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A Review on Performance Parameters of Antenna

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Abstract

Antenna Testing is an important process to evaluate the performance parameters of antenna. Typical parameters of antenna that need to be evaluated includes radiation pattern of antenna, gain of antenna, input impedance of antenna, Band width of antenna, Beam width of antenna, radiation resistance of antenna. This research presents a review of mathematical and experimental approach to evaluate the performance of antenna.

Index Terms— Antenna, Radiation pattern of antenna, Directive Gain, Power gain, Bandwidth.

Introduction

Antenna is a component that enables wireless communication between a set of devices. Antenna is required at Transmitter to convert electric power into electromagnetic waves and at receiver antenna convert electromagnetic waves into electric power.

Each antenna is designed for a particular frequency. The length of antenna decides the operative frequency of antenna. Length (L) of antenna required to operate on a particular frequency(f) is related by

$L = \frac{\lambda}{2}$ Where $\lambda = \frac{3*10^8}{f}$

In order to achieve the desired performance antenna need to be tested before it is actually deployed.

References [1] to [6] are used to review the performance parameters of antenna.

Performance Parameters of antenna includes:

(i) Radiation Pattern

It is well known fact that antenna is concerned with radiation of electromagnetic signals. Radiation pattern plots intensity and direction of radiated fields in space. When we plot the intensity and direction of radiated electric field it is called Electric field radiation pattern. When we plot the intensity and direction of radiated magnetic field it is called Magnetic field radiation pattern. When we plot the intensity and direction of radiated power it is called Power radiation pattern. Generally, we use spherical coordinates Fig (1) to plot the radiation pattern. In order to plot radiation pattern, Location of antenna is considered at origin and strength of field is plotted for various values of r, θ and Φ. If antenna radiates equally in all the directions it is called isotropic antenna.

The radiation pattern of isotropic antenna is as shown in Fig (2). From the Fig it is clear that for every point with distance r from the antenna the strength of radiated field is same for every value of theta and phi. Non isotropic antenna does not radiate equally in all the directions. It radiates more in one direction than some other direction.

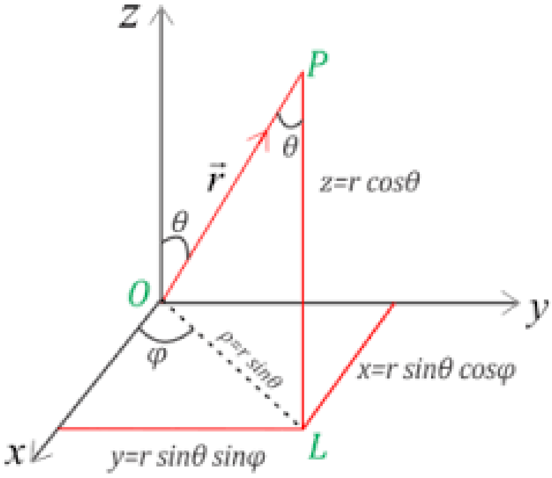

Figure.1 spherical coordinates system

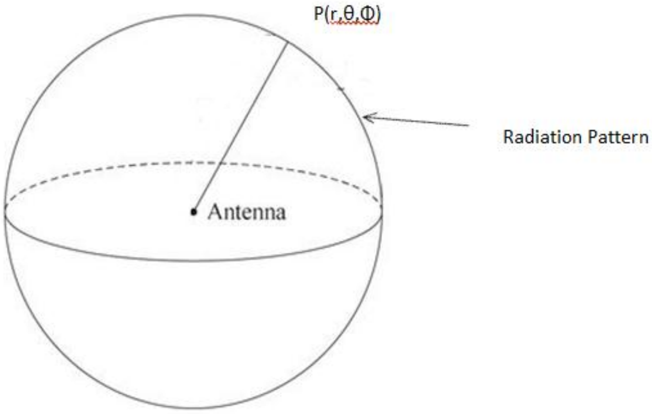

Figure.2 Radiation pattern of isotropic antenna

The radiation pattern of one of non-isotropic antenna is as shown in Fig (3).

This antenna radiates maximum in ($\theta = 90^0$, $\Phi = 0^0$) direction. Depending upon the strength of radiations, various regions of radiation pattern are classified as Major Lobe or main lobe, Side lob and back lob. Major lob of radiation pattern is the region where strength of radiation is maximum. Back lob is exactly in back of major lob i.e area of radiation pattern exactly 180° out of major lobe. All other portion of radiation pattern where signal is transmitted are known as side lobes. Usually side lobes are undesirable and various feeding methods are used to remove side lobes. The portion of radiation pattern where no signal is transmitted is termed as Null.

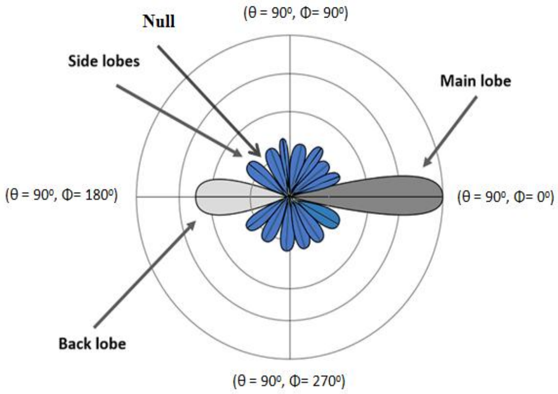

Figure.3 Radiation pattern of non-isotropic antenna

Another important parameter of radiation pattern is the beam width of lobes. Antenna beam width is the angular separation between the points of the main beam where strength of radiated signal reduces by 50% or by 3dB of its maximum value. In Fig (4) The maximum radiated power by main beam is P Max at point X. At points y and Z radiated power is P/2. So, angel between points Y and Z which is theta is beam width of main lobes.

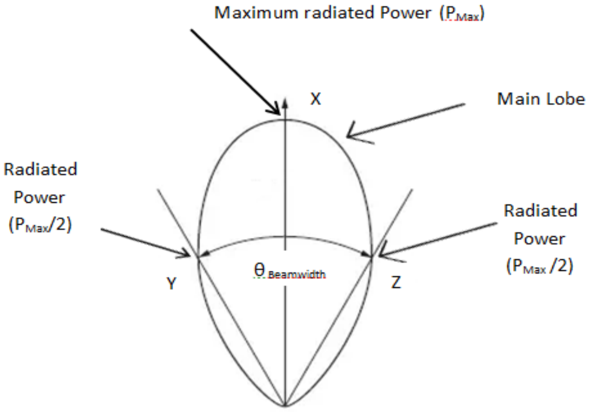

Figure.4 Beam width of lobes

Directive gain and Power Gain of antenna:

Radian: Radian is measure of plane angle and is defined as the angle subtended by the arc on the center of a circle. Consider a circle of radius r as shown in Fig (5).

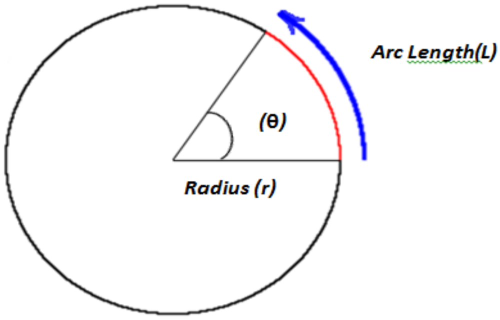

Figure.5 Radian angle

The angle in radian subtended by arc of length l on the center of circle is θ and is given by

$$\theta(radian) = \frac{Arc\ Length(L)}{Radius(r)}$$

As maximum arc length can be 2πr so there can be maximum 2π radian in a circle.

Steradian: It is used to measure the solid angle. It is defined as the angle subtended at the center by the Surface Area A of sphere. It is denoted by **Ω**. Consider a sphere of radius r as shown in Fig (6). The area A on the sphere subtends an angle **Ω** at the center. Solid angle **Ω** is given by

$$\Omega = \frac{A}{r^2}$$

As maximum area of sphere can be $4\pi r^2$ so there can be maximum of 4π Steradian in sphere.

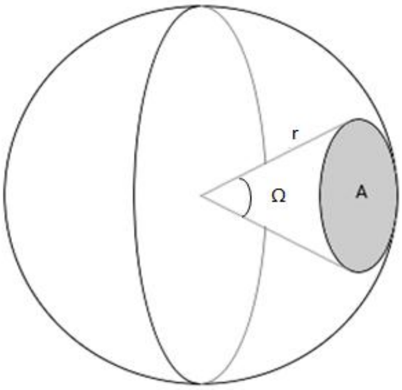

Figure.6 Steradian angle

Radiation Power density: Electromagnetic waves radiated by antenna possess energy. The power density which is power per unit area associated with electromagnetic waves is given by Poynting vector(P), which can be obtained by cross product of electric and magnetic field. i.e.

$$P = E * H = \frac{w}{m^2}$$

The total radiated power by antenna can be found by integrating Poynting vector(P) over the entire surface

$$P_{rad} = \oint (E * H)\ ds$$

In spherical coordinates Expression of surface area is given by

$$ds = \int_{\theta_1}^{\theta_2} \int_{\Phi_1}^{\Phi_2} r^2\ Sin\theta\ d\theta\ d\Phi$$

So

$$P_{rad} = \int_{\theta_1}^{\theta_2} \int_{\Phi_1}^{\Phi_2} (E * H) r^2\ Sin\theta\ d\theta\ d\Phi$$

Radiation Intensity: Radiation intensity in a given direction is denoted by U and it measures total power per unit solid angle.

So

$$U = \frac{P_{rad}}{\Omega} = \frac{P_{rad}}{\frac{A}{r^2}} = \frac{r^2\ P_{rad}}{A} = r^2\ P$$

Further Total radiated or received power can be calculated from U by using

$$P_{rad} = U * \Omega = U * \frac{A}{r^2} = U * \frac{\int_{\theta_1}^{\theta_2}\int_{\Phi_1}^{\Phi_2}(E*H)r^2 \, Sin\theta \, d\theta \, d\Phi}{r^2} = U * \int_{\theta_1}^{\theta_2}\int_{\Phi_1}^{\Phi_2} Sin\theta \, d\theta \, d\Phi$$

Directive Gain: Generally, all antennas are directional i.e they radiate more in one direction as compared to other directions. Directive gain is the measure of the capability of the antenna to radiate in particular direction.
Directive Gain can be calculated by measuring the radiation intensity in a given direction $U(r,\theta,\phi)$ and average radiation intensity $U(Avg)$. As there are total 4π Steradian in a sphere so average radiation intensity can be calculated by dividing total radiated power by 4π.

So expression of Directive Gain of antenna is given by

$$G_D = \frac{U(r,\theta,\phi)}{U(Avg)} = \frac{U(r,\theta,\phi)}{\frac{P_{rad}}{4\,\pi}} = \frac{U(r,\theta,\phi)\,4\pi}{P_{rad}}$$

Directive gain is dimension less quantity and is not related with efficiency of antenna. If antenna radiate more in one direction and Zero in some other direction then Directive gain of antenna is zero in direction of zero radiation and more than one in direction of maximum radiation.
Maximum value of directive gain is called the directivity of antenna so minimum possible value of directivity of antenna is One.
Power gain: Power gain basically indicated the capability of antenna to radiate by incorporating the efficiency of antenna.
Power Gain can be calculated by measuring the radiation intensity in a given direction $U(r,\theta,\phi)$ and average input radiation intensity $U_{in}(Avg)$.
Power gain is calculated by

$$G_P = \frac{U(r,\theta,\phi)}{U_{in}(Avg)}$$

Efficiency of antenna:
Efficiency of antenna is defined as the ratio of Radiated power to the input power supplied to antenna.
Mathematically $\eta = \frac{P_{Radiated}}{P_{input}}$
Or we may write
Dividing and multiplying by $4\pi U(r,\theta,\phi)$ Where $U(r,\theta,\phi)$ is the radiation intensity at location (r,θ,ϕ)

$$\eta = \frac{P_{Radiated} * 4\pi U(r,\theta,\phi)}{P_{input} * 4\pi U(r,\theta,\phi)}$$

By rearranging the equation, we get

$$\eta = \left\{\frac{P_{Radiated})}{4\pi U(r,\theta,\phi)}\right\}\left\{\frac{4\pi U(r,\theta,\phi)}{P_{input}}\right\}$$

We can write that

$$\eta = \left\{\frac{G_P}{G_D}\right\}$$

Radiation Resistance:
We are using antenna for radiating electromagnetic signals into space. Electromagnetic signals possess energy with them which can be calculated by using Poynting vector.
Radiation resistance is the fictitious resistance which when placed in series with the antenna consumes the same power as is actually radiated by the antenna.
If antenna radiates total of $P_{Radiated}$ Watts and there flows current I_a in the antenna, Radiation Resistance R_a can be calculated as

$$R_a = \frac{P_{Radiated}}{I_a^2}$$

$$R_a = \frac{U * \int_{\theta_1}^{\theta_2}\int_{\Phi_1}^{\Phi_2} Sin\theta \, d\theta \, d\Phi}{I_a^2}$$

$$R_a = \frac{\int_{\theta_1}^{\theta_2}\int_{\Phi_1}^{\Phi_2}(E*H)r^2 \, Sin\theta \, d\theta \, d\Phi}{I_a^2}$$

Voltage Standing Wave Ratio:
Another important parameter of antenna is VSWR. VSWR indicates how well the antenna impedance is matched to the device it is connected. If antenna impedance is matched with the source, then all the power supplied by the source is delivered to the antenna for the purpose of radiation as shown in
Fig (7)

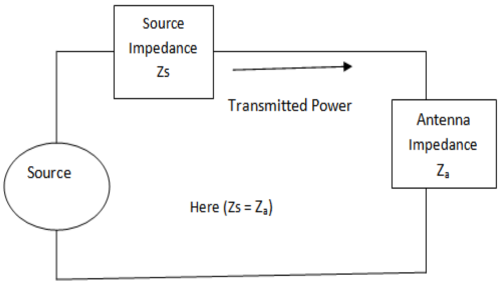

Figure.7 Transmitted power for matched load

If antenna impedance is matched with the receiver, then all the power supplied by antenna is delivered to the receiver. However, if antenna impedance is not matched with either source or receiver i.e antenna impedance is not equal to that of source or receiver then all the power supplied by source will not be delivered to antenna for the purpose of radiation and all the power supplied by antenna is not delivered to the receiver as shown In Fig (8). In this case Power is reflected back by antenna towards source. The strength of reflected power depends on the mismatch of source and antenna impedance.
Due to interference between Transmitted and Reflected signal, Maximum and Minimum of signals are obtained on the transmission line.
VSWR is the ratio of maximum to minimum signal along the line.

i.e. $VSWR = \frac{V_{maximum}}{V_{minimum}} = \frac{V_T+V_R}{V_T-V_R} = \frac{1+\frac{V_T}{V_R}}{1-\frac{V_T}{V_R}} = \frac{1+K}{1-K}$

Here K = Reflection coefficient = $\frac{Z_a - Z_s}{z_a + z_s}$
For perfectly matched $Z_a = Z_s$, K=0 and VSWR =1.

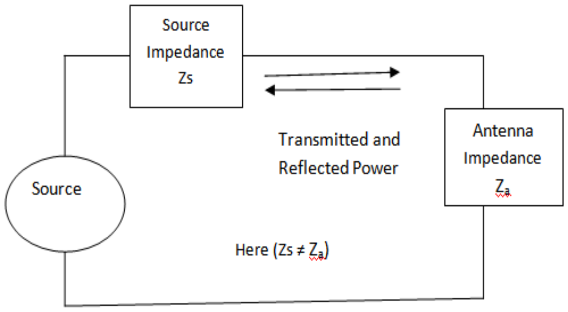

Figure.8 Transmitted power for unmatched load

Polarization:

Polarization of antenna provides the information about the orientation of Electric field transmitted by main beam of antenna with respect to time. It is classified as linear, elliptical and circular polarization.

Linear Polarization:

In this type of polarization electric field direction of propagating electromagnetic signal always remains along one axis. It may be horizontal, vertical or slant. Consider an electromagnetic wave propagating in Z direction as shown in fig. If Direction of Electric field of propagating wave is in X direction it is Horizontally polarized wave, If Direction of Electric field of propagating wave is in Y direction it is Vertically polarized wave.

Mathematically an electromagnetic wave propagating in Z direction can be represented as

$$E = E_o Sin\,(wt - \beta z)$$

For linearly polarized wave in y direction, we have

$$E = E_o Sin\,(wt - \beta z)\overrightarrow{a_y}$$

For linearly polarized wave in x direction, we have

$$E = E_o Sin\,(wt - \beta z)\overrightarrow{a_x}$$

For linearly polarized wave in slant direction, we have

$$E = E_o Sin\,(wt - \beta z)(\,\overrightarrow{a_x} + \overrightarrow{a_y}\,)$$

Here thing to consider is that the magnitude and phase of electromagnetic wave is same in x and y direction.

Circular Polarization:

Now consider that Electric field exist in x and y direction such that magnitude of electric field in both directions is same however they are different in phase by 90°.

i.e.

$$E_y = E_o Sin\,(wt - \beta z + 90^o)\overrightarrow{a_y}$$

$$E_x = E_o Sin\,(wt - \beta z)\overrightarrow{a_x}$$

Resultant field is given by

$$E = E_o Sin\,(wt - \beta z)\overrightarrow{a_x} + E_o Sin\,(wt - \beta z + 90^o)\overrightarrow{a_y}$$

$$E = E_o Sin\,(2\pi f t - \beta z)\overrightarrow{a_x} + E_o Sin\,(2\pi f t - \beta z + 90^o)\overrightarrow{a_y}$$

At Z=0

$$E = E_o Sin\,(wt)\overrightarrow{a_x} + E_o Sin\,(wt + 90^o)\overrightarrow{a_y}$$

For t=0, $E = E_o Sin\,(\,90^o)\overrightarrow{a_y} = E_o\overrightarrow{a_y}$

For t=.5,

$$E = E_o Sin\,(\pi)\overrightarrow{a_x} + E_o Sin\,(\pi + 90^o)\overrightarrow{a_y} = -E_o\overrightarrow{a_y}$$

If we plot E for various values of time t this will be the locus of circle as shown in Fig (9).

Similarly, if we take various values of time then it can be concluded that electric field traverses the circle. So, this type of polarization is called circular polarization.

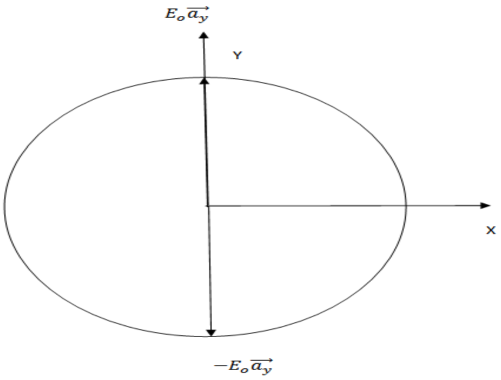

Figure.9 Circular Polarization

Elliptical polarization:

Now consider that Electric field exist in x and y direction such that magnitude and phase of electric field in both directions is different.

i.e.

$$E_y = E_2 Sin\,(wt - \beta z + \alpha^o)\overrightarrow{a_y}$$
$$E_x = E_1 Sin\,(wt - \beta z)\overrightarrow{a_x}$$

Resultant field is given by

$$E = E_1 Sin\,(wt - \beta z)\overrightarrow{a_x} + E_2 Sin\,(wt - \beta z + \alpha^o\,)\overrightarrow{a_y}$$

For Z=0, Resultant field E ig given by

$$E = E_1 Sin\,(wt)\overrightarrow{a_x} + E_2 Sin\,(wt + \alpha^o\,)\overrightarrow{a_y}$$

If we plot E for various values of time t this will be the locus of ellipse as shown in Fig (10). So, this form of polarization is called Elliptical polarization. Axial ratio signifies under such condition which is the ratio of Length of Major axis to the Length of minor axis.

Bandwidth:

Another parameter of interest of antenna is its bandwidth. Bandwidth is the range of frequencies over which antenna provides the desired characteristics. Bandwidth can be specified in terms of VSWR, input impedance, radiation resistance, polarization or antenna gain.

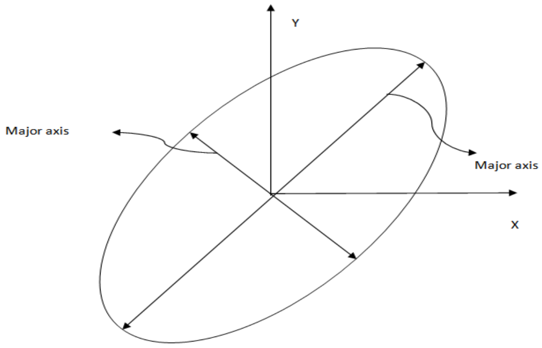

Figure.10 Elliptical Polarization

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