: *To make it easier to align the antennas later on in the exercise, lay a strip of masking tape along your working surface. On the tape, mark off separations of 60, 70, 80, 90, 100, 110 and 120 cm.*

☐ 4. Make the following adjustments:

On the pa9501Gunn Oscillator Power Supply

VOLTAGE . . . . MIN.
MODE . . . . 1 kHz
METER RANGE . . . . 10 V

On the pa9502SWR Meter

RANGE . . . . −30 dB
GAIN . . . . 10 dB (fully cw)
SCALE . . . . NORMAL
BANDWIDTH . . . . 20 Hz

On the pa9532Variable Attenuator

Blade Position . . . . 11 mm

☐ 5. Power up the pa9501Gunn Oscillator Power Supply and the pa9502SWR Meter. Wait 1-2 minutes to allow the power supply to warm up. Adjust the pa9510Gunn Oscillator's supply voltage to 8 V.

WARNING

For your safety, do not look directly into the waveguides or pa9535Horn Antennas while power is being supplied to the pa9510Gunn Oscillator.

☐ 6. Adjust the pa9532Variable Attenuator to obtain a reading of about −35 dB.

Adjust the CENTER FREQUENCY control to maximize the reading.

☐ 7. Vary the supply voltage to maximize the reading on the pa9502SWR Meter, and adjust the pa9532Variable Attenuator to obtain a reading of

−30 dB. This is the reference level; it is already recorded in the first row of Table 14-1.

☐ 8. For each ANTENNA SEPARATION r in Table 14-1, do the following:

a. Align the receiving antenna a distance r from the transmitting antenna.

b. Record the pa9502SWR Meter reading $S_R(r)$ in the RECEIVED SIGNAL LEVEL column of Table 14-1.

c. Calculate $S_R(r) - S_R(60)$, the difference in dB between the received signal level and the reference received signal level for an antenna separation of 60 cm, as indicated in the RELATIVE RECEIVED SIGNAL LEVEL column in Table 14-1, and record the value in that column.

ANTENNA SEPARATION	RECEIVED SIGNAL LEVEL	RELATIVE RECEIVED SIGNAL LEVEL
R	$S_R(r)$	$S_R(r) - S_R(60)$
cm	**dB**	**dB**
60	−30.0	0
70		
80		
90		
100		
110		
120		

Table 14-1. Determining the received signal level relative to $S_R(60)$ for various antenna separations.

☐ 9. From the values in Table 14-1, plot the curve of the RELATIVE RECEIVED SIGNAL LEVEL $S_R(r) - S_R(60)$ as a function of the ANTENNA SEPARATION r in Figure 14-9.

What is the relationship between the power of the received signal and the antenna separation?

____

____

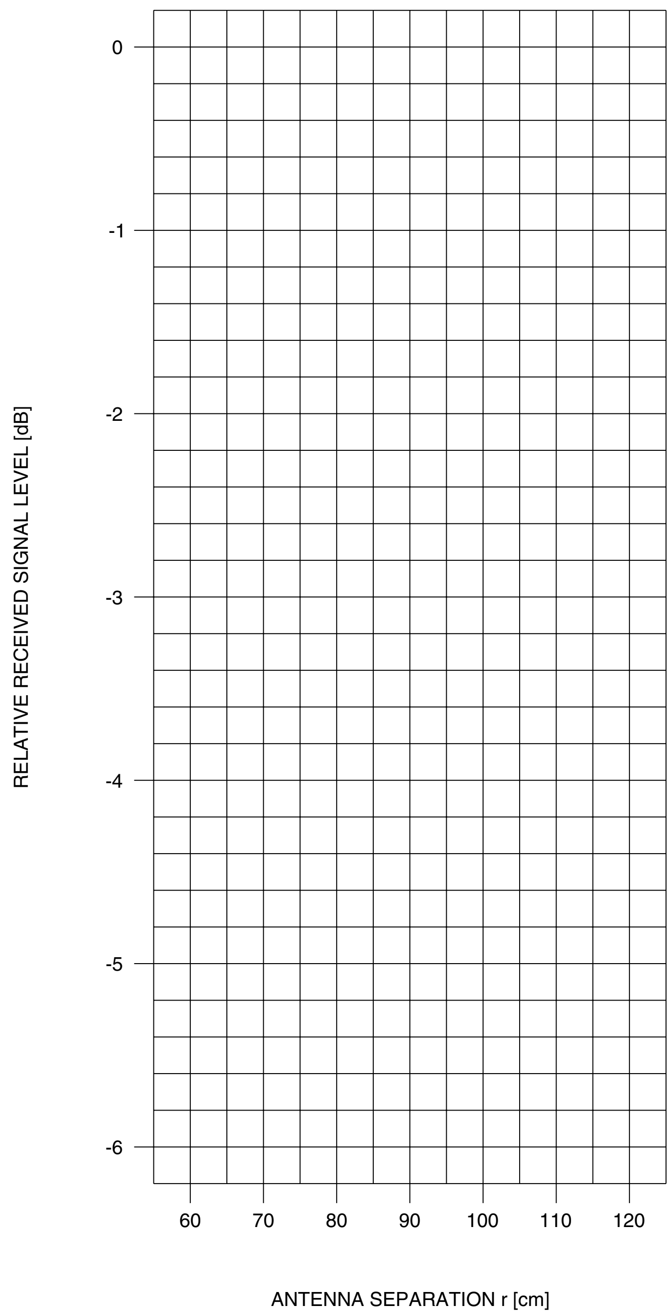

Figure 14-9. Curve of RELATIVE RECEIVED SIGNAL LEVEL as a function of the ANTENNA SEPARATION.

☐ 10. Disconnect the pa9510Gunn Oscillator's power supply cable from the pa9501Gunn Oscillator Power Supply. Make the connections shown in Figure 14-10.

☐ 11. Adjust the pa9532Variable Attenuator's blade position to about 11 mm. Reconnect the pa9510Gunn Oscillator's power supply cable to the pa9501Gunn Oscillator Power Supply.

☐ 12. Adjust the pa9532Variable Attenuator to obtain a reading of −30 dB on the pa9502SWR Meter. This is the reference level; it corresponds to the transmitted power P_T.

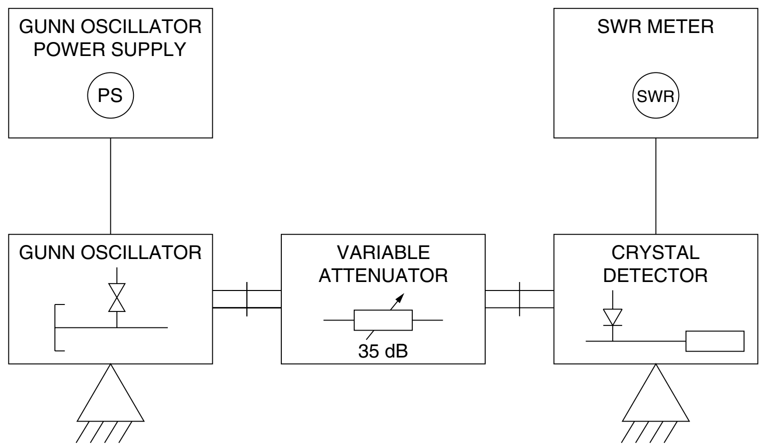

Figure 14-10. Setup used to obtain a reference level for determining the gain of the pa9535Horn Antenna.

Disconnect the pa9510Gunn Oscillator's power supply cable from the pa9501Gunn Oscillator Power Supply. Without changing the setting of the pa9532Variable Attenuator, make the connections shown in Figure 14-11.

☐ 13. Refer to Figure 14-8, and separate the antennas by a distance of 60 cm. Make sure that the antennas are lined up correctly. Adjust the pa9592Antenna Azimuth Indicator so that it indicates 0°.

☐ 14. Reconnect the pa9510Gunn Oscillator's power supply cable to the pa9501Gunn Oscillator Power Supply.

Record the level of the received signal as indicated by the pa9502SWR Meter.

Received Signal Level P_R = ______ dB

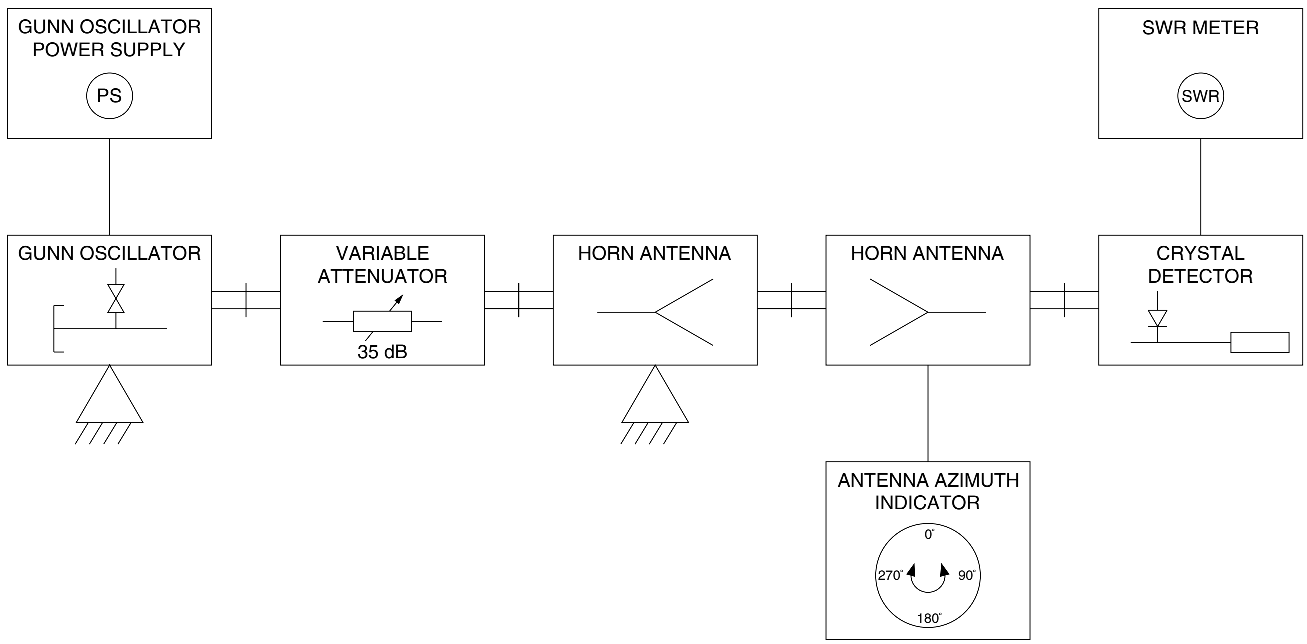

Figure 14-11. Setup used to measure the gain of an antenna.

☐ 15. Recalling from step 12 that $P_T = -30$ dB, calculate the POWER RATIO, i.e., the ratio of the received power to the transmitted power:

$$\text{POWER RATIO} = \frac{P_R}{P_T} \text{ in dB} = P_R(\text{dB}) - P_T(\text{dB})$$

$$= \_\_\_\_\_\_\_\_ + 30 = \_\_\_\_\_\_\_\_ \text{ dB}$$

Using Equation 14-6 below, calculate the value of this ratio.

$$\frac{P_R}{P_T} = 10^{(\text{POWER RATIO (dB)}/10)} \qquad (14\text{-}6)$$

$$\frac{P_R}{P_T} = \_\_\_\_\_\_\_\_$$

☐ 16. Using Equation 14-3 and the fact that microwave frequency is 10.5 GHZ, calculate the gain of each pa9535Horn Antenna.

$$G = \frac{4\pi r}{\lambda} \sqrt{\frac{P_R}{P_T}}$$

G = ______

Using Equation 14-7 below, calculate the gain of the antenna in dB.

$$G\ (dB) = 10 \log G = \_\_\_\_\_\_ \ dB \qquad (14\text{-}7)$$

☐ 17. Make sure that the antennas are aligned correctly. Adjust the pa9592Antenna Azimuth Indicator to read 0° with the antennas correctly aligned. Select the −30-dB RANGE on the pa9502SWR Meter and adjust the pa9532Variable Attenuator to obtain a reading of −30 dB. This is the reference level S_R (0°); it is already recorded in the first row of Table 14-2.

☐ 18. For each direction given in the ANTENNA AZIMUTH INDICATION θ column of Table 14-2, record the RECEIVED SIGNAL LEVEL S_R(θ) and calculate the POWER RATIO in dB using S_R(0°) as a reference level, as indicated at the top of the column.

ANTENNA AZIMUTH INDICATION θ	**RECEIVED SIGNAL LEVEL $S_R(\theta)$**	**POWER RATIO $S_R(\theta) - S_R(0°)$**	**ANTENNA AZIMUTH INDICATION θ**	**RECEIVED SIGNAL LEVEL $S_R(\theta)$**	**POWER RATIO $S_R(\theta) - S_R(0°)$**
degrees	**dB**	**dB**	**degrees**	**dB**	**dB**
0	−30.0	0	180		
10			190		
20			200		
30			210		
40			220		
50			230		
60			240		
70			250		
80			260		
90			270		
100			280		
110			290		
120			300		
130			310		
140			320		
150			330		
160			340		
170			350		

Table 14-2. Determining the POWER RATIO with respect to the 0° received signal level for the pa9535Horn Antenna.

☐ 19. From the results of Table 14-2, plot the radiation pattern of the antenna in Figure 14-12.

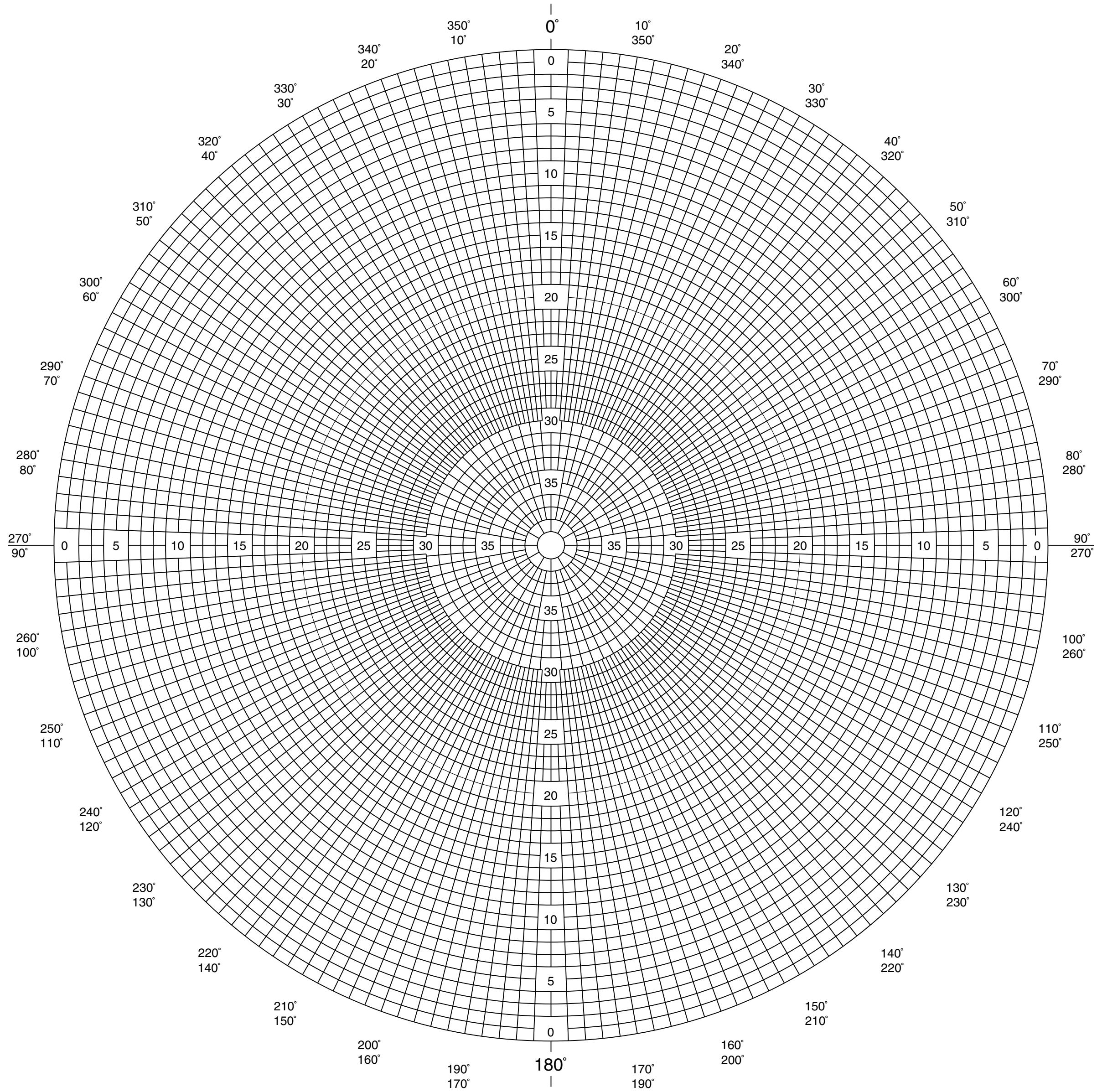

Figure 14-12. Radiation pattern of the pa9535Horn Antenna.

☐ 20. Disconnect the pa9510Gunn Oscillator's power supply cable from the pa9501Gunn Oscillator Power Supply.

Remove the receiving pa9535Horn Antenna and insert the Long Triangular Lens into the open end of the pa9522Crystal Detector. Adjust the antenna position indicator so that it indicates 0° when the lens is pointed directly towards the transmitting antenna.

Reconnect the pa9510Gunn Oscillator's power supply cable to the pa9501Gunn Oscillator Power Supply.

☐ 21. On the pa9502SWR Meter, select the −30-dB RANGE. Adjust the pa9532Variable Attenuator to obtain a reading of −30 dB on the pa9502SWR Meter. As before, this is the reference level S_R (0°), it is already recorded in the first row of Table 14-3.

☐ 22. For each direction given in the ANTENNA AZIMUTH INDICATION θ column of Table 14-2, record the RECEIVED SIGNAL LEVEL $S_R(\theta)$ and calculate the POWER RATIO in dB using $S_R(0°)$ as a reference level, as indicated at the top of the column.

ANTENNA AZIMUTH INDICATION θ	**RECEIVED SIGNAL LEVEL $S_R(\theta)$**	**POWER RATIO $S_R(\theta) - S_R(0°)$**	**ANTENNA AZIMUTH INDICATION θ**	**RECEIVED SIGNAL LEVEL $S_R(\theta)$**	**POWER RATIO $S_R(\theta) - S_R(0°)$**
degrees	**dB**	**dB**	**degrees**	**dB**	**dB**
0	−30.0	0	180		
10			190		
20			200		
30			210		
40			220		
50			230		
60			240		
70			250		
80			260		
90			270		
100			280		
110			290		
120			300		
130			310		
140			320		
150			330		
160			340		
170			350		

Table 14-3. Determining the POWER RATIO with respect to the 0° received signal level for the Long Triangular Lens antenna.

☐ 23. From the results of Table 14-3, plot the radiation pattern of the Long Triangular Lens antenna.

From the radiation patterns in Figures 14-12 and 14-13, which antenna is the most directional?

☐ 24. Turn the VOLTAGE control knob on the pa9501Gunn Oscillator Power Supply to its MIN. position. Place all power switches in the O (off) position, disassemble the setup, and return all components to their storage compartments.

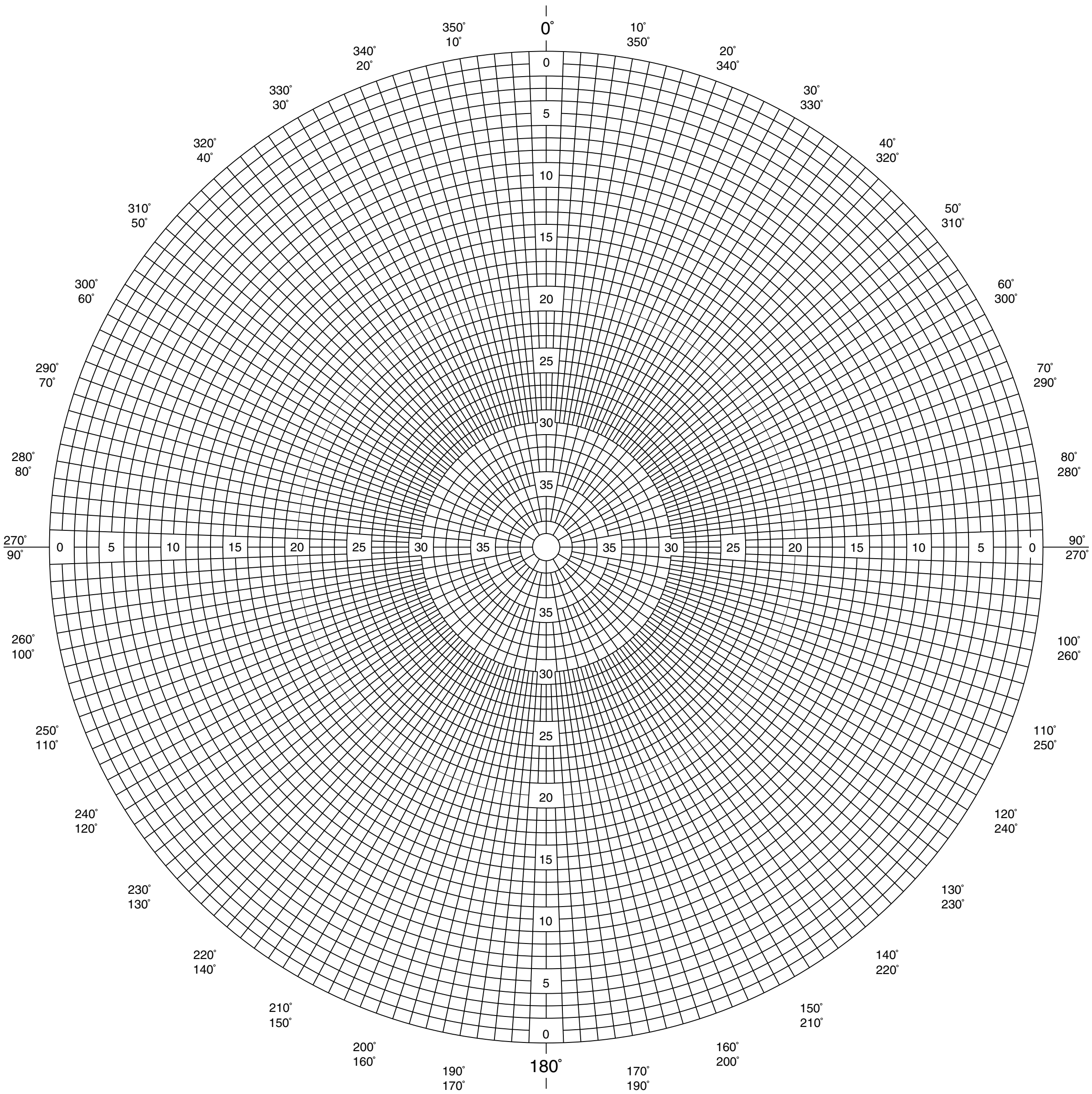

Figure 14-13. Radiation pattern of the Long Triangular Lens antenna.

CONCLUSION

In this exercise you learned that the propagation loss is a function of the square of the distance between the transmitting and the receiving antennas. You measured the gain of an antenna using the identical antenna gain measurement technique. You also plotted the radiation pattern of the pa9535Horn Antenna and of the Long Triangular Lens and you saw that the pa9535Horn Antenna is more directional than the Long Triangular Lens antenna.

REVIEW QUESTIONS

1. What does the free-space propagation loss represent?

   ____

   ____

2. Briefly describe the reference antenna method of antenna gain measurement.

   ____

   ____

3. The radiation pattern of a receiving antenna is given in Figure 14-14. What would be the radiation pattern if the same antenna was used to transmit a signal?

   ____

   ____

4. Someone moves away from a transmitting antenna and records the distance each time that the received signal decreases by 1 dB. What should be the distance ratio between any two successive measurements?

   ____

   ____

5. Why is it preferable to move antennas away from the ground when making antenna pattern measurements?

   ____

   ____

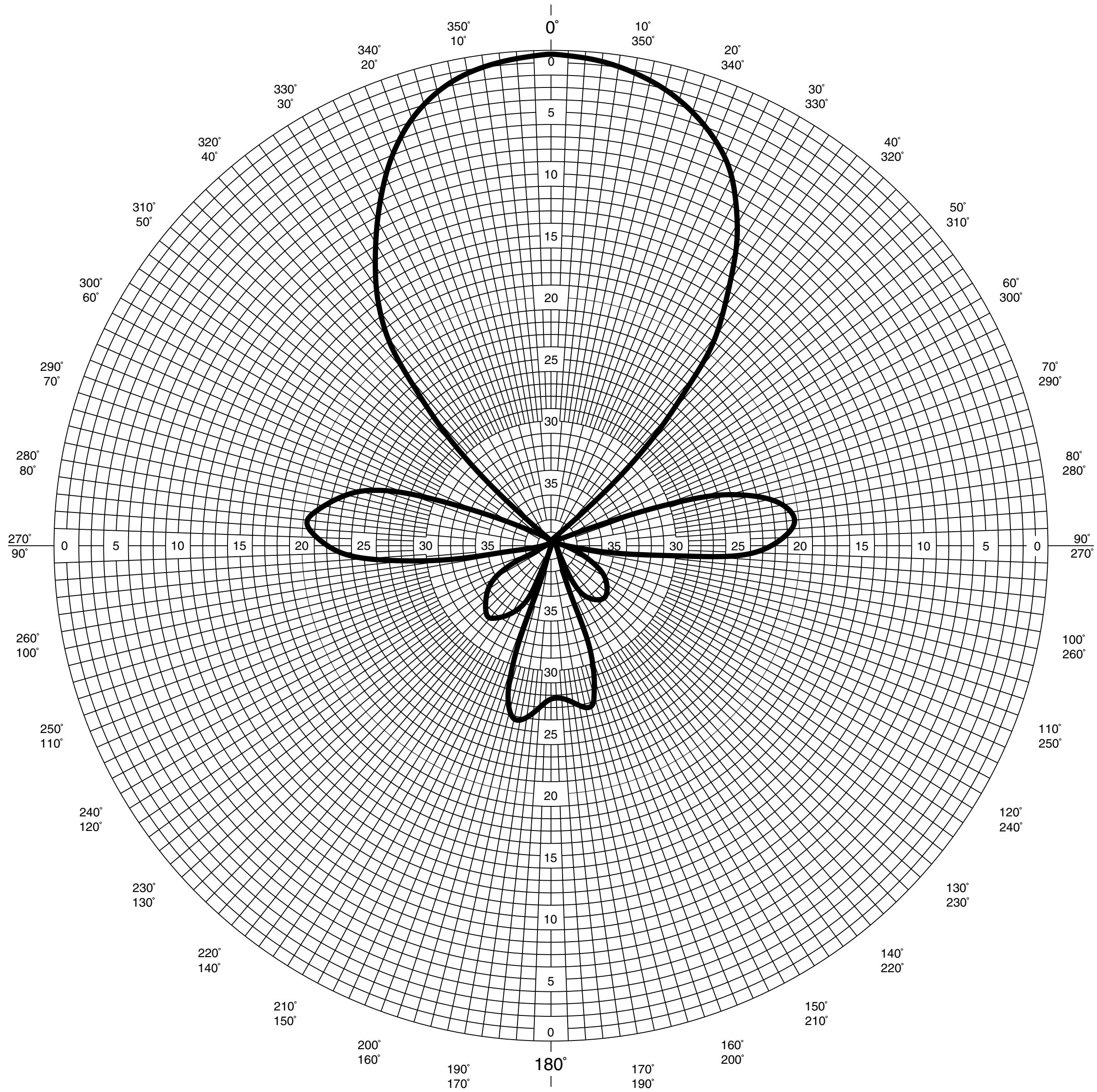

Figure 14-14. Radiation pattern of a receiving antenna.

Bibliography

BADENFULLER, A.J., *Microwaves: An Introduction to Microwave Theory and Techniques*, 2nd Edition, Oxford, U.K., Pergammon Press, 1979.
ISBN 0-08-024297-8

CHEUNG, W.S., LEVIEW, F.H., *Microwave Made Simple. Principles and Applications*, Dadham, Mass (U.S.A.), Artech House Inc., 1985.
ISBN 0-89006-173-4

CROSS, A.W., *Experimental Microwave*, Stevenage, U.K., Marconi Instruments Ltd., 1977.

GANDHI, O.P., *Microwave Engineering and Applications*, Elmsford, New York, Pergamon Press Inc., 1981.
ISBN 0-08-025588-4

GARDIOL, F., *Hyperfréquences*, Paris, France, Dunod, 1987.
ISBN 2-04-016953-9

GRIVET, P., *Physique des Lignes de Haute Fréquence et d'Ultra-Haute Fréquence*, Paris, France, Masson et Cie, 1969.

GUPTA, K.C., *Microwaves*, New Delhi, India, Wiley Eastern Ltd., 1979.
ISBN 0-85226-346-5

JOUQUET, M., *Ondes Électromagnétiques – Vol. 2: Propagation Guidée*, Paris, France, Bordas-Dunod, 1973.
ISBN 2-04-010141-1

KENNEDY, G., *Electric Communication Systems, 3rd Ed.*, New York, N.Y. (U.S.A.), McGraw Hill Book Co., 1985.
ISBN 0-070-34054-4

LAVERGHETTA, T.S., *Handbook of Microwave Testing*, Dadham, Mass (U.S.A.), Artech House Inc., 1981.
ISBN 0-89006-070-3

LIAO, S.Y., *Microwave Devices and Circuits*, Englewood Cliffs, New Jersey (U.S.A.), Prentice Hall Inc., 1980.
ISBN 0-13-581297-0

VASSALLO, C., *Théorie des Guides d'Ondes Électromagnétiques – Tome 1 et Tome 2*, Paris, France, Éditions Eyrolles, 1985.