Guide to Antenna Tests and Over-The-Air (OTA) Measurements

Practical Benefits to Optimizing Your Wireless Transmitter's Antenna Performance

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Complete EMC, Environmental Stress, and Photometric Testing

Contents

1 Overview

Measuring an antenna's performance when configured to a wireless device, or on its own, can provide a wide range of benefits.

- Designers can optimize an antenna's physical construction and radio performance based on product size, typical usage, manufacturing costs, and RF exposure
- Users benefit from increased range and improved signal quality
- Better transmission reliability can be achieved regardless of position or orientation of the device
- Reduced power consumption extends battery life
- Proper antenna placement relative to digital circuitry can increase receiver sensitivity
- An optimized antenna design will create a robust base station channel and produce better network communication performance

Antenna Basics

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What is an Antenna?

An antenna is a transitional structure between free-space and a guiding device or a transmission line, i.e. coaxial line or a hollow pipe waveguide, used to transport electromagnetic energy from the *transmitting antenna* to a *receiving antenna*

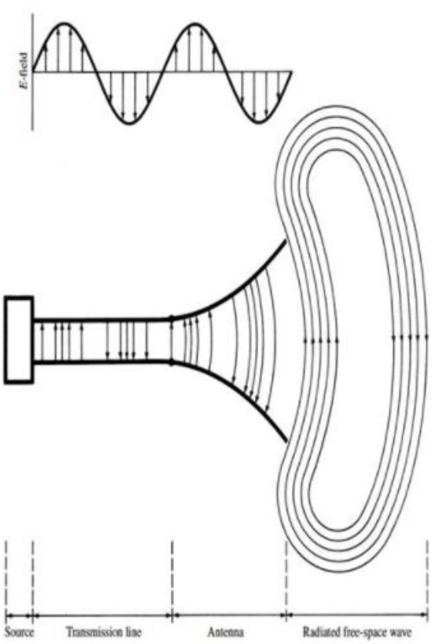

Figure 1

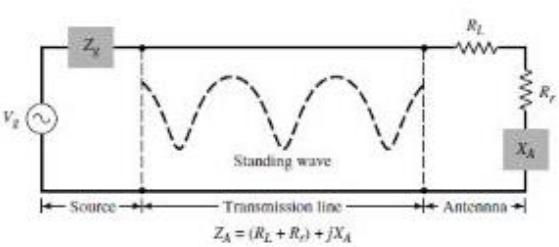

Figure 2

Z_A = *Antenna Impedance*
R_L = *Load Resistance*
R_r = *Radiation Resistance*
jX_A = *Reactance*
Z_g = *Source Impedance*

What causes an Antenna to radiate?

To create radiation, there must be a time-varying current or an acceleration (or deceleration) of charge. Radiation occurs when a wire is curved, bent, discontinuous, terminated or truncated.

When you configure an AC source on one end of a transmission line and an antenna at the other end of a transmission line, the antenna acts as a "Load" even though there is no traditional R-L-C load attached. The antenna does not dissipate the energy significantly as heat or mechanical motion rather it radiates RF energy into free-space. If it is a well-designed antenna, it radiates nearly all the power out into free-space in the form of EM waves (plane waves).

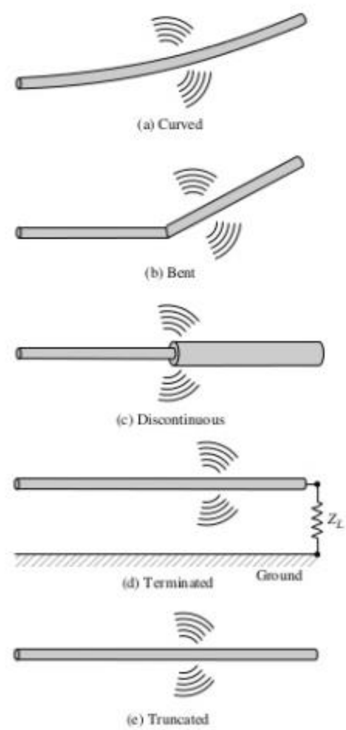

Figure 3

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What are the important Antenna parameters?

There are four main parameters to consider when designing antennas for wireless devices:

- S-Parameters
- Antenna Gain
- Antenna Efficiency
- Antenna Directivity

S-parameters are a complex matrix that show Reflection/Transmission characteristics (Amplitude/Phase) in frequency domain. Figure 5 shows a two-port device, which has four s-parameters. A two-port Network Analyzer is used to measure a two-port s-parameter system.

S11 and S22 are reflections on port 1 and port 2, respectively. These two ports can be used to measure antenna return loss, impedance , and voltage standing wave ratio (VSWR). These parameters can be determined for a single antenna or two antennas sharing the same ground plane.

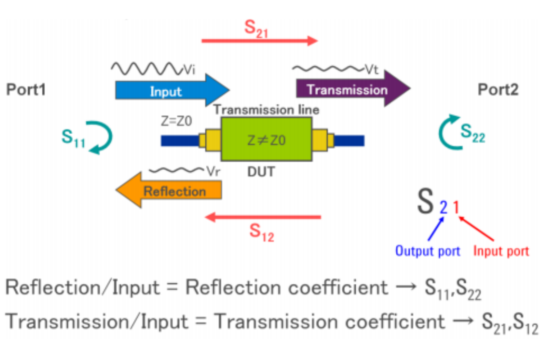

Figure 5

Figure 6 illustrates a typical S11 response (Return Loss) of an antenna connected to port 1 of a network analyzer. The magnitude of the return loss shows that when a certain power is delivered to the load (Antenna), how much power is reflected back in (dB). It also identifies the antenna resonant frequencies .

Figure 7 is a graphical representation of a typical antenna impedance known as impedance analysis on a "Smith Chart". This allows an easy way for an engineer to determine the mismatch between the antenna's impedance and the load impedance (typically 50 ohms). A good matching network reduces the mismatch and allows maximum energy transfer in the form of power to the antenna and eventually into free-space as electromagnetic waves.

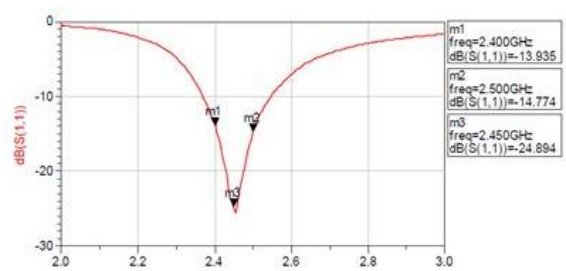

Figure 6

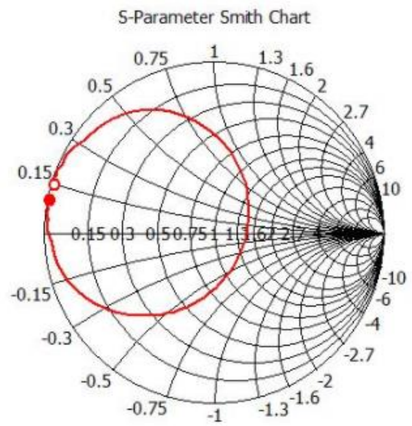

Figure 7

S21 and S12 for a two-port network identify the effect of one port on the other. S21 is the metric describing the effect on port 2 due to port 1 and vice versa. These parameters are used to determine insertion loss and isolation between two antennas sharing the same ground plane separated by some spatial distance (“d”).

Antenna Gain in the most simple terms describes how well the antenna converts input power into electromagnetic waves or radio waves headed in a specific direction. Mathematically, Gain is defined as:

Gain = Efficiency X Directivity

Antenna Efficiency is the ratio of the power delivered to the antenna relative to the power radiated from the antenna. An ideal antenna theoretically radiates all the power delivered making it a 100% efficient antenna.

However, an ideal antenna does not exist. In the real world, a highly efficient antenna is one that is well matched and has minimum power loss due to absorption, heat or other system losses.

Efficiency = $P_{radiated} / P_{input}$

Antenna Directivity is defined as the direction of maximum propagation of electromagnetic waves generated from single or multiple antenna sources. An antenna radiating equally in all directions is an omnidirectional antenna. Typical antennas used for cellular and IoT applications are omnidirectional in nature. This allows a better chance of receiving attenuated signals even though there is no direct line of site.

Antenna Measurements

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Measuring the antenna performance is critical for a successful antenna-transceiver design. Testing begins with return loss and impedance measurements. Tests for Efficiency, Gain, Directivity, Effective Isotropic Radiated Power (EIRP), Total Radiated Power (TRP) and Total Isotropic Sensitivity (TIS) are required to fully quantify the design measurements for an antenna. These parameters are typically measured in a fully anechoic chamber environment. ETS-Lindgren, MVG and Rohde & Schwarz are some of the leading providers of fully anechoic chambers, each providing their own unique solution to obtain antenna parameters.

What is Passive Antenna Testing?

A typical passive antenna environment is one in which the antenna port is isolated from the rest of the RF front end. The antenna port of the DUT is directly connected to a signal generator set to a desired frequency and amplitude. Figure 8 shows a typical antenna chamber setup. The DUT is placed on a turn table typically rotating 360 degrees (Azimuth). A receiving antenna, typically a horn antenna or patch antenna with dual polarization, is placed on a boom that moves from zero to 180 degrees (Elevation).

The DUT antenna transmits radio waves which are picked up by the antenna for the receiving instrumentation. Measurements are recorded continuously at several angles of Elevation (theta = 0 to 150) and Azimuth (Phi = 0 to 360) to provide a 2D or 3D view of the antenna radiation pattern. Efficiency, gain, directivity and EIRP are also calculated through software algorithms performing numerous computations.

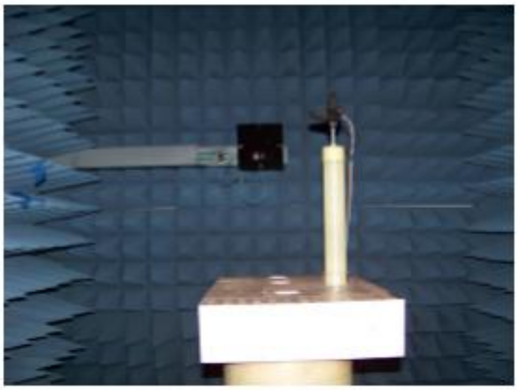

Figure 8

How are these results helpful?

These results help antenna engineers characterize their design. By evaluating efficiency and gain measurements, an antenna engineer can determine how well the antenna is performing and whether or not it meets design specifications. The antenna's 2D and 3D plots are useful for visualizing the amount of radiation and its directivity as well as the area of maximum gain.

For example, when designing a GPS antenna for a wireless handheld device, engineers must confirm the antenna is right hand circularly polarized (RHCP) with the beam pattern pointing towards the sky vs. pointing towards the ground. This allows the antenna to get better time to first fix, higher CNo and improved signal strength. Visually interpreting antenna patterns can help optimize these parameters.

Figures 9, 10 and 11 are 2D and 3D plots of an omnidirectional dipole antenna measured in a fully anechoic antenna chamber.

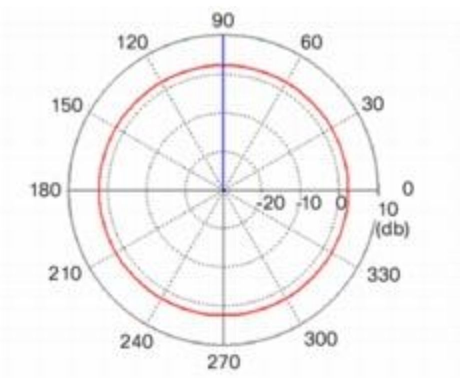

Figure 9 – Azimuth Plane

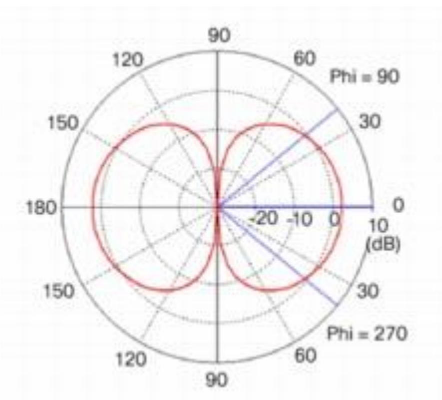

Figure 10 – Elevation Plane

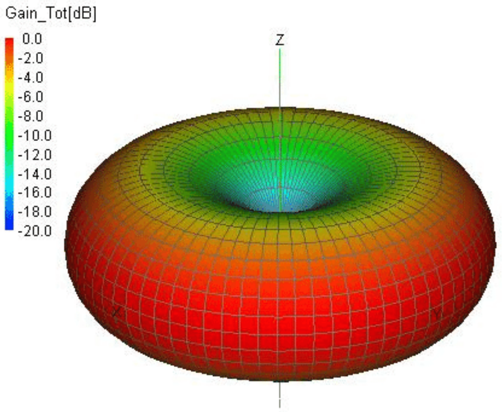

Figure 11

What is Active Antenna Testing?

A typical active antenna test environment is one in which the antenna is not isolated from the rest of the RF front end. In other words, the overall system (antenna plus RF front end) is measured to quantify performance. The figures of merit to qualitatively evaluate the antenna system are TRP and TIS. These parameters are measured in a fully anechoic antenna chamber.

TRP (Total Radiated Power) is the measure of power radiated by the antenna when it is connected to a RF transmitter averaged over a 3-D sphere.

TIS (Total Isotropic Sensitivity) is the measure of the average sensitivity of a receive antenna system when averaged over a 3-D sphere.

Antenna Measurements

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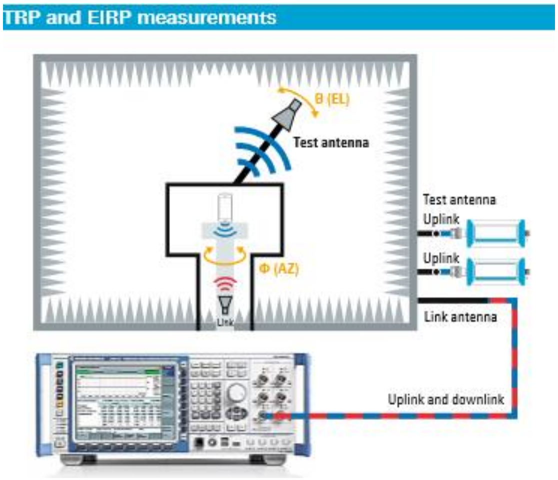

Figure 12

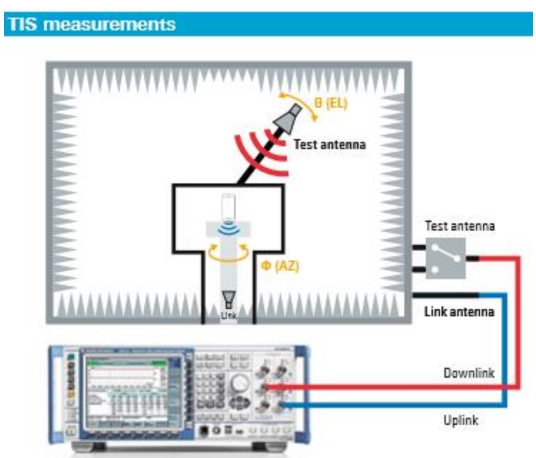

Figure 13

Why are these parameters important and for who?

TRP and TIS measurements are the fundamental parameters to determine the signal quality for a wireless device. They are the best figures of merit to gauge the overall system performance for any wireless device operating in the UHF bands.

These parameters are important for cellular wireless carriers and cellular standards committees such as PTCRB, GCF, 3GPP and CTIA, as well as for wireless forums such as WiFi alliance, BTsig, Zigbee alliance etc. Cellular carries pay close attention to these parameters and have specific requirements for TRP and TIS in free-space and various user configurations. The results gauge the integrated radio-host operation on a particular network under various conditions. Having devices with good TRP and TIS helps carriers maintain good user experience through fewer dropped calls in fading conditions and in fringe areas. It also helps carriers in planning and optimizing their infrastructure. Tables 1 and 2 identify typical TRP and TIS datasets taken for a portable wireless device in free-space, capable of operating in GSM, UMTS and LTE bands.

		Technology	Low Channel (dBm)	Mid Channel (dBm)	High Channel (dBm)	Conducted Power (dBm)
Free-Space	TRP	GSM 1900	27.5	27.8	27.5	30
		UMTS 2	20	20.5	20	24
		LTE B2 (SISO)	20	20.5	20	24

Table 1 – TRP

		Technology	Low Channel (dBm)	Mid Channel (dBm)	High Channel (dBm)	Conducted Sensitivity (dBm)
Free-Space	TIS	GSM 1900	-108	-108	-108	-111
		UMTS 2	-107	-107	-107	-110
		LTE B2 (SISO)	-95	-95	-95	-98

Table 2 - TIS

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