Wireless

A-GPS Antenna Performance: Over-the-Air Test Method

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With the rise in location-based services (LBS) applications and the need to meet E9-1-1 positioning requirements, the number of mobile cellular devices supporting Assisted GPS (A-GPS) is steadily growing. As a key enabling LBS technology, A-GPS offers customers higher position accuracy, quicker location fixes, and improved service coverage in difficult locations, such as urban and in-building environments. As a result, mobile operators and device manufactures are looking for testing choices that quantify and benchmark real-world A-GPS device performance.

Until recently, all industry-defined A-GPS test methodologies focused on testing the performance of a device over a cabled RF connection, bypassing the GPS antenna and associated circuitry. This approach does not give a complete picture of real-world device performance and its affect on end-user experience of LBS applications. To achieve this, testing must assess the performance of GPS antennas and other device factors that can only be determined with an over-the-air (OTA) test methodology (FIGURE 1).

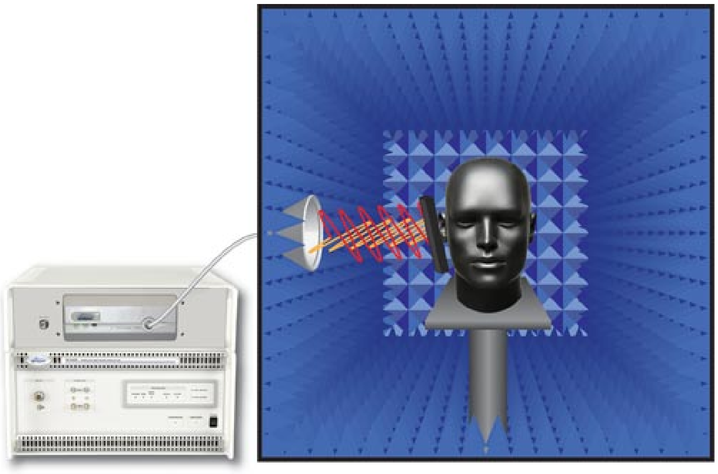

FIGURE 1. Over-the-air test methodology

The need for OTA performance testing of cellular and Wi-Fi wireless devices has long been a key requirement in the overall testing process. Over the years, standard OTA performance test plans have been created by organizations such as CTIA-The Wireless Association, 3GPP, and Wi-Fi Alliance. OTA testing is performed in a controlled radiated environment, called an anechoic chamber, using specialized equipment to provide a known signal to the device under test. A key aspect of this testing is that all signals are transmitted and received wirelessly, as they are in the real world. This ensures that all interaction factors between the radio and the rest of the wireless platform, including radiation pattern and platform interference, are taken into account when determining overall wireless performance.

More recently, industry organizations, including CTIA, have recognized the need to create standardized test procedures for A-GPS OTA testing to objectively specify and validate acceptable performance. A CTIA subgroup has completed a section on A-GPS OTA testing, incorporated in version 3.0 of the CTIA Test Plan for Mobile Station Over-the-Air Performance (hereafter referred to as the Test Plan). This article explains the general test methodology defined in this specification; it applies to Universal Mobile Telecommunications System (UMTS), Global System for Mobile Communications (GSM), and Code Division Multiple Access (CDMA) devices.

OTA Test Method

The goal of OTA testing is to obtain a snapshot of performance of the device under test (DUT) in all directions around it. For example, consider a requirement to compare the amount of light emitted from a lightbulb around the room in all directions. It is necessary to look at the lightbulb from all directions to measure and compare the results.

The radiated energy from or to the DUT is measured by placing a measurement antenna (MA) a fixed distance away from the device. Because the DUT can be randomly oriented with respect to the MA, a dual-polarized measurement antenna is used to measure two orthogonal polarizations, recording the total radiated energy irrespective of the relative orientation.

To cover all points on the surface of a sphere surrounding the device, it is necessary to be able to move the MA relative to the DUT in two orthogonal axes. This requires some form of spherical positioning system to move the MA and/or the DUT in spherical coordinates around theta (u) and phi (f) axes to achieve full spherical coverage.

FIGURE 2 illustrates a typical test system in which the DUT is rotated in two axes and which is capable of performing OTA testing for A-GPS.

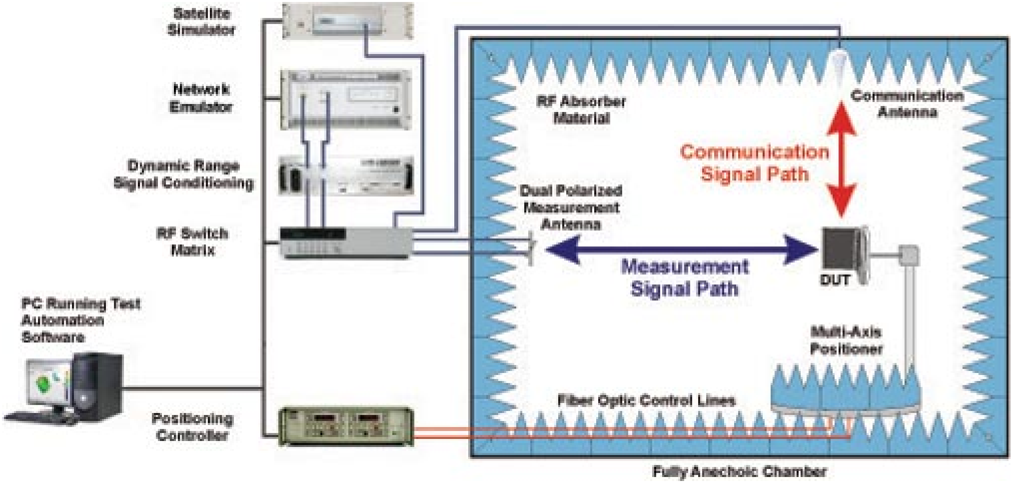

FIGURE 2. Typical test system (courtesy ETS-Lindgren)

Test Procedure and Interpretation of Results

Because the GPS radio is receive-only, the main interest is in evaluating receiver sensitivity from various directions around the device. The resulting effective isotropic sensitivity (EIS) pattern then determines the average radiated receiver sensitivity across the entire sphere around the device, referred to as total isotropic sensitivity (TIS), or across a portion of the sphere. In addition to determining the baseline radiated sensitivity of the GPS receiver, the effect of cellular communication on the GPS receiver is evaluated to ensure that the GPS receiver performance is not degraded due to interference from the mobile phone transmitter.

Test procedure consists of five steps:

- antenna pattern
- linearization
- radiated sensitivity
- TIS, upper hemisphere isotropic sensitivity (UHIS), and partial isotropic GPS sensitivity (PIGS) calculation
- intermediate channel degradation.

In addition to understanding the test method for A-GPS OTA, it is important to understand the significance of each measurement and how it is used to quantify the A-GPS performance of devices. This allows device manufacturers to create better-performing devices and helps network operators ensure that devices launched on their network will perform well.

Antenna Pattern

The first part of the Test Plan calls for measurement of the GPS antenna pattern. An antenna pattern can be represented visually to identify the wireless device's ability to effectively receive signals from different directions. Imagine the antenna at the center of the shape in FIGURE 3; the areas with large peaks signify the directions from which the antenna receives signals most effectively.

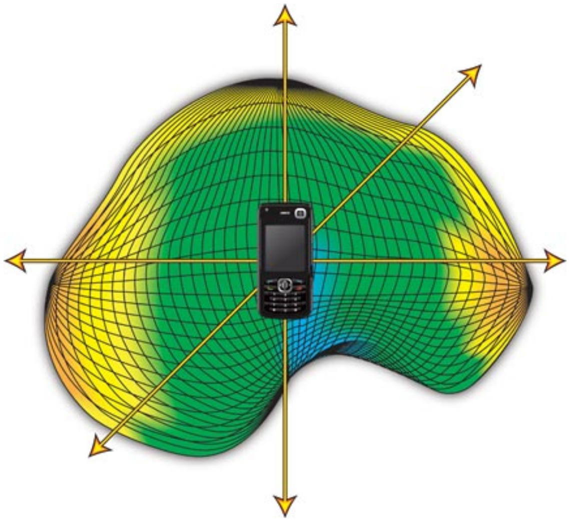

FIGURE 3. Directions with large peaks signify most effective signal reception

Antenna pattern measurement is important in quantifying the true performance of GPS antennas in mobile devices. As devices become smaller, more powerful, and less costly, trade-offs between size, cost, and performance become more difficult. This is also true for the GPS antennas now embedded in nearly all high-end mobile devices and an increasing number of mid-range and low-end devices. For these devices to deliver a good user experience of LBS, the GPS antenna pattern should be compromised as little as possible.

A device's antenna pattern can be affected by a number of factors including, but not limited to:

- GPS antenna design
- device form factor
- GPS antenna location in the device
- presence of a human head or hand near the device.

FIGURE 4 illustrates the effect of a human head on a GPS antenna pattern. Note the large valley at the location of the head.

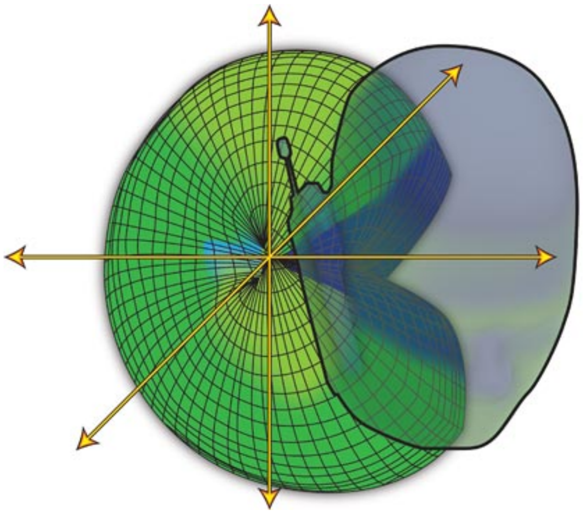

FIGURE 4. Effect of human head on GPS antenna pattern

For A-GPS OTA testing, the antenna pattern is established by radiating a known GPS signal-power level and obtaining full spherical coverage around the device. By keeping track of the GPS power levels that the DUT measures, it is possible to plot how well the device receives GPS signals at different angles of arrival.

For A-GPS, the metric used to characterize the antenna pattern is the carrier-to-noise ratio (C/N_0) of the GPS signal. For the CTIA-defined tests, 60 discrete positions are required for full spherical coverage. Measurements are made in two axes:five angles in the theta (θ) axis and 12 in the phi (φ) axis.

Additionally, two orthogonal antenna polarizations (for example, parallel to the theta (θ) and phi (φ) directions of motion) must be measured to determine the total power received at each point, for a total of 120 measurements (see FIGURE 5).

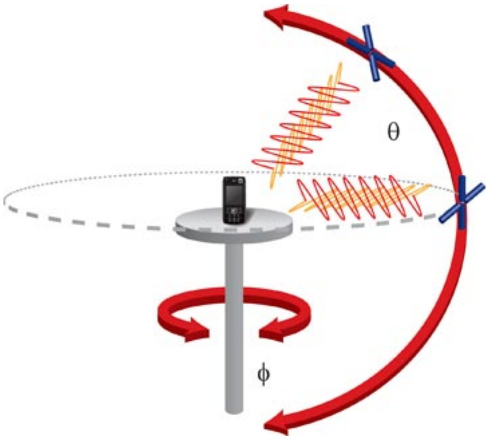

FIGURE 5. Measurement of two orthogonal polarizations determine total power received

Eight GPS satellites are simulated during the antenna pattern measurement. The C/N_0 ratio is measured by the device under test for each individual satellite, and the average C/N_0 is used as the metric for each discrete antenna pattern measurement.

Linearization

The antenna pattern produced in this manner relies on the DUT to perform measurements on the received GPS signals. However, the DUT is not a measurement device with a traceable calibration. To provide that traceability, the pattern measured by the DUT needs to be corrected to eliminate any non-linearities introduced by the DUT. By mapping the average or median C/N_0 report from the DUT back to a range of signal levels generated by the calibrated signal source (that is, GPS satellite simulator), a set of corrections for the pattern data can be obtained, essentially transferring the calibration traceability of the signal generator to the DUT. This linearization process results in much more accurate antenna pattern data once this correction is applied.

The linearization curve can be treated as a function of the output power of the GPS satellite simulator, such that the measured C/N0 or received signal strength (RSS) is given by:

$RSS_i = RSS(P_{SGi})$

Assuming that the RSS data is monotonic, an inverse function can be defined such that

$RSS_i = RSS(RSS^*(RSS_i))$

so that

$P_{SGi} = RSS^*(RSS_i)$

Once all of the measured RSS values in the pattern have been linearized, the pattern should be normalized by dividing each pattern value by the peak value in linear power units (equivalent to subtracting the peak from the pattern in dB). The entire process can be represented by the following equation:

$P(\theta,\varphi,Polarization) = RSS^*(RSS(\theta,\varphi,Polarization))/RSS^*(RSS_{Peak})$

where RSS_{Peak} is the maximum RSS determined in the pattern. The result is a relative pattern with a peak value of 1.0 (0 dB) for any polarization.

Radiated Sensitivity

Another important test step is to measure the radiated sensitivity, or EIS, of the device.

Average GPS signal levels in clear sky conditions are very low, typically –130 dBm, which are much lower than cellular signal levels. Therefore, it is important for a GPS-enabled mobile device to be able to receive in a low-signal environment. A device’s GPS sensitivity reflects, to a great extent, the ability of its antenna to receive low-powered signals.

The GPS performance of mobile devices is closely correlated with the user experience of location-based applications. When using devices indoors, or in areas where the sky is obstructed by trees or other obstacles, the already-low GPS signal levels are further attenuated. As a result, devices with good GPS sensitivity work in many situations where others with poorer sensitivity do not. Some devices on the market today can operate with GPS signal levels below –150 dBm.

Radiated sensitivity is measured by lowering the GPS signals until the DUT is unable to meet the specified performance requirements. The test is performed at the device orientation and MA polarization that resulted in the highest C/N0 measurement in the upper hemisphere. The satellite scenario and performance metrics used for the test are in accordance with the industry standards for the respective wireless standard in use (3GPP TS 34.171 for UMTS, 3GPP TS 51.010-1 for GSM, or TIA-916 for CDMA); with the exception that the actual sensitivity level is found, as opposed to determining pass/fail at a particular signal level.

Once the EIS has been determined at this one point, the remaining EIS points are estimated from the one measured EIS value and the linearized and normalized pattern data, rather than measuring each EIS point individually.

The resultant estimated EIS pattern is then given by:

$EIS(\theta,\varphi,Polarization) = EIS_{ref} / P(\theta,\varphi,Polarization)$

where all terms are in linear power units.

TIS, UHIS, PIGS Calculation

Once the complete EIS pattern is determined, the TIS, UHIS, and PIGS — all of which are isotropic sensitivity measurements — can be calculated.

As discussed previously, TIS is a metric that represents the average sensitivity of a device in a radiated environment (FIGURE 6). It represents the lowest signal level that the device would be able to operate with if it was radiated with equal power level from all directions. TIS is convenient because it is a single metric that represents the overall radiated sensitivity performance of the device, making it easy to benchmark devices against each other. For TIS, the entire spherical antenna pattern is used.

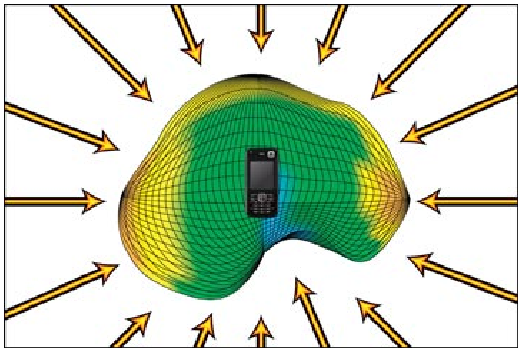

FIGURE 6. Total isotropic sensitivity (TIS)

The average power received by an antenna in a scattered environment when a right-hand spherical coordinate system is utilized can be represented as:

where:

$$TIS = \frac{4\pi}{\oint \left[\frac{1}{EIS_{\theta}(\theta,\phi)} + \frac{1}{EIS_{\phi}(\theta,\phi)} \right] \sin(\theta)\, d\theta\, d\phi}$$

$EIS_{\theta}(\theta,\varphi)$ = Power available from an ideal isotropic, theta-polarized antenna generated by the theta-polarized plane wave incident from direction (θ,φ) which, when incident on the EUT, yields the threshold of sensitivity performance.

$EIS_{\varphi}(\theta,\varphi)$ = Power available from an ideal isotropic, phi-polarized antenna generated by a phi-polarized plane wave incident from direction (θ,φ) which, when incident on the EUT, yields the threshold of sensitivity performance.

If data are available at uniform angular intervals in theta and phi such that:

N = number of angular intervals in the nominal theta range from 0 to π

M = number of angular intervals in the nominal phi range from 0 to 2π

i = index for each theta sample, i ranges from 0 to N

j = index for each phi sample, j ranges from 0 to M ,

we can approximate the TIS integral using the trapezoidal rule on the theta and phi integrals. The resultant TIS summation can be shown as:

$$TIS \cong \frac{2NM}{\pi \sum_{i=1}^{N-1} \sum_{j=0}^{M-1} \left[\frac{1}{EIS_{\theta}(\theta_i,\phi_j)} + \frac{1}{EIS_{\phi}(\theta_i,\phi_j)} \right] \sin(\theta_i)}$$

UHIS is similar in concept to TIS but represents the average radiated sensitivity performance of a device above the device’s horizon (FIGURE 7). UHIS is calculated by the partial summation of the EIS pattern over the upper hemisphere from theta (θ) = 0 to 90 degrees.

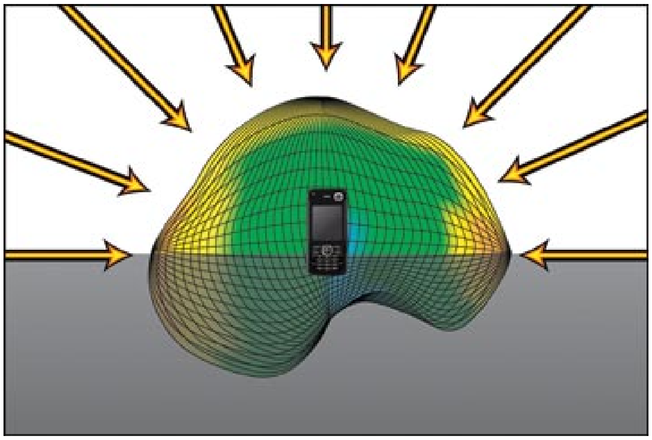

FIGURE 7. Upper hemisphere isotropic sensitivity (UHIS)

$$UHIS \cong \frac{2NM}{\pi\left(\sum_{i=1}^{\frac{N}{2}-1} cut_i + \frac{1}{2} cut_{\frac{N}{2}}\right)}$$

where

$$cut_i = \sum_{j=0}^{M-1}\left[\frac{1}{EIS_\theta(\theta_i,\phi_j)} + \frac{1}{EIS_\phi(\theta_i,\phi_j)}\right]\sin(\theta_i)$$

represents the weighted sum of each conical cut.

Similarly, PIGS is calculated using antenna pattern data from the upper hemisphere as well as 30 degrees below the horizon (FIGURE 8).

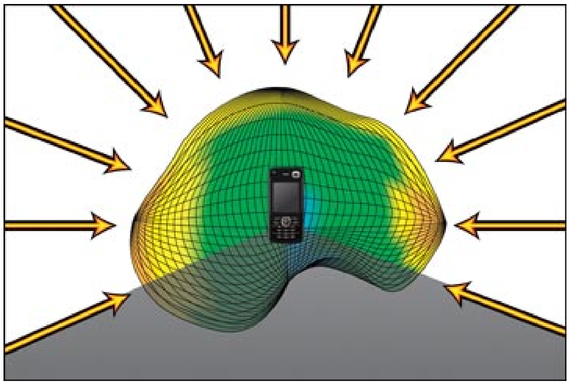

FIGURE 8. Partial isotropic GPS sensitivity (PIGS)

PIGS is an important metric because devices often receive signals reflected off the ground; for example, while standing indoors next to a window. Another advantage of using PIGS is the fact that the device will not be held in a completely vertical orientation with respect to the ground, so it can be considered to account for some range of variation around the vertical orientation.

$$PIGS \cong \frac{2NM}{\pi\left(\sum_{i=1}^{\frac{N}{2}} cut_i + \frac{1}{2} cut_{\frac{N}{2}+1}\right)}$$

where

$$cut_i = \sum_{j=0}^{M-1}\left[\frac{1}{EIS_\theta(\theta_i,\phi_j)} + \frac{1}{EIS_\phi(\theta_i,\phi_j)}\right]\sin(\theta_i)$$

represents the weighted sum of each conical cut.

Channel Degradation

In addition to measuring the EIS pattern to determine TIS and other related metrics, an intermediate channel degradation (ICD) test is performed for each band supported by the mobile device.

A-GPS performance may be affected by the device's active cellular connection, due to the cellular subsystems interfering with the GPS receiver. As a result, GPS performance can degrade due to self-jamming when different cellular channels are used. These effects can only be measured effectively using OTA testing, since the interfering cellular signal does not reach the GPS receiver in a conducted test.

ICD is an important measurement, because user experience can be severely affected when GPS performance degrades due to the use of cellular frequencies that may be specific to a given network. Even if a device is targeted for one network operator market and its associated frequencies, users may roam to other networks while traveling.

The ICD procedure tests the A-GPS performance across a variety of wireless operating channels (hereafter referred to as intermediate channels). To test this, a C/N_0 measurement is performed at the mid-channel frequency in a particular wireless operating band at the same pattern peak used for the GPS sensitivity measurement. The same C/N_0 measurements are repeated at various intermediate channels for that particular operating band.

The final ICD measurement is defined as the difference between the C/N_0 measurement at the mid-channel and the lowest C/N_0 at any intermediate channel (including the mid-channel). Therefore, the GPS intermediate channel degradation is always zero or greater. The ICD measurement is performed for each operating band that the device supports.

Typical Equipment and Setup

To avoid unwanted interference from outside signal sources, and to prevent interference with other communication systems, the DUT and MA must be shielded from the outside world. This is done by placing them inside an RF-shielded room. However, while the shield reflects external energy away from the DUT, it also reflects energy radiated from the DUT back towards the MA and vice-versa, which can result in the energy being measured more than once. This duplication occurs because the energy can be measured not only directly from the DUT, but also after it reflects off the walls of the room. To prevent this, the room must be lined with RF-absorbing material to reduce unwanted reflections. This produces a fully anechoic chamber where all of the walls, the floor, and the ceiling are lined with RF absorber.

Outside the chamber, the measurement antenna must be connected to test instrumentation to measure the power radiated from the DUT, or to transmit signals at a known level to the DUT to determine its receiver sensitivity. To determine the GPS receiver sensitivity of the DUT, a GPS satellite simulator provides the known downlink signal. A network emulator (NE) capable of supporting Wideband Code Division Multiple Access (WCDMA), GSM, and/or CDMA air interfaces in all frequency bands of interest provides the cellular signal.

Depending on what test instrument must be connected to the MA, it is often not practical to maintain the communication link to the DUT through the MA. Thus, a separate communication antenna typically provides a dedicated communication path between the NE and DUT. This can provide a low-loss uplink path when the MA is used for downlink-only tests. It can also provide bi-directional communication signaling when the MA is connected to a signal analyzer for power measurement.

Finally, a PC running test automation software is used to control the positioning system and capture the desired measurements from all orientations around the DUT.

Conclusion

The arrival of standardized A-GPS OTA testing is a significant event for the wireless industry. Industry bodies clearly recognize the need to test A-GPS OTA performance in the manner described in this article and are in the process of making this a mandatory test procedure. Companies that best understand how to make and interpret these measurements have an advantage in selling LBS or the platforms that deliver them. Ultimately, A-GPS OTA testing helps to assure the consumer of a superior end-user experience of location-based applications.

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