Application note 105: RF antennas and related formulas

RF transmitting antennas or "emitters" as they are often referred to, rank high on the list of major technical issues that include RF power amplifiers and the test standards themselves. Fortunately antenna fundamentals can be understood by just about anyone when presented in plain English. The purpose of this application note is to explain some of the standard antenna terms and the basic math required to calculate the RF field level with a given RF input power signal. This is the basis of a Radiated Immunity test system.

Standard Antenna Terms:

Free space - Free Space refers to a location where an antenna can operate without any external physical effects that would alter its performance. Metallic objects like the device under test and shielded room walls will reflect the transmitted RF signals. Such reflections will add to or cancel portions of the transmitted signals when the phase relationships are mathematically correct. This results in unexpected changes in the field level that can cause over and under testing of the device under test.

Radiator - A radiator can be any conductive element that is fed with or excited by an RF voltage or current. This applies to the elements of an antenna or a conductor in the test system or in the device under test. Even a physically short conductor can act as a radiator in an RF circuit.

Radiation - Radiation is the emission of energy from an antenna. This energy ideally consists of an electric or E-field and magnetic or H-field waves. (see polarization) The energy radiating from an antenna passes through three and sometimes more specific stages before the fields become well defined as vertical or horizontal components.

Near field radiation - Near field radiation from an antenna begins directly at the driven element or radiator. At this point the radiation components are "reactive" and are not easily defined as E-field or H-field. The level of these reactive components decreases very rapidly with distance from the radiator and are considered negligible at one or more wavelength from the radiator. Beyond this point the signals are typically considered to be far field radiation.

Far field radiation - Far field radiation is generally considered to begin one wavelength or more from the antenna, at which distance the radiated energy is no longer "reactive." The far field contains well defined E and H-fields and the power density falls as I/R^2. Far field performance is predictable and repeatable which is imperative for EMC testing applications.

Wavelength - The wavelength (lambda - λ) of a signal is the physical length of that signal in free space. Wavelength is measured as a unit of distance, typically in meters at lower frequencies and in millimeters at microwave frequencies. For example, a signal 1 meter in wavelength would be about 299.7 MHz in free space. Frequency is the number of complete signal cycles referenced to a time period, typically in seconds and abbreviated as Hz, kHz, MHz or GHz.

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Polarization - The polarization of an antenna is defined as the orientation of the electric field lines in the electrostatic and electromagnetic fields radiated by an antenna. Linearly polarized antennas in either the vertical or horizontal modes are typically used for EMC testing applications; as an example a vertical antenna would be perpendicular to the Earth's surface and a horizontal antenna would be parallel to the ground.

The antenna radiating element has a voltage gradient along its length that produces an electrostatic field from one end of the element to the other that extends outward or perpendicular from the antenna element. The H-field (or H-plane radiation) is a magnetic field emanating from the antenna element due to the current flowing through the radiating element. The E and H fields are separated by 90 degrees. A vertical antenna would have a vertically oriented E-field and a horizontal H-field radiation. A horizontally polarized antenna would have a horizontal E-field and a vertical H-field radiation.

Bandwidth - Bandwidth is the frequency range over which an antenna has been designed to operate. Antennas are typically resonant or "tuned" to a specific center frequency. Dipoles are a good example of a tuned or narrow-band radiator. The double ridged waveguide horn is an example of a broadband microwave antenna. The Log periodic is an example of a broadband antenna providing a compromise of physical size, frequency bandwidth and apparent gain.

Gain - Antenna gain is probably the least understood characteristic of an antenna. The first thing that must be understood is that gain is a relative term and one of the most important characteristics of an antenna. Gain can be related linearly or logarithmically and either way is referenced to what is called an isotropic radiator. By definition an isotropic radiator is an infinitely small theoretical point source of radiation which expands outward in a uniform spherical manner to infinity. Altering the shape of the radiation pattern (from spherical) in any manner concentrates the energy producing "apparent" gain.

As an example of an isotropic radiator consider a candle illuminating a small room. Although relatively dim, the entire room is illuminated and the intensity is relatively consistent. Now place a mirror ("reflector") to one side of the candle and the light traveling towards the mirror is now reflected causing the total amount of light to be increased in the direction of the mirror reflection.

If this were a perfect directional antenna the "apparent" gain would be a factor of two or 3 dBi. The term dBi is related to the radiation pattern of an isotropic radiator (a theoretical omni-directional antenna). Understand that this is pure theory and like a perfect mirror no such antenna exists in the practical world. There are beam widths, vertical radiation angles, side lobes, back lobes, front to back ratios and a host of other effects to contend with. These are all subjects for a future application note.

Radiation Pattern - The radiation pattern of an antenna is basically determined by its design. The pattern from a dipole will be like a donut on a wire and dependent on the antenna orientation. With a vertical dipole the donut will be like a wheel with its face parallel to the ground. With a horizontal antenna the donut will be on its side like a wheel ready to roll.

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Phase Center - The phase center of an antenna can be thought of as the primary point from which energy is emitted from an antenna. It is not necessarily the location of the driven radiator. The phase center of a dipole is the feed point directly between the two elements. The phase center of certain types of broadband antennas change with frequency, moving towards the tip or end of the antenna structure as the frequency increases.

Phase center shift can be problematic in a test situation as the distance between the point of radiation and the device under test changes with frequency. This shift can result in an increase or decrease in field intensity and cause over or under testing conditions. Commercial and Military standards address the phase center issue and the appropriate documents should be consulted to insure proper antenna placement prior to conducting a test.

RELATED FIELD STRENGTH FORMULAS:

1. Field Strength

$$E = \frac{\sqrt{30 \times G \times P}}{R}$$

$$P = E^2 \, x \, R^2(m)/30 \, x \, G$$

Where,
P - Power in Watts
G - Linear (numeric) gain of the antenna
R - Distance between the sensor and the antenna in meters

2. Field Measurements Units

$$E = \sqrt{F \times 0.377} \times 100 = 61.4 \times \sqrt{F}$$

$$F = \left(\frac{E}{100}\right)^2 \Big/ 0.377 = \left(\frac{E}{61.4}\right)^2$$

Where,
E is in V/M
F is in mW/cm^2

3. Antenna Gain Conversion

G(dBi) = 10 log G(linear)

G(linear) = Antilog [G(dBi)/10]

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Field Strength Examples at 1M:

The following are three examples of antenna field strength calculations at 1 meter distance. The gain of the antenna and the distance have been varied for each example to provide a more comprehensive understanding of these calculation examples. All calculations are based on linear (numerical) gain. The apparent gain of any antenna will vary with frequency and the RF power input as referenced in the calculations is at the input of the antenna.

20 V/M Calculations at 1M

Antenna parameters:

Antenna Gain - G(dBi) = 6 dB
Antenna Gain - G(linear) = 4

Variables:

E(v/m) - E field level - 20 V/M
R(m) - Distance in meters - 1 M
Pt(w) - RF power input to antenna - TBD

Antenna Gain Conversion

G (dBi) = 10 Log G(linear)
G(linear) = Antilog [G(dBi)/10]

Field Strength

$Pt=E^2xR^2/30xG_{(linear)}$ = *RF power input at antenna*

Calculation

$Pt=((20.0)^2x\ (1)^2)/(30\ x\ 4) = 3.3$ *watts*

50 V/M Calculations at 1M

Antenna parameters:

Antenna Gain - G(dBi) = 10 dB
Antenna Gain - G(linear) = 10

Variables:

E(v/m) - E field level - 50 V/M
R(m) - Distance in meters - 1 M
Pt(w) - RF power input to antenna – TBD

Antenna Gain Conversion

G (dBi) = 10 Log G(linear)
G(linear) = Antilog [G(dBi)/10]

Field Strength

$Pt=E^2xR^2/30xG_{(linear)}$ = *RF power input at antenna*

Calculation

$Pt=((50.0)^2x\ (1)^2)/(30\ x\ 10) = 8.3$ *watts*

200 V/M Calculations at 1M

Antenna parameters:

Antenna Gain - G(dBi) = 13 dB
Antenna Gain - G(linear) = 20

Variables:

E(v/m) - E field level - 200 V/M
R(m) - Distance in meters - 1 M
Pt(w) - RF power input to antenna - TBD

Antenna Gain Conversion

G (dBi) = 10 Log G(linear)
G(linear) = Antilog [G(dBi)/10]

Field Strength

$Pt=E^2xR^2/30xG_{(linear)}$ = *RF power input at antenna*

Calculation

$Pt=((200.0)^2x\ (1)^2)/(30\ x\ 20) = 66.6$ *watts*

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Field Strength Examples at 3M:

The following are three examples of antenna field strength calculations at 3 meters distance. The gain of the antenna and the distance have been varied for each example to provide a more comprehensive understanding of these calculation examples. All calculations are based on linear (numerical) gain. The apparent gain of any antenna will vary with frequency and the RF power input as referenced in the calculations is at the input of the antenna.

20 V/M Calculations at 3M

Antenna parameters:

Antenna Gain - G(dBi) = 6 dB
Antenna Gain - G(linear) = 4

Variables:

E(v/m) - E field level - 20 V/M
R(m) - Distance in meters - 3 M
Pt(w) - RF power input to antenna - TBD

Antenna Gain Conversion

G (dBi) = 10 Log G(linear)
G(linear) = Antilog [G(dBi)/10]

Field Strength

$Pt=E^2xR^2/30xG_{(linear)}$ = *RF power input at antenna*

Calculation

$Pt=((20.0)^2x\ (3)^2)/(30\ x\ 4) = 30$ *watts*

50 V/M Calculations at 3M

Antenna parameters:

Antenna Gain - G(dBi) = 10 dB
Antenna Gain - G(linear) = 10

Variables:

E(v/m) - E field level - 50 V/M
R(m) - Distance in meters - 3 M
Pt(w) - RF power input to antenna – TBD

Antenna Gain Conversion

G (dBi) = 10 Log G(linear)
G(linear) = Antilog [G(dBi)/10]

Field Strength

$Pt=E^2xR^2/30xG_{(linear)}$ = *RF power input at antenna*

Calculation

$Pt=((50.0)^2x\ (3)^2)/(30\ x\ 10) = 75$ *watts*

200 V/M Calculations at 3M

Antenna parameters:

Antenna Gain - G(dBi) = 13 dB
Antenna Gain - G(linear) = 20

Variables:

E(v/m) - E field level - 200 V/M
R(m) - Distance in meters - 3 M
Pt(w) - RF power input to antenna - TBD

Antenna Gain Conversion

G (dBi) = 10 Log G(linear)
G(linear) = Antilog [G(dBi)/10]

Field Strength

$Pt=E^2xR^2/30xG_{(linear)}$ = *RF power input at antenna*

Calculation

$Pt=((200.0)^2x\ (3)^2)/(30\ x\ 20) = 600$ *watts*

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