

### 3.1 INTRODUCTION

An antenna is basically a transducer. It converts radio frequency (RF) electrical current into an electromagnetic (EM) wave of the same frequency.

It produces electric and magnetic fields, which constitute an electromagnetic field. The transmission and reception of EM energy is obtained by this field. It forms a part of the transmitter as well as the receiver circuits. Its equivalent circuit is characterised by the presence of distributed constants, namely, resistance, inductance and capacitance. The current produces a magnetic field and a charge produces an electrostatic field. These two in turn create an induction field.

When RF signal is applied to an antenna, electric and magnetic fields are produced. They are shown in Fig. 3.1. These two fields constitute the EM wave. As a result, antenna is known as a generator/radiator of EM waves and it is also a sensor of EM waves.

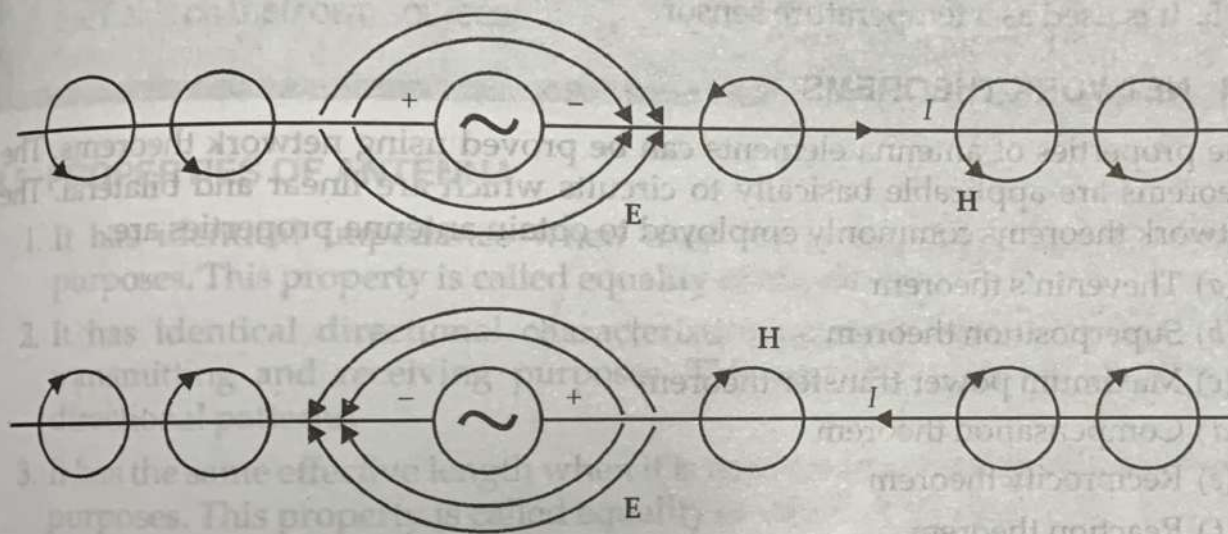


Fig. 3.1 Electric and magnetic fields produced by RF signals

The electric and magnetic fields of the EM wave are perpendicular to each other and hence  $\mathbf{E} \cdot \mathbf{H} = 0$ .

EM waves carry information signals from transmitter to receiver. There is no communication system without one type of antenna or the other. The antennas are characterised by several parameters. These parameters, antenna functions, elementary antennas and their radiation parameters are presented in this chapter.

### 3.2 DEFINITION OF ANTENNA

Antenna is also known as Aerial:

An antenna can be defined in the following different ways:

1. An antenna may be a piece of conducting material in the form a wire, rod or any other shape with excitation.
2. An antenna is a source or radiator of electromagnetic waves.
3. An antenna is a sensor of electromagnetic waves.
4. An antenna is a transducer.
5. An antenna is an impedance matching device.

6. An antenna is a coupler between a generator/transmission line and space or vice-versa.

### **3.3 FUNCTIONS OF ANTENNAS**

1. It is used as a transducer. That is, it converts electrical energy into EM energy at the transmitting end and it converts EM energy back into electrical energy at the receiving end.
2. It is used as an impedance matching device. That is, it matches/couples the transmitter and free space on the transmitting side and it matches/couples free space and the receiver on the receiving side.
3. It is used to direct radiated energy in desired directions and to suppress it in unwanted directions.
4. It is used to sense the presence of electromagnetic waves.
5. It is used as a temperature sensor.

### 3.5 PROPERTIES OF ANTENNA

1. It has identical impedance when used for transmitting and receiving purposes. This property is called equality of impedances.
  2. It has identical directional characteristics/patterns when it is used for transmitting and receiving purposes. This property is called equality of directional patterns.
  3. It has the same effective length when it is used for transmitting and receiving purposes. This property is called equality of effective lengths.
- These properties can be proved using Reciprocity theorem.

### 3.6 ANTENNA PARAMETERS

1. **Antenna Impedance,  $Z_a$**  It is defined as the ratio of input voltage to input current or

$$Z_a \equiv \frac{V_i}{I_i} \Omega$$

$Z_a$  is a complex quantity and it is written as

$$Z_a = R_a + jX_a$$

Here, the reactive part  $X_a$  results from fields surrounding the antenna. The resistive part,  $R_a$  is given by

$$R_a = R_l + R_r$$

$R_l$  represents losses in the antenna.  $R_r$  is called radiation resistance.

2. **Radiation Resistance,  $R_r$**  is defined as a fictitious or hypothetical resistance that would dissipate an amount of power equal to the radiated power.

or

$$R_r \equiv \frac{\text{power radiated}}{I_{\text{rms}}^2}$$

**3. Directional Characteristics** These are also called radiation characteristics or radiation pattern. These are of two types:

(a) **Field strength pattern** It is the variation of the absolute value of field strength as a function of  $\theta$ .

$E$  Vs  $\theta$  is called Field strength pattern.

(b) **Power pattern** It is the variation of radiated power with  $\theta$ .

$P$  Vs  $\theta$  is called Power pattern.

An antenna radiation pattern is a three dimensional variation of the radiation field. It is a pattern drawn as a function of  $\theta$  and  $\phi$ . The pattern consists of one main lobe and a number of minor/side lobes.

Typical 3-D radiation patterns are shown in Fig. 3.2.

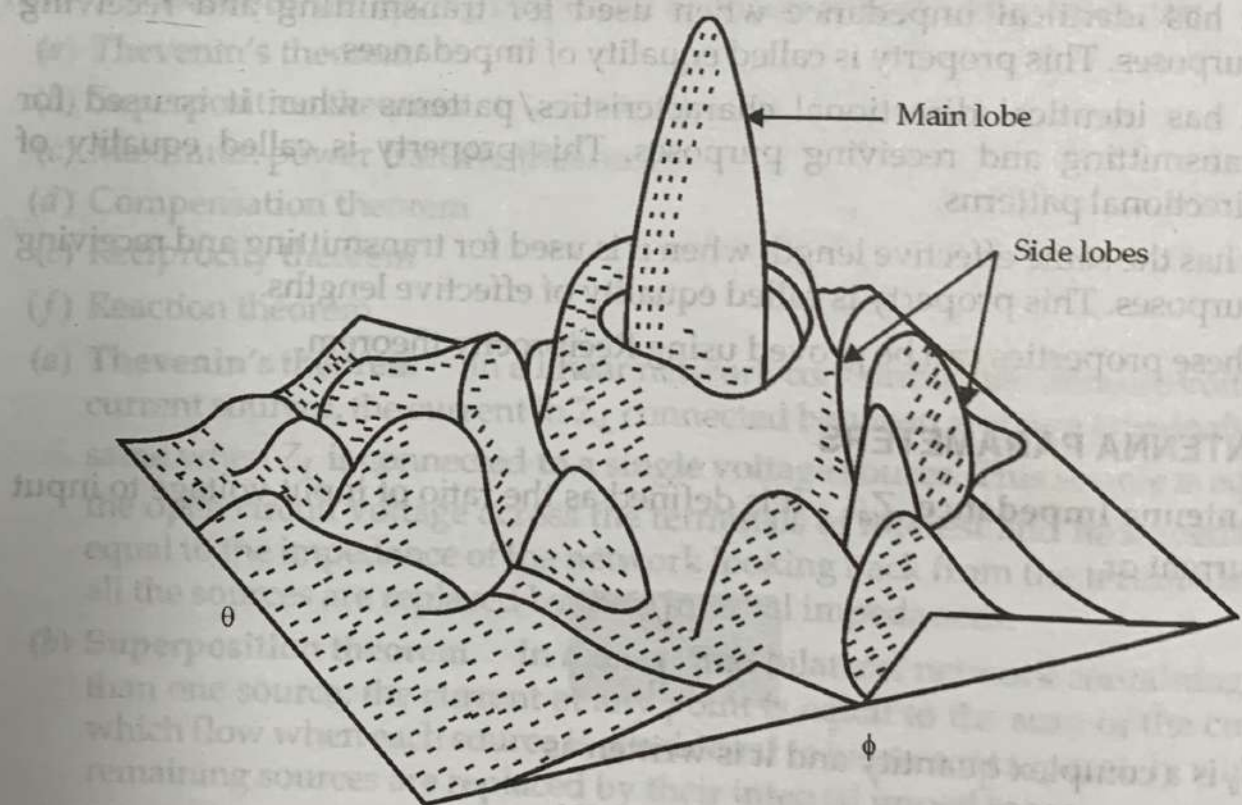


Fig. 3.2 (a)

**4. Effective Length of Antenna ( $L_{\text{eff}}$ )** It is used to indicate the effectiveness of the antenna as a radiator or receiver of EM energy.

**$L_{\text{eff}}$  of Transmitting Antenna** It is equal to the length of an equivalent linear antenna which radiates the same field strength as the actual antenna and the current is constant throughout the length of the linear antenna.

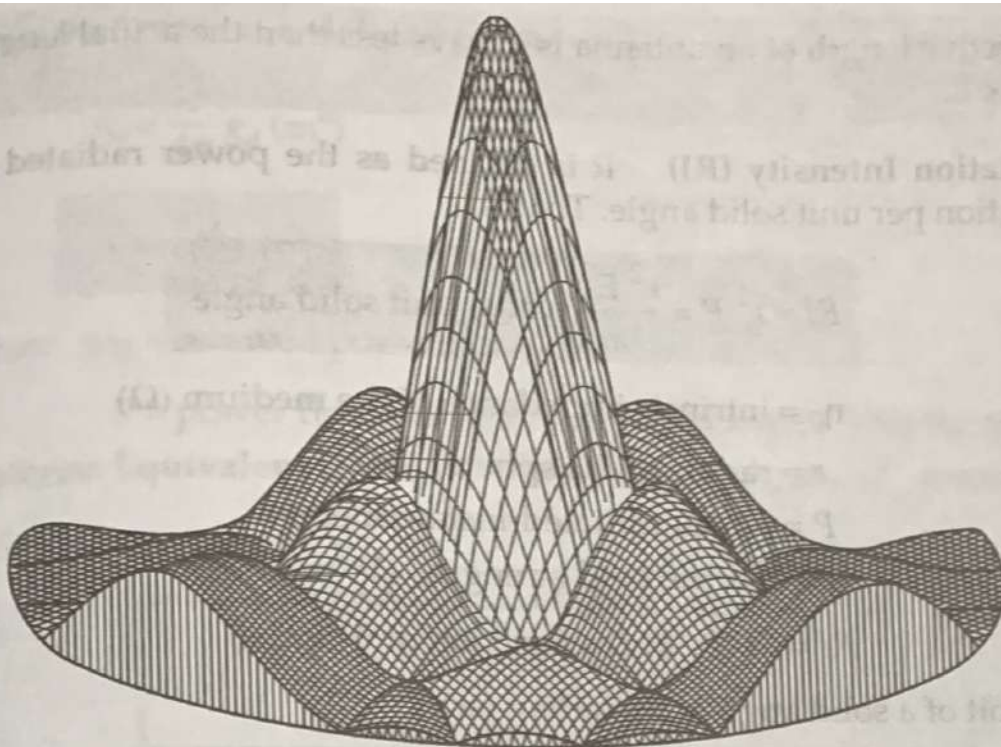


Fig. 3.2 (b) Typical 3-D radiation pattern

Refer the Fig. 3.3.

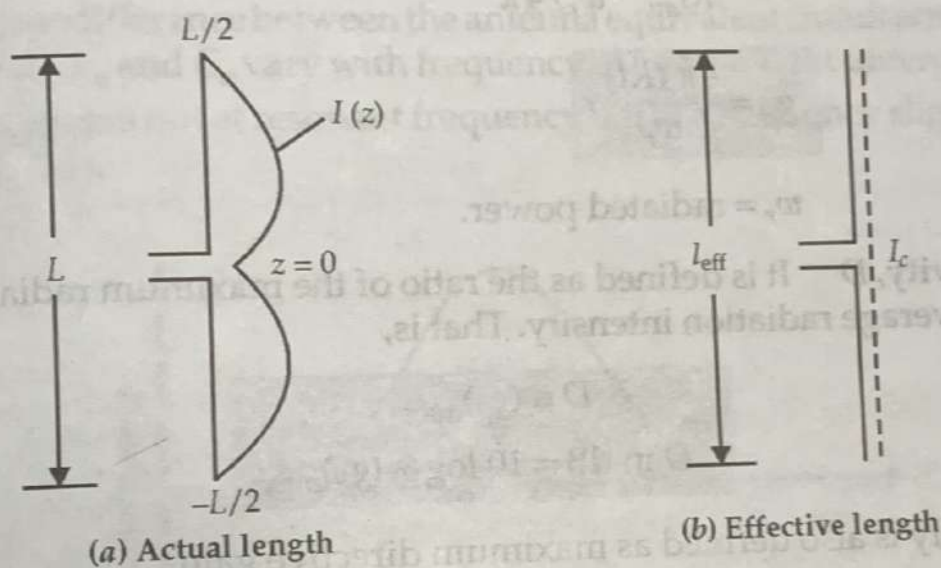


Fig. 3.3 Definition of effective length of transmitting antenna

$L_{\text{eff}}$  of transmitting antenna is defined mathematically as

$$L_{\text{eff}} (Tx) = \frac{1}{I_c} \int_{-L/2}^{L/2} I(z) dz \text{ (m)}$$

$L_{\text{eff}}$  of receiving antenna It is defined as the ratio of the open circuit voltage developed at the terminals of the antenna under the received field strength,  $E$ . That is

$$L_{\text{eff}} (Rx) \equiv \frac{V_{OC}}{E} \text{ (m)}$$

Effective length of an antenna is always less than the actual length. That is,  
 $L_{\text{eff}} < L$ .

5. **Radiation Intensity (RI)** It is defined as the power radiated in a given direction per unit solid angle. That is,

$$RI = r^2 P = \frac{r^2 E^2}{\eta_0} \text{ watts/unit solid angle}$$

Here  $\eta_0$  = intrinsic impedance of the medium ( $\Omega$ )

$r$  = radius of the sphere, (m)

$P$  = power radiated-instantaneous

$E$  = electric field strength, (V/m)

$RI = RI(\theta, \phi)$  is a function of  $\theta$  and  $\phi$

The unit of a solid angle is Steradian (sr).

6. **Directive Gain  $g_d$**  It is defined as the ratio of intensity of radiation in a specified direction to the average radiation intensity. That is,

$$g_d \equiv \frac{RI}{RI_{\text{av}}} = \frac{RI}{w_r/4\pi}$$

or

$$g_d = \frac{4\pi (RI)}{w_r}$$

$w_r$  = radiated power.

7. **Directivity,  $D$**  It is defined as the ratio of the maximum radiation intensity to the average radiation intensity. That is,

$$D \equiv (g_d)_{\text{max}}$$

$$D \text{ in dB} = 10 \log_{10} (g_d)_{\text{max}}$$

Directivity is also defined as maximum directive gain.

8. **Power Gain,  $g_p$**  It is defined as the ratio of  $4\pi$  times radiation intensity to the total input power. That is,

$$g_p \equiv \frac{4\pi (RI)}{w_t}$$

where

$$w_t = w_r + w_l$$

$w_l$  = ohmic losses in the antenna.

9. **Antenna Efficiency ( $\eta$ )** It is defined as the ratio of the radiated power to the input power. That is,

$$\eta \equiv \frac{w_r}{w_t} = \frac{w_r}{w_r + w_l} = \frac{g_p}{g_d}$$

10. **Effective Area** It is defined as

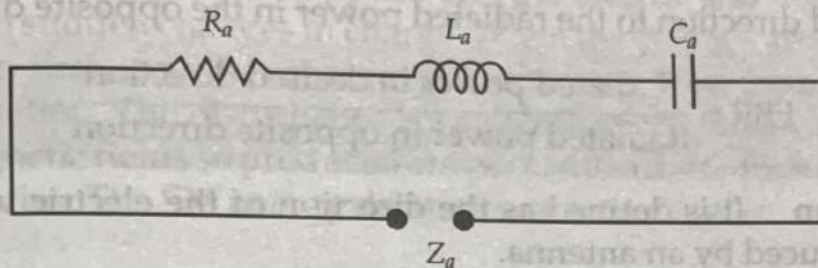
$$A_e = \frac{\lambda^2}{4\pi} g_d \text{ (m}^2\text{)}$$

or  $A_e \equiv \frac{w_R}{P} \text{ (m}^2\text{)}$

where  $w_R$  = received power (watt)

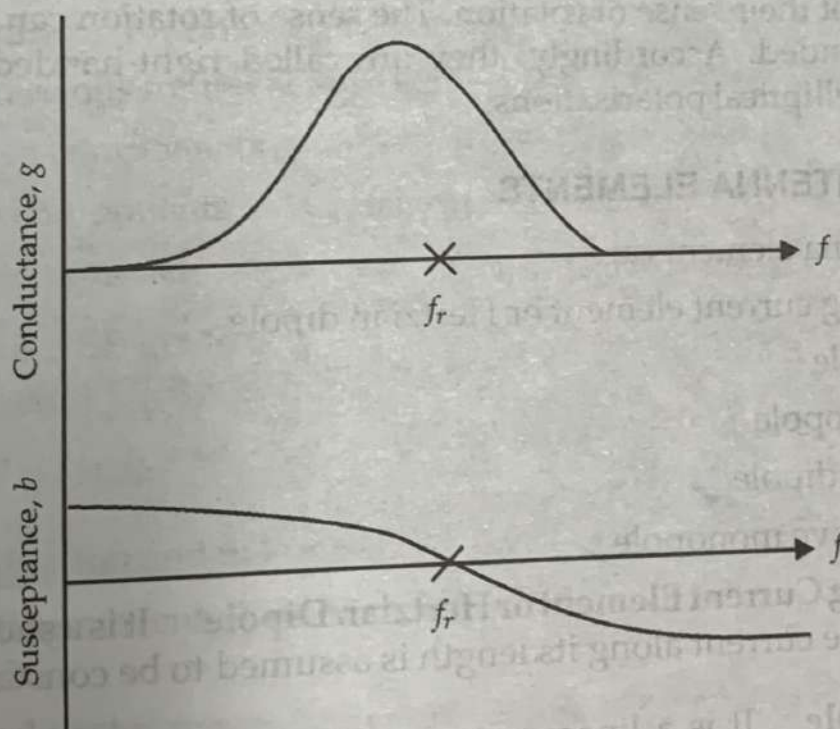
$P$  = power flow per square meter (watts/m<sup>2</sup>) for the incident wave.

11. **Antenna Equivalent Circuit** It is a series  $R_a$ ,  $L_a$  and  $C_a$  circuit (Fig. 3.4).



**Fig. 3.4** Antenna equivalent circuit

The main difference between the antenna equivalent circuit and an RLC circuit is that  $R_a$ ,  $L_a$  and  $C_a$  vary with frequency. As a result, the antenna conductance peak appears not at resonant frequency but at a frequency slightly away from  $f_r$  (Fig. 3.5).



**Fig. 3.5** Typical variation of antenna conductance ( $g$ ) and susceptance ( $b$ )

The antenna impedance,  $Z_a = R + j(X_L - X_C)$

where

$$X_L = \omega L, \quad X_C = \frac{1}{\omega C}$$

The corresponding admittance,

$$Y_a = \frac{1}{Z_a} = g + jb$$

Here  $g$  = conductance  
 $b$  = susceptance.

12. **Antenna Bandwidth** It is defined as the range of frequencies over which the antenna maintains its characteristics and parameters, like gain, front-to-back ratio, standing wave ratio, radiation pattern, polarisation, impedance, directivity and so on, without considerable change.
13. **Front-to-Back ratio (FBR)** FBR is defined as the ratio of radiated power in the desired direction to the radiated power in the opposite direction.

That is, 
$$\text{FBR} = \frac{\text{Radiated power in desired direction}}{\text{Radiated power in opposite direction}}$$

14. **Polarisation** It is defined as the direction of the electric vector of the EM wave produced by an antenna.

It is of three types:

- (i) Linear polarisation
- (ii) Circular polarisation
- (iii) Elliptical polarisation

Linear polarisation is again of three types, namely Horizontal, Vertical and Theta polarisations. Circular and elliptical polarisations can also be described in terms of their sense of rotation. The sense of rotation can be right-handed or left-handed. Accordingly, they are called right-handed or left-handed circular/elliptical polarisations.

### 3.7 BASIC ANTENNA ELEMENTS

The basic antenna elements are

- 1. Alternating current element or Hertzian dipole ✓
- 2. Short dipole
- 3. Short monopole
- 4. Half-wave dipole ✓
- 5. Quarter-wave monopole ✓

1. **Alternating Current Element or Hertzian Dipole** It is a short linear antenna in which the current along its length is assumed to be constant.
2. **Short Dipole** It is a linear antenna whose length is less than  $\frac{\lambda}{4}$  and the current distribution is assumed to be triangular.
3. **Short Monopole** It is a linear antenna whose length is less than  $\frac{\lambda}{8}$  and the current distribution is assumed to be triangular.

4. **Half-wave Dipole** It is a linear antenna whose length is  $\frac{\lambda}{2}$  and the current distribution is assumed to be sinusoidal. It is usually centre-fed.
5. **Quarter-wave Monopole** It is a linear antenna whose length is  $\frac{\lambda}{4}$  and the current distribution is assumed to be sinusoidal. It is fed at one end with respect to earth.