An introduction to Mobile Station Over-the-Air measurements

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ABSTRACT

Active antenna measurements are familiar to traditional antenna test range operators. Pulsed, multi-beam, multi-frequency, phased-array measurements have become quite popular for military and space-based applications. These combine typical antenna patterns with active RF excitation in order to create a system-like capability. A new type of measurements called Mobile Station Over-the-Air (OTA) Measurements is emerging, which attempts to include even more of the communication system (antenna, amplifier, receiver and electronics) in the measurement. Promoted by CTIA (Cellular Telecommunications & Internet Association), OTA measurements attempt to test system components closer to the environment in which they will be used. RF excitation is no longer just an RF source in pulsed or CW modes, but requires a Base Station Simulator (BSS) with protocols such as GSM, CDMA, Bluetooth, 802.11g, etc. Traditional antenna patterns are less important than the newly required measurements of TRP (Total radiated power) and TIS (Total isotropic sensitivity). Range operators must become familiar with these concepts in order to keep up with the ever-changing requirements of the future. This paper provides the reader with an overview of Mobile Station OTA measurements, techniques and sample data.

Keywords: CTIA, Mobile Station, cell phone, TRP, TIS, Base station simulator, GSM, CDMA

1 Introduction

The explosion of low-cost personal communication devices on the market such as cell phones, PDAs, laptops and other wireless devices has greatly benefited consumers when the devices work properly. In the U.S., most cell phones are purchased through service providers. These providers may co-brand their phones with their name and the actual manufacturer of the phone model (e.g., Sprint-Motorola, Sony Ericsson-ATT, etc.). In addition, many components of the phone may not be produced or assembled by the actual cell phone manufacturer. As can be seen, many different entities are involved in the end-product; however, when the phone does not work, it is the service provider who bears the full brunt of the complaints. If this is a new phone, the provider will often replace the phone with another of similar look, feel, and feature, telling the subscriber to go about his way and contact them again if he has any problems. This customer service is crucial to maintaining subscribers and gaining new ones, but it is very costly.

In order to reduce costs, service providers put pressure on cell phone manufacturers to return devices which may or may not be faulty, leaving the manufacturer to determine the problem. Compound these "connection" problems with other built-in phone features like: cameras, mp3 players, FM radios, Bluetooth, IRDA, WiFi, etc., and it is obvious that what was once a feature that would attract new subscribers is now a support nightmare for the telecom service provider.

In an attempt to reduce connection problems and insure that cell phones meet a minimum connection performance, many manufacturers are adopting a system testing and certification process promoted by the CTIA (Cellular Telecommunications & Internet Association). The CTIA seeks to encourage system-level (Over-the-air) tests which will give the consumer a better tested product.

As the growth in personal communication devices continues, certification programs like that of CTIA will become increasingly more popular and may be required for manufactures of wireless devices and components. Testing the complete system (the transmitter, receiver, and antenna) under controlled operating conditions is the goal.

The basic CTIA tests include: measurements of radiated power and sensitivity. This paper briefly describes these tests, and the test equipment and conditions required to perform them. In addition, several new concepts will be introduced that are not as familiar to classical antenna range operators.

2 Cell phone system tests

Cell phones operate in environments which are difficult to simulate. When different cell phones are tested for radiated power and sensitivity under similar conditions, their relative performance can be assessed. By simulating these "Over-the-air" (OTA) conditions during the cell-phone design stage, a phone's manufacturer will be confident that the production phase yields phones that work well in the "real world." Though not yet part of the CTIA specification, 100% production testing schemes are being considered for a subset of these conditions.

CTIA testing seeks to simulate the following conditions:

- Connection to a Base Station Simulator (BSS) using the appropriate connection protocols (GSM, CDMA, TDMA, etc.).
- Interaction between the transmitter, receiver, and antenna.
- Performance vs. angle between phone and cell tower.
- Performance in the presence of a head.
- Performance vs. antenna condition (integrated, extended, retracted).

Each test is made in a shielded anechoic chamber which creates an "interference-free and reflection-free" environment.

Figure 2-1 shows a block diagram of a typical OTA test setup. The basic components are:

Base station simulator (BSS) - Simulates the cell tower connection to the phone's transmitter, receiver and antenna.

Probe - Sends BSS signals to the phone and receives them from the phone.

Positioning system - Controls the angle between cell phone and BSS probe. This simulates the angle between the phone and the cell tower and allows measurements to be made over a range of spherical angles. CTIA specifies a grid of angles to be tested. These are shown in Table 2-1 and Table 2-2.

Simulated head – Simulates the presence of the user's head.

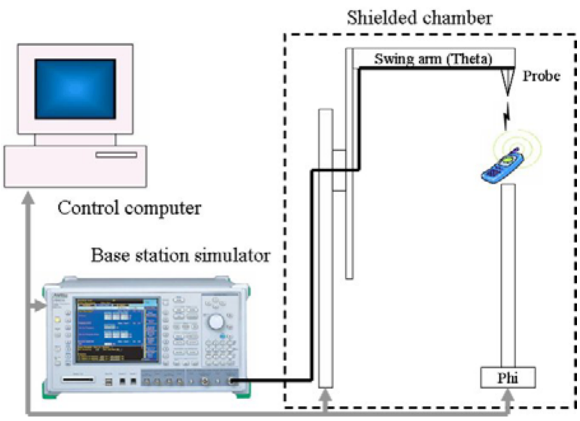

Figure 2-1 OTA test setup block diagram

Table 2-1 Radiated power grid angles

	Theta	Phi
Start	15°	0°
Delta	15°	15°
Number points	11	24
Range	15°-165° (every 15°)	0° - 345° (every 15°)

Table 2-2 Sensitivity grid angles

	Theta	Phi
Start	30°	0°
Delta	30°	30°
Number points	5	12
Range	30°-150° (every 30°)	0° - 330° (every 30°)

3 Range setup

Figure 3-1 shows the block diagram for the test setup. The motion controller consists of NSI's 700S-90 overhead swing arm. This type of system is a very good choice for OTA measurements because the device lies flat on the surface and thus its center of gravity does not change vertically during the scan. This is important because even though cell-phones are relatively lightweight, other wireless devices such as laptops and LCD monitors may not be. In addition, NSI's 700S-90 is a good choice because it has the capability to make Spherical near-field and far-field measurements. Figure 3-2 shows the 700S-90 installed on a range currently under going CTIA certification.

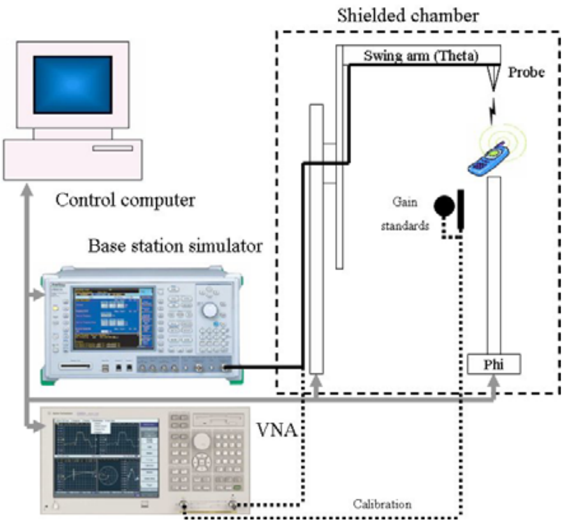

Figure 3-1 OTA Test setup block diagram

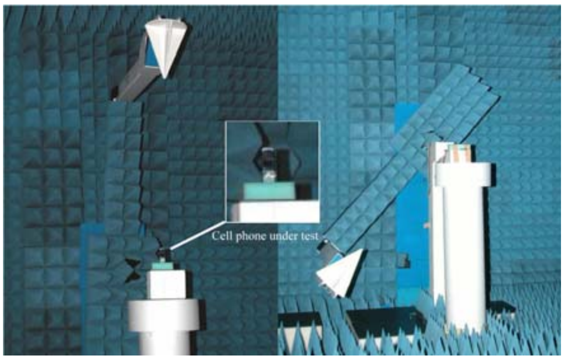

Figure 3-2 NSI 700S-90 Scanning system

4 Calibration

An important part of any test system is calibration. In this test system, calibration is necessary so that output power levels and power measurements made by the BSS, account for the path losses through the cables and probe, and space loss between the probe and cell phone.

Calibration is done using a set of standard gain antennas (low-gain, H and V-pol antennas) and a VNA. However, the VNA can be replaced with the BSS, if necessary (with reduced accuracy). Both polarization paths must be calibrated. In order to reduce the antenna's positional dependence in the range, low-gain H and V-pol standards must be used. Figure 4-1 shows two calibration standards. The one on the left is a Resonant Loop and the one on the right is a Sleeve Dipole. Because the gain standards are not very broadband, the calibration requires two sets of probes for improved accuracy to cover the cell phone operating bands (approximately 800-950 MHz and 1700-2000 MHz) The Calibration procedure involves:

1) Connecting a known gain standard and cable to the calibrated output of a power source.
2) Measuring the signal received through all cables in the system (complete path loss, including space loss).
3) Subtracting the gain cable loss from the measurement.
4) Computing the difference between the measured signal (EIRP) and that expected (Gain + Pin). The difference is the calibrated path loss.

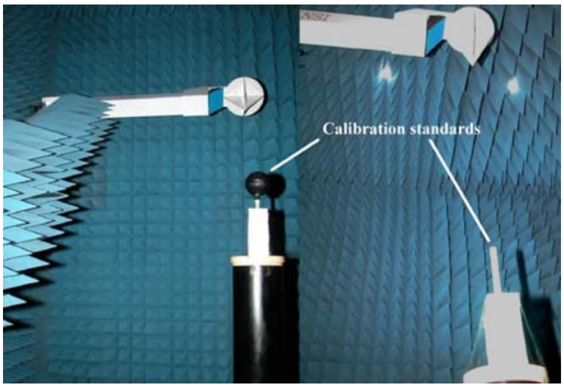

Figure 4-1 Calibration measurements

5 Radiated power

Radiated power measurements seek to determine the cell phone's ability to transmit power at various angles and polarization. The basic process is the following:

- Select the appropriate protocol and start a phone call with the BSS.
- Rotate the phone to various angles and make power measurements.

- Repeat at all angles (every 15 degrees) and two polarizations. Please see Table 2-1.

Figure 5-1 shows the 3D view of Radiated power measurements on a cell-phone. The plot is useful for analyzing the spherical data directly. It can be rotated in real time to view variations in the pattern. In this case the measurements were done in free-space (no simulated head) and indicate that, as designed, the cell-phone's antenna pattern attempts to reduce radiation in the direction of the user's head. Figure 5-2 shows a series of Phi-cuts at each Theta angle. In each figure the power includes the effects of both polarizations.

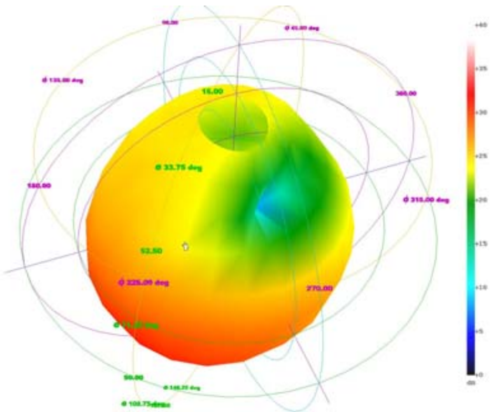

Figure 5-1 Radiation pattern – 3D view

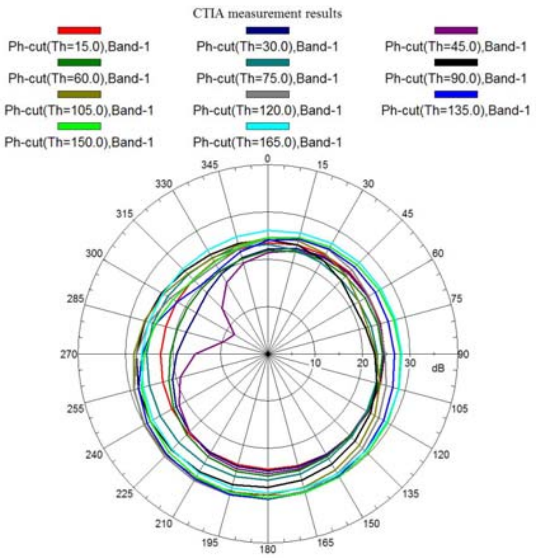

Figure 5-2 Radiation pattern – Multi-phi

In order to include some pattern information into a simple number, a figure of merit called TRP (Total radiated power) is calculated. This is the Radiated power integrated over the complete sphere. It is the complete (total) power radiated by the cell phone. In order to indicate how much power is radiated along the horizon, NHPRP45 and NHPRP30 are calculated. The Near-Horizon Partial Radiated Power figures of merit are calculated by integrating the power over a section of space near the horizon +/-45 deg. and +/-30 deg. from the horizon, respectively. Their formulas are shown below.

TRP (Total radiated power): Power measurements integrated over the complete sphere.

$$TRP = \frac{1}{4\pi}\int_{\theta=0}^{\pi}\int_{\phi=0}^{2\pi}(EiRP_{\theta}(\theta,\phi)+EiRP_{\phi}(\theta,\phi))\sin(\theta)d\theta d\phi$$

NHPRP45 (Near-Horizon Partial Radiated Power over +/- 45 deg near horizon): Power measurements integrated from theta = 45 to 135, over all phi angles.

$$\text{NHPRP45} = \frac{1}{4\pi}\int_{\theta\pi/4}^{3\pi/4}\int_{\phi=0}^{2\pi}(EiRP_{\theta}(\theta,\phi)+EiRP_{\phi}(\theta,\phi))\sin(\theta)d\theta d\phi$$

NHPRP30 (Near-Horizon Partial Radiated Power over +/- 30 deg near horizon): Power measurements integrated from theta = 60 to 120, over all phi angles.

$$\text{NHPRP30} = \frac{1}{4\pi}\int_{\theta\pi/3}^{2\pi/3}\int_{\phi=0}^{2\pi}(EiRP_{\theta}(\theta,\phi)+EiRP_{\phi}(\theta,\phi))\sin(\theta)d\theta d\phi$$

These three figures of merit indicate how well the cell phone can transmit power over typical angles (near the horizon) made with the cell tower. Unfortunately, they do not indicate how evenly distributed the radiated power is over angle. Since it is preferable that cell phones need not be oriented in a particular direction to make the connection, the radiated power pattern is also important. Table 5-1 shows the Radiation pattern figures of merit for the pattern of Figure 5-1.

Table 5-1 Radiated power performance

TRP	+26.0 dBm
NHPRP45	+24.5 dBm
NHPRP30	+23.0 dBm

6 Sensitivity

Sensitivity measurements seek to determine the cell phone's ability to receive low signals. Making these measurements is an iterative process which varies the BSS output power at the phone while measuring the Bit-Error-Rate (BER). When a target BER is achieved, the iteration is stopped and the output power at the phone is recorded as the sensitivity (i.e., the minimum power required to maintain a specified BER). To do this, the BSS is placed in Loop-back mode. In Loop-back mode the BSS transmits a bit pattern to the phone and the phone transmits it back. The returned bit pattern is then compared and the BER is determined. As the output power from the BSS to the phone is reduced, the BER increases.

The basic process is the following:

- Start a phone call with the BSS and place it in Loop back mode.
- Rotate the phone to an angle, set the output power level of the BSS, measure the BER.
- Raise or lower the BSS output power until the Bit error rate equals the target bit error rate (2.44% for GSM).
- Repeat at all angles and polarizations (every 30 degrees).

Figure 6-1 is a 3D view of sensitivity measurements on a cell-phone. Note that the sign of the Sensitivity data has been inverted. Figure 6-2 shows a series of Phi-cuts at each Theta angle. In each figure the power includes the effects of both polarizations.

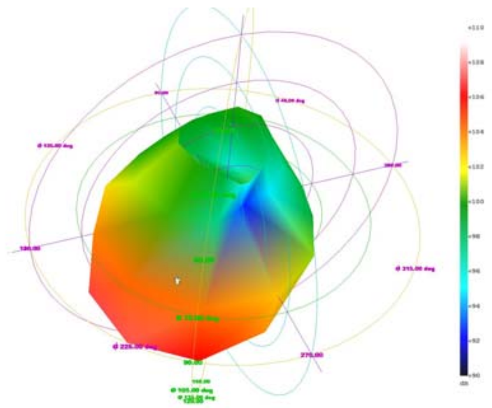

Figure 6-1 Sensitivity pattern – 3D view

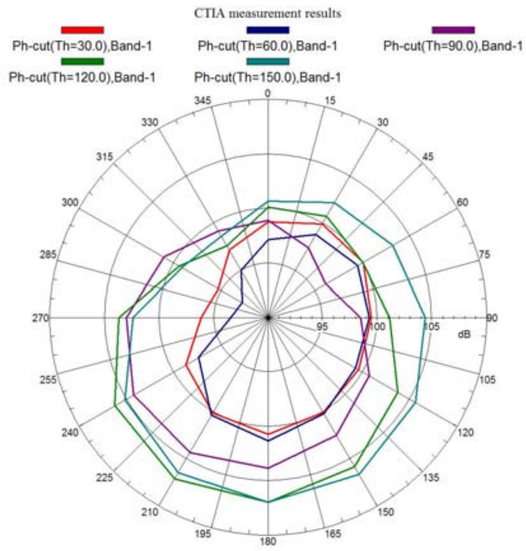

Figure 6-2 Sensitivity pattern – Multi-phi

There are two sensitivity figures of merit that are important for CTIA measurements. They are TIS (Total Isotropic Sensitivity) and NHPIS (Near-Horizon Partial Isotropic Sensitivity). Their formulas are shown below.

TIS (Total isotropic sensitivity): Sensitivity measurements integrated over the complete sphere.

$$TIS = \frac{4\pi}{\int_{\theta=0}^{\pi}\int_{\phi=0}^{2\pi}\left[\frac{1}{EIS_{\theta}(\theta,\phi)} + \frac{1}{EIS_{\phi}(\theta,\phi)}\right]\sin(\theta)\,d\theta\,d\phi}$$

NHPIS30 (Near-Horizon Partial Isotropic Sensitivity over +/- 30 deg near horizon): Sensitivity measurements integrated from theta = 60 to 120, over all phi angles.

$$\text{NHPIS30} = \frac{4\pi}{\int_{\theta=\pi/3}^{2\pi/3}\int_{\phi=0}^{2\pi}\left[\frac{1}{EIS_{\theta}(\theta,\phi)} + \frac{1}{EIS_{\phi}(\theta,\phi)}\right]\sin(\theta)\,d\theta\,d\phi}$$

These two figures of merit indicate how well the cell phone can receive power. Unfortunately, they do not indicate how evenly distributed the receiver's sensitivity is over angle. Table 6-1 shows the Sensitivity figures of merit for the pattern of Figure 6-1.

Table 6-1 Sensitivity performance

TIS	-101.8 dBm
NHPIS30	-98.6 dBm

7 Results/Summary

This paper presented the need to perform system-level, over-the-air (OTA) mobile-station measurements in order to lend confidence to cell phone service providers and suppliers of cell phone components and products. One accepted standard for these tests is being promoted by CTIA. This standard requires measurement of radiated power and sensitivity during normal operation of the device in a controlled environment. OTA measurements are more than just antenna or amplifier measurements; they include the complete RF and processing system. They require an RF simulator with appropriate protocols to communicate with real world devices. As wireless devices continue to proliferate, a wide variety of protocols will be generated and OTA measurements will become increasingly important.

8 References

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9. ACKNOWLEDGMENTS

The author would like to thank Ike Lin of WavePro Inc., Tao-Yuan, Taiwan for providing pictures, measurement data and encouragement for this paper.