# LTE Radiated Data Throughput Measurements, Adopting MIMO 2x2 Reference Antennas

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*Abstract*— **Long Term Evolution (LTE) requires Multiple Input Multiple Output (MIMO) antenna systems. Consequently a new over-the-air (OTA) test methodology need to be created to make proper assessment of LTE devices radiated performance. The antenna specific parameters i.e. total antenna efficiency, gain imbalance and correlation coefficient, are essential for a proper MIMO antenna system design. However it can't be use directly to assess the LTE device system performance, since a multiplicity of other factors are involved, e.g. power amplifier load-pull, low noise amplifier source-pull, self interference noise, baseband algorithm and other factors. Several standard organizations are working towards a consensus over the proper OTA MIMO test method, however so far results of measurement campaigns have ambiguous results not allowing a desirable progress [1]. Initially presented at one of several MIMO OTA standard meetings [2], the reference antenna was conceived considering the special case of uniform distribution of incoming power. This paper shows an antenna system that will aid standard organizations and research labs adopting anechoic or reverberation chambers to proper investigate OTA radiated performance, ruling out the LTE devices unknown MIMO 2x2 antenna performance.**

***Keywords-component; LTE; MIMO; OTA; antennas; data; throughput***

## I. INTRODUCTION

With main objective to benchmark MIMO OTA test methodologies, the MIMO 2x2 reference antennas were created to rule out the unknown LTE device antenna performance, and replace the device antenna by an MIMO 2x2 antenna system with known performance, eliminating this element from the OTA measurement variables. In this context a set of three antennas per each desirable band was created, allowing better repeatability and less measurement uncertainty among labs.

## II. REFERENCE ANTENNA CONCEPT

The MIMO 2x2 reference antennas were conceived during the first CTIA (Cellular Telecommunications and Internet Association) MIMO OTA Sub-Group meeting, and initially were designed to cover three LTE bands (2, 7 and 13). Conceptually for each band three antennas were designed to emulate a "good" MIMO antenna system figure of merit (FoM), i.e. low correlation coefficient *($\rho<0.1$)*, high total antenna efficiency *($\eta>90\%$)* and low gain imbalance ($\Delta G \cong 0dB$). Respectively the "nominal" MIMO antenna system has moderate correlation coefficient *($\rho \leq 0.5$)*, moderate total antenna efficiency *($\eta \geq 50\%$)* and low gain imbalance ($\Delta G \cong 0dB$). And finally the "bad" MIMO antenna system, having poor correlation coefficient *($\rho \geq 0.9$)*, moderate-to-poor total antenna efficiency *($\eta \leq 50\%$)* and low gain imbalance ($\Delta G \cong 0dB$).

Other than the electrical performance constrains, the reference antenna also needs to solve the potential problem with connecting any external antenna into a portable device. The connection between the portable device RF port and the external antenna, normally a coaxial cable, can potentially carry current in the outer conductor. The associated radiation perturbs the antenna system radiation and influence system parameters like correlation coefficient, absolute gain and gain imbalance [3]. For this reason the antenna was conceived attaching MIMO 2x2 external antennas to a RF enclosure, where the DUT and its RF connections are located. The initial prototype is shown in Fig. 1.

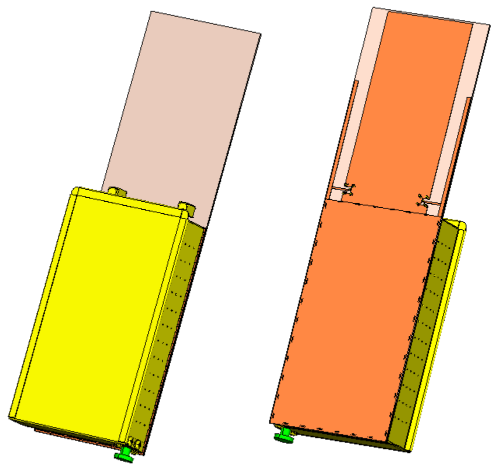

Figure 1a. MIMO 2x2 Reference Antenna concept. Front (left) and back (right) view of the closed antenna.

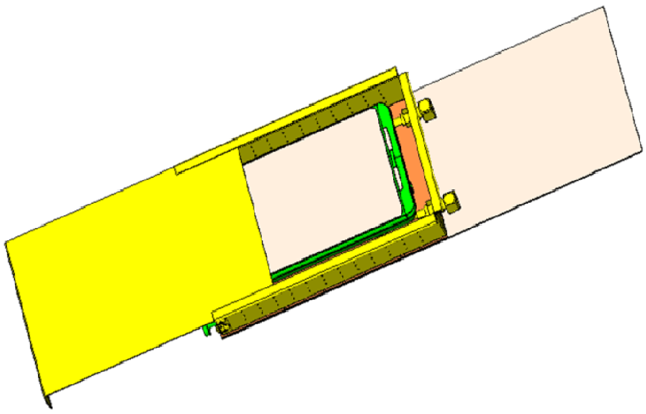

Figure 1b. MIMO 2x2 Reference Antenna concept. Open antenna with inserted active device.

## III. Analysis of Magnitude of Correlation Coefficient Impact on MIMO 2x2 System Capacity

The magnitude of the complex correlation coefficient between two antennas is shown in [4]. It can be seen, that the coefficient is predominantly defined by the complex radiation patterns of the antennas, in this case a generic scenario is presented where the incoming power is uniformly distributed in both theta and phi directions, it's understood that in the real environment this condition is unlikely to happen, however true in the reverberation and controlled anechoic test environment.

$$\rho_{12} = \frac{\left|\oint\{(XPR \cdot E_{\theta MA}(\Omega) \cdot E^{*}_{\theta SA}(\Omega) + E_{\phi MA}(\Omega) \cdot E^{*}_{\phi SA}(\Omega)\}d\Omega\right|^{2}}{\oint\{XPR \cdot G_{\theta MA}(\Omega) + G_{\phi MA}(\Omega)\}d\Omega \cdot \oint\{XPR \cdot G_{\theta SA}(\Omega) + G_{\phi SA}(\Omega)\}d\Omega} \quad (1)$$

$E_{\theta MA}$ ($\Omega$) is the vertical polarization complex radiation pattern from Main Antenna, $E_{\theta SA}$ ($\Omega$) is the vertical polarization complex radiation pattern from Secondary Antenna, $E_{\phi MA}$ ($\Omega$) is the horizontal polarization complex radiation pattern from Main Antenna, $E_{\phi SA}$ ($\Omega$) is the horizontal polarization complex radiation pattern from Secondary Antenna. $\Omega$ is the solid angle for a spherical coordinate system and *XPR* is cross-polar discrimination of the antennas.

The primary objective of implementing a MIMO system is to improve the system capacity. Considering the MIMO 2x2 system as focus in this study, the basic graphical representation of the antenna arrangement is shown in Fig 2.

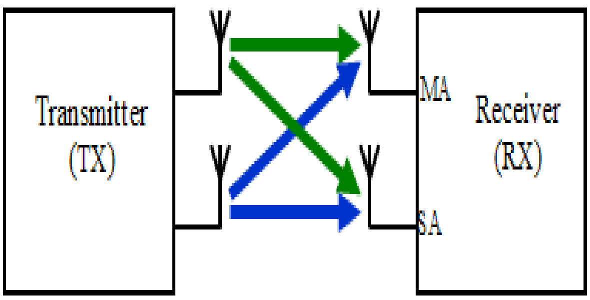


Fig 2. MIMO 2x2 system, graphical representation

Considering (1) from an analytic perspective only, the correlation coefficient can be controlled by varying both arguments and it appears that the cross correlation can be minimized simply by increasing the gain imbalance between the two antennas. However, from a system performance perspective, a high gain imbalance will not lead to improved MIMO performance since this condition in its extreme form is equivalent to the pure MISO system with just one antenna [5].

A successful MIMO antenna design requires that each pair of antennas have approximately the same power loss, same gain and closely uncorrelated. To optimize MIMO capacity several basic properties needs to be observed as summarized below:

1. Both antennas; Main Antenna and Secondary Antenna; needs to have appropriate radiated performance with minimum gain imbalance, ideally 0dB;
2. In the rich scattered environment the maximum capacity will occur when both receiver antennas where cross-polarized, consequently the antennas need to be uncorrelated;
3. The absolute phase response of the reference antennas are irrelevant, but not the phase per direction neither the relative phase relationship between the antennas and the gain imbalance, which defines the MIMO antenna system correlation coefficient;
4. The ideal MIMO 2x2 antenna system, considering ideal isolation between antennas (>20dB), gain imbalance 0dB, and correlation coefficient 0, will provide the double of capacity of counterpart SISO system (this statement is based solely on antenna parameters).
5. The antennas radiation patterns need to have similar directivity, two directional antennas with main lobe in opposite directions, will not enable acceptable MIMO performance in poor scattered environment.

## IV. Simulation Results

The MIMO 2x2 antenna system was initially simulated on CST Microwave Studio [6]. The antennas are self-resonant and based on the Inverted "F" antenna topology, as shown in Fig. 3 to 5. The figures illustrate the band 13 3D radiation patterns of each of the two antennas in the nominal, good and bad configurations including return loss and impedance characteristics.

The control of the magnitude of complex correlation coefficient is achieved through the reference ground plane placement between antennas radiators. Since the antennas are absolutely symmetric, the gain imbalance between the antennas is always near to 0dB, considering an environment which the fields arrives from all directions. With this feature, the gain imbalance between antennas can be artificially controlled through discrete RF attenuators placed between the DUT and reference antenna RF port, inside the RF enclosure.

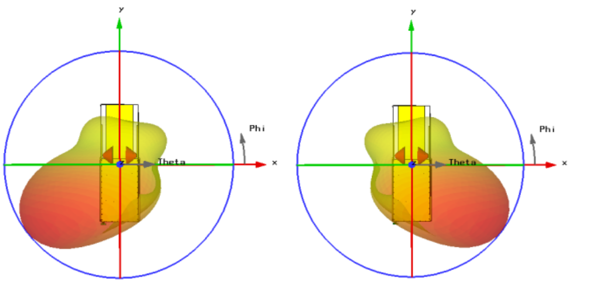

Figure 3a. Band 13 “Good” 2x2 MIMO antenna 3D radiation pattern @ 751MHz.

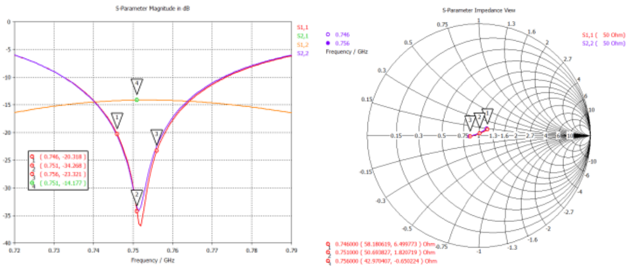

Figure 3b. Band 13 “Good” 2x2 MIMO antenna Return Loss and Impedance characteristic

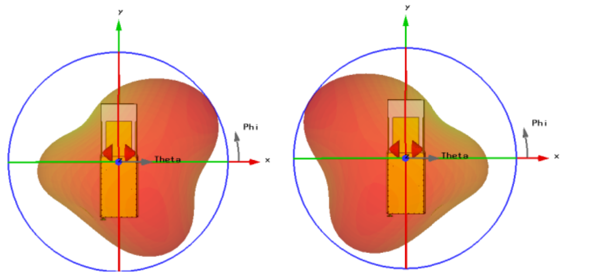

Figure 4a. Band 13 “Nominal” 2x2 MIMO antenna 3D radiation pattern @ 751MHz.

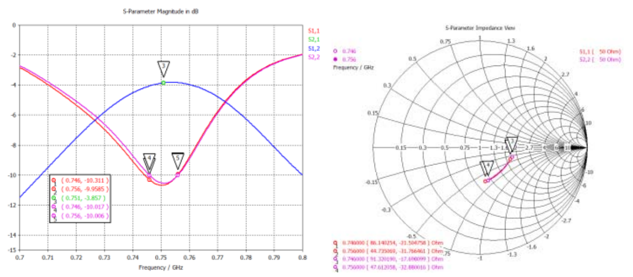

Figure 4b. Band 13 “Nominal” 2x2 MIMO antenna Return Loss and Impedance characteristic

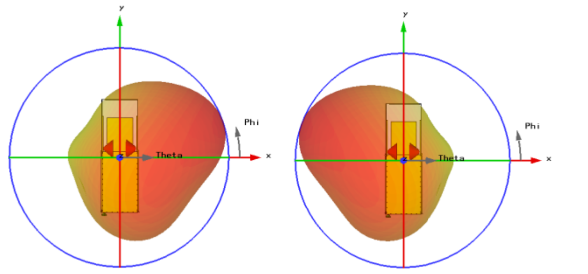

Figure 5a. Band 13 “Bad” 2x2 MIMO antenna 3D radiation pattern @ 751MHz.

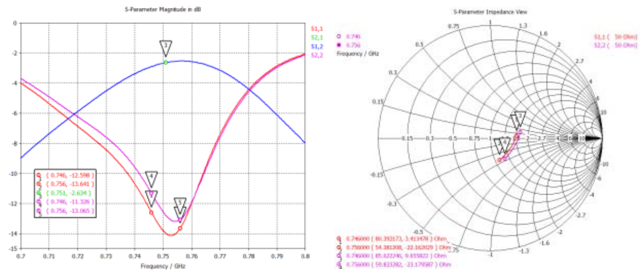

Figure 5b. Band 13 “Bad” 2x2 MIMO antenna Return Loss and Impedance characteristic

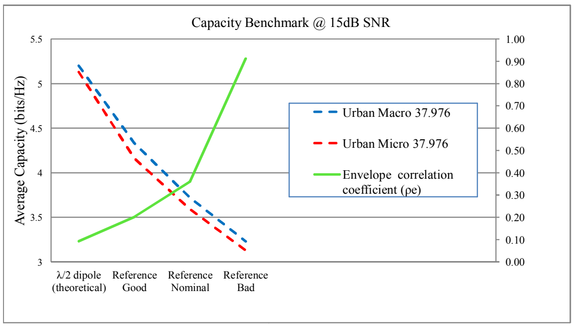


Figure 6. Simulated average capacity adopting B13 MIMO 2X2 reference antennas complex radiation pattern

Adopting the drops defined in 3GPP TR 37.976 [7], the average capacity was predicted based on full link simulation model, adopting SCME channel model and CTIA MIMO 2x2 reference B13 antennas measured radiation patterns (figure 6). These simulations only considered azimuth cut and vertical polarization.

## V. MEASUREMENTS RESULTS

The figure 7 demonstrates the realization of this antenna concept, the left picture indicates the bare PCB with the 2 antennas at the top on each side. Right, the RF shield attached and the active device inserted and the RF lit shown.

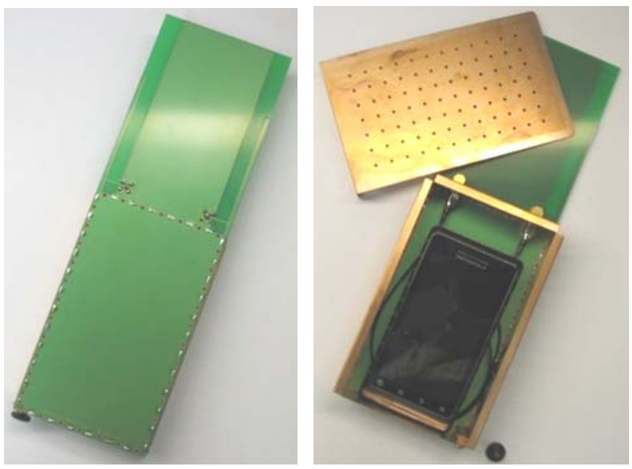

Figure 7. Band 13 “Good” MIMO 2x2 antenna prototype.

Similar to the simulation results, the figures 8 to 10, shows radiation pattern measured at full anechoic chamber, return loss and impedance characteristic of band 13 reference antennas. The overall FoM benchmark between simulation and measurements is done on tables 1 and 2.

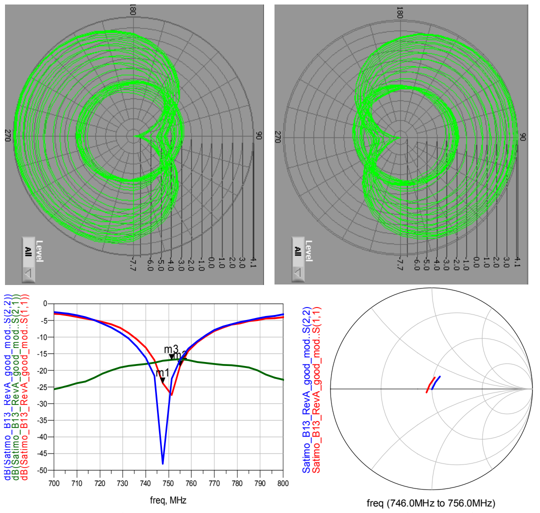


Figure 8. B13 "Good" MIMO 2x2 antennas, measured 2D radiation pattern (751MHz), Return Loss and impedance Characteristic.

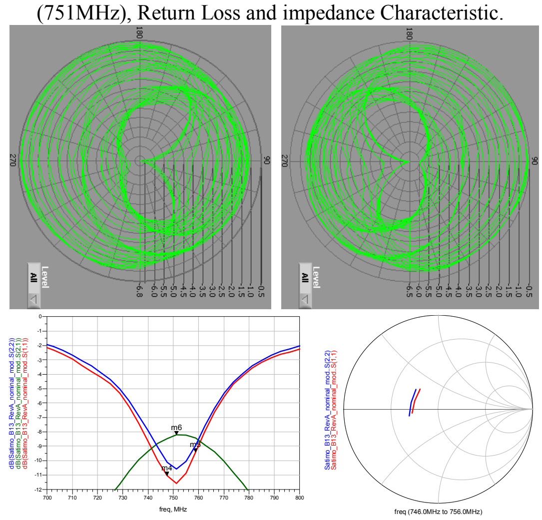

Figure 9. B13 "Nominal" MIMO 2x2 antennas, measured 2D radiation pattern (751MHz), Return Loss and impedance Characteristic.

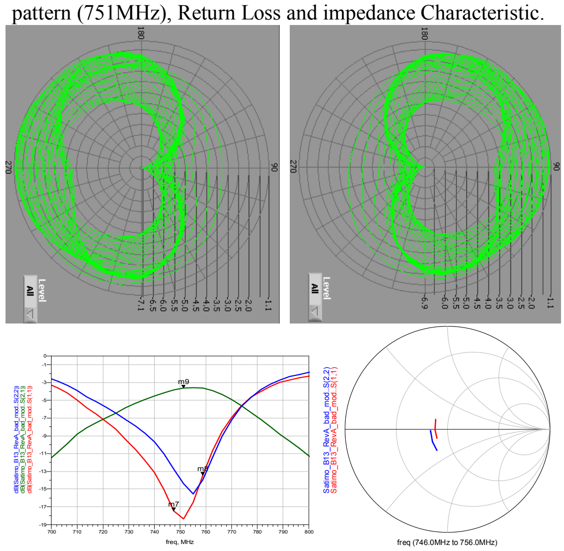

Figure 10. B13 "Bad" MIMO 2x2 antennas, measured 2D radiation pattern (751MHz), Return Loss and impedance Characteristic.

Table 1 B2/7/13 Total Antenna Efficiency

| | | Antenna 1 | | | Antenna 2 | | |
|---|---|---|---|---|---|---|---|
| | | 1930MHz | 1960MHz | 1990MHz | 1930MHz | 1960MHz | 1990MHz |
| Band | Antenna Configuration | η (%) | η (%) | η (%) | η (%) | η (%) | η (%) |
| 2 | Simulated "Good" 2x2 MIMO | 96.7 | 95.6 | 93.5 | 97.3 | 97.1 | 95.9 |
| | Measured "Good" 2x2 MIMO | 88.5 | 93.1 | 95.8 | 88.6 | 91.2 | 94.2 |
| | Simulated "Nominal" 2x2 MIMO | 59.9 | 60.4 | 59.7 | 58.7 | 59.7 | 59.3 |
| | Measured "Nominal" 2x2 MIMO | 62.9 | 63.1 | 60.8 | 65.9 | 63.8 | 62.4 |
| Band | Antenna Configuration | 2.62GHz | 2.655GHz | 2.69GHz | 2.62GHz | 2.655GHz | 2.69GHz |
| 7 | Simulated "Good" 2x2 MIMO | 91.4 | 91.2 | 91.1 | 90.1 | 90.1 | 88.9 |
| | Measured "Good" 2x2 MIMO | 91.9 | 93.6 | 87.9 | 95.3 | 89.9 | 82.2 |
| | Simulated "Nominal" 2x2 MIMO | 55.5 | 58.0 | 59.5 | 55.8 | 58.0 | 59.1 |
| | Measured "Nominal" 2x2 MIMO | 70.8 | 69.9 | 62.1 | 74.1 | 63.8 | 57.9 |
| Band | Antenna Configuration | 746MHz | 751MHz | 756MHz | 746MHz | 751MHz | 756MHz |
| 13 | Simulated "Good" 2x2 MIMO | 93.6 | 94.62 | 94.46 | 93.61 | 94.59 | 94.35 |
| | Measured "Good" 2x2 MIMO | 89.2 | 93.2 | 88.6 | 87.5 | 91.8 | 87.6 |
| | Simulated "Nominal" 2x2 MIMO | 53.7 | 58.5 | 54.9 | 52.5 | 57.3 | 54.1 |
| | Measured "Nominal" 2x2 MIMO | 60.1 | 58.8 | 57.2 | 60.0 | 58.8 | 57.3 |
| | Simulated "Bad" 2x2 MIMO | 40.6 | 41.6 | 37.9 | 40.4 | 41.8 | 38.4 |
| | Measured "Bad" 2x2 MIMO | 50.9 | 49.7 | 45.3 | 51.7 | 50.3 | 45.8 |

Table 2 B2/7/13 Gain Imbalance and Magnitude of Complex Correlation Coefficient

| | | Gain Imbalance (dB) | | | Mag Complex Cor. Coef. | | |
|---|---|---|---|---|---|---|---|
| Band | Antenna Configuration | 1930MHz | 1960MHz | 1990MHz | 1930MHz | 1960MHz | 1990MHz |
| 2 | Simulated "Good" 2x2 MIMO | 0.027 | 0.068 | 0.110 | 0.009 | 0.004 | 0.001 |
| | Measured "Good" 2x2 MIMO | 0.005 | 0.089 | 0.070 | 0.039 | 0.040 | 0.044 |
| | Simulated "Nominal" 2x2 MIMO | 0.088 | 0.051 | 0.027 | 0.450 | 0.460 | 0.460 |
| | Measured "Nominal" 2x2 MIMO | 0.202 | 0.048 | 0.113 | 0.403 | 0.395 | 0.377 |
| Band | Antenna Configuration | 2.62GHz | 2.655GHz | 2.69GHz | 2.62GHz | 2.655GHz | 2.69GHz |
| 7 | Simulated "Good" 2x2 MIMO | 0.062 | 0.053 | 0.106 | 0.019 | 0.024 | 0.029 |
| | Measured "Good" 2x2 MIMO | 0.155 | 0.174 | 0.288 | 0.056 | 0.054 | 0.049 |
| | Simulated "Nominal" 2x2 MIMO | 0.023 | 0.001 | 0.031 | 0.370 | 0.390 | 0.400 |
| | Measured "Nominal" 2x2 MIMO | 0.196 | 0.393 | 0.307 | 0.348 | 0.353 | 0.343 |
| Band | Antenna Configuration | 746MHz | 751MHz | 756MHz | 746MHz | 751MHz | 756MHz |
| 13 | Simulated "Good" 2x2 MIMO | 0.000 | 0.001 | 0.005 | 0.018 | 0.052 | 0.083 |
| | Measured "Good" 2x2 MIMO | 0.084 | 0.066 | 0.046 | 0.007 | 0.026 | 0.063 |
| | Simulated "Nominal" 2x2 MIMO | 0.101 | 0.087 | 0.065 | 0.614 | 0.576 | 0.539 |
| | Measured "Nominal" 2x2 MIMO | 0.004 | 0.000 | 0.009 | 0.603 | 0.556 | 0.519 |
| | Simulated "Bad" 2x2 MIMO | 0.025 | 0.027 | 0.054 | 0.921 | 0.906 | 0.888 |
| | Measured "Bad" 2x2 MIMO | 0.074 | 0.057 | 0.053 | 0.933 | 0.918 | 0.899 |

The antennas were tested in an MIMO OTA test system (figure 10), consisting of a circular array of dual polarized antennas in an anechoic chamber, fed by an 8 channel emulator through a set of low noise amplifiers, properly correlating, fade, scale, delay, and distribute the signal to each test probe in the chamber.

For the purpose of this test, the DUT was oriented vertically polarized, so only eight evenly spaced vertically polarized elements located every 45 degrees were used to generate the test environment. This configuration has been shown to produce an environment equivalent to the ideal free space condition for devices of the target size [8], and is thus considered sufficient for the purposes of this evaluation. The test procedure followed that outlined in 3GPP TR 37.976, for a 16 QAM downlink. The device under test (DUT) was rotated in 45 degree steps to capture throughput vs. power curves at each position and then determine the average throughput vs. power across all orientations. In addition to the OTA tests, a series of conducted tests were performed using both a constant tap (through connection) model and conducted models based on each of the OTA models where ideal dipoles were used as the modeled receiving antennas. The constant tap result was also compared to direct connection tests between the base station emulator and the DUT to confirm that the calibrated path through the channel emulator produced the same result as a direct connection.

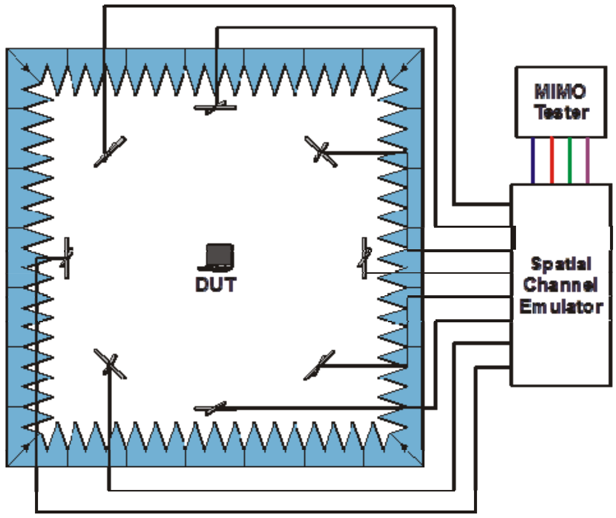


Figure 10. OTA data throughput measurement setup

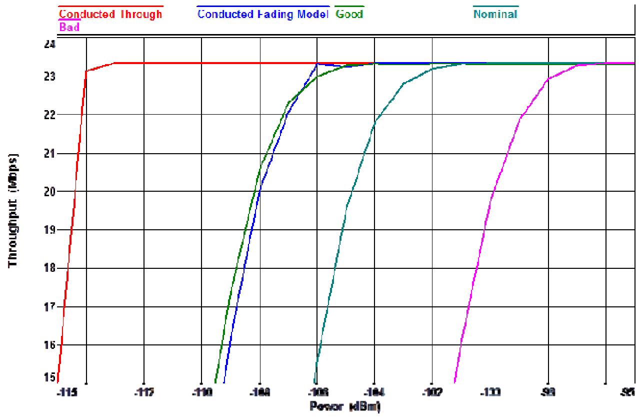


Figure 11. Data throughput measured with LTE device and B13 MIMO 2x2 Reference antenna

As indicated on figure 11, the band 13 reference antenna was evaluated in a MIMO anechoic chamber, where an arbitrarily spatial channel model was applied. The data throughput measured with "good" reference MIMO antenna (green curve), agrees well with LTE device conducted data throughout measured under same channel model (dark blue curve). While the "nominal" (light blue curve) and "bad" (pink curve), indicates that the reference antenna system can be used to discriminate over 8dB range, the "good" from "bad" MIMO antennas.

## VI. CONCLUSIONS

A reference MIMO 2x2 antenna concept has been presented including simulated and measurement benchmarked results. In this work the antenna related investigation has been carried out for the special case of uniform incoming power distribution only, however the system data throughput is demonstrated in a non-uniform spatial channel environment. These antennas demonstrate good discrimination between "good", "nominal" and "bad" designs, either on uniform or non-uniform environments, and will aid future research on MIMO OTA measurement methodologies, playing an important role minimizing measurement uncertainty, and validating test methodologies.


## Acknowledgement

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