# Experiments with $\lambda/2$, $\lambda$, and $3\lambda/2$ Dipoles

## EXERCISE OBJECTIVE

When you have completed this exercise, you will be familiar with the characteristics of $\lambda/2$, $\lambda$, and $3\lambda/2$ dipole antennas.

## DISCUSSION

### Resonance in dipoles

As stated previously, the current distribution of the dipole antenna is not uniform. Instead, it is zero at the ends of the antenna wires, and may be highest at the centre or at other points, depending on the length of the dipole and the frequency of the signal from the transmitter. Figure 1-34 shows the current distribution in centre-fed dipoles of lengths $\lambda/2$, $\lambda$, and $3\lambda/2$. In this figure, the arrows represent the current directions at a particular instant. The magnitude and polarity of the current at different points along the dipole is shown by the sinusoidal line.

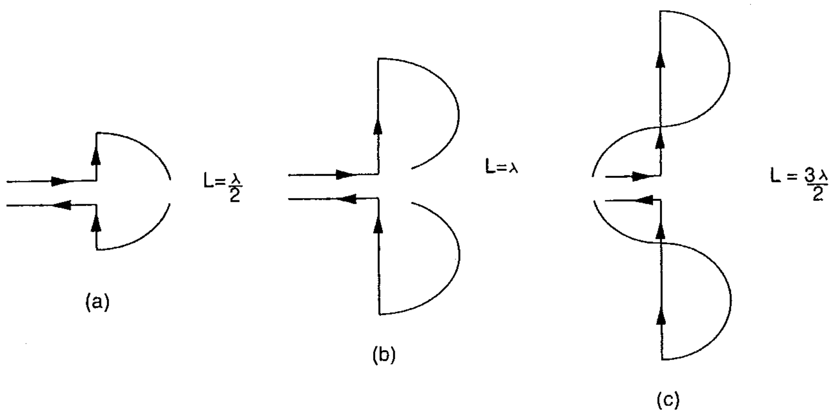


**Figure 1-34. Current distributions in centre-fed dipoles**

### Input impedance

A dipole of length $\lambda/2$, $\lambda$, or $3\lambda/2$ acts as an efficient radiator. This means that the antenna appears to be a resistive element–the current and the voltage are in phase, and therefore the reactance of the antenna is small. Note however, that a dipole of length $\lambda$ is very difficult to tune.

# Experiments with $\lambda/2$, $\lambda$, and $3\lambda/2$ Dipoles

If one measures the input impedance of a $\lambda/2$ or $3\lambda/2$ dipole antenna, one will find that the reactance is close to zero. The resistance is theoretically 73 Ω.

$$Z_{in} = R_{in} + jX_{in} = 73 + j0 \ \Omega \tag{1}$$

At other antenna lengths (greater than $\lambda/2$ but not equal to $\lambda$ or $3\lambda/2$), the input resistance is greater than 73 Ω and the reactance is not zero. Since the resistance is greater, the current is smaller; and because of the non-zero reactance, the voltage and current are out of phase. In this case, the antenna is not an efficient power radiator.

Table 1-1 gives formulas for calculating the approximate resistance of dipoles.

| **Length** <br> **L** | **Input Resistance** <br> **$R_{in}$ (Ω)** |
|---|---|
| $0 < L < \frac{\lambda}{4}$ | $20\pi\left(\frac{L}{\lambda}\right)^2$ |
| $\frac{\lambda}{4} < L < \frac{\lambda}{2}$ | $24.7\left(\pi\frac{L}{\lambda}\right)^{2.4}$ |
| $\frac{\lambda}{2} < L < 0.637\lambda$ | $11.14\left(\pi\frac{L}{\lambda}\right)^{4.17}$ |

**Table 1-1. Formulas for calculating input resistance of dipole antennas**

Figure 1-35 shows the input resistance $R_{in}$ and reactance $X_{in}$ as functions of antenna length. This graph shows that when the length is approximately $\lambda/2$ or $3\lambda/2$, the reactance is zero and the input resistance is close to 73 Ω. The figure applies to very thin-wire antennas.

This figure shows that when the antenna length is approximately equal to $\lambda$, the resistance is very high and the reactance is capacitive. The reactive part of the input impedance can be reduced to zero by reducing the antenna length to approximately 0.9 $\lambda$, but at this length, the resistance is at its maximum. It is for this reason that the $\lambda$ dipole antenna is very difficult to tune.

> **Note:** *The high impedance of the $\lambda$ dipole can be seen from Figure 1-34. This figure shows that the current is null at the centre of the antenna, where the transmission line is connected. The resistance is therefore infinite, in theory, at this point.*

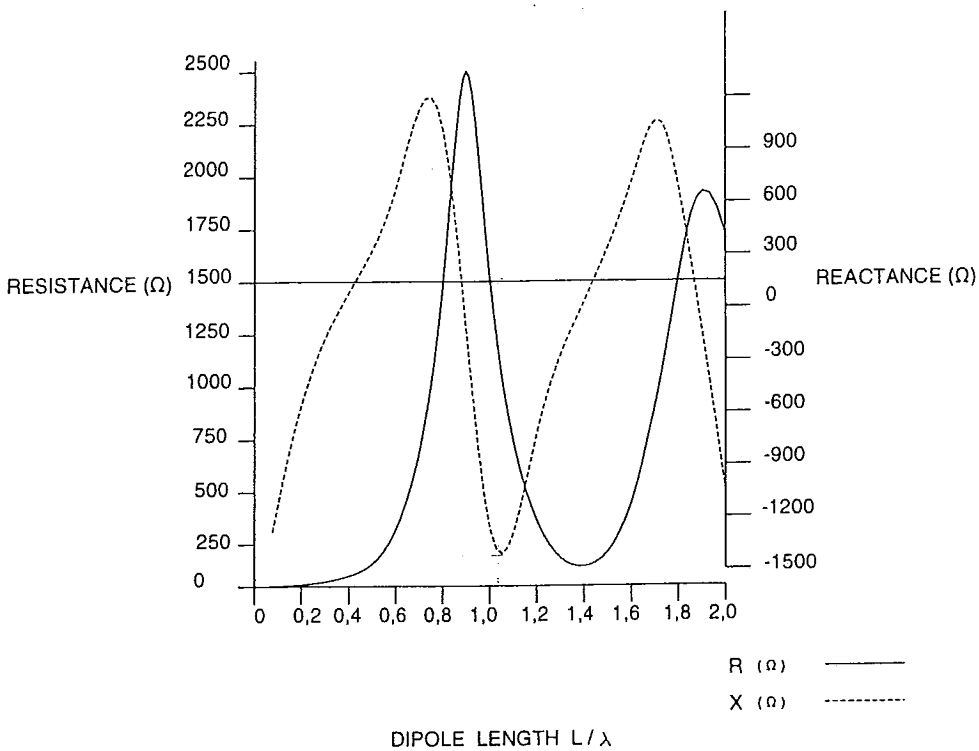


**Figure 1-35. Input resistance (solid line) and reactance (dotted line) of a dipole antenna as a function of antenna length.**

### Radiation patterns

In the H plane, the radiation pattern of the dipole antenna is approximately circular. In the E plane, it is described by Equation (2).

$$E_\theta = E_o \frac{\cos[(\beta L/2)\cos\theta] - \cos(\beta L/2)}{\sin\theta} \qquad (2)$$

where $E$ is the maximum value of $E_\theta$
$\beta = 2\pi/\lambda$

For $L = \lambda/2$, the equation becomes:

$$E_\theta = E_o \frac{\cos[(\pi/2)\cos\theta]}{\sin\theta} \qquad (3)$$

This has the shape shown in Figure 1-36. The maximum value $E_o$ is at $\theta = 90°$.

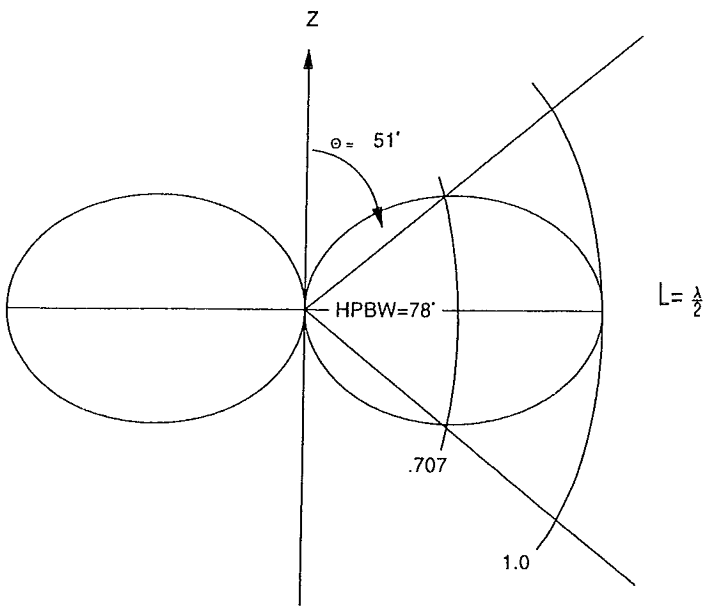


**Figure 1-36. Radiation pattern of the λ/2**

At $\theta = 51°$, $E_\theta = 0.707\ E_o$. This is the half power point. The half-power beamwidth is given by

$$\text{HPBW} = 2(90 - 51) = 78° \tag{4}$$

The directivity of the antenna is D = 1.64 = 2.15 dB.

The radiation pattern of the λ dipole and the 3λ/2 dipole are plotted in Figure 1-37. The directivity of dipoles longer than 1.25λ drops as the length is increased. This is because the currents in different parts of the dipole are such that the fields cancel each other. The resulting radiation pattern has many lobes.

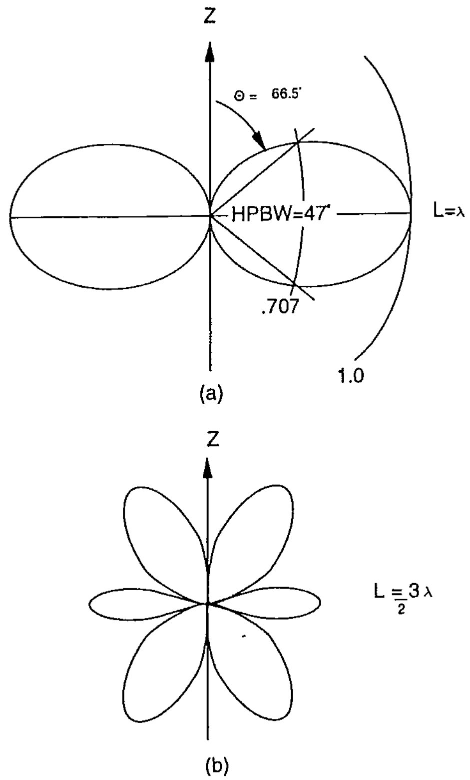


**Figure 1-37. Radiation patterns of the λ dipole (a) and the 3λ/2 dipole (b)**

### Antenna fields

The concept of fields is important in the study of antennas. One distinguishes three different regions for antenna fields: the **Rayleigh (near) field**, the **Fresnel field**, and the **Fraunhofer (far) field**, as illustrated in Figure 1-38.

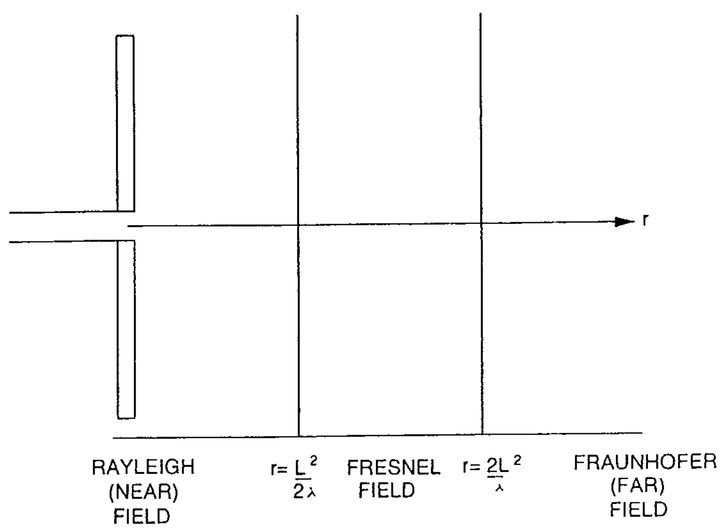


**Figure 1-38. Antenna field regions**

The far field is the region where

$$r > \frac{2L^2}{\lambda} \qquad (5)$$

where $r$ is the distance from the antenna
$L$ is the length of the antenna (or the largest dimension of the aperture).

This is the region of interest when studying antennas and it is the region where the antennas must be placed when plotting the radiation pattern or making other measurements.

If the transmit and receive antennas are of different lengths, the length of the longest antenna should be used as L in Equation (5). This will ensure that the correct region is being used.

> **Note:** *The antennas should never be placed in the Rayleigh (near) field for measurement. In some cases it may be acceptable to place them in the Fresnel field.*

### Procedure Summary

In this exercise you will plot the radiation pattern of $\lambda/2$, $\lambda$ and $3\lambda/2$ dipole antennas. You will observe how the impedance of the $\lambda$ dipole affects the efficiency of this antenna. You will determine the far-field region of an antenna. You will evaluate the half-power beamwidth of the $\lambda/2$ and $\lambda$ dipoles and, finally, the directivity of the $\lambda/2$ dipole 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. Place an antenna mast with horizontal clips on the transmission support. Clip the Yagi antenna on the mast, oriented for an acquisition in the E plane, and connect it to the 1 GHz OSCILLATOR OUTPUT of the RF Generator, using the long SMA cable.

☐ 3. Choose the appropriate pair of wires and set up a $\lambda/2$ dipole by simply inserting the wires into the bottom of the dipole connector, as you did in Exercise 1-1.

☐ 4. Place the antenna mast with vertical clips on the sliding support of the Antenna Positioner. Install the $\lambda/2$ dipole on the mast.

Using the sliding support, ensure that your antenna is in line with the rotation centre of the Antenna Positioner. The dipole is oriented to rotate in the E plane.

Screw the 10 dB attenuator to the RF input on top of the Antenna Positioner. Connect the antenna to the attenuator using the short SMA cable.

☐ 5. Position the antennas a distance of r = 1 m apart. Adjust them so that they are at the same height and directly facing each other.

☐ 6. Make the following adjustments:

On the RF Generator

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

☐ 7. Set the 1 GHz OSCILLATOR RF POWER switch on the RF generator to the ON position. Use the Attenuation control to optimize reception of the signal.

Start your acquisition. Store the radiation pattern in the antenna1 data box, making sure you select the correct plane.

☐ 8. Remove the antenna mast with vertical clips from the sliding support and replace it with the second antenna mast that has horizontal clips. Disconnect the short SMA cable, and replace it with the intermediate one. Install your dipole on the new mast making sure that it rotates in the H plane.

Rotate the Yagi antenna so that it is vertically polarized.

Perform a new acquisition and store it as the H plane of antenna1.

Orient the patterns so that their MSP is at 0°.

> **Note:** *Due to the reflections of the signal from the table, the modules, or any other object, it is possible that the maximum amplitudes of the E and H planes may differ slightly. To minimize this problem, short distances have been privileged between the transmitting and receiving antennas. However, since reflections are not easy to predict, we consider a difference of 1 or 2 dB as acceptable in your various acquisitions.*

Plot the acquired patterns.

☐ 9. Remove the dipole antenna from the mast and remove the wires from the connector.

Choose the appropriate pair of wires to make a $\lambda$ dipole and insert them into the bottom of the dipole connector. Clip this new antenna on the mast.

☐ 10. Your antennas are ready to rotate in the H plane. Optimize reception of the signal and start an acquisition.

Make the appropriate modification (including the replacement of the intermediate cable with the short one), then perform an acquisition of the radiation pattern of this antenna in the E plane. Store these two patterns in the antenna2 data box.

Plot the acquired patterns.

☐ 11. Compare the patterns of the $\lambda$ and the $\lambda/2$ dipoles. Do they have the same gain (MSL) (Do not forget to take into account the difference in attenuation levels.)? Which antenna has the better gain? Give the difference between their MSLs.

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☐ 12. We observed in Step 11 that, due to the high value of its resistance, the $\lambda$ dipole is not an efficient power radiator. Evaluate the impedance of the $\lambda$ dipole.

Record the length of the antenna.

Length of the $\lambda$ dipole $L_\lambda$ = ______ cm = ______ $\lambda$

Referring to Figure 1-35, give the approximate input impedance of this antenna.

$Z_{in}$ = ______ Ω

☐ 13. Remove the dipole antenna from the mast and remove the wires from the connector; replace them with the appropriate wires to make a $3\lambda/2$ dipole. Clip this new antenna on the mast.

☐ 14. Using Equation (5), calculate the distance required in order to be in the far-field region with this set-up. The $3\lambda/2$ dipole is longer than the Yagi antenna so

$$L = \frac{3\lambda}{2} = \_\_\_\_\_\_\_\_ \text{ m}$$

Then

$$r > \frac{2L^2}{\lambda} > \_\_\_\_\_\_\_\_ \text{ m}$$

Position your antennas at a distance [r + 10 cm] apart.

☐ 15. Optimize the reception of the signal and perform an acquisition of the E plane.

Make the appropriate modifications, then perform an acquisition of the H-plane radiation pattern. Store the E- and H-plane patterns of the $3\lambda/2$ dipole in the antenna3 data box. Plot the acquired patterns.

**Note:** *Carefully examine the plots of the E- and H-plane radiation patterns in order to understand the relation between these patterns. Observe that the signal level of the H plane should equal the maximum signal level of the two small lobes of the E plane. However, the $3\lambda/2$ dipole is particularly sensitive to reflections from the mast or other objects. Because of this, the H-plane pattern may be distorted and the signal level of the two patterns can diverge significantly.*

☐ 16. Make the appropriate modifications in order to perform an E-plane acquisition. Remove the wires from each socket of the connector.

The short sections of wire on both sides (inside the plastic block of the connector) act as a short dipole having a total length of approximately 4 cm or $0.125\lambda$.

Position the antennas a distance of r = 1 m apart. Set the attenuation level to 0 dB, then perform an acquisition of the E plane. Do not store the pattern. Plot the acquired pattern before deleting it.

Compare this radiation pattern with the E-plane pattern of the $\lambda/2$. Taking into account the difference in attenuation levels, give the difference between the maximum signal level obtained using this short dipole and that obtained from the $\lambda/2$ dipole. Referring to Figure 1-35, explain this result.

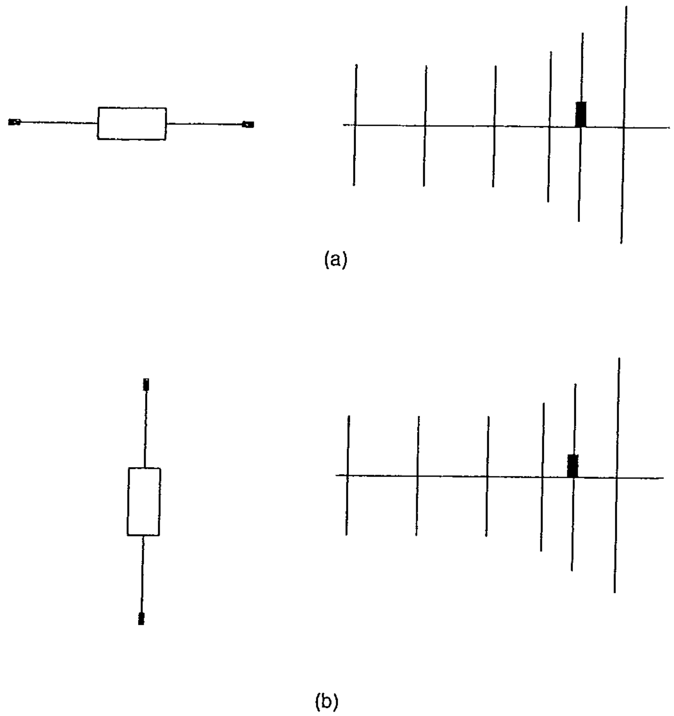


**Figure 1-39. Alignment of a dipole with the transmission antenna producing a null (a) and a maximum (b) in the radiation pattern**

☐ 17. You now have the radiation patterns of your three antennas. Make sure that their MSPs are oriented to 0°, then observe the spatial representation of the patterns with the E-H and 3-D options.

Plot the three E-H plots and the three 3-D plots.

To properly understand the 3-D representations of the different radiation patterns of 1 GHz antennas, it is important to carefully examine the plot of the E plane. For example, notice that the nulls of a dipole are formed when the receiving antenna is perpendicular to the transmission antenna, and that its maximums appear when the antennas are parallel.

To obtain a representative 3-D image of an antenna pattern, you have to position the nulls of the E plane on the 90°- 270° axis, as shown in Figure 1-40.

This positioning is normally done automatically, when you orient the MSP of the dipole antennas to 0° or 180°. However, you will have to do this adjustment by yourself when the radiation patterns are not symmetrical, or for certain types of 1 GHz antenna such as, for example, the monopole.

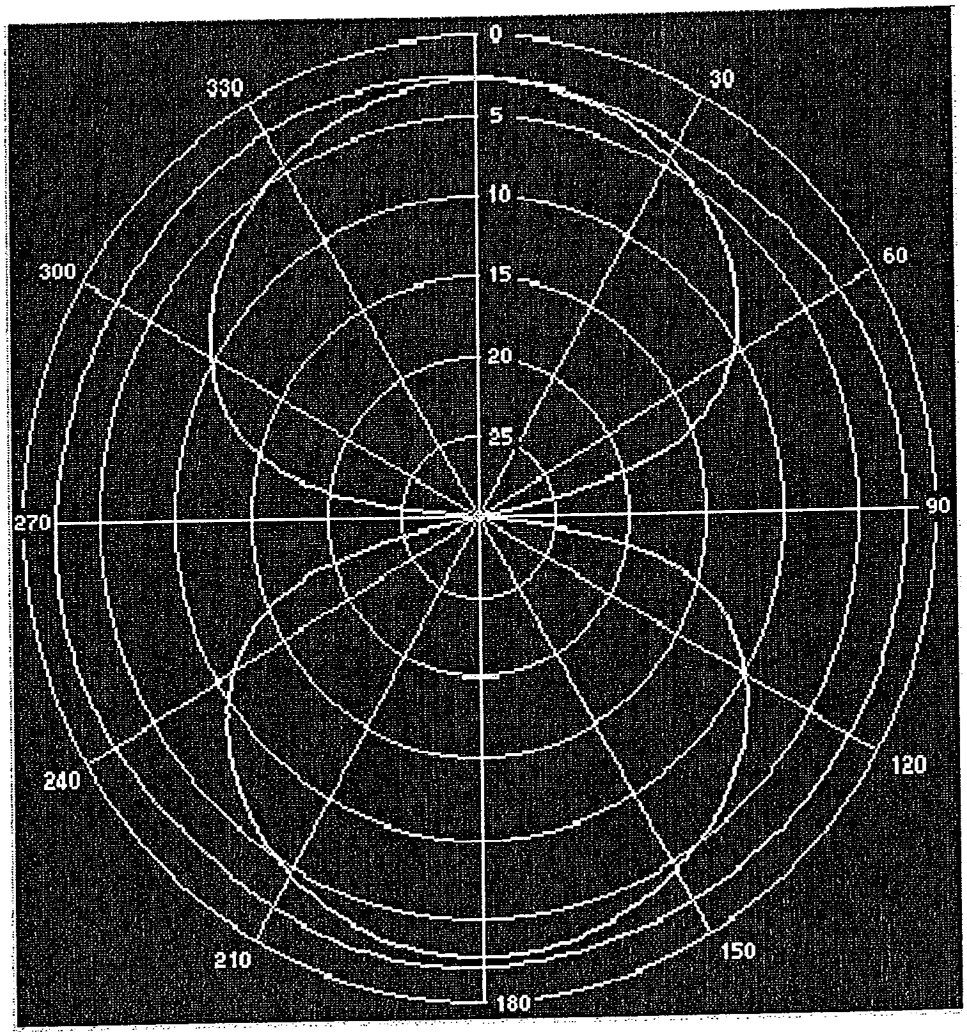


Figure 1-40. Position of the E plane producing a correct 3-D representation

After having saved the patterns of antenna1, antenna2 and antenna3, print the radiation patterns (in the 2-D configuration) together, for each antenna. Also print the 3-D representation of the $\lambda/2$ dipole and keep it as reference for Exercise 1-5.

### Half-power beamwidth and directivity

☐ 18. Evaluate the half-power beamwidth of the $\lambda/2$ and $\lambda$ dipole's E-plane patterns.

$HPBW_{E-\lambda/2}$ = ______ °

$HPBW_{E-\lambda}$ = ______ °

Compare your evaluations of the HPBW of the E planes with the theoretical value.

☐ 19. From the formula

$$D \approx \frac{26000}{HPBW_E \cdot HPBW_H}$$

estimate the directivity of the $\lambda/2$ dipole.

**Note:** *Since the radiation pattern in the H plane is circular, let $HPBW_H = 180°$.*

D = ______

Remember that the formula used to evaluate the directivity is not very accurate in the case of an antenna having a large radiation beam; the calculation is used only to give an approximation of the gain.

### OPTIONAL EXPERIMENT

NOT REQUIRED

The following experiment can be performed if you have an optional 1 GHz directional coupler.

### Matching of the $\lambda/2$, $\lambda$ and $3\lambda/2$ dipoles

☐ 20. Refer to Step 20 of Exercise 1-1 to correctly set up the directional coupler.

☐ 25. Are the results consistent with the theory? Explain.

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☐ 26. 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 plotted the measured radiation patterns of the $\lambda/2$, $\lambda$ and $3\lambda/2$ dipoles and visualized their representations in space. You observed that, due to its impedance, the $\lambda$ dipole antenna is not an efficient power radiator. You compared the theoretical half-power beamwidths of the E plane of the $\lambda/2$ and $\lambda$ dipoles with the ones calculated from their measured radiation patterns. Finally, using the HPBW value, you gave an approximate evaluation of the directivity of the $\lambda/2$ dipole.

## REVIEW QUESTIONS

1. Among the three dipoles you have studied, which one, as far as signal transmission is concerned, offers the best performance, and why is this so?

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2. If the directivity of the $\lambda$ dipole is better than that of the $\lambda/2$ dipole, why wasn't this antenna chosen as the answer to Question 1?

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3. Briefly explain the relation between the current, the impedance and the length of a dipole.

4. Does the distance of 1 m satisfy the condition for far-field measurements with the λ/2 and λ dipoles operating at 915 MHz? Give the minimum separating distances required by these antennas.

5. Demonstrate that the half-power beamwidth of a λ/2 dipole is 78°.