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Verification of Emulated Channels in Multi-Probe Based MIMO OTA Testing Setup

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***Abstract*—MIMO OTA testing methodologies are being intensively investigated by CTIA and 3GPP. Different channel emulation techniques to create a desired propagation environment in an anechoic chamber have been proposed in the literature. In this paper, the focus is on the measurement verification of two channel emulation techniques, namely plane wave synthesis and prefading signal synthesis in a practical multi-probe anechoic chamber setup.**

***Index Terms*—multi-probe, MIMO OTA testing, anechoic chamber, plane wave synthesis technique, prefading signal technique, measurement verification.**

I. Introduction

Multiple input multiple output (MIMO) technique is an attractive and promising technology to improve performance of wireless communication systems. With MIMO technology being adopted by new wireless technologies such as LTE, LTE-Advanced and WIMAX, mobile network operators and manufactures urgently require standard test methods to test the MIMO device performance. The most realistic way to test MIMO devices is to test them as they are used in realistic scenarios. MIMO over the air (OTA) testing, which is considered as a promising solution to evaluate MIMO device performance in realistic situations, has attracted huge interest from both industry and academia [1]. Standardization work for the development of the MIMO OTA test methods is ongoing in CTIA, 3GPP and IC1004.

Many different MIMO test methods have been proposed which vary widely in how they emulate the propagation channel. Size and cost of the testing system are also quite different for various proposals. An overview of different test methodologies under consideration was presented in [2].

One promising approach is a multi-probe anechoic chamber based method where multipath environments can be physically emulated in a controllable manner. The main challenges are how to generate realistic temporal and spatial characteristics of the channel. Two techniques have been proposed and investigated. One technique is the plane wave synthesis (PWS) technique[4], [10]. The PWS technique can be extended for generation of frequency and spatially selective fading radio channel models [4]. The other technique is named prefading signal technique (PFS) and has been implemented in commercial tools [3], [4], [5].

Only very few publications have addressed the measurement verification of these techniques in a practical multi-probe based MIMO OTA testing setup in the literature. In [10], the PWS technique was verified by measurements in a preliminary setup for vertical polarization. Wood masts were used to support and fix the OTA probes. A more accurate multi-probe configuration inside anechoic chamber is built in Aalborg university in order to alleviate intensive and time-consuming probe placement calibration. Also, this setup will decrease the probe placement inaccuracies including orientation error and location mismatch, which will be critical to the accuracy of field synthesis [11]. Paper [12] presents some experimental and simulated results applying the PFS method. However, measured temporal characteristics such as power Doppler spectrum (PDS) and temporal correlation function (TCF) were not shown and compared with simulation results. Also, Virtual uniform linear array (ULA), that is, one dipole positioned on different locations, was used for spatial correlation investigation, and hence the antenna coupling effects were excluded. Two practical dipoles are used in the measurements for spatial correlation study, and the PDS and TCF were investigated.

The main contributions of this work are:

- Investigation on measurement uncertainty level of a practical MIMO OTA test system.
- Investigation on how well we can approach a plane wave inside a test zone with a more accurate multi-probe configuration.
- Investigation on how well we can recreate the desired channel (both temporal and spatial characteristics) by PFS technique in a practical setup.

II. Measurement system

A. Configuration of MIMO OTA setup

Figure 1 illustrates a general setup for the multi-probe anechoic chamber based method. Probes are located on a horizontally oriented ring and a device under test (DUT) is placed at the center of the anechoic chamber.

Figure 2 shows the practical anechoic chamber setup in the measurement system. 16 dual polarized horn antennas are equally spaced and fixed on a metallic OTA ring. The OTA ring is covered by absorbers to avoid reflections during the test. Two Elektrobit channel emulators F8 are used to feed the probes (as shown in Figure 2).

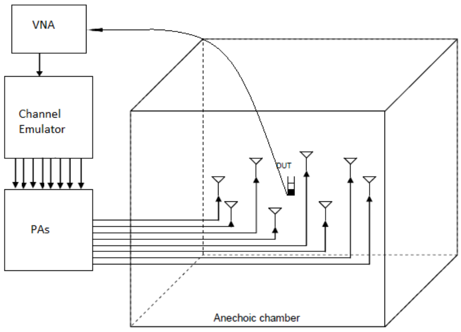

Figure 1. An illustration of the MIMO OTA setup. The measurement system used for verification purpose consists of a Vector Network Analyzer (VNA), one or several channel emulators, an anechoic chamber, dual polarized horn antennas, DUT, turntable that supports the DUT, cables and power amplifiers. The test zone defines the maximum dimension of the DUT and is an area where the target channel characteristics can be reproduced with certain accuracy.

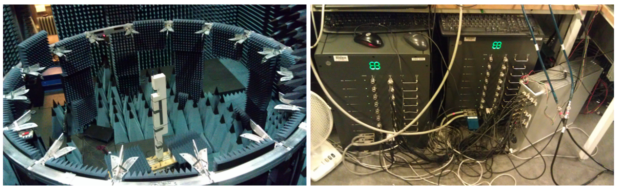

Figure 2. Practical anechoic chamber setup in the measurement system (left) and the two Electrobit F8 channel faders used in the measurement (right)

III. Channel Emulation techniques

A. Static PWS technique

The basic idea of PWS is that a plane wave with arbitrary impinging AoA can be created inside the test zone by selecting appropriate complex weights for the probes, as detailed in [4] for vertical polarization. For the sake of simplicity, same notations are adopted in this paper. One constraint with the practical system is that probe weights are limited since the output gain of channel emulator is constrained to 0dB. Weights g_k for a vertical polarized (z-polarized) single plane wave can be obtained by solving the optimization problem as follows:

$$\min_{\mathbf{G}} \|\mathrm{F}_{\boldsymbol{z}}\boldsymbol{G} - \mathrm{T}_{\mathrm{z}}\|_2^2 \quad (1)$$

$$\text{s. t.} \quad 0 \leq |g_k| \leq 1 \, \forall k \in [1, K]$$

where $||\cdot||_2$ denotes the second order norm. $\mathrm{G} = \{g_k\}$ is a vector of the complex weights for probes. $\mathrm{T_z}$ is a vector of vertical polarized complex target field. F_z is a transfer matrix of known coefficients from probes to locations inside the target area. The optimization is a quadratic programming problem with linear constraints, which can be solved using the cvx package in Matlab with high efficiency [13].

B. PFS technique

The PFS was described in [5], [8] and [5]. In this technique, temporal characteristics of the channel are reproduced with the help of a channel emulator, so the focus is on reproducing spatial aspects of the channel, which is new and critical as we extend single input single output (SISO) OTA to MIMO OTA testing. For MIMO OTA testing, it is desired with a limited number of probes to generate an arbitrary number of clusters with associated arbitrary Angle of Arrivals (AoAs) and Azimuth Spreads (ASs) impinging the test zone. The essence of this technique is to find proper power weightings for each probe such that channel spatial characteristics can be created. Spatial correlation has been selected as the main figure of merit to characterize the channel spatial information.

The antenna pattern is generally assumed to be omnidirectional for channel emulation purpose. The target spatial correlation is calculated as:

$$\rho = \int_{-\pi}^{\pi} \exp(-j2\pi \frac{d}{\lambda} \sin(\phi)) PAS(\phi) d\phi \quad (2)$$

where PAS is the target power azimuth spectrum distribution of the clusters and d is the antenna separation between the two antennas.

The emulated spatial correlation can be calculated as:

$$\widetilde{\rho} = \sum_{k=1}^{K} P_k \cdot \exp(-j2\pi \frac{d}{\lambda} \sin(\theta_k)) \quad (3)$$

where P_k and θ_k are the power weights and angular location for the kth probe, respectively. The power weights can be obtained by solving the optimization problem as follows:

$$\min_{\mathrm{P}} \|\widetilde{\rho}(\mathrm{P}) - \rho\|_2^2 \quad (4)$$

$$\text{s. t.} \quad 0 \leq P_k \leq 1 \, \forall k \in [1, K]$$

where $\mathrm{P} = \{P_k\}$ is a vector of the probes power weights.

Spatial correlation between antenna u and v considering the antenna pattern can be determined according to:

$$\rho_{ant} = \frac{\int_{-\pi}^{\pi} G_u(\phi) \cdot G_v^*(\phi) \cdot PAS(\phi) d\phi}{\sqrt{\int_{-\pi}^{\pi} |G_u(\phi)|^2 PAS(\phi) d\phi \cdot \int_{-\pi}^{\pi} |G_v(\phi)|^2 PAS(\phi) d\phi}} \quad (5)$$

where $G_u(\phi)$ and $G_v(\phi)$ are the complex radiation pattern for antenna u and v respectively.

Similarly, once the optimum power weights vector P is found in 4, the emulated spatial correlation with antenna pattern can be written as:

$$\widetilde{\rho}_{ant} = \frac{\sum_k G_u(\theta_k) \cdot G_v^*(\theta_k) \cdot P_k}{\sqrt{\sum_k | G_u(\theta_k) |^2 P_k \cdot \sum_k | G_v(\theta_k) |^2 P_k}} \quad (6)$$

The measured spatial correlation between antenna u and v is calculated according to definition:

$$\rho_{meas} = \frac{\sum_i (s_{u_i} - \overline{s}_u)(s_{vi} - \overline{s}_v)}{\sqrt{\sum_i (s_{u_i} - \overline{s}_u)^2 \cdot \sum_i (s_{vi} - \overline{s}_v)^2}} \quad (7)$$

where s_{u_i} and s_{v_i} are the complex signals received at antenna u and v at ith time instant respectively. $\overline{s}_u$ and $\overline{s_v}$ are the mean received signal over time at antenna u and v, respectively.

IV. Measurement results

A. MIMO OTA setup accuracy level investigation

System accuracy measurements help us define sources of measurement uncertainty. Main testing items include:

- Investigation of power coupling level between OTA probes for both polarizations.
- Investigation of reflection level inside the anechoic chamber for both polarizations
- Investigation of the amplitude and phase drifting level of the MIMO OTA setup for each component of the measurement system and for the whole system should be investigated.
- Checking the stability of the pedestal. The pedestal that supports the DUT is not completely static shortly after sledge moving or turntable rotating. It is important to find the required waiting time.
- Investigation of inaccuracy level at test zone center when rotating the dipole.

The results were reported in detail in [14] and a summary of the measurement results for the MIMO OTA setup accuracy investigation is shown in Table I.

To sum up, mainly three factors contribute to inaccuracies of the measurements: pedestal instability after sledge movement, field variation over rotation at test zone center and reflections inside the chamber. Those phenomenon will affect our results for PWS and PFS verification measurements. Those inaccuracies are probably caused by cable reflections, rotary joint, non-omnidirectional antenna radiation pattern, dipole placement error (not perfectly vertically positioned or not ideally located in the test zone center) or reflections inside chamber. [1]

B. Measurement results for PWS technique

In order to measure the field synthesized by the PWS technique, a Satimo calibration sleeve dipole is fixed on the turntable and rotated on a circle with various fixed radiuses to the test zone center. In order to obtain enough samples to measure the field inside and outside the test zone, the sledge is rotated in 1 degree steps and 11 points separated with 1cm are sampled for every orientation on the sledge.

A single plane wave with AoA 90^0 at frequency 2450MHz was considered as the target synthesis scenario. Simulated and measured phase variations over orientation of the turntable are shown in Figure 3. The measured phase variation follow the synthesized field quite well. Deviations between measurement and simulation in term of power and phase for various radius are shown in Table II. Compared with the results reported in [10], better match between measurement and simulation is achieved. [2]

Table I
Results from accuracy investigation of the MIMO OTA setup

Area of investigation	Results
Power coupling between probes	• Low frequency co-polarized: < -30 dB • High frequency co-polarized: < -40 dB • Cross-polarized (self): < -20 dB
Reflection level inside anechoic chamber	• The largest reflection, which is located 0.2m away from the main peak, is around 10 dB less than main peak. • All the other reflections are at least 25dB lower than the main peak
F8 signal drift	• Maximum Phase and power variation are 4 degrees and 0.2dB, respectively. • The signal is quite stable over time. 10 hour testing present similar results as 10 minute testing.
PA signal drift	• Maximum phase and power variation are 0.5 degrees and 0.3dB over 10 minutes, respectively. • Higher signal drifting level was observed during PA warm up stage.
Chamber signal drift	• Maximum phase and & power variation are 1.6 degrees and 0.16dB over 10 hours respectively.
Full OTA system signal drift	• At frequency 2450 MHz, maximum phase variation and maximum power variation are 5.7 degrees and 0.26dB over 6 hours respectively • At frequency 900 MHz, maximum phase variation and maximum power variation are 2.4 degrees and 0.1 dB over 10 hours respectively.
Turntable motion	• Required rotational settling time: 2 sec • Required radial settling time: 20 sec • Pedestal not stable after sledge movement
Inaccuracy level at center of test volume	• At frequency 900 MHz, maximum power and phase variations are as high as 2dB and 10 degrees over orientations. • At frequency 2450 MHz, maximum power and phase variations are as high as 1dB and 20 degrees over all orientations.

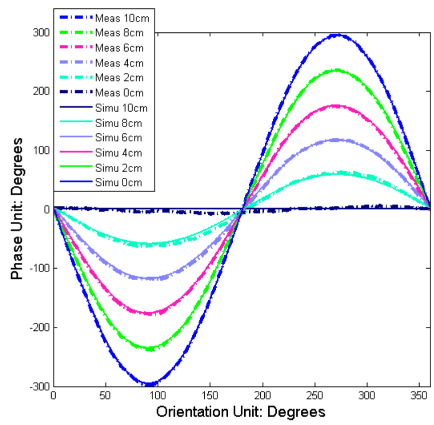

Figure 3. Deviations between measured and simulated phase for various radius

[1]Detailed analysis of those inaccuracies is ongoing and results will be included in the final paper.

[2]More target scenarios with one or two fader units will be included in the full paper.

Table II
STATISTICS OF PHASE AND POWER DEVIATIONS FOR VARIOUS RADIUS

Radius (unit: cm)	0	2	4	6	8	10
Max power deviation (dB)	0.6	0.5	0.4	0.4	0.4	0.4
Max phase deviation (degree)	8.7	7.6	5.2	5.0	5.4	4.5

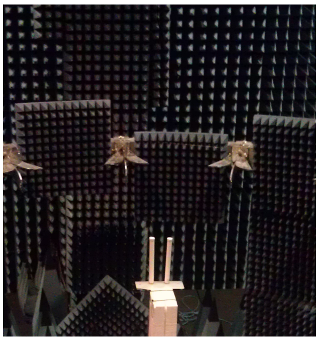

Figure 4. An illustration of two sleeve dipoles at 2100MHz used in the measurement system

C. *Measurement results for PFS technique*

As shown in Figure 4, two sleeve dipoles separated by 0.5λ were used for PFS spatial correlation verification measurements. The measured radiation patterns for the two antennas are shown in Figure 5. Due to the close-by antenna coupling impact, the dipole antenna patterns are not omnidirectional. Also, the two dipole antenna patterns are not perfectly mirrored due to the fact that both dipoles are not perfectly vertically placed.

For PFS verification measurements, we only consider single cluster case from 3GPP Spatial Channel Model(SCM) model for simplicity. Also only vertical polarization is considered in the measurement.

Four scenarios are synthesized and measured. The details are listed in Table III. The same spatial correlation curves are expected for scenario A and scenario B. One channel emulator and 8 probes were used to emulate scenario A, B and D, while two channel emulators and 16 probes were used for scenario C.

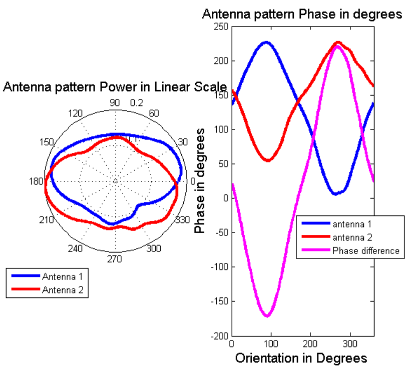

Figure 5. Measured radiation patterns of the two sleeve dipoles

Table III
SYNTHESIZED AND MEASURED SCENARIOS FOR PFS TECHNIQUES

Scenario name	Details
Scenario A	• Laplacian-shaped Single cluster with AoA=0 degrees and AS = 35 degrees • Direction of Travle (DoT): 0 degrees, Moblie speed : 20m/s
Scenario B	• Laplacian-shaped Single cluster with AoA=0 degrees and AS = 35 degrees • Direction of Travle (DoT): 90 degrees, Moblie speed : 20m/s
Scenario C	• Laplacian-shaped Single cluster with AoA=11.25 degrees and AS = 35 degrees • Direction of Travle (DoT): 0 degrees, Moblie speed : 20m/s
Scenario D	• Laplacian-shaped Single cluster with AoA=22.5 degrees and AS = 35 degrees • Direction of Travle (DoT): 0 degrees, Moblie speed : 20m/s

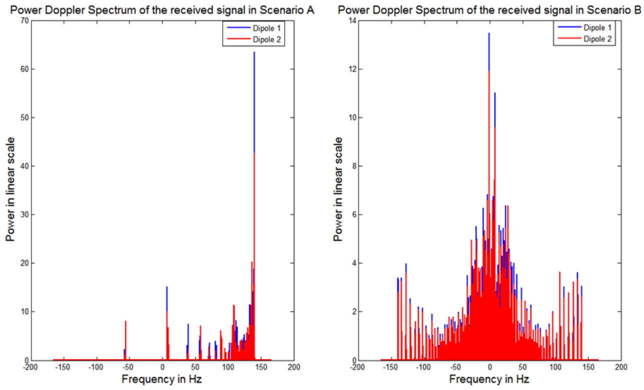

Figure 6. PDS of the signals reveived by the two dipoles at certain orientation in scenario A(left) and B (right)

1) *Temporal characteristics :* The cumulative distribution function (CDF) for the signal received at the two dipoles at certain orientation are Rayleigh distributed in all the considered scenarios in the measurements, as expected.

The PDS of the signals received by the two dipoles at certain orientation in scenario A and B are shown in Figure 6, similar tendencies can be observed for both scenarios when compared with target PDS for Laplacian distributed PAS. It is difficult to directly compare PDS due to fact that channels are created by ray based model in the channel emulator. We can transform the spiky power Doppler spectrum to a continuous TCF. [3]

2) *Spatial Characteristics :* Comparison between simulated and measured spatial correlation for scenario A, B, C and D are shown in Figure 7. The equations for calculating the spatial correlations are detailed in Section III-B. The antenna patterns are assumed omnidirectional for target spatial correlation and emulated spatial correlation. As we can see in the results, the simulations and measurements match quite well for all the considered scenarios.

The correlations with measured antenna pattern are quite different from correlations with omnidirectional antenna pattern.

The deviations between the target spatial correlation and the emulated spatial correlation in scenario D is larger than the deviations in scenario A. This is due to the fact that emulation

[3]This work will be performed and included in the final paper.

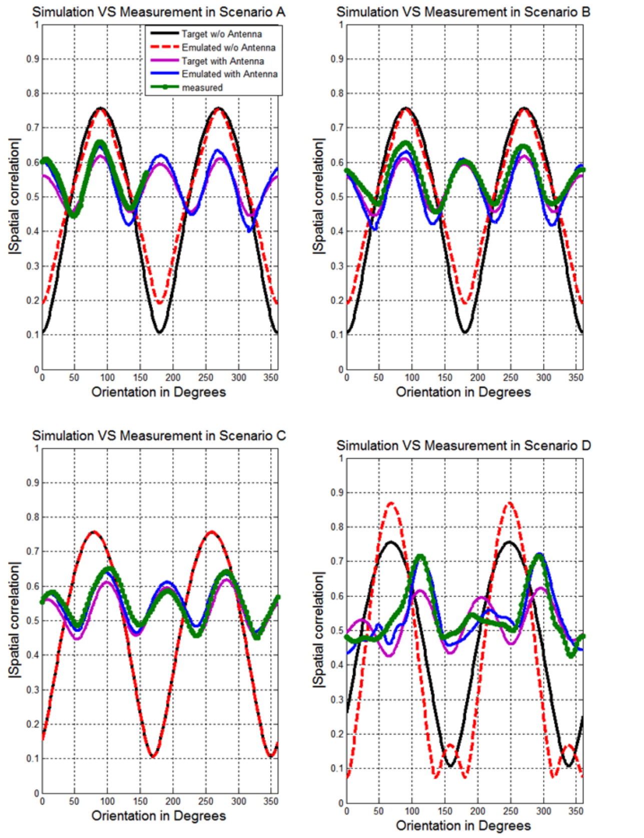

Figure 7. Comparison between simulated and measured spatial correlation for scenario A (up left), B (up right), C (down left) and D (down right)

accuracy depends on the channel. The test zone performance is expected to be the best if the cluster is arriving to the test zone from the direction where one of the OTA antennas are located (e.g. AoA = 0^o), while the worst case is the cluster impinging from an angle exactly in the middle of two adjacent OTA probes (e.g. AoA = 22.5^o in 8 probe configuration).

Deviation between target spatial correlation and emulated spatial correlation in scenario C is much smaller than in other scenarios because the number of probes used in scenario C is 16. The more probes we use, the better emulation accuracy is expected.

The deviation between the emulated and target spatial correlation with antenna pattern is expected to be larger than without antenna pattern. The power weights are optimal for the omnidirectional antenna case, non-omnidirectional antenna pattern will effectively change the power weights.

V. Conclusion

In this contribution, a new multi-probe based MIMO OTA setup at Aalborg University is introduced. Detailed investigation on the system accuracy shows that there are mainly three factors which will contribute to inaccuracies of the measurements: pedestal instability after sledge movement, field variation over rotation at test zone center and reflections. PWS verification measurement results show that good match can be achieved between the measured and simulated static field in the new setup. Promising results can be obtained in PFS verification measurements. Good matching in terms of both temporal and spatial characteristics between the measured and simulated channels can be achieved.

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