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Measurement Uncertainty Investigation in the Multi-probe OTA Setups

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***Abstract*—Extensive efforts are underway to standardize over the air (OTA) testing of the multiple input multiple output (MIMO) capable terminals in COST IC1004, 3GPP RAN4 and CTIA. Due to the ability to reproduce realistic radio propagation environments inside the anechoic chamber and evaluate end user metrics in real world scenarios, the multi-probe based method has attracted huge interest from both industry and academia. This contribution attempts to identify some of the measurement uncertainties of the practical multi-probe setups and provide some guidance to establish the multi-probe anechoic chamber setup. This contribution presents the results of uncertainty measurements carried out in three practical multi-probe setups. Some sources of measurement errors, i.e. cable effect, cable termination, etc. are identified based on the measurement results.**

***Index Terms*—MIMO OTA, multi-probe, anechoic chamber, measurement uncertainty, plane wave synthesis**

I. Introduction

The Multiple Input Multiple Output (MIMO) technique is a promising technology to improve wireless communication systems [1]. With MIMO technology being adopted by new wireless technologies such as LTE [2]. Over the air (OTA) testing of MIMO capable terminals has attracted huge attention from both industry and academia [3], where a multi-probe anechoic chamber based method is a promising candidate. Various contributions have addressed issues related to OTA testing of MIMO capable terminals in a multi-probe anechoic chamber, i.e. channel modeling [4]–[6], validation of the implemented channel models [7], [8], end user metrics evaluation [9].

As a mandatory step for standardization, it is required to analyze the sources of errors and uncertainties in the measurements. Very few contributions have addressed the measurement uncertainties in a multi-probe OTA system. In [10], uncertainty analysis in total radiated power (TRP) and total isotropic sensitivity (TRS) is specified. However, the measurement uncertainty analysis defined for OTA testing of single antenna terminals will be not sufficient for the MIMO OTA testing, as the testing system, which includes one or several channel emulators, is more complicated. Furthermore, different figure of merits (FoMs) will be adopted for MIMO OTA testing. In [11], several sources of uncertainties and errors were listed and classified for the multi-probe setup. In recent 3GPP RAN4 meetings, measurement uncertainty evaluation of the multi-probe method has been discussed [12]. In [8], plane wave synthesis (PWS) in a practical setup was investigated and possible reasons for the deviations were briefed. In [13], measurement verification results of two channel emulation techniques, namely PWS and prefaded signal synthesis (PFS) in a practical multi-probe anechoic chamber setup were presented. Possible factors that introduce the measurements inaccuracies were discussed as well. Some deviations existed in the results and the exact causes were missing.

This paper attempts to compare and understand measurement uncertainty levels with different labs, i.e. at Aalborg university (AAU), Denmark, Motorola Mobility (MM), USA and ETS-Lindgren (ETS), USA., thus to show key aspects related to the multi-probe system setup design. Main contributions of this work are:

- Uncertainty measurements in three different practical multi-probe setups are presented. The sources of the errors that exist in the previous contributions are identified.
- Measurement results of the field synthesis for horizontal polarization are reported for the first time in the literature.

II. Multi-probe anechoic chamber setups and testing items

Figure 1 shows a simplified version of the multi-probe setup for testing a device under test (DUT). The DUT is placed on a pedestal in an anechoic chamber and surrounded by multiple probes mounted on an OTA ring. The probes are uniformly distributed located on a horizontally orientated ring with equal spacing in all the setups. The specifications of the three setups are detailed in Table I.

The main testing items of the measurement uncertainty investigations are detailed below:

a) Dipole radiation pattern measurements: The basic idea is to measure the radiation pattern of a calibration dipole which is located at the test area center. Ideally, the measured complex pattern should be constant over orientations. However, due to the system no-idealities, e.g. cable effect, dipole placement, etc. maximum gain and phase variations are up to 2dB and 10 degrees at 900MHz, and up to 1dB and 20 degrees at 2450MHz [13].

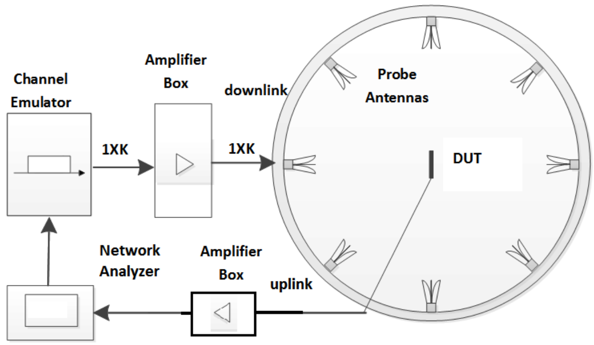
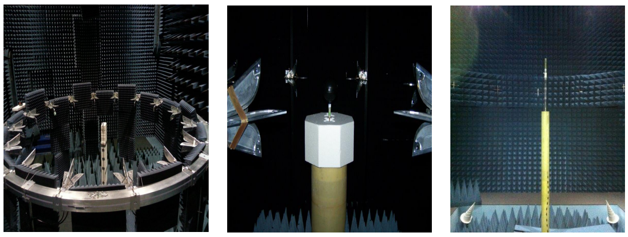


Figure 1. An illustration of the multi-probe based MIMO OTA setup. The main components are a vector network analyzer (VNA) or base station emulator (BSE), one or several radio channel emulators, an anechoic chamber, OTA probe antennas, power amplifiers (PAs) and a DUT.

Table I
SETUP SPECIFICATIONS

	AAU	MM	ETS
Chamber size	10m x 10m x 7m	3m x 3m x 2.4m	4.9m x 4.9m x 3.7m
OTA ring size	An aluminum ring with radius $R = 2$ meters. The ring is partially covered by absorbers, as shown in Fig. 2(a)	Radius $R = 1.2$ meters. Wood masts have been used to support and fix the horn antennas, as shown in Fig. 2(b)	A ring with radius $R = 2$ meters. The ring is fully covered by absorbers. The probes are loaded with absorbers, as shown in Fig. 2(c)
OTA probe	16 dual polarized horn antenna designed by AAU [14], as shown in Fig. 3(a)	8 dual polarized horn antenna designed by AAU, as shown in Fig. 2(b)	16 dual polarized Vivaldi antenna designed by ETS, as shown in Fig. 3(b)
Turntable	Polystyrene placed on top of the turntable to support the DUT, as shown in Fig. 4(a)	As shown in Fig. 4(b)	As shown in Fig. 4(c)
Channel emulator used	Two Anite Propsim F8s	Anite Propsim F16	Anite Propsim FS8 and Spirent VR5
Turntable move-ment	Rotational and linear slide combined movement supported	Rotational movement supported only	Rotational and linear slide combined movement supported
Cable to DUT	Cable directly connected to DUT	Choke and cartridge at various frequency bands used	Ferrite loaded cable used, as shown in Fig. 4(c)

b) Turntable stability: The turntable that supports the DUT is not completely static shortly after the turntable rotating and linear sliding. As reported in the turntable stability measurement in the AAU setup in [13], the rotational movement is stable, while the linear slide movement is not stable and 20s of settling time is required. In the MM setup, the linear slide movement is not supported. In the ETS setup, both movements are supported. The turntable movement in the MM and ETS setups are stable.



(a) OTA ring at AAU (b) Chamber at MM (c) Chamber at ETS

Figure 2. Anechoic chamber in three setups

(a) Horn antenna (b) Vivaldi antenna

Figure 3. Probe antennas used in AAU/MM (left) and ETS (right).

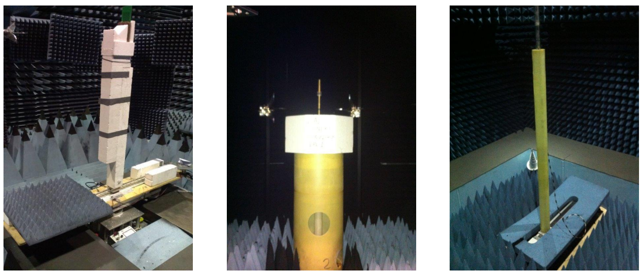
c) Channel emulator stability: Signal drifting level of the channel emulator over short term and long term is investigated. Measurements showed that the signal drifting level of different channel emulators over long term and short term is negligible, and the results are not detailed in the paper.

d) System frequency flatness: Frequency flatness level is investigated in the three setups. Unflat frequency response of the OTA system can be introduced by the channel emulator, termination of the cables (probe antenna) and mismatch between the components.

e) Power Coupling between probes: Power coupling level between probes for both polarizations is investigated in the three setups. Power coupling levels between probes and between polarizations are investigated.

f) Reflection inside the chamber: The reflection level in the three setups is investigated.

g) Plane wave synthesis : Verification results of the PWS technique for vertical polarization with the AAU setup were reported in [8], [13]. In this contribution, better results are achieved with MM and ETS setups as the cable effect and turntable stability issues were addressed. Also, measurement



(a) Turntable at AAU (b) Turntable at MM (c) Turntable at ETS

Figure 4. Turntable in different setups

results of the PWS for horizontal polarization are presented.

III. Measurement Results and Discussion

A. Dipole radiation pattern measurements

In [13], it is concluded that the inaccurate results of radiation pattern measurements are probably caused by cable effect or dipole placement error. The position of the calibration dipoles are carefully calibrated with the laser positioner in the three setups. In the MM setup, the cartridges and chokes for various frequency bands are used to connect to the DUT. In the ETS setup, a Ferrite loaded cable is used. Measurement results in the MM and ETS setup are shown in Figure 5 and Figure 6, respectively. Note that the gain patterns are not normalized. Measurements performed in the MM setup were without the channel emulator. The measured gain and phase pattern variation of a calibration dipole are negligible. The gain and phase pattern is quite omnidirectional, as expected. The main reason for the small variation is due to the fact that the dipole is not located in the rotation center (with an offset of around 5mm), as the phase variation follows a sinusoid curve. Measurement result in the ETS setup is shown in Figure 6. The dipole is rotated every 1^o and for every orientation 31 points separated with 1cm are sampled over the test area. The complex radiation pattern results are extracted from the measurements (samples with $r = 0$cm). The gain and phase variation, though rather small, is mainly caused by the position accuracy of the dipole. To sum up, cable effect can be minimized by use of choke and cartridge, or Ferrite loaded cable.

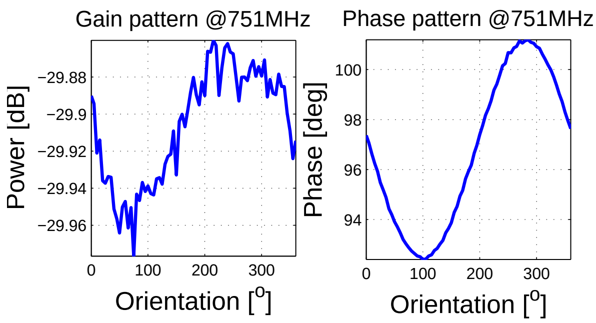


Figure 5. Gain pattern (left) and phase pattern (right) measurement results in MM setup.

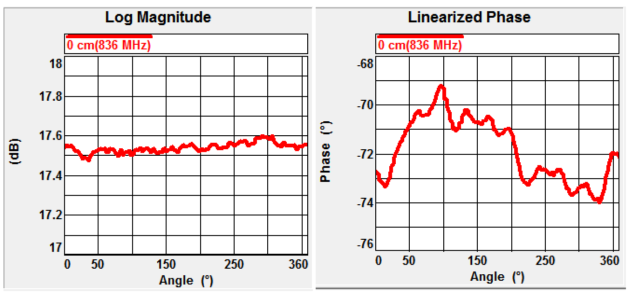


Figure 6. Gain pattern (left) and phase pattern (right) measurement results in ETS setup.

B. Ripples over frequency

In the previous measurements in the AAU setup [15], we investigated the impact of power variation over frequency on spatial correlation. Due to the nonidealities of the channel emulators, the power values are not constant over the LTE band. Also, the cable reflection can cause ripples over frequency band. To show the impact of cable reflection, a measurement was planned in the MM setup. In the first measurement, we measured the S21 of the OTA system (without the channel emulator) with one probe active and the rest terminated with 50Ω loads. In the second measurement, we performed the same measurement with the active probe and the rest non-terminated. The result is shown in Figure 7, where failure to terminate is seen to cause large ripples. The small ripples over frequency with cable terminated might be due to the cable frequency response or the mismatch between components. To investigate the mismatch between components, an additional PA of 20dB and an attenuator of 20dB were added into the system in the measurement in the ETS setup. The ripples caused by mismatch between components are up to around 0.5dB from 600MHz to 7 GHz in the ETS setup.

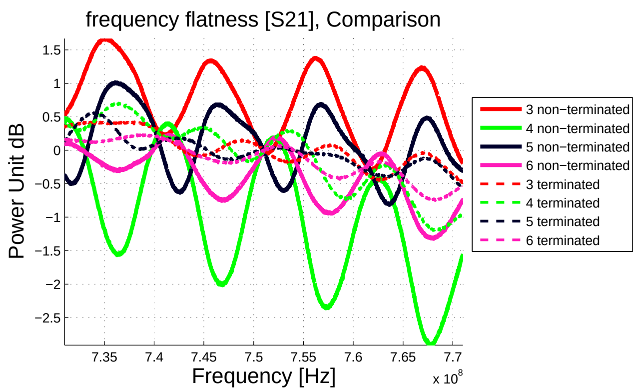


Figure 7. Frequency flatness over 40MHz measured in the MM setup. The number in the legend indicates the active horn index.

C. Power Coupling between probes

Scattering within a multi-probe setup and its impact on measurement uncertainty is investigated in [16]. It is demonstrated that the power coupling level needs to be controlled. In the previous power coupling measurements reported in [8], the cable frequency response and the PA frequency response are not compensated. Different probe antennas are investigated for the OTA systems, e.g. the horn antenna in the AAU and the MM setup, the dual-polarized Vivaldi antenna implemented in a cross form in the ETS setup. The power coupling results in the ETS setup (with cable and PA compensated) are shown in Figure 8 for the vertical polarization. The OTA probe located on the boresight direction of transmitting probe presents the maximum coupling at high frequency. The higher the frequency is, the more directive the Vivaldi antenna becomes. The power coupling will have negligible impact on the synthesized field structure.

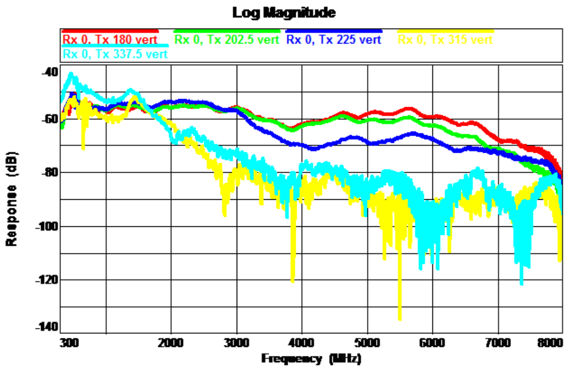


Figure 8. Power coupling between probes for the vertical polarization in the ETS setup. The value in the legend indicates the angular location of the probes.

D. Reflection inside the chamber

Measurement procedure of the reflection study was detailed in [8]. A wideband horn antenna is located in the middle of the test zone and measurements are performed in frequency domain. The frequency domain data is transformed by an inverse FFT to yield a time domain signals. Same reflection measurements were repeated in the MM and ETS setup, and no big reflections were identified in the results. To investigate the impact of a intentional reflector on the results. A metallic plate was placed in the chamber in the ETS setup. The result with an intentional reflector is shown in Figure 9. The reflection level is low as the reflector was not placed in the main lobe direction of the receive horn antenna.

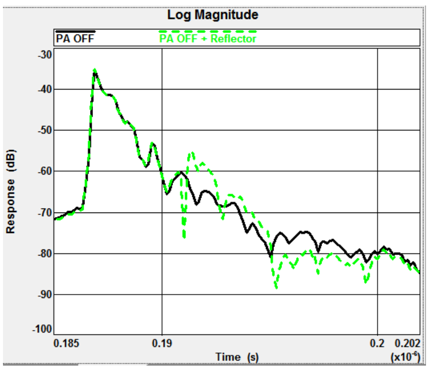


Figure 9. Reflections with/without intentional reflector inside the chamber. Rx antenna: horn

E. Plane wave synthesis

1) Target scenarios and measurement setup: In the previous PWS measurements in the AAU setup, although good agreement was achieved between the measurement and target plane wave (PW), the inaccuracy due to the cable effects, as discussed in Section III-A, was embedded in the results. In the MM setup, as linear slide movement was not supported, the DUT was offset manually with specified radius, as detailed in Table II. Vertically and horizontally polarized static PW with different angle of arrivals (AoAs) are selected as the target scenarios.

Table II
PWS MEASUREMENT DETAILS

	MM	ETS
Target scenario	A. Vertically polarized PW with AoA = 0^o B. Vertically polarized PW with AoA = 22.5^o C. Horizontally polarized PW with AoA = 0^o D. Horizontally polarized PW with AoA = 22.5^o	
Rx antenna	Calibration dipole/magnetic loop at 751MHz	Calibration dipole/magnetic loop at 836MHz
Active OTA probes	8 OTA probes are equally spaced and fixed on the OTA ring	
Rx positions	the linear slide is rotated every 5^o with specified offsets to the rotation center ((0cm, 0.25λ, 0.35λ, 0.5λ)	the linear slide is rotated every 1^o and 31 points separated with 1cm are sampled for every orientation.

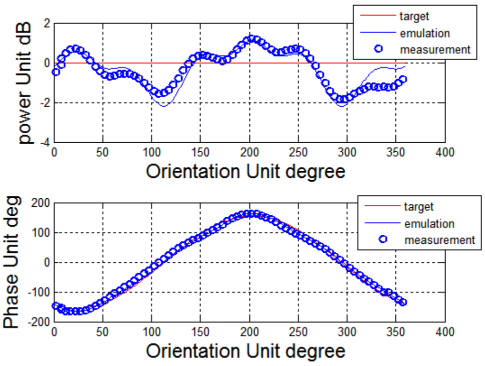


Figure 10. Comparison between the measurement, emulation and target for the power (up) and phase (down) in the MM setup for scenario B.

2) Results: An example of the measurements in the MM setup is shown in Figure 10. The measured power is normalized to its mean and the simulated phase curve is shifted to match the measured phase. The deviation between the target and emulation is due to the fact that only limited probes are used. Very good match is achieved between the measurement and emulation.

Results of the PWS measurements performed in the ETS setup are shown from Figure 11 to Figure 14. Overviews of the measured power and phase distribution over the test area for the target scenario A, B, C and D are shown in Figure 11, Figure 12, Figure 13, Figure 14 respectively. Ideally, uniform power and linear phase distribution along propagation direction are expected inside the test area. The measurement generally match with the target very well. The test area performance depends on the target channel models. As a summary, good agreement can be obtained between the measured PW and the target PW both for the vertical and horizontal polarizations.

IV. CONCLUSION

In this contribution, we presented the uncertainty measurements performed in three different multi-probe setups. Main findings of the work are:

- Cable effect will distort the radiation pattern of the DUT and hence affect the results of the measurements. By use

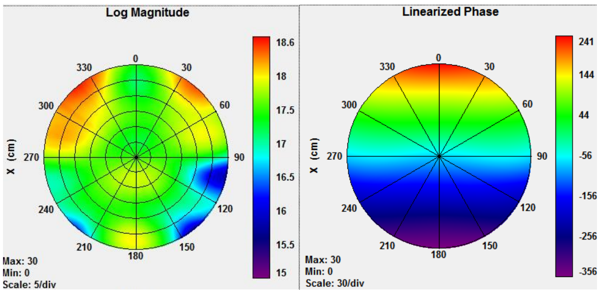


Figure 11. Measured power (left) and phase (right) distribution over test area for the target scenario A.

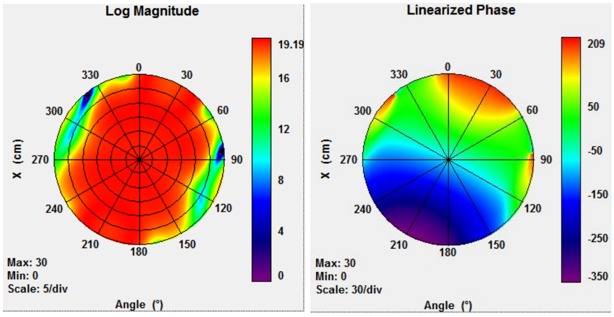


Figure 12. Measured power (left) and phase (right) distribution over test area for the target scenario B.

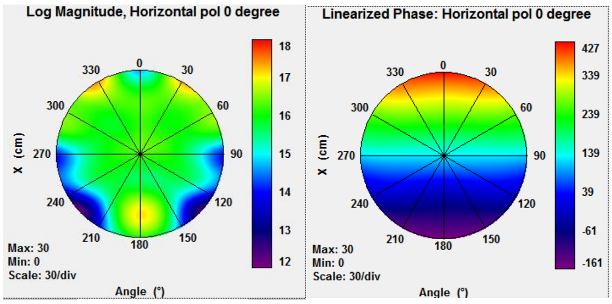


Figure 13. Measured power (left) and phase (right) distribution over test area for the target scenario C.

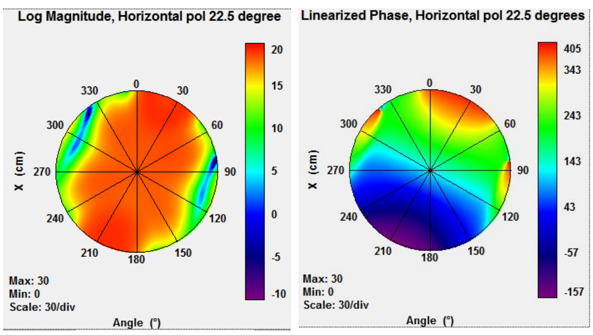


Figure 14. Measured power (left) and phase (right) distribution over test area for the target scenario D.

of a choke/cartridge or Ferrite loaded cable, the cable effect can be minimized. Field synthesis measurements demonstrated the improved results with chokes/cartridges and Ferrite loaded cables.

- Polystyrene that used to support the DUT in the AAU setup introduces instability after movement. Turntables used in the MM and ETS setup are more stable.
- Unflat frequency response of the OTA system can be introduced by the channel emulator, termination of the cables (probe antenna) and mismatch between the components.
- Good agreement between the measured plane wave and the target plane wave both for the vertical and horizontal polarizations is obtained in the MM and ETS setup.

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