

Clarify Antenna Gain For Accurate Mobile Measurements

Understanding the true meaning of “antenna gain” can help improve the accuracy of handset measurements.

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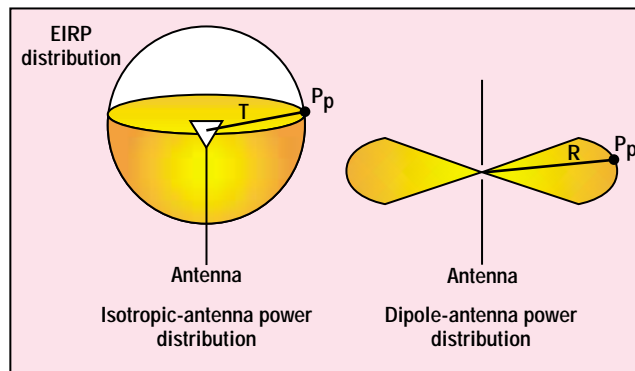
MEASUREMENT accuracy is important to mobile-telephone manufacturers and to service providers. Power and frequency are two key parameters that must be generated and measured by a mobile unit to ensure proper operation within specified limits. Accurate measurements of the power received and transmitted by the mobile unit will ensure that battery life is maximized, RF radiation is minimized, and appropriate coverage is realized.

In order to test a mobile unit, a physical or inductive connection must be made with the device's RF path. This may occur with a physical or galvanic connection or through an inductive-antenna coupling mechanism. Each method must account for distinct RF characteristics in order to produce accurate tests. The goal is to test and calibrate a mobile unit in order to produce the most accurate signal at the antenna. When a mobile unit is tested at the galvanic connection, and the appropriate characterization of that connection's deviation

from the antenna's response is not accurately taken into account, the actual response of the antenna may be compromised.

Many different technical aspects of mobile-telephone transmissions are often incorrectly lumped under the generic term “antenna gain.” In order to make more accurate mobile-telephone measurements, it is first necessary to understand the true meaning of antenna gain and how it applies to mobile-telephone transmissions and testing.

Antenna gain is a term used to relate the isotropic radiative power (IRP) of a particular antenna to the peak radiated power of other antenna designs, such as dipole or monopole antennas. At times, the industry has lumped other losses and compensation factors together with antenna gain in order to relate the response of the physical RF connector to that of the antenna. This misinterpretation can cause confusion when trying to accurately determine the response of a mobile telephone through either the



1. The radiation pattern of an isotropic antenna differs from that of a dipole antenna due to the distribution of power. Antenna gain is a conversion factor used to compare patterns from different antennas.

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antenna or the galvanic connection.

Antenna gain is defined as the ratio of the maximum radiated power density at a particular point from the antenna to the power density radiated by a reference antenna at the same point. The reference antenna, in most cases, is isotropic. The power that is radiated from an ideal isotropic antenna extends into space equally in all directions. It forms a sphere around the zero point of the antenna. In reality, antennas do not radiate isotropically. The dipole antenna, for example, radiates in a donut-shaped plane that extends perpendicularly to the length of the antenna.

An isotropically radiating antenna can be compared to a dipole antenna through a conversion factor known as antenna gain. The conversion factor is considered a gain conversion because the total power from the two antennas remains constant, but the power is distributed over a more compressed area with the dipole antenna (Fig. 1). The power at a point along the peak radiation path of the dipole antenna will be at a higher level than the power at an equivalent point from the isotropic antenna, at the same distance r from the antenna.

Antenna gain can be derived through some simple relationships. The isotropic power at a particular point, P_p , can be derived as:

$$P_p = P_r/4\pi r^2$$

For example, if the values of $r = 100$ m and $P_r = 100$ W are applied, Eq. 1 becomes:

$$\begin{aligned} P_p &= 100 \text{ W}/[4\pi(100)^2] \\ &= 1/400\pi = 0.795 \text{ mW/m}^2 \\ &= -0.996 \text{ dBm/m}^2 \end{aligned}$$

The derivation of the antenna gain for a short dipole antenna can be shown as:

$$P_{\text{dipole}}/P_{\text{isotropic}} = G = kD,$$

with $D\lambda/2$ dipole = 1.64, and

$$k = R_r/(R_r + R_l)$$

where:

R_r = the radiation resistance,

R_l = the ohmic loss in the antenna,

k = the antenna efficiency factor, and

D = the directivity of the antenna.

Assuming that $k = 1$, the dipole has negligible ohmic loss, and the maximum antenna gain for a half-wave dipole antenna can be calculated from:

$$G = (1)(1.64) = 1.64 = 2.15 \text{ dB}$$

The equivalent power transmitted to the same point, P_p , from a half-wave dipole antenna is then:

$$P_p = 1.64(0.795) = 1.30 \text{ mW/m}^2 = +1.14 \text{ dBm}$$

A typical mobile telephone uses a dipole-antenna configuration to transmit RF signals, with the antenna as one pole and the body of the mobile telephone as the other pole. The impedance (radiation resistance, R_r) of the antenna facing free space is ideally matched by a matching network, in order to optimize power transmission from the mobile unit's source. In order to evaluate a mobile station under test (MSUT), a connection must be made to the RF path, either through the antenna (over-the-air coupling) or through a galvanic connection. A galvanic connection has a characteristic impedance of 50 Ω , which is interfaced to standard test equipment through 50- Ω RF cables. The RF characterization through the galvanic connection differs from the real-world use of the mobile transmission through an antenna, which radiates into free space.

Free space has a characteristic impedance of 377 Ω . In order to design a mobile telephone that transmits optimum power into free space, the RF path must contain a matching network to produce an equivalent input impedance as close to R_r (76 Ω for a half-wave dipole) as possible. Under ideal conditions, this is the case. But in the real world, a mobile unit's matching network is not designed around producing an impedance match of R_r . This is because the equivalent impedance of the mobile unit in a real-world environment can change unpredictably by placing reactive or resistive loads near the body of the telephone. A load can be a human hand or head, a

car kit, or any other material that has dielectric characteristics that are different from those of free space. By having unpredictable changes in the mobile unit's equivalent impedance, mismatch in the mobile unit to RF path transition is inevitable. This mismatch will produce inefficiencies in the overall power transferred into free space, as well as power that is incident onto the antenna from free-space radiation. These effects will be predominant when testing through the antenna compared to testing at the RF connector.

This may be evident even in a precisely controlled testing environment where over-the-air testing may be a preferred method of creating an interface to the RF signal. In most mobile-telephone test environments, the mobile unit is placed within an anechoic environment that contains an RF-absorbent material that is used to reduce reflections, which are the cause of high standing-wave ratios (SWRs) within the anechoic chamber. These standing waves add in phase (constructively) and out of phase (destructively), producing inaccuracies in the observed and measured power into and out of the mobile telephone. An anechoic chamber environment can approach the conditions exhibited by free space if all power incident on the walls is absorbed. In addition, as cables, connectors, and other mounting fixtures are placed within the anechoic chamber, more variation in characteristic impedance from the original optimum impedance will be observed. Even though the mobile unit is designed to transmit and receive optimally in contact with a human operator (a large dielectric mass), test environments may not accurately represent the equivalent environment. These differences in environment will have an impact on the mobile unit's equivalent impedance, causing inaccurate RF test response and calibration factors.

As can be seen in Fig. 2, a typical mobile telephone's RF path is switched between the antenna and the galvanic connection. If testing is performed through the galvanic connection, the telephone will be tested and possibly calibrated to specifica-

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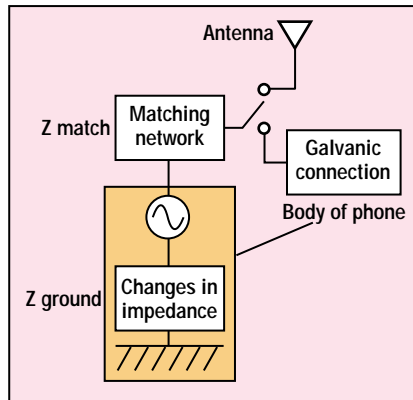
tions that will not be applicable or repeatable in the real-world use of the telephone. If the manufacturer is going to test the telephone through the galvanic connection, a characterized compensation value must be determined in order to translate the measured results into an equivalent value to represent how the mobile unit will respond through the antenna connector. The standards are not very clear on the definition of "antenna connector." It is possible to test the mobile unit through the galvanic connection and obtain desirable results. At the same time, however, the response through the antenna could be unsatisfactory from the service provider's or even the customer's point of view.

It is difficult to determine if a manufacturer's telephone design implements an optimized match through the RF antenna (real-world operation has been taken into account) or if it was optimized to perform best through the RF connector (manufacturing and calibration has been taken into account). The manufacturer may have designed the mobile's RF circuitry using three different methodologies:

1. The matching network was designed to provide optimum performance when tested through the galvanic connection. If this is the case, the calibration process must make appropriate adjustments to account for the actual response of the mobile through the antenna. Antenna gain and other galvanic-connection-to-antenna compensation factors must be taken into account.

2. The matching network was designed to provide optimum performance when operating through the antenna. This is the most desired method, but is difficult to test or verify performance of the mobile unit due to the factors previously described.

3. The matching network was designed to provide a compromise in performance between the antenna and the galvanic connection. Even if this method is used, and the mobile unit is tested and calibrated through the galvanic connection, compensations must be accounted for to ensure accurate performance through the antenna.



2. In testing a mobile telephone, the unit's RF path is typically switched between the antenna and the galvanic connection, which can generate misleading results compared to real-world use.

Many manufacturers find it easier to test to a standardized physical RF connection, due to the 50- Ω characteristic impedance of the antenna interface and the test equipment. For this reason, the minimum performance standards of mobile telephones have developed the test specifications around the galvanic connection.

The minimum performance standards for code-division-multiple-access (CDMA) mobile units (TIA/EIA-98-C specifications) require that most tests be performed through the antenna connector. Some of the tests, however, such as CDMA maximum transmit power, must fall within the bounds of an effective-IRP (EIRP) reference. In order to test "in the spirit of the standards," a correction factor must be applied to approach the true response at the point of the mobile unit's antenna. The standards, as well as many manufacturers, classify this as "antenna gain." Since the point of test is the galvanic connection, there are many factors that contribute to this overall correction factor that should be applied to the measurement result. Antenna gain is only one of these factors. To define this correction factor as antenna gain is not accurate. Antenna gain only accounts for the relation of the transmission/reception of the antenna to a particular point compared to a reference level at that same point.

A short dipole antenna will have antenna gain of no more than 2.15 dB, assuming zero ohmic loss in the antenna. In many cases, manufacturers have recommended antenna-gain compensations up to 3 dB. When considering the antenna-gain definition, if the dipole antenna is transmitting in all directions and is suffering losses, then a 3-dB gain-compensation value is highly improbable. The reason for the higher proposed antenna-gain values is because other compensation values may have been incorporated, such as:

- Galvanic-to-antenna coupling.
- Matching network mismatches between the galvanic connection and the antenna.
- Mobile calibration inconsistencies between the galvanic connection and the antenna.

In order to hold true to the definition of antenna gain, the compensation value that characterizes the difference between testing at the galvanic connection to the actual response at the antenna should be referred to as a term other than antenna gain. An appropriate term may be "galvanic-to-antenna-port compensation factor."

In summary, the term "antenna gain" is often misapplied by the high-frequency industry when used in reference to mobile-telephone manufacturing and testing. The goal of testing and calibrating an MSUT is to ensure that the telephone will operate to the satisfaction and expectations of the customers. If the telephone is tested through a galvanic connection, a compensation factor must be used to translate the measured results to that of an equivalent operation through the antenna. This compensation factor is not antenna gain, but could be more accurately called the "galvanic-to-antenna-port compensation factor." Antenna gain is still a useful parameter for producing accurate mobile-telephone measurements, but it must be additive depending on the type of test performed. ••

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