Exercise 2-3

Circular Polarization and Helical Antennas

EXERCISE OBJECTIVE

When you have completed this exercise, you will be familiar with circular polarization and the characteristics of helical antennas operating at 10 GHz.

DISCUSSION

Circular polarization

All of the antennas seen so far in this manual are linear polarization antennas. In the case of the straight-wire antennas, such as dipoles, folded dipoles, and monopoles, the related electric field has the same orientation as the physical wire. With a transmitting horizontal dipole, for example, the E field is in the horizontal plane and the H field is in the vertical plane. The same antenna best receives waves whose E field is in the horizontal plane.

The loop antenna is also linearly polarized. For example, a vertical full-wave loop antenna fed from the bottom behaves somewhat like a horizontal dipole and produces a horizontally polarized wave. If we move the feed from the bottom to the left or right side, the wave will be vertically polarized.

A rectangular waveguide also transmits a linearly polarized wave. While performing E- and H-plane measurements in previous exercises, you verified that both the transmitting and receiving antennas must use the same polarization. If both transmitting and receiving antennas are aligned and adjusted for the same polarization, the signal will be received well. However, if one antenna is then rotated by 90°, only a weak signal will be received due to cross-polarization isolation. In theory, cross-polarization isolation should be infinite and no signal should be received, but in practice, cross-polarization isolation is not perfect.

The polarization of an antenna can also be elliptical or circular. **Elliptical polarization** results from the combination of two electric field vectors (you can think of these two vectors as two linearly polarized waves) which are perpendicular to each other, have the same frequency, and are travelling in the same direction. The phase relation between these two waves as well as their amplitudes can have different values. If the amplitudes of the two vectors are identical and if they are exactly 90° out of phase, we have **circular polarization**. If one vector or the other has a zero amplitude, the polarization is linear. Linear and circular polarizations are special cases of elliptical polarization.

In order to have circular polarization, the electric field must be made to rotate rapidly. There are a number of ways this can be accomplished.

One way is to transmit both a vertically polarized wave and a horizontally polarized wave 90° out of phase. This is somewhat analogous to tracing a Lissajous figure of a perfect circle on an oscilloscope by sending sinusoidal waves 90° out of phase into the X- and Y-axis inputs.

Another way is to send an electric wave along a helix of appropriate dimensions. As the wave travels along the helix, it produces a rapidly rotating electric field. This principle is used in helical antennas.

The rotation of the electric field can be either clockwise or counterclockwise. If the fingers of your right hand curl in the direction of rotation when the thumb points in the direction of propagation, the polarization is said to be **right-hand circular polarization**. The opposite sense of rotation gives rise to **left-hand circular polarization**.

With circular polarization, the effect of cross-polarization isolation is very marked. A right-hand circularly polarized antenna cannot receive a left-hand circularly polarized signal, and vice versa. Each antenna can, however, receive with some attenuation a linearly polarized signal in any orientation.

Although linear polarization is perfectly adequate for many situations, circular polarization is very useful in certain types of communications. One example is satellite communications where it is difficult to maintain a constant antenna orientation. Excessive fading would result if linear polarization were used. With circular polarization, the strength of the received signal is fairly constant regardless of the satellite antenna orientation.

Helical antennas

Figure 2-22 illustrates a typical axial-mode helical antenna, that is, a helical antenna which is designed to have a pencil-beam radiation pattern oriented along the axis of the helix away from the ground plane.

Helical antennas of this type are useful for a number of applications. Besides their very desirable radiation pattern, they offer a large bandwidth and an input impedance of 120 to 140 Ω.

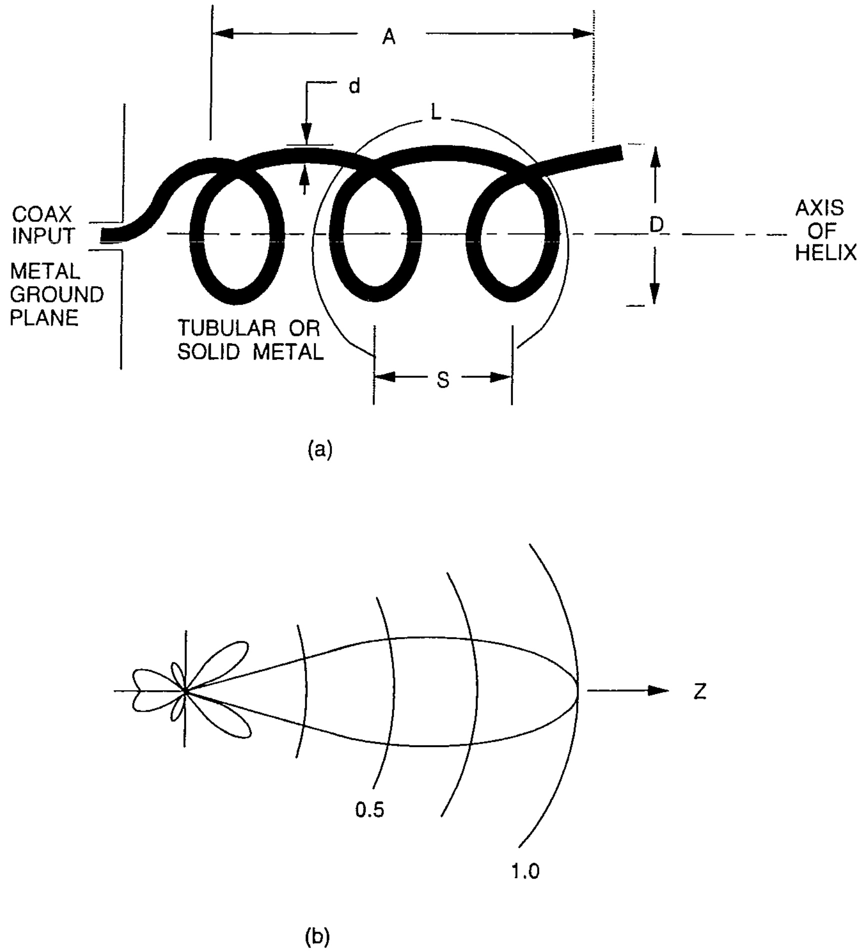

Figure 2-22. Axial-mode helical antenna: (a) geometry (b) pencil-beam radiation pattern

The symbols used to describe the helix are as follows:

N = number of turns
S = spacing between turns = C tan α
A = axial length = NS
D = diameter of helix
d = diameter of conductor
C = circumference = πD
L = length of one turn
α = pitch angle = $\tan^{-1}(S/C)$

The helix will radiate in the axial mode when the circumference of the helix is in the order of magnitude of one wavelength. A fairly wide range of frequencies can be used. This range corresponds to

$$\frac{3}{4}\lambda < C < \frac{4}{3}\lambda \qquad (1)$$

The sinusoidal wave travels along the helix from the ground plane towards the opposite end. For this reason, the helical antenna is called a **travelling-wave antenna.**

To understand how the helical antenna operates, consider one loop of a helix of circumference λ, as shown in Figure 2-23.

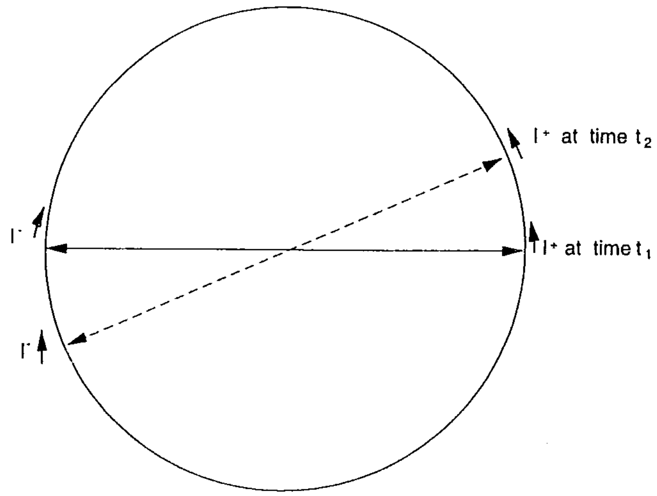

Figure 2-23. One loop of a helical antenna ($C = \lambda$)

At a given instant of time t_1, the current is positive on one side of the loop and negative on the opposite side, since the circumference of the loop is λ. This is shown in the figure by the fact that the arrows at I^+ and I^- point in the same geometrical direction. This gives rise to a kind of dipole.

A very short time later, at time t_2, the current has travelled a short distance down the helix. The dipole has now rotated slightly. The dipole effectively rotates at a frequency equal to that of the transmitted wave.

The radiation pattern towards the sides of Figure 2-23 will be zero. The radiation will be along the axis of the helix.

It would be reasonable to think that if the fields of each loop forming the helix were all superposed and in phase, they would add up to give a strong radiation pattern along *both* ends of the axis of the helix, as shown in Figure 2-24. However, this is not the case. Propagation delays along the helix cause phase differences which modify the radiation pattern, giving it one lobe in the axial direction instead of two, as in Figure 2-22(b). The helical antenna can be modeled as an endfire array which, because of the position of its elements and the phases of the currents, has only one lobe in the endfire direction.

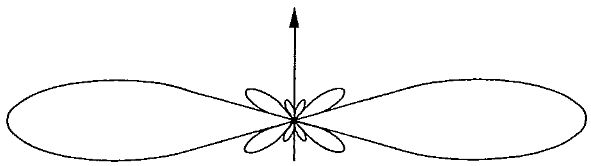

Figure 2-24. Fan beam radiation pattern

The direction of the winding of the helix determines the direction of polarization. When viewing the helix from the ground-plane end, a clockwise winding produces right-hand circular polarization, and a counterclockwise winding produces left-hand circular polarization.

Axial ratio and gain

While receiving a circularly polarized signal, the response of a helical antenna should, ideally, remain constant as the electric field of the signal rotates.

To illustrate this, imagine a linearly polarized antenna, such as a dipole, used for transmission and a helical antenna used for reception. The polarization of the transmitted signal could be changed by rotating the dipole by a certain angle. An ideal helical antenna would produce the same response for all orientations of the dipole, that is, for all polarizations. Since the helix is of finite length, however, it is slightly asymmetric. It therefore responds to some polarizations slightly better than others.

The measure of the response of a helix to different polarizations is called the **axial ratio**, also known as the **circularity**. This is defined as the ratio of the amplitude with the polarization that gives the maximum response to the amplitude with the polarization that gives the minimum response. An antenna which responds equally to all polarizations has an axial ratio of 1.0 (or 0 dB).

The axial ratio is given by

$$AR = \frac{2N + 1}{2N} \qquad (2)$$

where AR is the axial ratio
N is the number of turns in the helix.

The axial ratio can be measured by transmitting between a linearly polarized antenna and the helical antenna. By rotating one of the antennas and measuring the maximum and minimum amplitudes, the axial ratio can be calculated directly as the ratio of these two amplitudes.

Ideally, a helical antenna has an axial ratio between 1 and 1.1 (0 and 0.83 dB). To obtain such results, however, the open end of the helix should be tapered. In practice, for a constant diameter helix, it is not uncommon to encounter axial ratios around 1.12 (1 dB).

The gain of the helical antenna can be expressed empirically as

$$G \approx 8.3 \left(\frac{\pi D}{\lambda} \right)^{[(N-2)^{1/2}-1]} \cdot \left(\frac{NS}{\lambda} \right)^{0.8} \cdot \left[\frac{\tan(12.5°)}{\tan(\alpha)} \right]^{(N/2)^{1/2}} \quad (3)$$

Normal mode of radiation

It is possible to make a helical antenna with an entirely different radiation pattern, as shown in Figure 2-25. This helical antenna operates in the normal mode of radiation, that is, the direction of maximum radiation is normal to the axis of the antenna.

For normal mode operation, the circumference of the helix must be small compared to the wavelength. This makes the current distribution nearly uniform in amplitude and phase along the helix. This type of helix is electrically small and its efficiency is low.

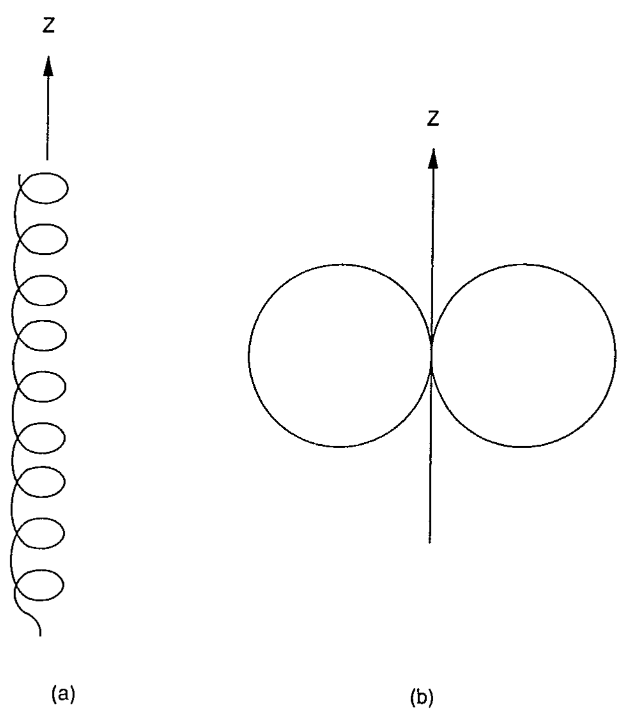

Figure 2-25. Normal-mode helical antenna: (a) geometry (b) radiation pattern

Radomes

The helical antennas included in the Antenna Training and Measuring System are protected by a **radome**. Radomes, or radar domes, are protective housings for millimeter-wave or microwave antennas. They are shaped to cover the antenna and are usually made of low-loss dielectrics of thickness much smaller than a wavelength.

Because of reflections, refractions, and losses, a radome modifies the electrical characteristics of the antenna it covers. These changes usually result in some distortion of the radiation pattern. The gain, beamwidth, sidelobe levels, and polarization characteristics may be altered. In the case of the helical antennas in the Antenna Training and Measuring System, the presence of the radome reduces the half-power beamwidth slightly and increases the levels of the side lobes.

Procedure Summary

In this exercise you will learn to differentiate between a right-hand (RHP) and a left-hand (LHP) polarized helical antenna. You will plot the radiation patterns of these two antennas and evaluate their half-power beamwidth. You will measure the gain of the helix and compare your results with the calculated theoretical value. Finally, you will complete this exercise by evaluating the axial ratio, also called the circularity, of the helical antenna.

PROCEDURE

Setting up the equipment

☐ 1. The main elements of the Antenna Training and Measuring System, that is the Data Acquisition Interface/Power Supply, the RF Generator, the Antenna Positioner and the computer, must be properly set up before beginning this exercise. Refer to Section 4 of the User Manual for setting up the Antenna Training and Measuring System, if this has not already been done.

☐ 2. Insert the antenna mast with locking ring into the transmission support. Couple a large horn antenna onto the waveguide-to-coax adapter. Using the plastic holder, attach the horn antenna to the mast, polarized horizontally. Install the long SMA cable on the 10 GHz OSCILLATOR OUTPUT of the RF Generator, then connect the antenna.

☐ 3. Place the other antenna mast with locking ring on the sliding support of the Antenna Positioner. Attach the small horn antenna to the mast, making sure that it is in line with the rotation centre of the Antenna Positioner and oriented for an E-plane acquisition.

Using the intermediate SMA cable, connect the receiving antenna to the RF input on top of the Antenna Positioner.

☐ 4. Position the antennas a distance of r = 1.5 m apart. Adjust them so that they are at the same height and directly facing each other.

☐ 5. Make the following adjustments:

On the RF Generator

10 GHz OSCILLATOR MODE .... 1 kHz
10 GHz OSCILLATOR RF POWER .... OFF
1 GHz OSCILLATOR RF POWER .... OFF

Power up the RF Generator and the Power Supply.

Turn on the computer and start the LVDAM-ANT software.

Radiation pattern

☐ 6. Set the 10 GHz OSCILLATOR RF POWER switch on the RF Generator to the ON position.

CAUTION!

For your own safety, never look directly into the horn antenna while the RF POWER switch is ON.

☐ 7. Using the Attenuation control, optimize reception of the signal. Start your first acquisition.

Store the radiation pattern in the antenna3 data box. Orient the pattern so that the MSP is at 0°.

☐ 8. Remove the receiving antenna. Replace the receiving mast with the one that has horizontal clips. Fasten to the mast one of the two right-hand polarized (RHP) helical antennas supplied with the system. Ensure that the antenna is in line with the rotation centre of the Antenna Positioner and oriented as shown in Figure 2-26.

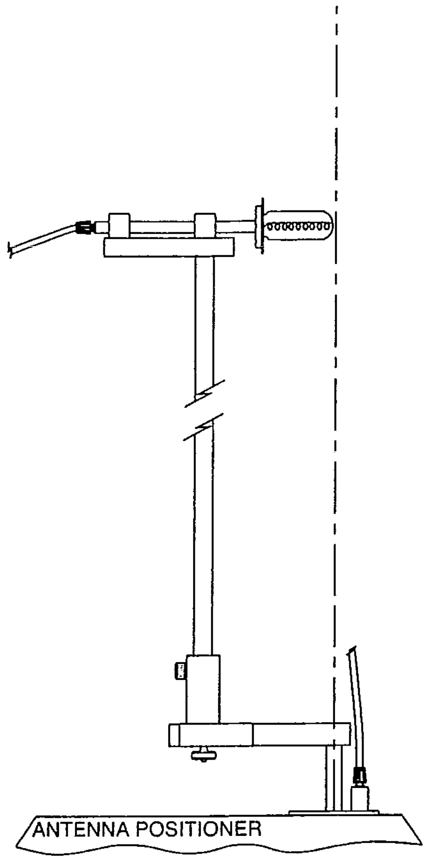

Figure 2-26. Set-up of the RHP helical antenna

Connect the receiving antenna to the RF input on top of the Antenna Positioner.

☐ 9. Referring to Figure 2-27, make sure that the antennas are at a distance of r = 1.5 m apart.

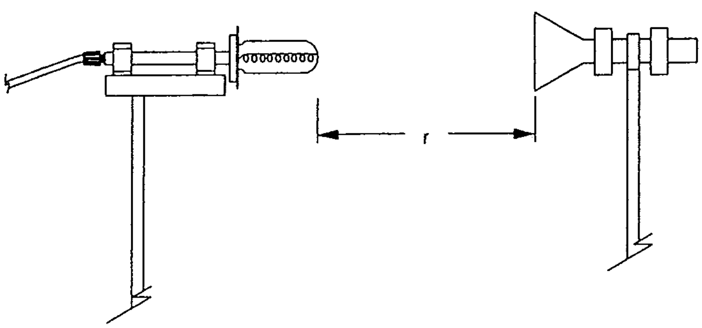

Figure 2-27. Distance r between the antennas

☐ 10. Keep the same attenuation level as for the horn antenna and perform an acquisition. Store the radiation pattern as the E plane of antenna1 and orient the pattern so that its MSP is at 0°.

☐ 11. Rotate the transmission horn antenna by 90° so that it is oriented for an H-plane acquisition.

Do not change the attenuation level. Perform another acquisition. Store this new pattern as the H plane in the antenna1 data box and adjust its MSP to 0°.

Plot the patterns acquired in Steps 7, 10, and 11.

☐ 12. Compare the E and H planes in the antenna1 data box; do you observe a significant difference in their maximum amplitudes? Considering that the receiving antenna has not been rotated to perform the H-plane acquisition, explain this result.

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☐ 13. Remove the receiving antenna and replace it with the left-hand polarized (LHP) helical antenna. Referring to the preceding steps, make the correct set-up and perform acquisitions of the E and H planes of this antenna. Keep the same attenuation level used for the RHP helix. Store the radiation patterns in the antenna2 data box.

Plot the acquired E- and H-plane patterns.

☐ 14. Save the data stored in the antenna1 and antenna2 data boxes, then print the 3-D representations of these two antennas. Note the similarity between the radiation patterns of the RHP and LHP helical antennas.

HPBW and gain of a helical antenna

☐ 15. Evaluate the half-power beamwidth of the helical antennas.

RHP helix: $HPBW_E$ = ______° $HPBW_H$ = ______°

LHP helix: $HPBW_E$ = ______° $HPBW_H$ = ______°

☐ 16. Use the following equation to calculate the gain of the helical antennas given the following dimensions:

$D = 8.4$ mm
$N = 15$ turns
$S = 6.1$ mm
$\alpha = 13°$

$$G = 8.3 \left(\frac{\pi D}{\lambda}\right)^{[(N+2)^{1/2}-1]} \cdot \left(\frac{NS}{\lambda}\right)^{0.8} \cdot \left[\frac{\tan(12.5°)}{\tan(\alpha)}\right]^{(N/2)^{1/2}}$$

G = ______

G (dB) = 10 log G = ______dB

☐ 17. Using the small horn antenna as a reference, measure the gain of the helical antennas.

Record the following values:

$MSL_{E\ plane}$ of the RHP helix : P_{RHP} ______ dB

$MSL_{E\ plane}$ of the LHP helix : P_{LHP} ______ dB

$MSL_{E\ plane}$ of the horn: P_{Ref} ______ dB

Referring to Exercise 1-3 to obtain the gain of a small horn (G_{Ref}), calculate the gain of the helical antennas.

Note: *When a linearly polarized antenna is used to acquire a circularly polarized signal (or vice-versa), a part of the signal is not received; half of the power can be observed to be lost. Therefore, to obtain the real gain of a helical antenna evaluated in such a manner, 3 dB must be added to the result.*

$G_{RHP} = P_{RHP} + G_{Ref} - P_{Ref} + 3$ dB = ______ dB

$G_{LHP} = P_{LHP} + G_{Ref} - P_{Ref} + 3$ dB = ______ dB

Note: *This measurement could also have been performed using the H plane.*

Circularity and axial ratio

☐ 18. Remove the two antennas. Replace the transmission mast with the one that has horizontal clips, then attach an RHP helix to it. Install the other RHP helical antenna on the receiving mast. Position the antennas a distance of 1 m apart, facing each other. Optimize the attenuation level, then make an acquisition. Replace the E-plane radiation pattern in the antenna3 data box by this new one.

Replace the transmission antenna with the LHP helix, then perform a new acquisition. Store this pattern as the H plane of antenna3.

Plot the two patterns acquired in this step.

☐ 19. Compare the two patterns in the antenna3 data box. Were you expecting this result? Explain.

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☐ 20. An important parameter of the helical antenna is the circularity of its polarization. This is known as the axial ratio.

Using the following equation, calculate the theoretical axial ratio of the helix antennas.

$$AR = \frac{2N + 1}{2N}$$

where N = the number of turns in the helix

AR = ______

AR (dB) = 20 log (AR) = ______ dB

☐ 21. One way to measure the axial ratio of a helical antenna is to rotate a linearly polarized antenna through 360° in a plane perpendicular to the axis of the transmitting helix as shown in Figure 2-28. The ratio of the maximum to minimum received signal is the axial ratio. An abbreviated version of this measuring method is used in the following steps.

☐ 22. Remove the receiving antenna and the mast with horizontal clips. Place a mast with locking ring on the sliding support and attach a large horn antenna to this mast. Make sure that the receiving and transmitting antennas are facing each other. Adjust the signal level approximately 5 dB under the saturation level and note the exact value of this signal ($Signal_1$).

Rotate the horn antenna by 90°, as if to acquire a pattern in the other plane. Make sure that both antennas are still facing each other. Do not modify the attenuation level. Now record the received signal ($Signal_2$).

$Signal_1$: ______ dB $Signal_2$: ______ dB

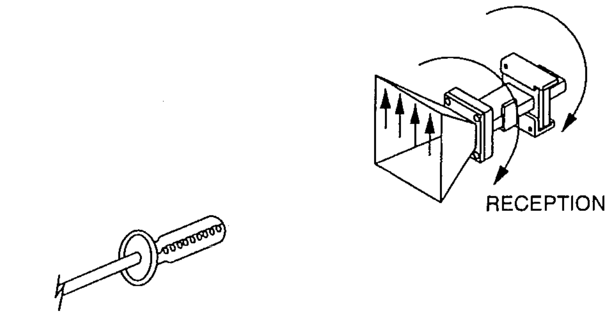

Figure 2-28. Rotation of the linearly polarized antenna in a plane perpendicular to the axis of a helix.

☐ 23. Using the centre line of the radome as reference, rotate the helix by 45°, as shown in Figure 2-29, while maintaining the alignment with the receiving horn.

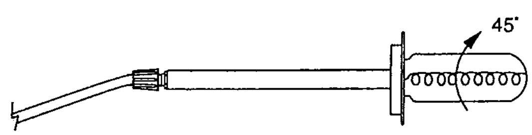

Figure 2-29. Rotation of the helix by 45°

Do not modify the attenuation level. Note the signal received in this plane, then, after having again rotated the horn antenna by 90°, record the signal received in the other plane.

$Signal_3$: ________dB $Signal_4$: ________dB

☐ 24. Taking the highest of these four values as the maximum and the lowest as the minimum, establish the axial ratio of the helical antenna.

$$\frac{Signal_{max}}{Signal_{min}} = Signal_{max}(dB) - Signal_{min}(dB)$$

______- ______ = ______ dB

☐ 25. Make sure you have saved your radiation patterns if you expect to use them in the future, then exit the LVDAM-ANT software. Place all power switches in the O (off) position, turn off the computer, disassemble the set-up, and return all components to their storage compartments.

CONCLUSION

In this exercise, you observed that the gain of a helical antenna is similar in both the E and H planes due to the circularity of its polarization. Using the 3-D option, you visualized the representation in space of this type of antenna. Using the small horn gain as a reference, you measured the gain of an RHP and an LHP helix. Finally, the results of the cross-polarization experiment and the measured axial ratio allowed you to assess the efficiency of the circularity of the helical antenna's polarization.

REVIEW QUESTIONS

1. Define circular polarization.

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2. What is the relation between elliptical, linear and circular polarizations?

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3. Could a 4-turn helical antenna be considered as a good antenna to receive different linear polarizations? Explain.

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4. Explain the main difference between the normal and axial modes of a helical antenna.

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5. What is the purpose of a radome? Does it influence the electrical characteristics of an antenna?

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