Understanding Antenna Parameters

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An antenna is a device to transfer the guided electrical signal/energy into free space via electromagnetic wave or to capture the electromagnetic energy from the space and transfer it back to the electrical signal. Here the explanation of the common antenna parameters:

1. Operation Frequency:

Antennas are frequency-dependant devices. Each antenna is designed for a certain frequency band. Beyond the operating band, the antenna rejects the signal.

2. Input Impedance & VSWR:

As electromagnetic waves travel through the different parts of the antenna system, from the source to the feed line to the antenna and to the space, they may encounter differences in impedance at each interface. Depending on the impedance match, some fraction of the wave's energy will reflect back to the source, forming a standing wave in the feed line. The ratio of the maximum voltage to the minimum voltage in the feed line is defined as Voltage Standing Wave Ration (VSWR). A VSWR of 1:1 is ideal (100% of the power is transmitted). AVSWR of 2:1 is acceptable (it mean 89% of power is transmitted).

The input impedance is the ratio of the input voltage to the current at the antenna port. The input impedance is a complex quantity that varies with frequency

$$\boldsymbol{Z}_{in}(f) = \boldsymbol{R}_{in}(f) + j\boldsymbol{X}_{in}(f).$$

If the electromagnetic wave can be treated as light (In fact, light is electromagnetic wave), then the impedance is corresponding to the media index. When the light goes from one media to another (such as air to water), reflection happens since the index of the water and the air is different. This is true for the antenna system. If the impedance is kept as the same from the device to the feed line to the antenna, the power won't be reflected and the total power will be transmitted.

The most commonly used feed line impedance is 50 Ohm or 75 Ohm. So the antenna impedance is commonly turned to be 50 Ohm or 75 Ohm to match the device and feed line impedance. The impedance is tuned by inserting matching networks, which use lumped elements (inductors and capacitors) for low frequency applications, or a section of transmission line for high frequency applications, where lumped elements can't be used.

3. Efficiency:

Efficiency is the ratio of power actually radiated by an antenna to the electrical power it receives from a transmitter. A dummy load may have a VSWR of 1:1 but an efficiency of 0, as it absorbs all the incident power, producing heat but radiating no RF energy;

Efficiency is defined as the ratio of power radiated by the antenna to the total power input to the antenna.

$$Efficiency = \frac{Radiated\ Power}{Total\ Power}$$

The loss of the power is due to the resistance in the antenna system, which results in heat generation rather than radiation.

There are two factors which contribute to the efficiency:

a) Resistance in the conductor: At RF frequency, the current flows only on the surface of the conductor and this results in high loss. The higher the frequency, the shallower the depth of the current, and the higher the resistance, which leads to higher loss
b) Loss in the dielectric substrate.

Usually, the efficiency of 80% - 90% is considered a very good achievement. Most miniature antenna design can only achieve 50% efficiency or less.

There are tradeoffs between the antenna size and the efficiency. A quarter wave antenna operates at the maximum efficiency. when the structure becomes smaller, the antenna becomes capacitive, which has to be conjugate matched with a inductor (built as part of the antenna for high frequency application or lump circuit for low RF frequency application). The resonance between the capacitive load and the matching inductor will generate heat and lower the antenna efficiency. So, antenna usually should be built as large as the real state is allowed.

4. Radiation Patterns and beamwidth:

Radiation patters are graphical representation of the electromagnetic power distribution in free space. The radiation pattern of an antenna is typically represented by a 3D graph, or polar plots of the horizontal and vertical cross sections, as shown below:

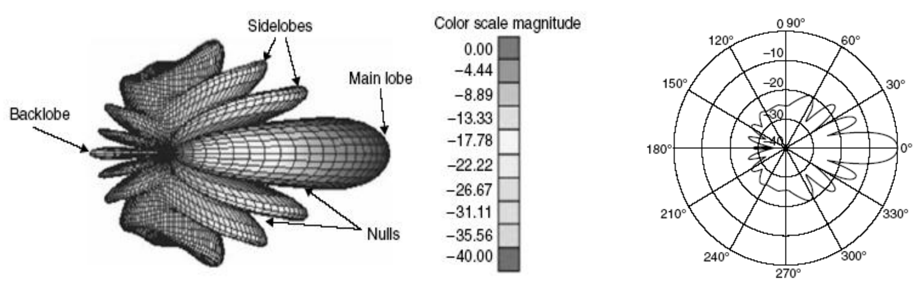


Figure 1: 3D radiation Pattern and the Polar plot of a complex antenna

Beam width of the antenna is considered to be the angular width of the half power reradiated within a certain cut through the main beam of the antenna, where the most of the power is radiated.

5. Antenna Gain and Directivity

Commonly, a basic theoretical antenna is used as reference to define the antenna gain. The reference antenna is isotropic point source radiator, which radiate the power equally in all directions in free space. Physically, such an isotropic point source does not exist. Most antennas’ gains are measured with reference to an isotropic radiator and are rated in decibels with respect to an isotropic radiator (dBi).
So the power density of an isotropic radiator is:

$$Piso = \frac{Total\ Power}{Total\ Area} = \frac{E}{4\pi R^2}$$

And the antenna gain is defined as:

$$Gain\ (dBi) = 10\ log \frac{P_{max}}{P_{iso}}$$

As an example, a 3dBi antenna doubles the power of the isotropic antenna gain in the direction of radiation.

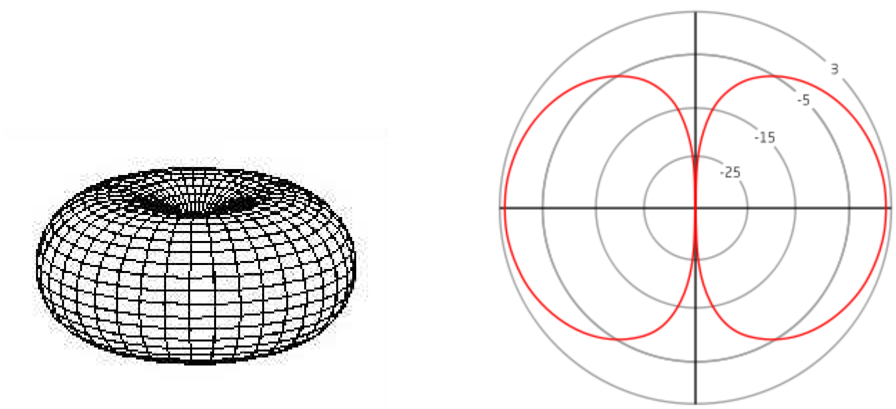


Figure 2: the 3D Radiation Pattern and the gain (in dBi) of a half-wave dipole, A dipole has 2.15dBi gain.

Antenna directivity, by definition is the ratio of maximum radiation intensity (power per unit surface) radiated by the antenna in the maximum direction divided by the intensity radiated by a hypothetical isotropic antenna radiating the same total power as that antenna. Directivity is identical to the peak value of the directive gain; these values are specified without respect to antenna efficiency, thus differing from the power gain (or simply "gain") whose value *is* reduced by an antenna's efficiency.

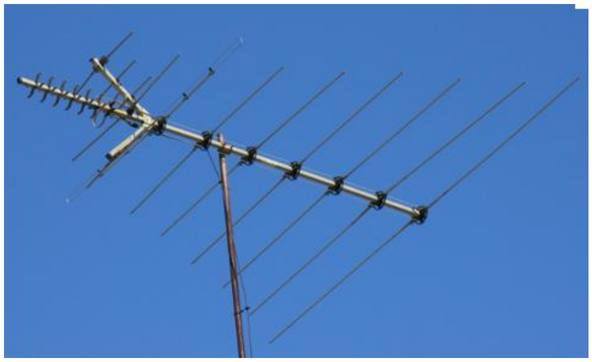
$$Gain = Directivity - Efficiency$$

6. Antenna Polarity

The *polarization* of an antenna is the orientation of the electric field (E-plane) of the radio wave with respect to the Earth's surface. Polarity is determined by the physical structure of the antenna and by its orientation.

For example, the whip antenna on top of a police car's roof is vertical polarized since the E field is in the same direction as the whip, which is vertical. TV antenna is horizontal polarized since the E-field is in the same direction as the receiver antenna metal bar, which is horizontal.

(a)



(b)

Figure 2: (a) Vertical Polarized Antenna, (b) Horizontal Polarized Antenna

7. Power handling Capability

The parameter specifies how much power it can input before the antenna is overheaded/damaged.

8. Effective Area/Aperture

The antenna effective area is defined as: the ration of the available power at the terminals of a receiving antenna to the power flux density of a plane wave incident on the antenna from that direction. If the direction is not specified, the direction of maximum radiation intensity is implied.

The formula calculates effective area as a function of its power gain G:

$$A_{eff} = \frac{\lambda^2}{4\pi} G$$

For linear wire antenna, simply increasing the size of antenna does not guarantee an increase in effective area; however, with other factors being equal, antennas with higher effective areas are generally larger.

For Aperture antennas, such as horns and parabolic reflectors, the aperture efficiency is the ratio of effective area to its physical areal. For simple designs, the aperture efficiency is 0.35~0.55. However, with carefully designed and constructed reflector antennas, it can be in the 0.65~0.75 range, and as high as 0.85. Factors limiting the aperture efficiency are non uniform illumination of the aperture, phase variations of the aperture field (typically due to surface errors in a reflector and high flare angle in horns), and scattering from obstructions.

9. Other Parameters

Most electrical parameters have been explained. Some of the mechanical parameters are as important as the electrical parameters. The following table listed some of the important mechanical parameters:

Input Connector	SMA, TNC, BNC, N, etc.
Operational Temperature	-40 °C ~ + 85 °C
Environmental	Water proof/humidity/shock absorption
Dimension	The size and shape of the antenna

$$P_r = \frac{P_t G_t}{4\pi R^2} A_{eff} = \frac{P_t G_t}{4\pi R^2} \cdot \frac{\lambda^2}{4\pi} G_r = \frac{\lambda^2}{(4\pi R)^2} G_t G_r P_t$$