Impact of Probe Placement Error on MIMO OTA Test Zone Performance

Fan, Wei; Nielsen, Jesper Ødum; Carreño, Xavier; Franek, Ondrej; Knudsen, Mikael; Pedersen, Gert Frølund

Impact of Probe Placement Error on MIMO OTA Test Zone Performance

Wei Fan[1], Jesper Ø. Nielsen [1], Xavier Carreño[2], Ondrej Franek [1], Mikael B. Knudsen [2], Gert F. Pedersen[1]

[1] APNet, Department of Electronic Systems, Faculty of Engineering and Science, Aalborg University,
DK-9220 Aalborg, Denmark {wfa, jni, of, gfp}@es.aau.dk

[2] Intel Mobile Communications, DK 9220 Aalborg, Denmark {xavier.carreno, mikael.knudsen}@intel.com

Abstract—**Standardization work for MIMO OTA testing methods is currently ongoing, where a multi-probe anechoic chamber based solution is an important candidate. In this paper, the probes located on an OTA ring are used to synthesize a plane wave field in the center of the OTA ring, and the EM field for each probe is obtained using FDTD simulation. This paper investigates the extent to which we can control the field structure inside the test zone where the device under test is located. The focus is on performance deterioration introduced by probe placement error including OTA probe orientation error and location mismatch, which are general non-idealities in practical MIMO OTA test systems.**

I. INTRODUCTION

Multiple Input Multiple Output (MIMO) technique, which employs multiple antennas both at the transmitter and receiver side in communication systems, has been an attractive and promising methods to increase wireless system performance in terms of data throughput and reliability. New wireless technologies such as LTE, LTE-Advanced and WiMAX require the employment of multiple antennas in mobile terminals.

Mobile network operators and manufactures urgently require standard test methods which are suitable to test the MIMO device performance. The most realistic way to test MIMO devices is to test them as they are used in the final product, so-called MIMO Over-The-Air (OTA) testing. Standardization work for the development of MIMO OTA test methods is currently ongoing. Several approaches were proposed and are under investigation. One of the candidates is the multi-probe anechoic chamber based MIMO OTA testing method [1].

To ensure accurate and reliable OTA test results, the test system must produce an accurate test environment in the entire physical region that contains the device. There is a great research interest to accurately emulate plane waves with arbitrary directions and polarizations illuminating the test zone. [3][4][5]. For plane wave field synthesis with multiple probes in an anechoic chamber, the fundamental question is to which extent we can control the field structure inside the test zone where the device under test is located. Two key issues must be addressed:

- What is the relation between the physical dimension of the test zone and the number of OTA antennas for a given emulation accuracy?

- Additionally, what is the impact of location error and orientation error of the probe antennas on the test zone field behavior? Those system non-idealities will further deteriorate the emulation accuracy.

In [3], the synthesis of fields with multiple probes was discussed based on spherical wave expansion. The power deviation of the synthesized field is studied. However, the study was based on the assumption that the OTA probes are located in the far field so that ideal plane wave is generated from each OTA probe. Also, only the power deviation was selected to evaluate the field performance. Phase calibration of the MIMO OTA system is required for field synthesis inside the test zone and hence phase deviation over the test zone is also critical to investigate for field synthesis [4]. In [5], the plane wave synthesis technique was verified by measurement in a practical MIMO OTA setup. The multi-probe setup is shown in Figure 1 (left) . As explained in the paper, deviations between measurement and simulations have been found with respect to phase and power after phase and amplitude calibrations are performed for each probe. OTA probe antenna placement errors were identified as possible factors accounting for these inaccuracies.

A more accurate multi-probe configuration is illustrated in Figure 1 (right). All the probes are fixed on a metallic ring, which is covered by absorbers. This configuration requires no intensive and time-consuming probe placement calibration with a laser-positioner and system accuracy is improved.
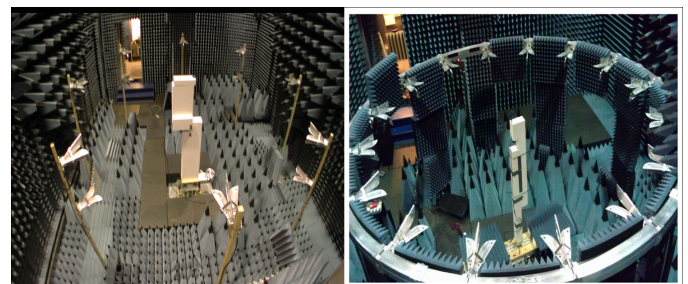

Figure 1. Multi-probe setup inside an anechoic chamber in [5] (left) and an accurate multi-probe configuration (right)

In this paper, plane wave fields are synthesized in a simple way where weighting of the OTA probes is based on the Least Square Error (LSE) optimization technique, which is detailed in II.B. Deviations due to location and orientation mismatch of

the probes are investigated in detail. Statistics of both power and phase deviation inside the test zone are presented.

II. METHOD

A. OTA probe field simulation

The study is based on a circular two dimensional multi-probe system where 8 OTA antennas are located on a horizontally oriented ring with equal spacing between them. The radius of the OTA ring is 2.5m. Simple dipole antennas are orientated perpendicularly to the OTA ring in the FDTD simulation. The study is carried out at 2.655GHz and cell resolution is selected to be 0.005m. The probe locations in the FDTD simulation are illustrated in Figure 2. Angle of Arrival(AoA) of the plane wave is defined in the counter-clockwise direction and AoA 0 degrees is defined as the wave illuminating the test zone from probe one. Compared with pure field radiation with far field assumption, FDTD simulation is considered for field simulation because it is a general approach that can incorporate near field effects of directive antennas and include backscattering effect of other probes, though negligible in this study. The EM field for each OTA probe is obtained using Finite Difference Time Domain (FDTD) simulator developed at APNet, Aalborg University [2].

There are two embedded errors in the FDTD simulations that need special attention. First, FDTD simulations suffer from dispersion error which is caused by the discretization of the continuous field. Waves traveling in directions parallel to the grid (odd probes) have lower velocity, which will contribute to a faster decreasing phase and magnitude. Second, in the FDTD simulation, it is impossible to locate 8 probes exactly on the circle. Discretization of the locations for the OTA probes with even number is required. This discretization introduces a phase shift of up to approximately 10 degrees, while the power variation is negligible. Considering the fact that the test zone is located in the far field of the OTA probes in the simulation, we can remove these effects by normalizing the fields of the OTA probes with even number to the ones with odd number so that the field responses are equal for all the OTA probes. For the current work, we consider only the case with vertically polarized target field.

According to the relation between the required number of OTA antennas and the dimension of the test zone proposed in [3], the physical dimension of the test zone will be around 0.7 wavelengths as we select number of probes to be eight.
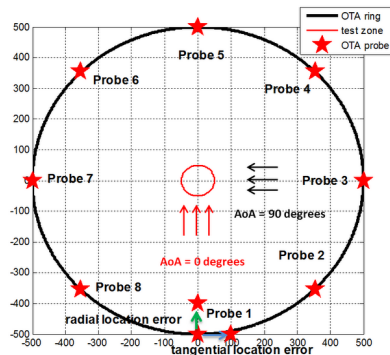

Figure 2. An illustration of OTA probe location [unit: cells]

B. Plane wave synthesis and optimization

In this study, the target plane wave field in the test zone is a field with uniform power distribution and ideal linear phase front along the impinging plane wave direction. The target field vector $\mathbf{T}_{1 \times M}$ contains the field for M sampled points inside the test zone (with diameter 0.7 wavelength). The element (i,j) in the transfer matrix $F_{K \times M}$ is defined by the field variation from i-th OTA probe to the j-th sample point in the test zone which is obtained from the FDTD simulation. Here K denotes the number of OTA probes. Then the complex weighting vector $\mathbf{G}_{1 \times K}^{Opt}$ of the OTA probes is obtained by using LSE technique:

$$\mathbf{G}_{1 \times K}^{Opt} = \arg \quad \min_{\mathbf{G}_{1 \times K}} \left\| \mathbf{G}_{1 \times K} \mathbf{F}_{K \times M} - \mathbf{T}_{1 \times M} \right\| \qquad (2)$$

The number of samples inside the test zone M must be equal or larger than the OTA probe number K to solve the equations. In this study, the total allocated power for the 8 OTA probes are assumed to be the same.

C. Figures of Merit (FoM) to characterize test zone

With the optimum weighting vector $\mathbf{G}$, the synthesized field $\widetilde{\mathbf{T}}$ inside the test zone can be calculated by:

$$\widetilde{\mathbf{T}} = \mathbf{G} \mathbf{F} \qquad (3)$$

The power at the test zone center in the scenario where the AoA of synthesized plane wave is 0 degrees is normalized to 0dB and selected as a reference for the following study. The phase deviation is defined as the deviation of synthesized field phases from the ideal phase plane :

$$E = phase(\widetilde{\mathbf{T}}) - phase(\mathbf{T}) \qquad (5)$$

As illustrated in Figure 3, a plane wave impinging the test zone with AoA 270 degrees is synthesized, the phase deviations between simulated phase plane and ideal phase plane is shown in Figure 5.
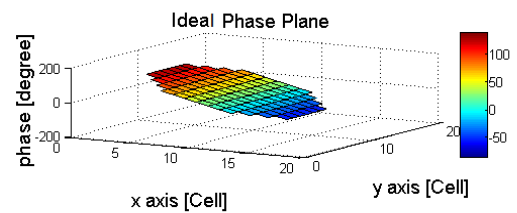

Figure 3．Simulated and target phase plane of waves with AoA 270 degrees

Figure 4 and Figure 5 show the statistics of the power and phase deviations. Over the whole test zone, the maximum power variation is 0.5 dB while the maximum phase variation is 3 degrees. STD error and error delta corresponds to the standard deviation and maximum variation of the error, respectively. Note that errors without presence of probe placement error are due to limited number of probes. Error levels will decrease with more probes.
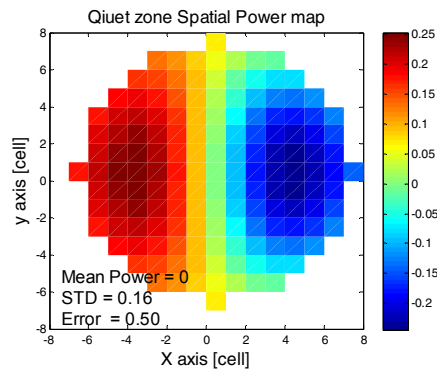
Qiuet zone Spatial Power map

Mean Power = 0
STD = 0.16
Error = 0.50

Figure 4. Power deviation and statistics inside test zone.(unit: dB)

Phase difference and error statistics

Mean Error = -1.51
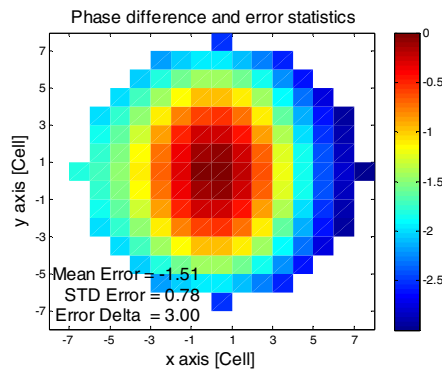STD Error = 0.78
Error Delta = 3.00

Figure 5. Phase deviation and statistics inside test zone.(unit: degree)

III.   SIMULATION RESULTS

A. Results for ideal scenario

If the synthesized plane wave illuminates the test zone from the direction where one of the OTA antennas are located, the test zone performance is expected to be the best since essentially excitation of only one relevant probe will synthesize almost the correct field. While the worst case is the synthesis of plane wave field impinging from an angle exactly in the middle of two adjacent OTA probes. This is verified by the simulation results as illustrated by the red curve in Figure 7. Table I shows the deviation with respect to phase and power for the best case and worst case. The offset of the mean power varies with AoA of the synthesized plane wave field and is due to the coherent summation of fields of different probes. One way to deal with it is to make the total power of probes flexible to compensate the offset. Table I also presents the theoretical results we can possibly obtain by using only 8 OTA probes when the probe configuration is perfect.

TABLE I DEVIATION STATISTICS FOR BEST CASE AND WORST CASE

	Statistics	Best Scenario	Worst Scenario
Phase [degree]	Mean error	-1.51	-1.49
	Error STD	0.78	1.19
	Error delta	3.00	6.91
Power [dB]	Mean	0	-4.75
	STD	0.16	0.19
	Delta	0.50	0.85

B. Results for non-ideal scenario

1) Orientation error study

If directional antennas are selected as OTA probes, orientation error will effectively modify the **G** vector and hence modify the field behavior in the test zone. Note that simulation results highly depend on the antenna pattern of the probe antenna. We investigated the impact of orientation error introduced by using a horn antenna as described [6].

The spherical coordinate system adopted here is described in Figure 6. For the sake of simplicity, we assume that only OTA probe one presents orientation error, while the others remain in the ideal orientation. We will also only present the simulation results for θ orientation error in the following study, but we should expect both orientation errors in practical measurement systems.
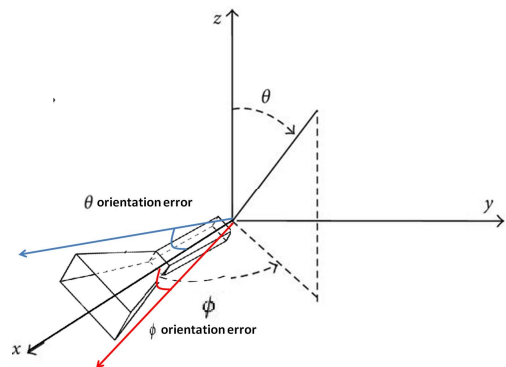
Figure 6. An illustration of orientation error

Figure 7 show the simulation results for plane wave with different AoAs in terms of mean and standard deviation of phase errors. Four curves correspond to phase performance with ideal antenna orientation, 5, 10 and 15 degrees orientation error respectively. As we can see, probe orientation error will slightly deteriorate field performance. At AoA 0 degrees, since probe one is most dominant, the mean power and mean phase shift introduced by orientation error correspond to the power and phase shift in the antenna radiation pattern, while the test zone "quietness" is preserved. At AoA 45 degrees, probe two with ideal orientation is dominant, so field performances as ideal case are observed. Plane wave of AoA 22.5 degrees is still the most critical scenario to synthesize. Table II lists the statistics for all the scenarios for the most critical case.

TABLE II STATISTICS FOR ORIENTATION ERROR STUDY IN MOST CRITICAL AoA CASE

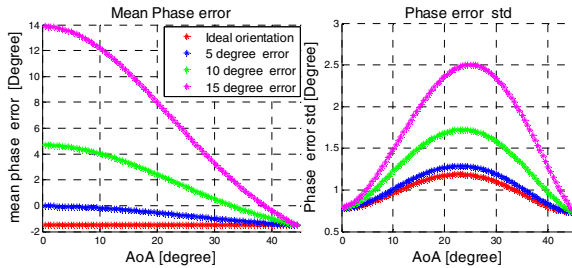|	Statistics	Ideal orientation	5 degrees	10 degrees	15 degrees
Phase [degree]	Mean error	-1.49	-0.65	1.96	6.83
	Error std	1.19	1.29	1.72	2.47
	Error delta	6.9	7.22	8.17	10.39
Power [dB]	Mean	-4.75	-4.85	-5.11	-5.46
	STD	0.19	0.21	0.31	0.60
	Delta	0.85	0.98	1.49	2.54

Figure 7. Phase error statistics for theta orientation error study

2) Location mismatch study

For location mismatch study, ideal antenna orientation is assumed. Antenna location mismatch is classified into tangential location error (perpendicular to the OTA ring) and radial location error (along the radius), which is illustrated in Figure 2. For the sake of simplicity, we assume that only OTA probe one presents location mismatch error, while again the others remain in the ideal position.

a) Tangential location error

Figure 8 show the simulation results for plane waves with different AoAs in terms of mean and standard deviation of phase errors. At AoA 0 degrees, OTA probe one is most dominant, the mean power and mean phase shift with respect to the ideal location correspond to the power and phase variation introduced by the propagation distance difference.
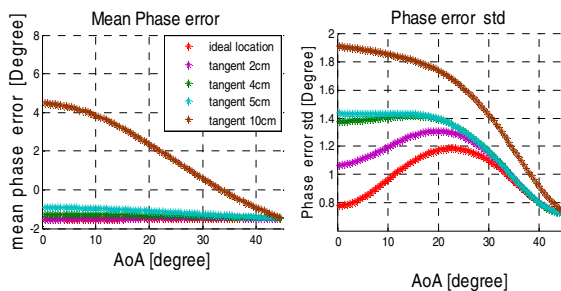

Figure 8. Phase statistics for tangential location error study

b) Radial location error

Radial location error is expected to be most critical since large phase shifts are introduced. As illustrated in Figure 9, radial error of 3cm will dramatically change the field performance and the synthesized field will be no longer the plane wave field with the target AoA.
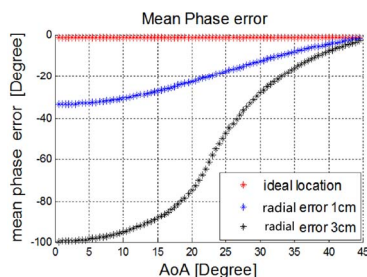

Figure 9. Phase statistics for radial location error study

At AoA 0 degrees, probe one is most dominant. The mean power and mean phase shift with respect to the ideal location correspond to the power and phase variation introduced by the propagation distance, that is, 1cm radial location error corresponds to approximately 32 degrees phase shift.

However, we found out that the synthesized field with radial location error of 3cm is still approximately a plane wave but with a non-desired AoA. For example, if we want to generate a field with AoA 10 degrees with radial error of 3cm for probe one, the actual synthesized field is with AoA approximately 0.1 degree, which is significantly different from the target AoA. This effect will be problematic for plane wave synthesis.

IV. CONCLUSION

In this paper, the impacts of errors in probe location and orientation on the test zone performance are investigated. Power and phase deviations vary with the AoA of the synthesized field and were found. Up to 15 degrees orientation error was studied, deviations of up to approximately 10 degrees and 2.5 dB for the phase and power, respectively. With the presence of tangential errors of 10cm, up to 1.5dB power deviations were found. Radial location errors are shown to be most critical, since the synthesized field for a radial error of 3cm is no longer the plane wave field with the target AoA. Note, it is assumed that only one OTA probe presents placement errors, and the impact of each placement error is investigated independently, while in practical measurement setup we should expect all forms of placement errors on all the probes.

V. REFERENCES

[1] Measurement of radiated performance MIMO and multi-antenna reception for HSPA and LTE terminals (Release 11) 3GPP TR 37.976 V1.5.0 (2011-05), R4-112505.

[2] A. Taflove, ed., Computational Electrodynamics: The Finite-Difference Time-Domain Method, Third Edition. Norwood, MA: Artech House, 2005.

[3] T. A. Laitinen, P. Kyosti, J.-P. Nuutinen, and P. Vainikainen, "On the number of OTA antenna elements for plane-wave synthesis in a MIMO-OT A test system involving a circular antenna array," in The 4th European Conference on Antennas and Propagation (EuCAP'lO), Barcelona, Spain, Apr. 12-16, 2010.

[4] Pekka Kyösti, Tommi Jämsä, and Jukka-Pekka Nuutinen, "Channel Modelling for Multiprobe Over-the-Air MIMO Testing," International Journal of Antennas and Propagation, vol. 2012, Article ID 615954, 11 pages, 2012. doi:10.1155/2012/615954.

[5] W. Fan, X. Carreño, J. Nielsen,K. Olesen, M. Knudsen, G. Pedersen. "Measurement Verification of Plane Wave Synthesis Technique Based on Multi-probe MIMO-OTA setup", Proc. Vehicle Technology Conference (VTC 2012-Fall), 2012 IEEE 76th, Québec City, Canada, September 3-6 , 2012. (accepted)

[6] O. Franek, G. F. Pedersen, "Spherical Horn Array for WideBand Propagation Measurements," IEEE Transactions On Antennas And Propagation, 59, 2011 (7) p. 2654-2660.