Antenna Concepts
An antenna is a device that provides the transition from a guided wave on a transmission line or waveguide to an electromagnetic wave propagating in free space. Antennas are used both at the transmitter and the receiver. This module will introduce some of the terminology and definitions associated with antennas. The emphasis will be directed toward the practical interpretation of the various definitions and associated specifications.

Typical Antenna Types

Some Antenna Definitions
Isotropic Radiator. A fictitious antenna that would radiate equally well in all directions in three dimensions.
Radiation Pattern. A plot of the relative intensity of the radiation.
Directivity and Gain. Measures of the maximum intensity for a directional pattern. They differ by an efficiency factor with gain being less than the intensity by an efficiency factor.
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**Power Density and Radiation Intensity**

Assume an ideal isotropic radiator with power $P_r$.

The power density $p_r$ at radius $r$ is

$$p_r = \frac{P_r}{4\pi r^2}$$

Radiation Intensity $U$ is the power per solid angle.

$$U = \frac{P_r}{4\pi} \text{ watts/steradian (W/sr)}$$

Note that $U = r^2 p_r$.

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**Example 1.** The power density 10 km from a transmitting antenna is 0.06 $\mu$W/m$^2$. Determine the radiation intensity.

$$U = r^2 p_r = (10^4)^2 \times (6 \times 10^{-8})$$

$$= 6 \text{ W/sr}$$

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**Example 2.** The radiation intensity from a transmitting antenna is 50 W/sr. Determine the power density of a receiving antenna 25 km from the transmitting antenna.

$$p_r = U = \frac{50}{(2.5\times10^4)^2}$$

$$= 8 \times 10^{-8} \text{ W/m}^2$$

$$= 0.08 \mu\text{W/m}^2$$
Near Field and Far Field

There are two regions of electric and magnetic fields surrounding an antenna. They are called (1) the near field and (2) the far field. The far field is considered to start at a distance

\[ R_f = \frac{2D^2}{\lambda} \]

where \( \lambda \) is the wavelength and \( D \) is the physical linear dimension of the antenna.

Example 3. Determine the distance from a 100-MHz half-wavelength dipole antenna to the far field.

\[ \lambda = \frac{3\times10^8}{f} = \frac{3\times10^8}{100\times10^6} = 3 \text{ m} \]

\[ \frac{\lambda}{2} = \frac{3}{2} = 1.5 \text{ m} \]

\[ R_f = \frac{2D^2}{\lambda} = \frac{2(1.5)^2}{3} = 1.5 \text{ m} \]

Example 4. Determine the distance from a 2.3-GHz parabolic reflector antenna with a diameter of 18.3 m to the far field.

\[ \lambda = \frac{3\times10^8}{f} = \frac{3\times10^8}{2.3\times10^9} = 0.13 \text{ m} \]

\[ R_f = \frac{2D^2}{\lambda} = \frac{2(18.3)^2}{0.13} = 5.15 \times 10^7 = 5.15 \text{ km} \]

Measurement of the far field pattern is more difficult for a high-gain antenna.
Radiation Patterns

Since three-dimension plots are difficult to show, it is customary to display two radiation plots: (1) the E-plane pattern and (2) the H-plane pattern. These patterns are in orthogonal planes and are referred to as the principal plane patterns. These patterns for a half-wave dipole antenna are shown on the next slide.

Gain Functions

A gain function $G(\theta, \phi)$ can be normalized to the maximum gain $G_{\text{max}}$ as follows:

$$g(\theta, \phi) = \frac{G(\theta, \phi)}{G_{\text{max}}}$$

The decibel form of the gain is

$$g_{\text{dB}}(\theta, \phi) = 10\log_{10}[g(\theta, \phi)]$$

On the next slide, a polar plot is shown in (a) and a rectangular plot is shown in (b).
Other Antenna Pattern Properties

Directivity and Gain

Directivity $D = \frac{U_{\text{max}}}{U_0} = \frac{\text{maximum radiation intensity}}{\text{average radiation intensity}}$

Directivity is also given by

$D = \frac{\text{maximum power density}}{\text{power density from an isotropic radiator}}$

Directivity $D$ is based on an efficiency of 100%. Gain $G$ is based on input power to antenna and includes effects of losses in antenna.
Relationship Between Directivity and Gain

Let $\eta_r$ represent the antenna efficiency.

\[ \eta_r = \frac{\text{power radiated}}{\text{power input to antenna}} = \frac{G}{D} \]

Gains will be referred to an isotropic radiator.

Example 5. An antenna is transmitting 200 W. The maximum power density at 10 km is 3.184 mW/m$^2$. Determine the directivity.

\[ P_r = \frac{P_t}{4\pi r^2} = \frac{200}{4\pi (10^4)^2} = 0.1592 \text{ } \mu\text{W/m}^2 \]

\[ D = \frac{3.184 \times 10^{-3}}{0.1592 \times 10^{-6}} = 20,000 \]

\[ D_{\text{iso}} = 10\log 20,000 = 43.01 \text{ } \text{dB} \]

Example 6. An antenna with a directivity of 16 dB is transmitting 1 kW. Determine the maximum power at a distance of 50 km from the antenna.

\[ D = 10^{16/10} = 10^1.6 = 39.81 \]

\[ P_{t,\text{max}} = D \left( \frac{P_t}{4\pi r^2} \right) \]

\[ = 39.81 \left( \frac{1000}{4\pi (50 \times 10^3)^2} \right) \]

\[ = 1.267 \text{ } \mu\text{W/m}^2 \]
Example 7. An antenna has an efficiency of 95% and the directivity is 33 dB. Determine the antenna gain in dB.

\[
D = 10^{33/10} = 10^{3.3}
\]

= 1995.26

\[
G = \eta D = (0.95)(1995.26)
\]

= 1895.5

\[
G_{db} = 10\log 1895.5
\]

= 32.78 dB

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Effective Area of Antenna

An antenna will "capture" a certain amount of the power incident upon it. The amount can be described in terms of a capture area, measured in m², which may or may not be closely related to the actual physical area. It can be shown that the capture area \( A_e \) is given by

\[
A_e = \frac{\lambda^2}{4\pi} \quad \text{or} \quad G = \frac{4\pi}{\lambda^2} A_e
\]

where \( G \) is referred to an isotropic source.

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Example 8. Determine the effective area of a 5-GHz antenna whose gain is 15 dB.

\[
\lambda = \frac{c}{f} = \frac{3 \times 10^8}{5 \times 10^7} = 0.06 \text{ m} = 6 \text{ cm}
\]

\[
G = 10^{15/10} = 10^{1.5} = 31.623
\]

\[
A_e = \frac{\lambda^2}{4\pi} G = \frac{(6 \times 10^{-3})^2}{4\pi} (31.623)
\]

= 9.059 \times 10^{-7} \text{ m}^2
Polarization

- By definition, the polarization of a wave is the orientation of the electric field relative to the earth. There are two types: linear and elliptical. In linear, the E vector remains fixed, while in elliptical, the E vector rotates.
- Linear polarization can be classified as horizontal or vertical.
- Elliptical polarization can be classified as right-hand (RH) or left-hand (LH).
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**Antenna Impedance**

- The antenna impedance is the ratio of phasor voltage to phasor current at the input. It is a function of frequency and ideally should be resistive at the operating frequency.
- The radiation resistance $R_{rad}$ is the value that defines the power radiated $P_{rad}$ in terms of the rms antenna current $I_{rms}$.

$$R_{rad} = \frac{P_{rad}}{I_{rms}^2}$$

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**Example 9.** An antenna has an rms current of 3 A at the input and is transmitting 1 kW. Determine the radiation resistance.

$$R_{rad} = \frac{P_{rad}}{I_{rms}^2} = \frac{1000}{3^2} = 111.1 \, \Omega$$

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**Summary**

- Antennas are used to provide a transition between a transmitter or receiver and electromagnetic waves.
- By focusing the power in one or more directions, the antenna can achieve an apparent power gain.
- An antenna may be described by a radiation pattern having a beamwidth and other properties.
- An antenna possesses an input impedance which is dependent on the frequency.