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MIMO TIS/TRP active testing with second-generation mode-stirred chambers

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Abstract

With the first 4G trials scheduled for 2010 and the compulsory use of MIMO into both WiMAX and LTE standards, MIMO technology has finally exploded. Mobile Internet Peripherals and Devices are said to take a market share of 30% of all handsets and non-handsets wireless devices by 2013. In this complex scenario, antenna engineering has gained a tremendous importance. While the use of multiple antennas in the base station or access point (AP) is usually feasible, user terminals have size and weight restrictions that make the use of conventional antenna elements such as dipoles or patch antennas problematic. Thus, novel array topologies and antenna elements for multi-antenna systems are of great interest. But not only new geometries and designs are required, but also the antenna engineer is faced with a novel way to evaluate performance. While the parameters to characterize antennas in general are well defined and worldwide accepted, the way to evaluate the performance of an antenna array for MIMO is still an open issue, since multiple new concepts have to be considered, such as pattern diversity, correlation among elements, fading environment or polarization diversity, among others. Typical active parameters being currently tested for 2G and 3G systems are Total Radiated Power (TRP) and Total Isotropic Sensitivity (TIS). 4G systems are already envisioned to require more complex active testing due their inherently embedded MIMO technology. In this article, the way of using a second generation mode-stirred chamber (EMITE Ing E300 MIMO Analyzer) connected to a radiocommunications tester (Rohde & Schwarz CMU200) to characterize wireless devices by measuring TRP and TIS is described. Measurements have been performed for the UMTS system, but are simply extended to other systems. Since second-generation mode-stirred chambers can emulate a wide variety of Rayleigh, Rician, isotropic and non-isotropic scenarios, the procedure described in this paper opens the door for more advanced evaluation of active parameters for a variety of fading scenarios, which is unheard of in the wireless communications arena.

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1. Introduction

Wireless systems using Multiple-Input Multiple-Output (MIMO) signals are based upon the conversion of multipath propagation, initially considered to be a handicap, into the solution to their limited transmission capacities. This is done by parallel transmission channels enabled by simply using more antennas at the transmission and/or reception ends. Since there is an increasing demand for data transmission velocities, these MIMO systems have received a tremendous scientific attention in the last years. We can say it is the MIMO momentum at the scientific arena, and this is due to the initially predicted ergodic capacities, which could linearly increase as the number of antennas was increased. The result was an unheard-off prediction of spectral efficiencies, with its consequent potential impact in both the scientific and commercial senses. Yet, the incredibly large number of publications on the MIMO issue in the last few years has provided a better comprehension about MIMO systems, which have demonstrated to be much more complicated than initially predicted. In any case, the radio performance of the mobile phone depends on its antenna and it needs to be tested both during the design and the production phases. Active antenna measurements have indeed become quite popular for wireless applications. These combine typical antenna patterns with active RF excitation in order to create a system-like capability. The idea is to have measurements which include more of the communication system (antenna, amplifier, receiver and electronics) in the measurement. Initiated by CTIA (Cellular Telecommunications & Internet Association), Over The Air (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 Continuous Wave (CW) modes, but requires a Base Station Simulator (BSS) with wireless protocols such as GSM, CDMA, Bluetooth, HSDPA, 802.11g, etc. Conventional OTA testing allow for compliance testing of wireless devices due to the traceable nature of measurements. Hence, a comparison of devices under test (DUTs) tested in different systems to within a known level of measurement uncertainty is required, particularly for measuring power and sensitivity of the DUT as specified in several test standards. Typical single point metrics include Effective Isotropic Radiated Power (EIRP) and Effective Isotropic Sensitivity (EIS). Typical integrated (total) surface metrics include Total Radiated Power (TRP) and Total Isotropic Sensitivity (TIS). TIS and TRP metrics have become increasingly important for carriers, as they can quantify OTA performance with a single value. Verification is accomplished by performing an independent evaluation utilizing criteria defined by the wireless industry. In fact, traditional antenna patterns are less important than the newly required measurements of TRP and TIS for wireless communications systems. Since the TRP/TIS definition is based on the concept of a scalar communication channel, both do not account for the matrix nature of the MIMO channel and are so far insufficient as performance metrics for MIMO terminals [3]. Yet, being able to perform TRP/TIS measurements in more general MIMO test beds is a first step towards MIMO testing standardization. In this paper, the way of using a second generation mode-stirred chamber (EMITE Ing E300 MIMO Analyzer) connected to a radiocommunications tester (Rohde & Schwarz CMU200) to characterize wireless devices by measuring TRP and TIS is described. Measurements have been performed for the UMTS system, but are simply extended to other systems. Since second-generation mode-stirred chambers can emulate a wide variety of Rayleigh, Rician, isotropic and non-isotropic scenarios, the procedure described in this paper opens the door for more advanced evaluation of active parameters for a variety of fading scenarios, which is unheard of in the wireless communications arena. The alternatives to MSCs are the near-field magnetic scanner Lab Express by EMScan, which cannot perform measurements with a phantom, and the CTIA-approved anechoic chamber with the great circle cut spherical scanning method or the Satimo Stargate (SG) system with the conical cut spherical scanning method, both extremely expensive.

2. The Mode-Stirred Chamber

As an alternative to time-consuming channel measurements or 3-D radiation pattern measurements, a uniform multipath environment can be generated artificially in a mode-stirred chamber (MSC) and it can be used to evaluate antenna arrays for MIMO. In its first generation version, the mode-stirred chamber operates in a reverberating mode, and it was called reverberation chamber. A reverberation chamber is a controlled environment to optimally create a rich multipath environment. Multiple radio waves are transmitted, and by using several metal stirrers the electromagnetic waves are reflected and diffracted several times. Thus, the main principle is to create a multi-wave environment, as opposed to the operation of an anechoic chamber, based on receiving a single wave coming line-of-sight (LoS) from the transmitter and avoiding any reflection. A reverberation chamber provides a statistically repeatable environment for characterizing MIMO antennas, by measuring H matrices (MIMO channel) to compute the theoretical capacity. Since the antennas are measured in a controlled environment, it is straightforward to compare the performance of different antennas with this method. As compared with the ideal i.i.d. channel, the reverberation chamber measurement slightly overestimates the capacity results. This has to do with the inherent limitation of first-generation chambers to emulate only Rayleigh-fading scenarios with no preferred direction of arrival or departure of waves. In these chambers, the i.i.d. channel results represent an upper bound of theoretical capacity. First generation reverberation chambers have demonstrated their ability to accurately emulate multipath propagation typically found at urban scenarios, despite their inherent limitations. These compact cameras can validate simulations made for patterns of MIMO diversity or capacity, where all the signal arrival directions have the same probability. These inherent limitations of first-generation systems have been overcome with second-generation mode-stirred chambers. The second generation chambers, available by two vendors worldwide, allow for an operation in both reverberating and non-reverberating modes through the use of multiple multimode cavities coupled in diverse ways. Second-generation systems are therefore able to accurately emulate realistic fading scenarios, and with their inherent ability to measure antenna prototypes and effect, such as the presence of the user or efficiency, they represent the most accurate laboratory method to date. The MIMO Analyzer Series by EMITE Ing is a second-generation mode-stirred chamber. The MIMO Analyzer E300, depicted in figure 1, is a second generation reverberation chamber with dimensions of 0.82m x 1.425m x 1.95m, eight wall-mounted antennas, different DUT-holder stirring positions, polarization stirring due to the different orientation of the wall-mounted printed-antenna exciting elements, two mechanical stirrers with a large number of different positions for each platform position, 12 iris-coupling aperture stirring and variable frequency stirring. The use of a rotating platform is avoided by smart stirring and holder 3D position. The S-parameters are gathered between the measured port and the transmitting antennas for all variable positions and for all frequency points. The statistics of the measured S-parameters are equivalent to the statistics of the field components. This should be no surprise, since a measurement between two antennas is essentially a measurement of the transfer function of a given radio propagation environment. In our case, the measured S-parameters give the transfer function of the MSC and hence the environment statistics. The innate repeatability of measurements in MSCs is an excellent feature for MIMO measurements. Measured S-parameters between the transmitting antennas (Smn) and the MIMO array antennas (Snn) are first averaged over N stirred positions by,

$$\bar{S}_{mn} = \frac{1}{N}\sum_{stir} S_{mn} \qquad \text{and} \qquad \bar{S}_{nn} = \frac{1}{N}\sum_{stir} S_{nn} \tag{1}$$

At low frequencies it is also advantageous to perform stirring over a small frequency band. This is named frequency stirring, and it is performed to get more independent field samples representing a richer multipath environment. Changing the frequency changes the electrical size of the chamber, which has the effect of exciting different modes. Since some commercial systems like GSM use frequency hoping, this feature of MSCs emulates realistic environments. The processed S-parameters represent estimates of the channel matrix **H** of multipath communication channels set up between the transmitting antennas and the MIMO array inside the chamber ($\mathbf{h_{ij}}$). Since in a real scenario there will obviously be path losses which will vary from one location to another or from one type of scenario to another, channel normalization has to be considered. If an instantaneous normalization of the MIMO channel **H** is used, the effect of path loss and slow and shadow fading is removed from the channel matrix. With this assumption, the received power to transmit power ratio is calculated at each snapshot or time instant, averaged over all the Tx-Rx links. This is equivalent to use the Frobenius norm by,

$$H(n)_{norm} = \sqrt{N_T N_R}\frac{H(n)}{\|H(n)\|_{Frob}} = \sqrt{N_T N_R}\frac{H(n)}{\sqrt{\sum_{i=1}^{N_T}\sum_{j=1}^{N_R} h_{ij}h_{ji}^*}} \tag{2}$$

This method is equivalent to considering a fixed SNR at the receiver (averaged over all the receivers), which is the same as assuming a perfect transmitted power control for each user in the system, as well as unlimited power at the transmitter. It is clear that these assumptions can only be considered an ideal case, but from a system point of view and for algorithm testing purposes it is a widely accepted and used method to compute the system capacity. In this way, many different measured MIMO parameters can be provided. The MIMO Analyzer Graphic User Interface provides measurements of MIMO performance parameters (Correlation [ρ], Efficiency and the presence of the user [η], Diversity gain [ADG, EDG, IDG], Diversity gain loss [DGL], Mean effective gain [MEG], Effective MEG [EMEG], MIMO Capacity [C_{MIMO}], MIMO Capacity loss [CL_{MIMO}]); MIMO fading parameters (Rician-fading K-factor [K-factor], Eigenvalues [λ_i] and Number of multipath components [MPC]); MIMO physical parameters (Number of Scatters [NS], Power angular spectrum [PAS], Angle of Arrival [AoA] and Angular Spread [AS]). Through this research, MIMO active power parameters (Total radiated power [TRP] and Total isotropic sensitivity [TIS]) were also included in the MIMO Analyzer firmware.

Figure 1: The E300 MIMO Analyzer by EMITE Ing and CMU200 Universal Radio Communication Tester by Rohde & Schwarz.

3. Procedure to Measure TIS and TRP with MSCs

3.1. Calibration of the MSC

The main parameter to calibrate in a MSC is the average power transmission over a complete stirrer sequence. This will be determined by the amount of loss present in the chamber's main cavity and elsewhere, so it is of great importance to keep the same power-absorbing objects in the main cavity during the calibration measurement as when the measurement of the actual test unit is performed. For the calibration measurement, a reference antenna with known radiation efficiency must be used. Dipole antennas are convenient for this because of their predictable efficiency and low gain. For broadband measurements, antennas with higher bandwidth are preferred. The reference antenna must also be placed in the chamber in such a way that it is far enough from any walls, mode stirrers, chamber loading, or other object so that the environment for the reference antenna, taken over the complete stirring sequence, resembles a free space environment. The procedure can be performed in the following steps:

1. Make sure the MSC has been autocalibrated by a standard full two-port procedure from the VNA and to all output antennas, and not just up to the MSC output ports.

2. Place all objects that will be used in the test measurement inside the chamber's main cavity.

3. Place the reference antenna in the chamber's main cavity, keeping the distance from other objects as described before.

4. Connect the reference antenna measure the S parameters for each of the mode-stirrer positions defined in the stirrer sequence and for each of the 8 transmitting antennas.

5. Calculate the average power transfer function and antenna mismatch.

The mismatch correction due to the reference antenna R_{TRf} for N different stirred positions is defined by,

$$\bar{S}_{TRf} = \frac{1}{8N}\sum_{i=1}^{8}\sum_{n=1}^{N} S_{TiRf}(n) \qquad R_{TRf} = 1 - \|\bar{S}_{TRf}\|^2 \tag{3}$$

The transfer function HT represents the average net power transmission in the main cavity of the chamber once corrected for mismatch on both transmit antennas and antennas under test, as well as radiation efficiency of the reference antenna, given by,

$$HT = \frac{\frac{1}{8N}\sum_{i=1}^{8}\sum_{n=1}^{N} \|S_{TiRf}(n)\|^2}{R_{ref}} \frac{1}{\eta_{ref}} \tag{4}$$

For example, for a UMTS measurement at 2100 MHz, measured results using a calibrated half-wave dipole ($\eta_{ref} = 0.9$) provided a chamber gain [2] of -21.50 dB.

3.2. Measurement of Total Radiated Power

TRP is the total RF channel power radiated by a wireless terminal, and it is calculated by integrating the measured Effective Isotropic Radiated Power (EIRP) data over the measurement sphere. The total radiated power from a cellular phone depends on how much power is conducted from power input to the antenna, and how good the antenna is at transforming that to radiated power-in other words, the antenna's efficiency. Efficiency is greatly dependent on material that absorbs radiated power, and since the typical usage scenario of wireless devices requires the device to be held close to a human head, the efficiency number for antenna will be different in a position close to human tissue. This means that characterizing an antenna using efficiency typically requires free-space efficiency and an efficiency measured next to a standardized phantom head. A good example is a wireless carrier requiring a handset to meet a TRP of +22 dBm in the GSM850 band when the device is held next to a head. Since the nominal conducted power in GSM850 is +33 dBm, the antenna efficiency and the changes caused by the head are allowed to cause a degradation of 11 dB and still be able to meet the TRP number. This is what it can be measured with the MIMO Analyzer. The TRP measurement procedure for the E300 is similar to the radiation efficiency procedure described earlier.

The main difference is that the network analyzer is replaced by a base station simulator and power meter. The base station simulator is used to establish and maintain a connection to the UE and control its traffic channel and output power. The power meter is used to sample the transmitted power and could be a spectrum analyzer or a base station simulator with integrated power meter. Thanks to the agreement with Schmid and Partner Engineering AG (SPEAG), TRP measurements in the E300 MIMO Analyzer are performed in simulated-use position using the CTIA-approved SAM v4.5BS phantom. Figure 2 provides for a benchmarking of TRP measurements. The TRP measurements are performed in the following steps,

1. Make sure the MSC has been autocalibrated by a standard full two-port procedure from the VNA and to all output antennas, and not just up to the MSC output ports.
2. Place the DUT in the chamber. In the case of simulated-use testing, place the unit in the intended position relative to the SAM v4.5 phantom.
3. The E300 GUI will page the test unit, put it to radiate with maximum output power and control the traffic channels of interest.
4. The E300 GUI will drive the power meter to sample the transmitted power in each position of the mode stirrers.
5. The E300 GUI will calculate the TRP value by taking an average of all power samples and applying the calibration as

$$TRP = \frac{1}{8N} \sum_{i=1}^{8} \sum_{n=1}^{N} \frac{P_i(n)}{HT}$$

where $P_i(n)$ is the received power sample from transmitting antenna i and stirrer position n, and N is the total number of stirrer positions.

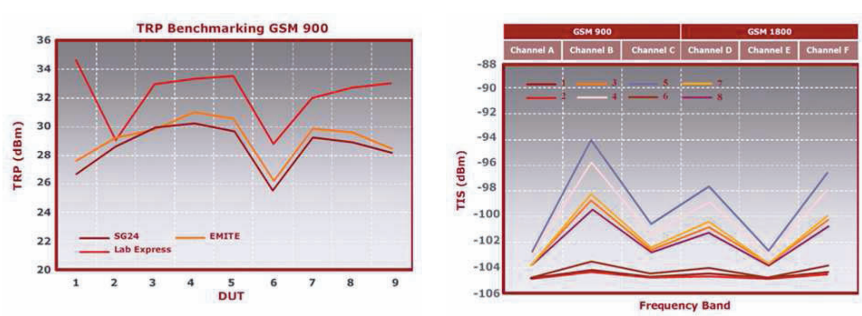

Figure 2: TRP (left) and TIS (right) benchmarking.

3.3. Measurement of Total Isotropic Sensitivity

Sensitivity measurements in wireless communications seek to determine the cell phone's ability to receive low signals. Making these measurements is an iterative process which varies the base station (BS) output power at the phone while measuring the Bit-Error-Rate (BER) or the Frame Erasure Rate (FER), depending on the system. When a target BER/FER 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/FER). Sensitivity is measured by lowering the BS Traffic Channel (TCH) power level until the specified digital error limit is exceeded. The TCH power that was required to obtain the error limit is the sensitivity value. To do this, the BS is placed in loop-back mode. The BS transmits a bit pattern to the phone and the phone transmits it back. The returned bit pattern is then compared and the BER/FER is determined. As the output power from the BS to the phone is reduced, the BER/FER increases. Therefore, TIS is a figure of merit of overall radiated sensitivity of a wireless terminal. It is calculated as the integral of the measured Effective Isotropic Sensitivity (EIS). The process is standardized by CTIA. An equivalent parameter, total radiated sensitivity (TRS), is standardized by the 3GPP organization for UMTS [1]. Figure 2 provides for a benchmarking of TIS measurements. The procedure can be done in the following steps:

1. Make sure the MSC has been autocalibrated by a standard full two-port procedure from the VNA and to all output antennas, and not just up to the MSC output ports.
2. Place the DUT in the chamber. In the case of simulated-use testing, place the unit in the intended position relative to the SAM v4.5 phantom.
3. The E300 GUI will page the test unit, direct it to the traffic channel and put it in loop-back mode, set the BS simulator to a specific output power and perform the BER/FER measurements.
4. The E300 GUI will increase or decrease the BS output power as needed and repeat step 3 until the lowest output power is found that gives a BER/FER better than the specified target BER/FER.
5. The E300 GUI will repeat steps 3 and 4 for each position of the mode stirrers.
6. The E300 GUI will calculate the TIS value as,

$$TIS = \frac{(\frac{1}{8N}\sum_{i=1}^{8}\sum_{n=1}^{N} P_{BSSi}(n))^{-1}}{HTR_{fix}}$$

where $P_{BSSi}(n)$ is the output power from the base station simulator when this is adjusted to give the specified BER/FER in the test unit for transmitting antenna i and position n of the mode stirrers.

4. Conclusions

Unfortunately, TIS or TRP as required by CTIA do not indicate how evenly distributed the energy is over angle or for a variety of environments. Due to the fact that TRP/TIS measurements are performed in free-space-like environments, real handset behaviour may differ considerably. In consequence, more complicated compliance active testing is expected for 4G systems. With the use of second-generation mode-stirred chambers, TRP/TIS active measurements could be provided for wide variety of fading environments, Rayleigh, Rician, isotropic and non-isotropic ones. This opens the door for future 4G active testing standardization.

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