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The Effects of the Use of DRx Antenna Structure on the Rx Performance of Smartphones

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Abstract: Receiving the power emitted from the base station by smart phones and providing effective signaling is seen as a very critical problem. In order to eliminate this situation, some antenna technologies have been developed and started to be used in smart devices. The smart phones, which were developed by adhering to the DRx (Diversity Receive) design scheme, best perceived the signals emitted from the base station, thus increasing the Rx performance of the developed products. 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, because a TRP measurements used to verify your transmitter or transmitter antenna design. A TIS measurement used to verify how your receiver or receiver antenna design performs. In this study, we aimed to determine the Rx performance of the DRx scheme used in smartphones by using 3D radiation test setup (TIS - Total Isotropic Sensitivity).

Keywords: DRx (Diversity Receive) module, EIRP measurement, OTA test, Radiation efficiency for mobile phones, 3D TIS test for mobile.

Introduction

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 are very meaningful for wireless devices/applications. A single point metrics include Effective Isotropic Radiated Power (EIRP) and Effective Isotropic Sensitivity (EIS). Based on this, Over The Air (OTA) measurements attempt to test system components closer to the environment in which they will be used. 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, because a TRP measurements lets you to verify your transmitter or transmitter antenna design. A TIS measurement lets you to verify how your receiver or receiver antenna design performs.

Diversity Receive (DRx) module combines switch, RF Filter and LNA (Low Noise Amplifier) in a single module in the RF Receiver. By amplifying received signal, DRx (Diversity Receive) module improves receiver sensitivity and data throughput while reducing receiver noise figure. Diversity receive modules were used for various applications such as antenna cable loss compensation circuit for LTE data antenna, 3G/4G/5G multimode cellular handsets and tablets etc. Specifically, diversity schemes enhance reliability by minimizing

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the channel fluctuations due to fading. To define TIS, the receiver sensitivity meaning should be defined, as it is a function of sensitivity (W. Xue, F. Li and X. Chen, 2021).

Sensitivity measurements in wireless communications seek to determine the cell phone's ability to receive low signals. The lowest power level that can be received by the handset while maintaining connection with the base station, the lower the TIS measurements, means the better sensitivity of the handset. 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 (target is 2.0%). 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 can also have measured by lowering the BS Traffic Channel (TCH) power level until the specified digital error limit is exceeded (2.0%). 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 (>2.0%). 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) at every point at the intersection of a spherical grid.

Method

Coordinate System

The definition of TRP and TIS measurements are based on a spherical coordinate system. The spherical coordinate system describes any point in 3D space relative to the coordinate system origin with three spherical coordinates (r, θ, ϕ). A point on a sphere with radius r around the origin is described with (θ, ϕ), with elevation $\theta \in$ (0°, 180°) and azimuth $\phi \in$ (0°, 360°). The equator is located at θ = 90° elevation. For measurements, the DUT is located in the coordinate system origin and the measurement antenna is located in direction (θ, ϕ) relative to the DUT. As the path loss caused by the distance between DUT and measurement antenna must be calibrated for the test system, the radius r is not required (ITU-T, 2019).

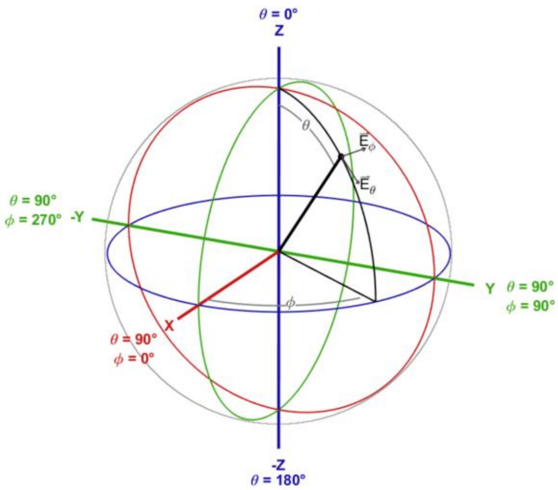

Figure 1. Spherical coordinate system

At each measurement point, two orthogonal components of the field are measured, defined as the theta polarization E_{θ} and phi polarization E_{ϕ}, pointing along the corresponding rotation vectors θ and ϕ, respectively. The theta polarization vector points along the positive direction of increasing theta values, and the phi polarization vector points along the positive direction of increasing phi values.

Transmitter Performance

The signal power as received by the measurement receiver test instrument is corrected by the corresponding signal path correction of the currently active signal path as determined during calibration. The resulting value is the EIRP of the current polarization in the current measurement direction. To access the total radiated power of the DUT, the EIRP in all direction is spatially averaged:

$$TRP = \frac{1}{4\pi}\int_0^{2\pi}\int_0^{2\pi} EIRP(\theta,\phi)\cdot\sin(\theta)\,d\theta\,d\phi \tag{1}$$

As the EIRP is measured as vertical and horizontal component with a dual polarized probe antenna at sampled measurement locations, the TRP is approximated with:

$$TRP \approx \frac{\pi}{2NM}\sum_{n=0}^{N-1}\sum_{m=0}^{M-1}\left(EIRP_\theta(\theta_n,\phi_m) + EIRP_\phi(\theta_n,\phi_m)\right)\sin(\theta_n) \tag{2}$$

The measurement locations (θ_n, ϕ_m) are defined in a grid on a sphere around the DUT. The angular spacing of measurement points is chosen as a trade-off between measurement time and accuracy, while for low directivity antennas as used in typical UE for 2G, 3G, and 4G a low sampling of 15° is sufficient.

Receiver Performance

The measurement site is expected to be validated and calibrated. The signal received by the DUT shall be transmitted with a calibrated test instrument. To access the EIS of the receiver in a given direction, the transmitted signal is reduced in power until the error criteria (e.g., bit error ratio (BER) or frame error rate (FER) is above a defined threshold. The lowest signal power that still enables the receiver to be within the error criteria limits, corrected by the corresponding signal path correction of the currently active signal path, is the EIS of the receiver for the given direction and polarization (K. A. Remley, C. J. Wang, D. F. Williams, 2016). The total isotropic sensitivity (TIS) is the EIS spatially averaged over the whole sphere around the DUT:

$$TIS = \frac{4\pi}{\int_0^{2\pi}\int_0^{\pi}\left(\frac{1}{EIS_\theta(\theta,\phi)} + \frac{1}{EIS_\phi(\theta,\phi)}\right) sin\theta d\theta\, d\phi} \tag{3}$$

For TIS determination, it is not sufficient to rely on the conducted sensitivity of the receiver combined with the radiation pattern of the used antenna, as signal strength and noise received by the antenna will vary and is influenced by the DUT itself. To determine the TIS from sampled measurement points, the TIS is approximated with:

$$TIS \approx \frac{2NM}{\pi\sum_{i=1}^{N-1}\sum_{j=0}^{M-1}\left(\frac{1}{EIS_\theta(\theta_i,\phi_j)} + \frac{1}{EIS_\phi(\theta_i,\phi_j)}\right)\sin(\theta_i)} \tag{4}$$

EIS_θ (θ_i, ϕ_j) and EIS_ϕ (θ_i, ϕ_j) are the determined effective isotropic sensitivity in the direction (θ_i, ϕ_j) in the theta and phi polarization. The measurement locations (θn, ϕm) are defined in a grid on a sphere around the DUT. The angular spacing of measurement points is chosen as a trade-off between measurement time and accuracy, while for low directivity antennas as used in typical UE for 2G, 3G, and 4G a low sampling of 15° is sufficient.

Measurement Frequencies

The radiation patterns of handset antennas can be expected to be frequency dependent. Achieved TRP and TRS values can vary over frequency and shall be measured in three channels in a frequency band (low, mid and high channel). The specified bands will be chosen to cover national or regional aspects. For any DUT, frequencies are selected based on the supported frequency bands of all supported wireless communication standards of the device and the admitted frequencies in the region the DUT is to be operated (W. Xue, F. Li and X. Chen, 2021).

OTA Testing with RTS65 Chamber

The RTS65 from Bluetest is a Reverberation Test Chamber for Bluetooth, WLAN, 2G, 3G, 4G LTE, mm-Wave, and the latest 5G NR standards. The chamber can be used for applications from 500 MHz to 40 GHz. It can be configured to support up to 16 antenna configurations up to 6 GHz and two mm-Wave antenna configurations at 40 GHz and 43 GHz. The 16 antennas configuration can for example support four LTE carriers with 4x4 MIMO in four different frequency bands. With its 40/43 GHz capability, the chamber is also usable for 5G NR and the combination of sub-6 GHz LTE carriers and sub-6 GHz or mmWave 5G NR carriers (Non-Standalone).

Figure 2. RTS65 3D chamber overview

As shown in Figure 2., RTS65 chamber consists of a shielded reverberation chamber with reflecting walls. The device to be tested is placed on a turntable. The reflective walls in combination with moving reflectors (mode stirrers), and the turntable, create a Rayleigh faded rich isotropic multipath environment (RIMP) inside the chamber. This environment is very well suited for antenna and radio performance evaluation of modern multi-antenna (MIMO) devices.

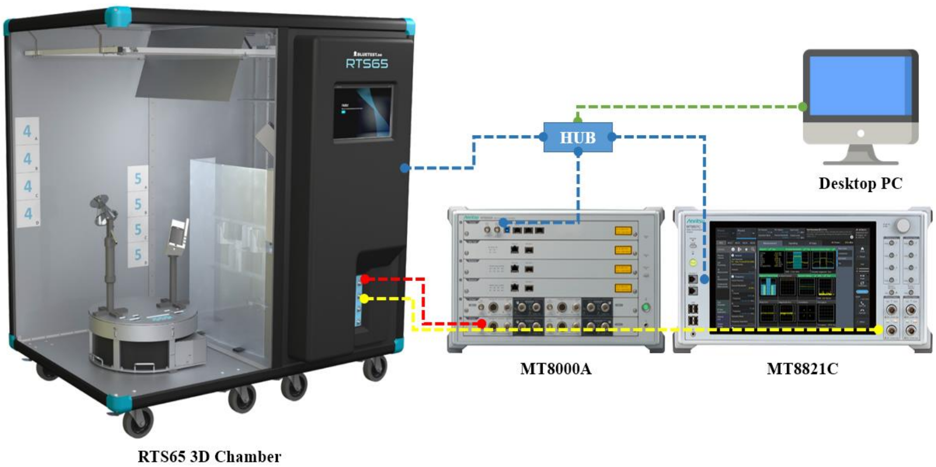

Figure 3. RTS65 3D chamber setup overview

The device is typically used for measuring Antenna Efficiency and MIMO/Diversity gain, Total Radiated Power (TRP), Total Isotropic Sensitivity (TIS) and Data Throughput vs received power. These measurements are done using a vector network analyzer or radio communication tester connected to one or several of the chamber measurement antennas. In our setup, we are using MT8821C and MT8000A equipment. A basic structure explained in (Figure 3). The connection between the equipment, chamber and Desktop PC provided over HUB.

TIS Test Method and Procedure

The DUT is placed in a free-space holder on a rotation table within the anechoic RF chamber and the communication between the DUT and the command module is established via over-the-air inside the chamber. The command module converts the commands of Test PC to control the DUT to the required test channel. To determine the TIS the reference antenna in the RF chamber transmits at the DUT, and the TX power is lowered until the radiated sensitivity BER or PER limit reaches a given threshold. The DUT then rotates in increments of 30 degrees along the vertical axis. At each vertical position, the horizontal axis steps in increments of 30 degrees. The horizontal and vertical polarization are measured at each position. After all measurements are completed, the sensitivity is calculated at each measurement point and the TIS is automatically calculated. This process repeated for all test channels (Y. Feng and W.L. Schroeder, 2009). The test procedure as follows:

- DUT shall receive TX packets from a Signal Generator's output.
- Signal Generator transmits a standard conforming signal and packet.
- Measure free space effective isotropic sensitivity (EIS) pattern. Adjust the TX downlink signal level until the BER=0.04% threshold is reached. The downlink step size shall be no more than 0.5 dB when the downlink power is near sensitivity.
- Calculate using EIS pattern. For a complete sphere measured with N Theta intervals and M Phi intervals, both with even angular spacing, the Total Isotropic Sensitivity will be calculated an automated calculation tool.

Results and Discussion

We completed TIS test process for A54 5G model in our lab for LTE bands. In the scope of this test process, we tested B1, B5, B12, B20, B28 for FDD bands and B38, B40, B41 for TDD bands. Our test cases planned as standard set measurement and PRx antenna measurement. Standart SET means that all the antenna functions are activated (DRx & PRx antennas are enabled). Only PRx means that DRx antennas bloked for test purposes. Please note that before to check the Table.1.

Table 1 - TIS Measurement Results for both FDD/TDD Bands

Bands	B1	B5	B12	B20	B28	B38	B40	B41
Test Channel	300ch	252ch	5095ch	6300ch	9410ch	3800ch	39150ch	40620ch
Standart SetTIS(dBm)	99.39	93.03	95.78	93.25	92.29	93.03	94.19	94.08
Only PRx Set TIS(dBm)	95.81	88.00	89.74	88.92	86.40	89.44	90.90	90.22
Delta	3.58	5.03	6.04	4.33	5.89	3.59	3.29	3.86

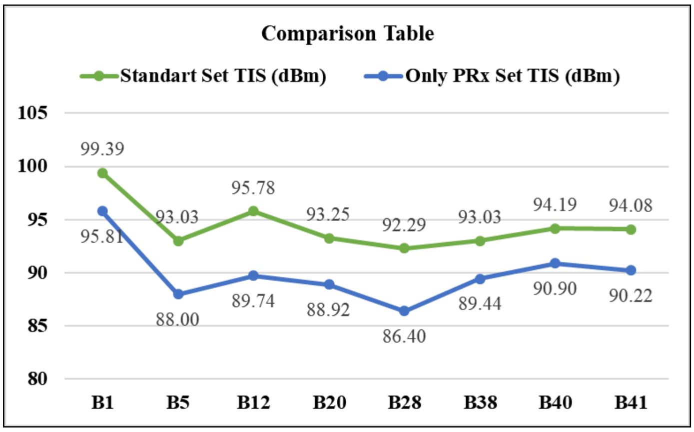

Figure 4. Comparison table for both FDD/TDD Bands

In Table-1, we can see the test bands, test channels, and test results. Please also note that especially there are 3 channels (low, mid and high channel) for each band, although we measured all the channels, only shared mid channel results to summarize the table. According to test results we measure in our Lab, there is 3.29 ~ 6.04 dBm difference between the standart set and only PRx set as shown in (Table.1). We also figured Delta for quick review as shown in (Figure 4). As we can see, standart set results better than only PRx set.

Conclusion

The use of the DRx antenna scheme in next-generation smartphones is a necessity, especially for 5G technology. When high frequencies are used in communication areas such as 4G and 5G technologies, the signals emitted from the base station radiate effectively over shorter distances. In addition to this, due to environmental and geographical factors, there is a significant attenuation in the signals, which prevents effective communication between the base station and the users, and causes a significant decrease in data rates and signal strength. Therefore, we have to use next-generation antenna combinations to improve Rx performance in smartphones. As a result of this study, it has been observed that the use of the DRx antenna scheme in smartphones has a direct impact on the Rx performance of the smartphone.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Acknowledgements or Notes

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