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Lab Assignment # 2

Antenna Design

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Purpose

The intent of this experiment is to familiarize students with basic antenna properties, design, and construction. Students calculate necessary dimensions and make two antenna types: omnidirectional and directional which will be used in this and future experiments. In this experiment students will measure the antennas' gain vs. frequency and radiation patterns.

Equipment:

- Signal Generator Agilent E4400B: 250 kHz – 1 GHz
- Spectrum Analyzer Agilent ESA–L1500A: 9 kHz-1.5 GHz
- Metal Wire (at least 12 gauge Copper to be stiff enough)
- Dowel
- Shaped metal sheets

Introduction:

To describe antenna performance, we must first define the basic parameters. The most important parameters are radiation pattern, directivity, gain, bandwidth, polarization, and impedance. All parameters are perfectly symmetric: they apply equally to transmitted and received signals.

The Antenna radiation pattern is defined as a mathematical function or a graphical representation of the radiation properties of the antenna as a function of space coordinates. The radiation pattern is the two- or three-dimensional spatial distribution of radiated energy as a function of the observer's position along a path or surface of constant radius. In practice, the three-dimensional pattern is measured and recorded in a series of two-dimensional patterns. Antenna radiation patterns can be divided into three main categories: isotropic, directional and omnidirectional.

An isotropic radiator is defined as "a hypothetical lossless antenna having equal radiation in all directions" (Figure 1). It is an ideal and not a technically realizable antenna, but is often taken as a reference for expressing directive properties of actual antennas. A directional antenna has the property of radiating or receiving electromagnetic waves more effectively in some directions than in others (Figure 2). The direction of highest gain is called the major (main) lobe; all others are called side lobes (and may be subclassified into side, minor, and back lobes). The design of an antenna's shape and size is based on the working frequency, desired gain, and main lobe size, and number and maximum permitted gains of side lobes (sometimes we want side lobes with the aim of getting signals from other directions than the main one). The omnidirectional antenna has non-directional pattern in a given plane, and a directional pattern in any orthogonal plane (Figure 3).

Figure 1. The radiation pattern of an isotropic radiator

a) three-dimensional b) linear

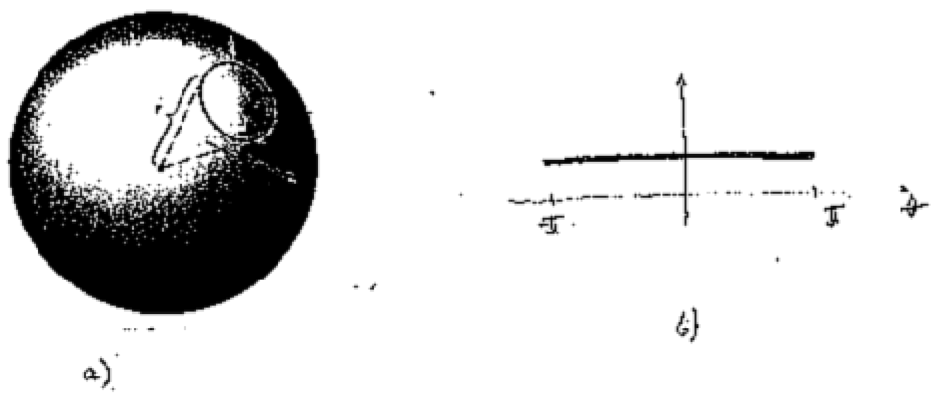


Figure 2. The radiation pattern of a directional antenna

a) three-dimensional b) linear

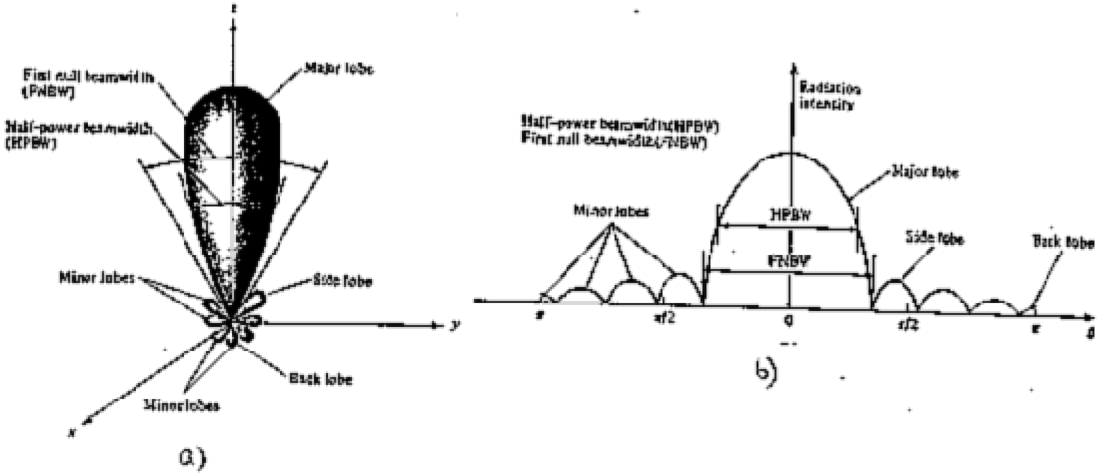
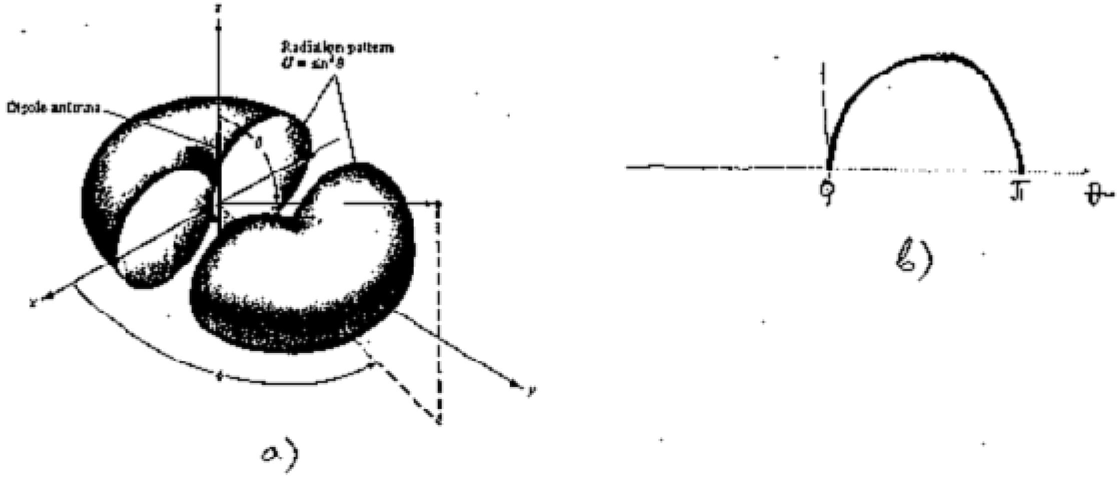


Figure 3. The radiation pattern of an omnidirectional antenna

a) three-dimensional b) linear



The *antenna directivity* is defined by IEEE Standard Definitions of Terms for Antennas as “the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions. The average radiation intensity is equal to the total power radiated by the antenna divided by 4π. If the direction is not specified, the direction of maximum radiation intensity is implied”. Therefore, the directivity is a measure that describes only the directional properties of the antenna, and is controlled only by the pattern.

The *relative antenna gain* is the “the ratio of the power gain in a given direction to the power gain of a reference antenna in its reference direction”. The power input must be the same for both antennas. The reference antenna is usually an isotropic dipole, horn, or any other antenna whose gain can be calculated or is known. The gain of an antenna is describing its performance by taking into account the efficiency of the antenna as well as its directional capabilities.

The *antenna bandwidth* is defined as “the range of frequencies within which the performance of the antenna, with respect to some characteristic, conforms to a specified standard”. The considered characteristic can be input impedance, pattern, beamwidth, polarization, side lobe level, gain, beam direction or radiation efficiency. The bandwidth can be considered as the range of frequencies on either side of a center frequency. For broadband antennas, the bandwidth is usually expressed as the ratio of the upper-to-lower frequencies (e.g. 10:1). For narrowband antennas, the bandwidth is expressed as a percentage of the frequency difference (upper minus lower) over the center frequency of the bandwidth (e.g. 5%). All the characteristics of an antenna do not necessarily vary in the same manner, or are even critically affected by the frequency, so the specifications are set in each case to meet the needs of the particular application.

The *antenna polarization* in a given direction is defined as “the polarization of the wave transmitted by the antenna. When the direction is not stated, the polarization is taken to be the polarization in the direction of maximum gain”. Polarization may be classified as linear, circular or elliptical.

The *input impedance* is defined as “the impedance presented by an antenna at its terminals or the ratio of the voltage to current at a pair of terminals or the ratio of the appropriate components of the electric to magnetic fields at a point”. An antenna’s input impedance is generally a function of frequency. Thus the antenna will be matched to the interconnecting transmission line and other associated equipment only within a bandwidth. The impedance is important for determining antenna efficiency. All power sources have internal impedance. Maximum power is transferred to an external device when its impedance matches the source internal impedance.

Antenna Types:

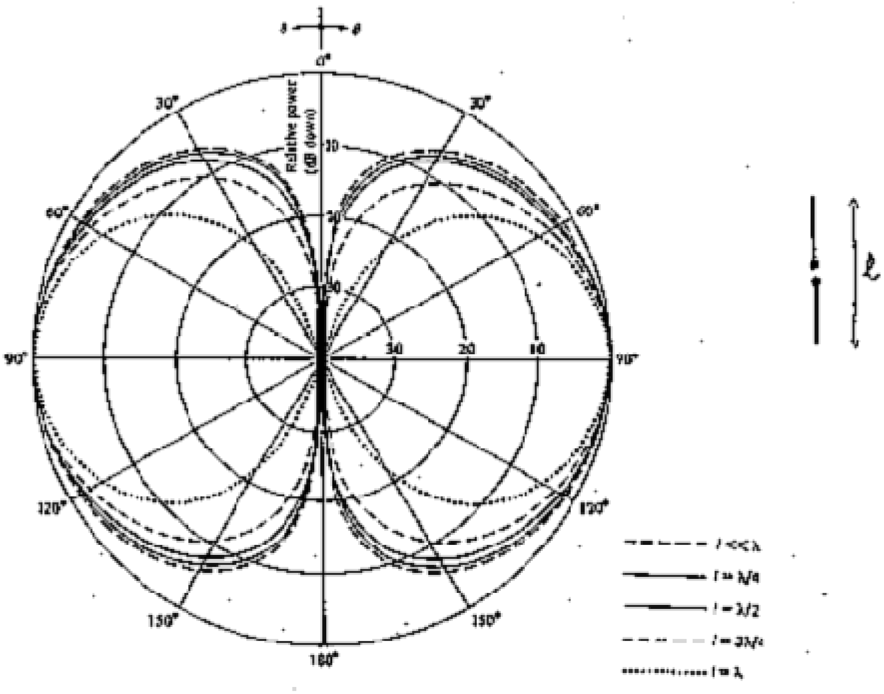
The simplest and most common antennas for public communications are wire antennas. They are some of the oldest, simplest, cheapest, and most versatile for many applications. Theoretically, they can be made of an infinitesimal (very thin) wire or a thicker wire or a cylinder, with or without coatings.

There are many antenna designs. For example:

- dipoles of different lengths,
- linear elements near or on perfect conductors,
- vertical dipole in front of a reflector,
- helical antenna, or
- Yagi-Uda or Log-periodic antenna.

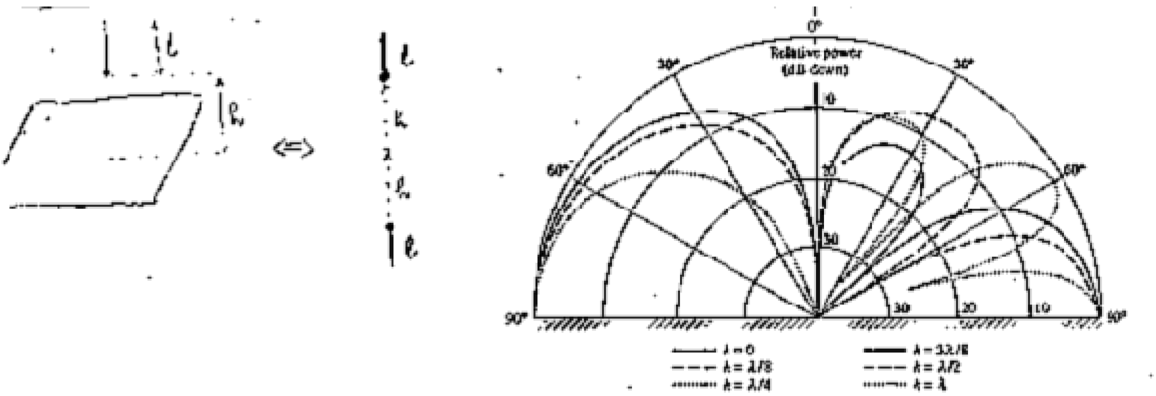
The gain of a thin dipole depends on its length (Figure 4). The half-wavelength dipole ($l=\lambda/2$) is a commonly used omnidirectional antenna. Its radiation resistance is very near to the 75 W characteristic impedance of some transmission lines, which simplifies its impedance matching to the line.

Figure 4. Construction and two-dimensional pattern for a thin dipole



A perfect conducting plane acts as a mirror. A dipole above a conducting plane produces a virtual antenna underneath. This antenna configuration acts as a set of two dipoles (without a reflecting plane) and minimizes the influence of obstacles existing under the plane. The radiation pattern of this antenna system depends on the position of the element relative to the plane (Figure 5). In general, for $h>\lambda/4$ minor lobes are formed. The number of lobes depends on a length of a dipole and its distance to the perfectly conducting plain.

Figure 5. Construction and two-dimensional pattern for a vertical infinitesimal electric dipole above an infinite perfect electric conductor.

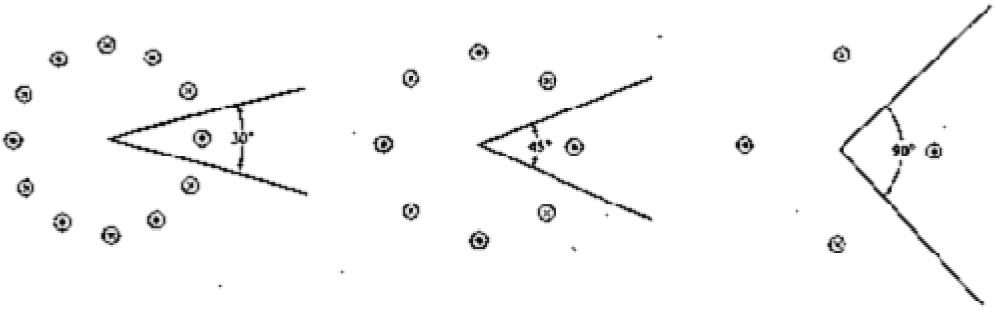


The quarter-wavelength vertical monopole *(l*=λ/4) over a reflecting plane *(h=0)* acts as an *l*=λ*/2* dipole, thus representing the most used omnidirectional antenna of that type (Figure 6). Theoretically, the reflecting plane should be infinite, but in practice a λXλ plane is sufficient.

Figure 6. The quarter-wavelength vertical monopole over a reflecting plane

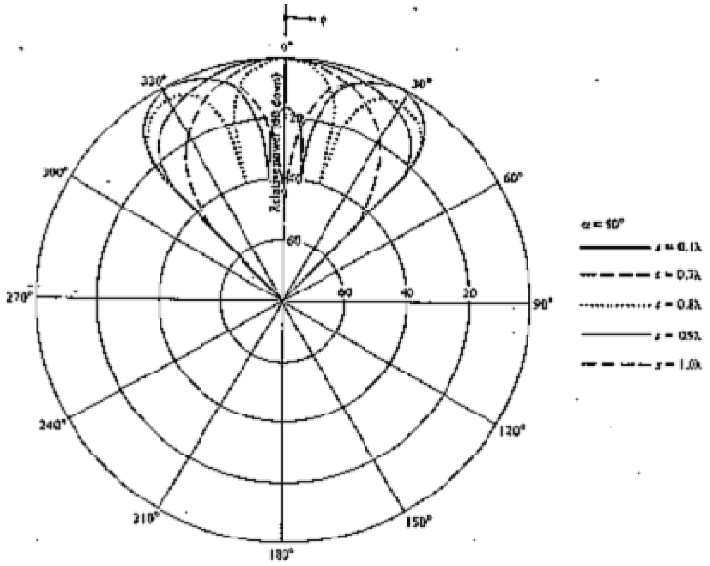
To better focus the energy in the desired direction, the geometrical shape of the plane reflector must be changed so as to prohibit radiation in the unwanted directions. This antenna configuration is known as the corner reflector. Because of its simplicity in construction, it has many applications. In most practical applications an angle of 90° is used. However, the angle can be different, but must have a value of α=180°/*n*, thus producing different number *(*2*n*) of virtual images (Figure 7). The angle covered by the main lobe and the total number of lobes depend on a shape of the reflector (plane or cornered), dimensions, and the distance from the dipole. For reflectors with infinite sides, the gain increases as the included angle between the planes decreases. To maintain a given system efficiency, the space between the vertex (cross-section of the reflecting planes) and the feed element must increase as the included angle of the reflector decreases, and vice-versa. All of this, however, may not be true for some finite size plates.

Figure 7. Corner reflectors and their images for angles 30°, 60°, and 90°



To gain some insight into the performance of a corner reflector, Figure 8 for α=*90°* and different spacing of the antennas from the vertex is presented. It is evident that for a small spacing the pattern consists of a single major lobe, whereas multiple lobes appear for the larger spacing. For *s*=λ the pattern exhibits two lobes separated by a null along the *F=0°* axis.

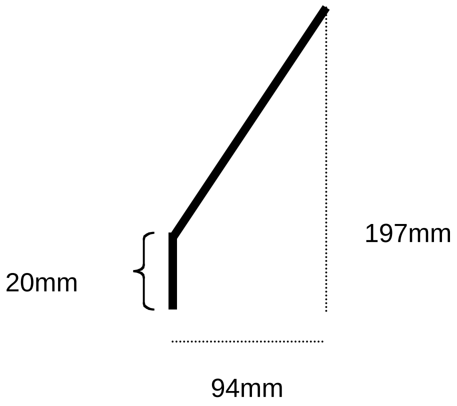
Figure 8. Normalized radiation patterns for α=*90°* corner reflector



The construction and radiation pattern of a simple bent-dipole directional antenna, which does not need a reflecting plane, and is suitable for VHF or higher frequencies, is given in Figure 9.

Figure 9. Construction of a bent dipole directional antenna.

(Notaros directional antenna at 1GHz.)



Design Of Helical Antenna

Another basic configuration of an electromagnetic radiator is that of a conducting wire wound in the form of a screw thread forming a helix. The helical antenna (Figure 10) has a simple and practical construction, and in most cases is used with a ground plane. It has a shape of a conducting wire wound in the form of a screw. The number of turns (N), diameter (D), and spacing (S) between turns determine antenna gain and directivity

The total length of the antenna is

$$L_N=NL_o=Nsqrt(S^2+C^2)$$

Where D is the diameter, $C=\pi D$ is the circumference of the Helix, S is the spacing between turns and $L_o = sqrt(S\_+C\_)$ is the length of the wire between each turn.

Another important parameter is the pitch angle, α, which is the angle formed by a line tangent to the Helix wire and a plane perpendicular to the Helix axis. The pitch angle is defined by

$$\alpha=tan^{-1}(S/C)$$

When $\alpha = 0°$, then the winding is flattened and the helix reduces to a loop antenna of N turns.

On the other hand, when $\alpha = 90°$ then the helix reduces to a linear wire.

There are 2 modes of operation for the Helix antenna :

1) **Normal mode**

In the normal mode of operation the field radiated by the antenna is maximum in a plane normal to the helix axis, as shown in the **Fig. 10.2**. For this mode $NL_o \ll \lambda$

2) **Axial (Endfire) mode**

In this mode of operation, there is only one major lobe and its maximum radiation intensity is along the axis of the Helix, as shown in the **Fig.10.3**. The minor lobes are at oblique angles to the axis. To excite this mode, the Diameter, D, and the spacing, S, must be large fractions of the wavelength.

Figure 10. Construction of a helical antenna

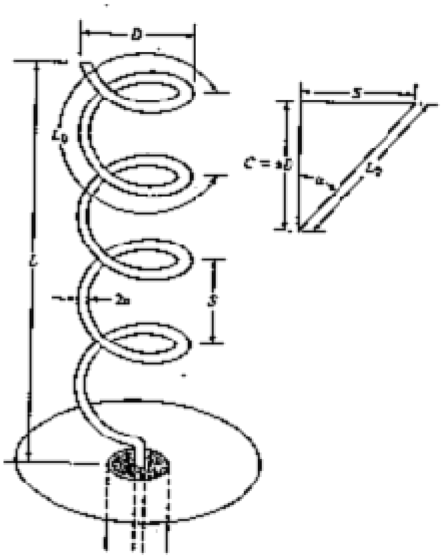
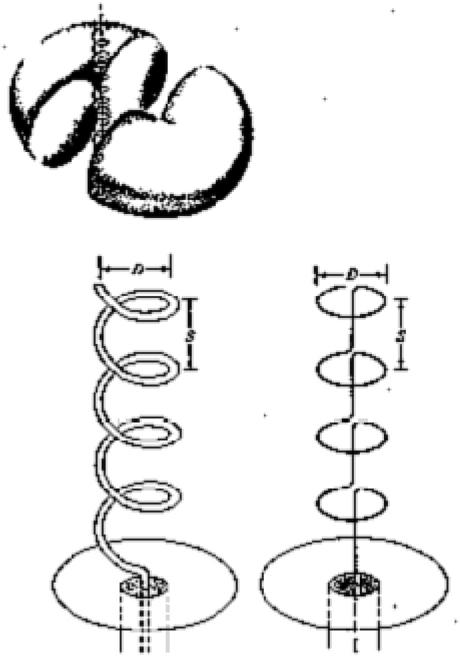


Figure 10-1 Helical antenna with ground plane.



(a) Normal mode (b) Equivalent

Figure 10-2 Normal (broadside) mode for helical antenna and its equivalent.

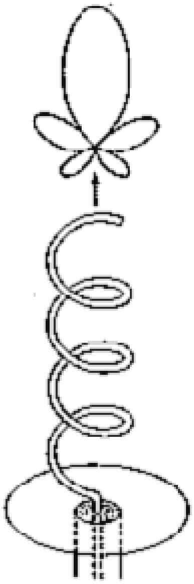
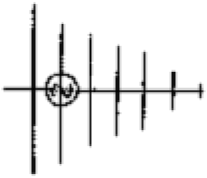


Figure 10-3 Axial (endfire) mode of helix.

The Yagi-Uda antenna (Figure 11) consists of a number of linear dipole elements, one of which is energized directly by a feed transmission line, while the others act as a parasitic radiators. They are widely used as the home TV antennas and in all other cases where broadband antennas are necessary in the HF (3-30 MHz), VHF (30-300 MHz), and UHF (300-3,000 MHz) bands. The lengths and spacing between dipoles determine the antenna characteristics. The log-periodic antenna is of a similar structure.

Figure 11. Basic construction of Yagi-Uda antenna

Fig. 11



PRE-STUDY

Exercise 1

For each of the following antennas i.e. dipole, corner reflector, bent dipole, helical, compute the ideal dimensions for 90MHz and again for 900MHz.

LAB PROCEDURES

Note 1: The output amplitude of the Signal Generator should be less than 0dB whenever it is connected to the Spectrum Analyzer otherwise the Spectrum Analyzer can be damaged. We suggest that the value of the output signal should be set less than –20dBm.

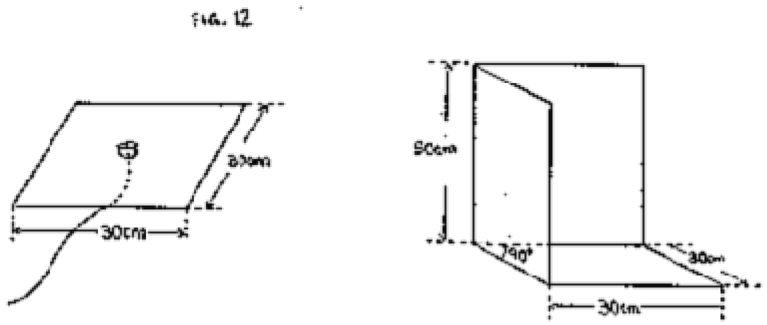
Note 2: With aim of getting *real* characteristics of the antenna all measurements should be done in an anechoic chamber. Our measurements will be done outdoors and indoors, in the ITP lab with a lot of metallic equipment in the vicinity of both antennas, so the obtained characteristics will be slightly distorted from the real. To minimize these distortions, keep the vicinity of the antennas and the radio path as clear as possible of clutter and people.

All measurements should be done outdoors far from any reflecting surfaces. We will make measurements on the roof of the Engineering building (where power supply for the Signal Generator can be obtained by using a long power cord). The Spectrum Analyzer is portable, has its own battery, and thus does not represent any difficulty for outdoor measurements. In case of a bad weather, the radiation patterns will be measured indoors by placing the antennas above lab tables and other obstructions.

Construction of the antennas

Construct 3 antennas, the first two are simple dipoles above a ground plane. Cut two pieces of copper wire to the length computed in the Pre Lab exercise for 900MHz. Insert each into a ground plane, which has a connector attached to it. Choose one of the three directional antennas: corner reflector, bent dipole or helical and build it. For the corner reflector simply attach the sheet metal reflector to the ground plane. For the bent dipole, carefully follow the dimensions and angles in figure 9. For the corner reflector simply attach the sheet metal reflector to the ground plane.

Figure 12 Ground Plane and Corner Reflector



For the helical antenna decide on either axial or end fire mode and design a number of turns and spacing. Wrap the metal coil of determined length around a dowel taking care of the number of turns as well the angle in which the coil is wrapped. Start by inserting the coil in the notch provided on the dowel then winding the coil around the surface of the dowel. When the entire coil has been wound gently remove the coil without disturbing the configuration of the helical coil. Place the coil in the connector attached to the metallic surface.

Determining the signal distortion

In the first step connect the signal generator output to the spectrum analyzer input (Figure 13.a) and trace and store the frequency-characteristics of a received sinusoidal signal in the 900 MHz band. The signal generator should transmit an unmodulated carrier at a frequency for which the antenna is designed, and the spectrum analyzer should be tuned to receive the same frequency.

The signal generator parameters should be:

Frequency: f = 900MHz
Amplitude: -20dBm
Modulation: off
RF: on

The spectrum analyzer parameters should be:

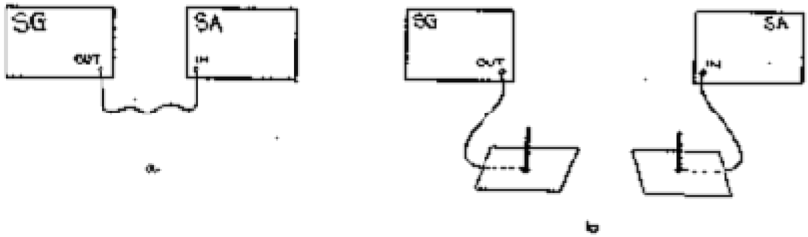
Frequency: center frequency f = 900MHz
Span: 20 kHz
Amplitude: -20dBm

In the second step connect one 900MHz dipole antenna to the output of a signal generator, and the 900MHz dipole antenna to the input of a spectrum analyzer (Figure 13.b). Store the received signal frequency-characteristics for a separation of $d > 10\lambda$ between the two antennas.

Repeat using your directional antenna attached to the Spectrum analyzer.

Figure 13. Connection of the equipment

fig. 13



Amplitude ≤-20dBm

Print the obtained characteristics by attaching a printer to the spectrum analyzer.

Bandwidth of a dipole antenna

Use the spectrum analyzer with one 900MHz dipole antenna as a transmitter and the signal generator with the other 900MHz dipole antenna as a receiver. Put two antennas at least *10λ* apart. Transmit signals of different frequencies starting from antenna's center frequency by gradually increasing and decreasing frequencies. Measure the received signal level and sketch a curve of normalized antenna gain as a function of a signal's frequency. Do the same measurement for the directional antenna attached to the Spectrum Analyzer.

Radiation pattern of a dipole antenna

You will measure the radiation pattern of omnidirectional and directional 900 MHz antennas in the 900MHz band. Attach a 900MHz dipole antenna to the output of the signal generator, and the other 900MHz dipole antenna to the Spectrum Analyzer input. Keep the positions of the transmitting and receiving antennas the same, with the spacing between them of at least 10λ. Orient both the antennas vertically, rotate the receiving antenna and measure the received signal's level for different angles. Measure the level of a received signal in steps of around 10°-20°. Later measure additional points at critical angles (e.g. peaks and nulls). This is the **horizontal radiation** pattern.

Now set both antennas on their side. Repeat the experiment. This is the **vertical radiation** pattern Repeat using your directional antenna being careful to use the same locations as in the omnidirectional case.

Polarization:

Repeat the above experiment for each of your antennas by placing the transmit antenna horizontal (parallel to the ground) and rotating the receive antenna from horizontal to vertical. Take measurements every 10°-20°.

POST-LAB (GROUP) EXERCISES

Exercise 2

Attach and comment on the plotted signal characteristics of a “clean” sinusoidal signal received over coaxial cable and over antennas. Discuss the obtained curves.

Exercise 3

When both antennas are identical the antenna effects are doubled (in dB). Using the frequency with max signal as a reference, plot the relative gain of a single antenna as a function of frequency for the two dipoles. Repeat this plot for the directional antenna. Subtract out (in dB) the effect of the dipole antenna from your measured data.

Exercise 4

An ideal dipole has a gain of 2.15dB in the direction of max gain. Normalize all of your measurements so that the dipole has a gain of 2.15dB. Plot the gain as a function of vertical and horizontal angle for each antenna. What is the 3dB beam width in each direction for each antenna. Compare gains and beamwidths for the omidirectional and directional antennas.

Exercise 5

Plot the received signal as a function of polarization angle for each antenna and comment.

References

Books

1. Balanis Constantine A, *Antenna Theory : analysis and design, 2nd Edition,* John Wiley and Sons, Inc.