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Abstract — **With the commercialization of MIMO devices, accurate over-the-air testing has become a major research area in mobile communications. Several test methods are investigated in the related work. This paper discusses the anechoic chamber method and specifically deals with reflections between probes on the multi-probe ring. It is shown that reflections are at least 25 dB below the direct path. The paper also raises the difficulties to accurately measure the level of reflections in a real setup, due to instabilities.**

1 Introduction

Along with the standardization of Long Term Evolution (LTE) and LTE-Advanced (LTE-A) [1], handsets supporting Multiple-Input Multiple-Output (MIMO) technology have appeared on the market. MIMO devices, as opposed to Single-Input Single-Output (SISO) devices, use several antennas in order to enhance their performance. In order to rank devices, Over-The-Air (OTA) testing is required. SISO OTA and MIMO OTA testing differ in their consideration of the propagation characteristics of the radio channel. While SISO OTA measurements reflect the performance of the DUT in an isotropic environment only, MIMO OTA testing also takes into account realistic channel conditions. The MIMO OTA testing environment needs to create a spatially diverse radio channel, for the antennas on the MIMO DUT to exhibit a multiplexing gain. Contrarily to SISO OTA testing, an isotropic channel model cannot be used.

The two main challenges of MIMO OTA testing are defining the channel conditions and physically creating such a channel in the radiated domain. Channel emulation is discussed in [2, 3, 4]. Realizing defined channel conditions has been investigated with different setups. They can be categorized in two groups: reverberation chamber based methods and anechoic chamber based methods. An overview is given in [5]. This paper focuses on the anechoic chamber method with a multi-probe ring. The probes are used to recreate specific channel conditions, by applying proper power weighting on

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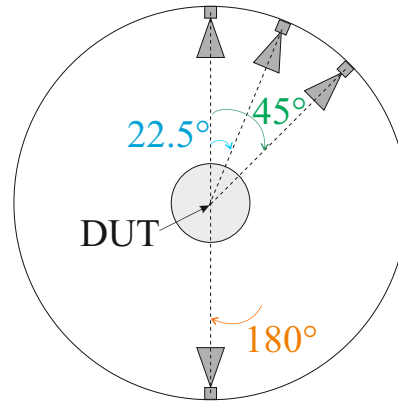†Xtel ApS, Alfred Nobels Vej 21, 9220 Aalborg, Denmark

Figure 1: Investigated MIMO OTA setup.

each probe. As the number of probes increases, channel flexibility is improved. However, a larger number of probes on the ring increases scattering from the other probes. Investigating reflections inside the multi-probe ring is the aim of this work.

2 Setup

In the investigated scenario, a DUT is placed at the center of the multi-probe ring, in an anechoic room. The MIMO OTA setup creates a radio channel environment, where the signal can arrive to the DUT from many different directions simultaneously. Specifically, the probes create a known Angle of Arrival (AoA) at the DUT, which maps to a known channel model. It is possible to create an arbitrary number of clusters with associated mean AoA and Azimuth Spread (AS) impinging the DUT.

Reflections inside the ring can alter the channel environment. The reflections that are investigated are the ones due to scattering between probes. Three different locations are investigated. The location at the angle 22.5 degrees represents the immediate neighbor in a 16-probes ring setup. The location at the angle 45 degrees represents the immediate neighbor in a 8-probes ring setup. The location at the angle 180 degrees represents reflections due to the opposite probe alone. A schematic of the investigated configurations is given in Fig. 1.

To test LTE and LTE-A devices, operation in the range from 700 MHz to 6 GHz is required [1].

(a) Probe [6].   (b) Simulation setup.

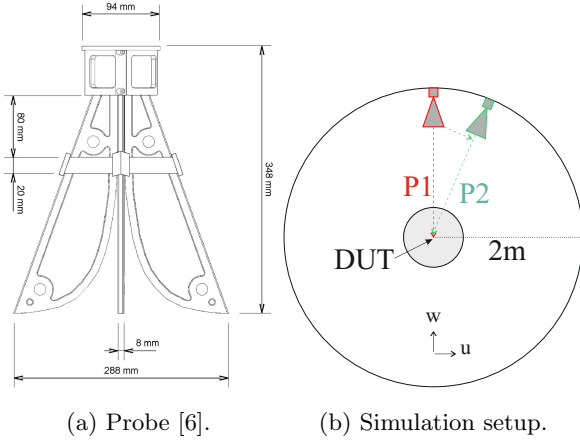Figure 2: MIMO OTA testing in anechoic room.

Figure 3: Level of the reflections compared to the direct path.

However, the following focuses on the range from 700 MHz to 2.6 GHz, as it is the current LTE development. As the testing frequency decreases, the distance between the probes becomes electrically smaller. For a ring of radius 2 m, a 22.5 degrees separation corresponds to 0.78 m, which represents 2 λ at 750 MHz for example. Therefore, scattering from neighboring probes can be significant. The probes are wideband dual-polarized horn antennas, shown in Fig. 2a and detailed in [6].

The simulation setup is shown in Fig. 2b. When one probe is transmitting to the DUT, two paths can be taken: the direct path P1 or the reflected path P2. Simulations using the integral equation solver of the CST tool [7] will be used to determine the level of the field due to reflections compared to the field on the direct path. That is to say, what is the level of the fields following P2 compared to the level of the fields following P1.

3 Simulated reflections between probes

This section evaluates through simulations the level of reflections that occur between an active probe and a scattering probe. For this calculation, two simulations are performed. The first simulations contains only the active probe and the DUT, thus providing the fields on the direct path P1 only. The second simulation contains both probes and the DUT, as shown in Fig. 2b. Consequently, the second simulation provides the addition (constructive or destructive) of the fields from all paths, direct P1 and reflected P2. In order to conclude on the level of the reflected fields, one needs to make the following manipulations on the complex E fields ($\underline{E}$) received at the DUT.
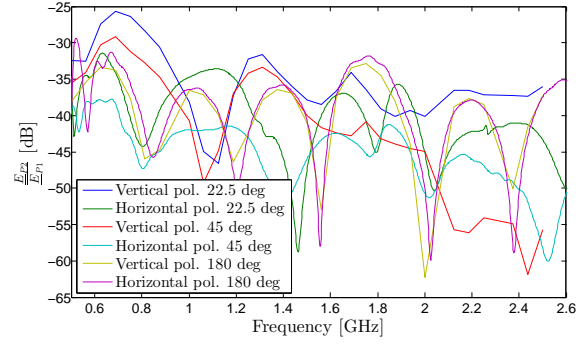
$$\underline{E}_{Sim1} = \underline{E}_{P1} \qquad (1)$$
$$\underline{E}_{Sim2} = \underline{E}_{P1} + \underline{E}_{P2} \qquad (2)$$

$$\frac{\underline{E}_{P2}}{\underline{E}_{P1}} = \frac{\underline{E}_{Sim2}}{\underline{E}_{Sim1}} - 1 \qquad (3)$$

The results corresponding to Eq. (3) are computed and shown in Fig. 3, for the three locations of Fig. 1 and both polarizations. It is observed that the level of reflections increases as the frequency decreases and reaches -25 dB at 700 MHz.

4 Measured reflections between probes

This section deals with the measurements of the level of reflections in the chamber. Similarly to the simulations, in order to perform a reflection level measurement, one needs two measurements. The first one with the DUT and the active probe alone; the second one with the DUT and both probes. Applying Eq. (3) on the fields measured at the DUT, the level of the reflections due to the scattering probe can be determined. Measurements are performed for the cases where the scattering probe is placed at 22.5 degrees and at 180 degrees.

4.1 Measurements

Reflection level measurement are performed at 740 MHz and at 2.6 GHz. The magnitude and phase for a full azimuth rotation of the DUT are shown in Fig. 4 and Fig. 5, for 740 MHz and 2.6 GHz respectively. The addition of the second probe creates a ripple on the magnitude of the received fields. The ripple is most significant for the higher frequency, when the second probe is placed 180 degrees away from the active probe. The difference, from the fields received at the DUT for the active probe alone
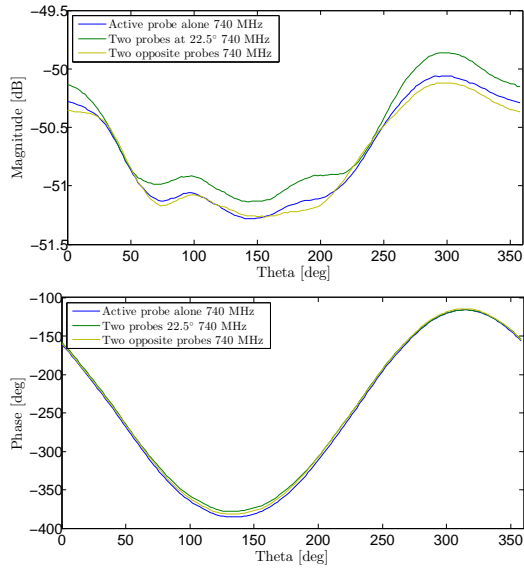
Figure 4: Measured magnitudes and phases at 740 MHz.

Figure 5: Measured magnitudes and phases at 2.6 GHz.

and for both probes, is plotted in Fig. 6. The magnitude variation is negligible for both frequencies: 0.2 dB. However, the phase variation is significant at the higher frequency: up to 20 degrees.

The measured levels of reflection are plotted in Fig. 7. They average to -24 dB for the 22.5 degrees case and to -27 dB for the 180 degrees case, at 740 MHz. At that frequency, the simulations predicted -26 dB and -33 dB respectively. The agreement between simulations and measurements is acceptable. However, at 2.6 GHz, the measured level of reflection averages to -14 dB for the 22.5 degrees case and to -17 dB for the 180 degrees case. These values are not in agreement with the simulations, that predicted -40 dB at the maximum. The large phase variation is the cause of the high reflection results. Moreover, it may indicate a misplacement of the DUT during the test.

4.2 Testing accuracy

Especially for the high frequencies, the distance between probe and DUT has a large impact on the phase variation. Therefore accurate positioning of the DUT is critical. In the following, the impact of the DUT misplacement on the measurement of reflection is quantified.

During the test, adding or removing probes may cause the entire structure to move. As a consequence, the pedestal supporting the DUT is not likely to be in the center of the ring anymore. If the placement of the DUT relative to the probes is changed between the first measurement (the active
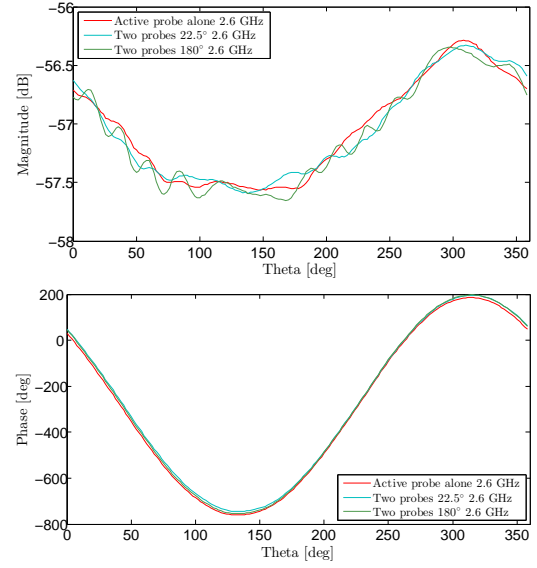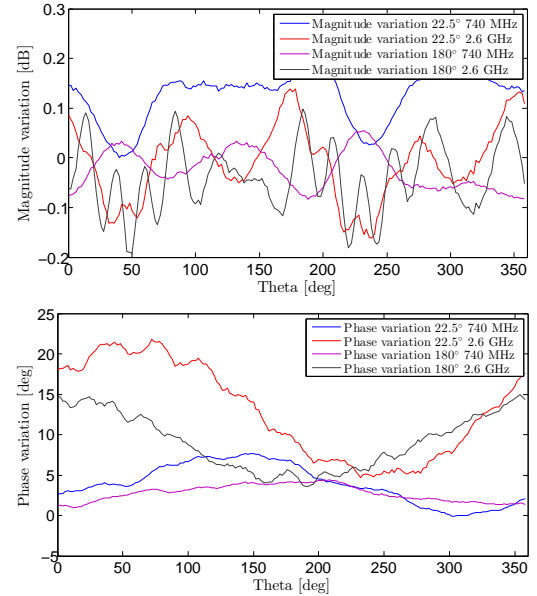

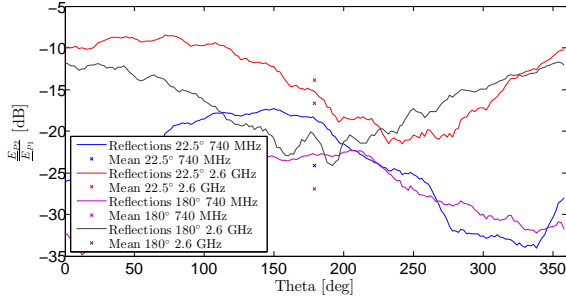Figure 6: Measured variations in magnitude and phase at 2.6 GHz.

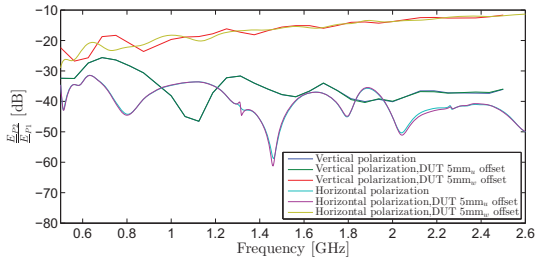Figure 7: Measured level of the reflections at 2.6 GHz.

Figure 8: Level of the reflections if the DUT is misplaced during the test.

probe alone measurement) and the second measurement (two probes), the accuracy of measurement is compromised.

Simulation sets are performed, where the DUT is misplaced by 5 mm between the first and second simulation. The misplacement occurs either in the w direction, or in the u direction, according to the axes detailed in Fig. 2b. The levels of reflection are calculated when the DUT has moved during the test. They are plotted in Fig. 8 for the 22.5 degrees case, in both polarizations.

The simulation results show a reflection level up to -10 dB. However, it does not mean that the reflections are higher. It means that the reflections cannot be accurately calculated, because of the misplacement of the device during the test. A tolerance of less than 5 mm is required to measure the level of reflections due to additional probes in the chamber. Alignment of the device on w-axis is particularly critical. It can be seen on Fig. 8 that misplacement causes the largest inaccuracy, when happening along w-axis. That is because the distance, thus the phase, exhibit a larger variation. Additionally, one can note that the impact of misplacement increases with frequency. This can cause calibration and repeatability issues at the high bands.

5   Conclusion

While the evaluation of the reflections in simulation is fairly straightforward, measurements rely on the mechanical stability of the setup. The accuracy of the position of the DUT between measurements can have a critical impact on determining the level of reflection in the setup, which has an impact on the testing abilities. The results show that misplacement of the DUT in the second measurement of only a few mm in the w-axis is critical and leads to not being able to measure the reflections in the setup. Particular care needs to be given to relative positions during successive measurements and tolerance for the placement of the DUT relative to the center of the ring needs to be determined prior to testing.

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