Validating FR2 MIMO OTA Channel Models in 3D MPAC

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***Abstract*—Fifth Generation (5G) technology is about to set its global footprint. Its success relies heavily on the standardization process, which is rapidly progressing to specify verification metrics and test methodologies for 5G New Radio (NR) device certifications. For this purpose, three-dimensional (3D) multi-probe anechoic chamber (MPAC) has been selected as a reliable reference solution for creating an accurate test environment. This paper reports first ever FR2 MIMO over-the-air (OTA) channel models validation measurements according to 3GPP specified verification procedure. The evaluated validation metrics include power-delay profile (PDP) and power-angular spectrum (PAS) similarity percentage (PSP). The measurement results closely follow the simulated and theoretical references, thereby demonstrating the feasibility of FR2 MIMO OTA channel models validation procedure adopted by 3rd Generation Partnership Project (3GPP).**

***Index Terms*—Channel emulator, three-dimensional Multi-probe Anechoic Chamber (3D MPAC), FR2, mm-Wave, MIMO over-the-air (OTA), cluster-delay-line (CDL), urban microcellular (UMi), channel models validation, power-delay profile (PDP), power-angular spectrum (PAS), PAS similarity percentage**

I. Introduction

With an ever-increasing demand of mobile data rates, a full-scale rollout of Fifth Generation (5G) wireless networks is now indispensable. Recognizing this need, the major stakeholders are currently involved in intense standardization efforts to accelerate the development and subsequent deployment of 5G technology. The authority to set mobile communication standards fall on 3rd Generation Partnership Project (3GPP), which is mandated by Global Certification Forum (GCF) for protocol, radio frequency (RF), and radio resource management (RRM) conformance test specifications to accentuate 5G New Radio (NR) device certification. Keysight Technologies has been leading the validation of test cases for 5G device certification.

Both chipset manufacturers and mobile operators are striving hard to facilitate fast conformance to 5G commercialization activities. One of the main technology domain of 5G conformance testing is the utilization of millimeter-Wave (mm-Wave) spectrum with beam-steering in both standalone and non-standalone mode, providing more radio resources [1-2]. With highly integrated radio systems at mm-Wave frequency bands, i.e., the Frequency Range 2 (FR2) specified by [3], over-the-air (OTA) testing will most likely be the high-end mode for device performance testing since the antennas of device-under-test (DUT) are the part of the test system chain [4], [5]. The 3GPP Technical Specification Radio Access Network (TS-RAN) group is consistently focused on studying and defining radiated metrics and test methodologies for the verification of multi-antenna reception performance of NR user equipment (UE). The standardization activities of this group are published in the form of a technical report, 3GPP TR 38.827 [6], which also specifies 3D multi-probe anechoic chamber (3D MPAC) methodology for FR2 multiple-input multiple-output (MIMO) OTA performance testing. Together with other test vendors, Keysight Technologies is at the forefront of these standardization activities.

To ensure that the target propagation conditions are accurately created in the device test zone during conformance testing, it is crucial to validate the test environment including chamber with probes, the fading emulator, and their joint capability to reconstruct the target channel model statistics within the test zone. For this purpose, [6] specifies a complete set of FR2 channel models validation metrics along with their measurement procedures. These include power-delay-profile (PDP), Doppler/temporal correlation, power-angular spectrum (PAS) similarity percentage (PSP), cross-polarization and power validation. Since PAS is considered significant for 5G NR beam management, the evaluation of PSP is deliberated thoroughly and a pragmatic validation procedure is laid out in Section 7.4.1.6 of [6].

Channel models validation measurements at FR2 are challenging due to several factors, such as, short wavelength at mm-Wave frequencies, and large number of required spatial samples for PAS estimation that could result in long measurement times. These challenges are further highlighted in [7]. In this paper, we present the validation measurements for PDP and PSP metrics. The exemplary results substantiate the feasibility of FR2 MIMO OTA channel model validation procedure defined in [6], as these are in proximity of simulated and theoretical references. To author's best knowledge, this study is the first to validate the FR2 MIMO OTA models according to 3GPP specified procedure.

The paper is organized in IV sections. Section II presents FR2 MIMO OTA channel models verification measurements. Section III analyses, discusses and compares measurements with respect to the simulated and theoretical references. Finally, Section IV concludes the paper.

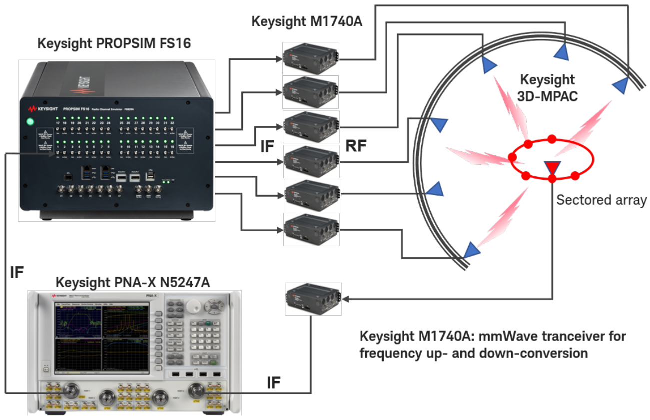

Fig. 1. FR2 MIMO OTA channel model validation measurement setup.

Fig. 2. 3D MPAC FR2 MIMO OTA channel model measurement system in Keysight Lab.

II. Channel models validation measurements

This section describes FR2 MIMO OTA Channel models validation measurements performed at 28 GHz frequency band for the two most key validation metrics, PDP and PSP. The measurement system is fully calibrated prior to carrying on validation measurements.

A. FR2 MIMO OTA channel model

3GPP TR 38.827 [6] defines CDL-C urban microcellular (UMi) and indoor office (InO) non-line-of-sight (NLOS) channel model scenarios for NR FR2 MIMO OTA and their cluster parameters are available therein. The measurements in this paper are based on CDL-C UMi model. In Section 7.3 of [6], the base station beamforming configuration for channel model emulation specifies one strongest transmitting beam from the codebook of 128 beams-grid. Hence, CDL-C UMi channel model emulation with the strongest transmitting beam profile was generated using Keysight Channel Studio GCM software. The base station narrow beam filters the number of significant clusters on the device side and could be reasonably reconstructed by six probes of the chamber.

B. Measurement System

The measurement setup for FR2 MIMO OTA channel models validation is illustrated in Figure 1, which mainly includes the following components.

1. Keysight PNA-X N5247A network analyzer as a main data acquisition device.
2. Keysight F8820A PROPSIM FS16 benchtop for emulating fading channel model in the test environment.
3. Keysight M1740A mm-Wave transceivers for frequency up- and down-conversion.
3. Keysight F9660A 3D Multi-Probe Anechoic Chamber (3D MPAC) having six OTA probes with 3GPP specified locations.

The measurement antenna-under-test (AUT) is an omnidirectional ultra-wideband ($26.5-40$ GHz) bicone antenna mounted on the electro-mechanical rotator inside 3D MPAC with the aid of an RF transparent fixture. The half-power beamwidth (HPBW) of AUT is $45°$ in elevation. Figure 2 presents the measurement system setup in Keysight Lab.

C. Measurement Procedure

The Section 7.4.1.1 of [6] discusses the measurement procedure for evaluating PDP in detail. The network analyzer transmits a frequency sweep signal over the span of 200 MHz, stepping through 1101 discrete frequency points, to the reference AUT via test system and records 1000 frequency response traces of the fading channel. These measured traces are then Fourier transformed using a post-processing software to evaluate channel impulse responses $h(t,\tau)$, which are then averaged over time for removing fast fading to obtain PDP, as given by the expression in (1). The measurement environment must be kept static and carefully handled to avoid introducing additional uncertainties and noise in the measurement system.

$$P(\tau) = \frac{1}{T}\sum_{t=1}^{T} |h(t,\tau)|^2 \tag{1}$$

The Section 7.4.1.6 of [6] provides a detail description of PSP measurement procedure and gives an option to choose between frequency- or time-domain measurement methods. The measurements elaborated in this paper are frequency-domain measurements with vector network analyzer as the main data acquisition device. The PSP validation measurements aim at evaluating PSP for characterizing FR2 channel model under test in the test zone of 3D MPAC. The basic idea is to the measure and estimate the PAS around the test zone and to compare it to the known theoretical PAS of the target channel model, using the PSP metric. For PSP validation measurement, only vertical polarization validation is required. It is essentially a virtual array configuration realized in 3D MPAC through a $\phi-\theta$ positioning system. The measurement array is a semicircle and sectored array configuration, as illustrated in Figure 3, where complex channel frequency response is measured at each antenna location 0.5λ wavelength apart. The vertical sectors of the measurement array are limited to $60°$ ($\pm 30°$) and the horizontal sector to $180°$ ($\pm 90°$)

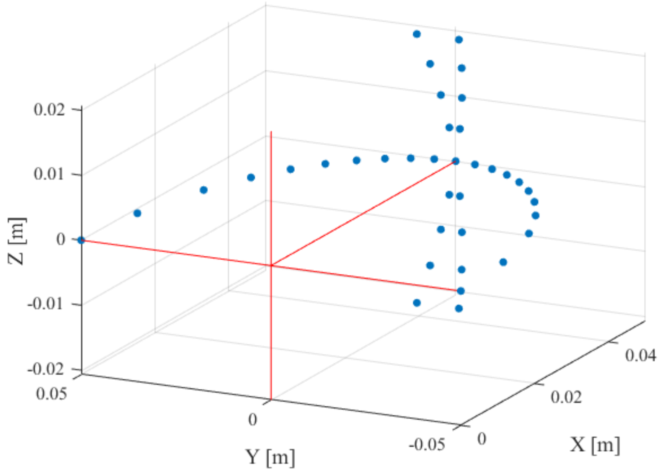

Fig. 3. Virtual array configuration for measurements with spatial samples $K = 37$.

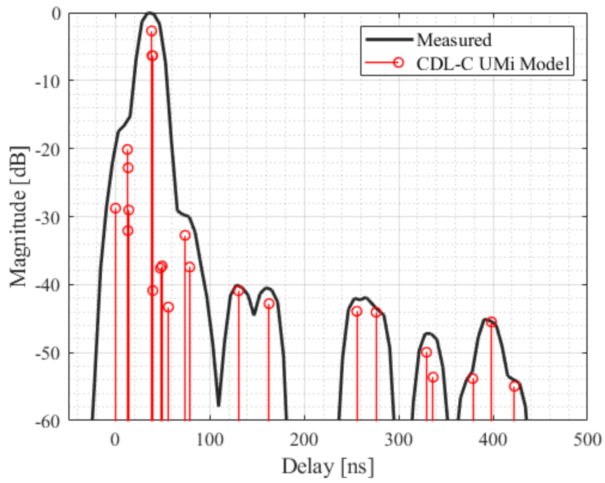

Fig. 4. PDP for FR2 CDL-C UMi MIMO OTA model at 28 GHz with the strongest base station transmitting beam.

with the broadside direction pointing towards the probes. The virtual array configuration for the PSP validation is composed of semicircle arrangement (1 x horizontal and 2 x crossed vertical). The radius of the array element locations with respect to the center of the test zone is 5 cm, which is equivalent to the half of the test zone radius at 28 GHz. For different frequency bands, the radius of the sectored semicircles measurement array remains fixed at 5 cm while the spatial sampling of the array varies. This measurement essentially validates the proper angular behavior in the test zone.

For PSP measurements, as illustrated in 1, the Port1 of the network analyzer transmits a continuous-wave (CW) signal at the center frequency of 28 GHz through the fading emulator, and radiating them via N probes within the anechoic chamber. The radiated signals are then received at the test antenna that is positioned inside the test zone. The AUT is mounted on a ϕ–θ positioner which is capable of moving the antenna to predefined spatial locations on a fixed radius from the center of the test zone according to the measurement array configuration. Finally, the signal is received at Port2 of the network analyzer. The most suitable approach for the PSP validation is based on an omnidirectional antenna, as the test setup can be automated easily. Alternatively, a directional antenna could be used but may requires frequent re-positioning.

III. Results and Discussion

The measured and reference PDPs for CDL-C UMi channel model are plotted simultaneously in Figure 4. We can observe that the measured PDP follows nicely the delay taps from the reference with a minor difference in power (2 dB), which can be attributed to the measurement uncertainties. Furthermore, it is difficult to accurately compare the PDPs with theoretically infinite bandwidth and measured limited-bandwidth. The measured bandwidth was 200 MHz and Hann windowing function was used to reduce the side-lob-level.

The PAS in Figure 5 (a-c) are obtained at range length of 1 m by employing the strongest beam from the codebook of 128 beam-grid with a 4×4 DUT sampling array. For the target channel model, the reference PAS in Figure 5 (a) is a ray-based theoretical PAS evaluated with the far-field assumptions, while the OTA PAS in Figure 5 (b) is the simulated PAS calculated using OTA probe weights.

The measured PAS, illustrated in Figure 5 (c), is obtained with the following three-step process:

1. In the first step, the discrete azimuth and elevation direction-of-angles (DoA) are estimated using MUSIC algorithm for the measurement array configuration shown in Figure 3. Multiple Signal Classification (MUSIC) is a high-resolution direction-finding algorithm that utilizes eigenvalue decomposition of the covariance matrix observed at an antenna array. Here, MUSIC DoA estimation uses the near-field information, i.e., the range length, as comprehensively described in [7]. Figure 6 shows the estimated DoA compared to actual probe locations. We can see that probe directions are estimated reasonably with slight offset in the elevation. This could be explained by the limited coverage of the measurement antenna radiation pattern in elevation. The estimation errors corresponding to six probe locations are given in Table I. It is noteworthy that peak-to-noise ratio of the pseudo-spectrum obtained with MUSIC algorithm could become significant if the data is noisy.
2. The powers are then calculated from the estimated DoA and auto-covariance matrix of the received signal. This received signal is the frequency response including fading characteristics. A near-to-far field compensation is applied for the transfer function from the probes to the measurement array positions. The estimated powers are shown in Figure 7 along with theoretical reference and the difference is given in Table I.

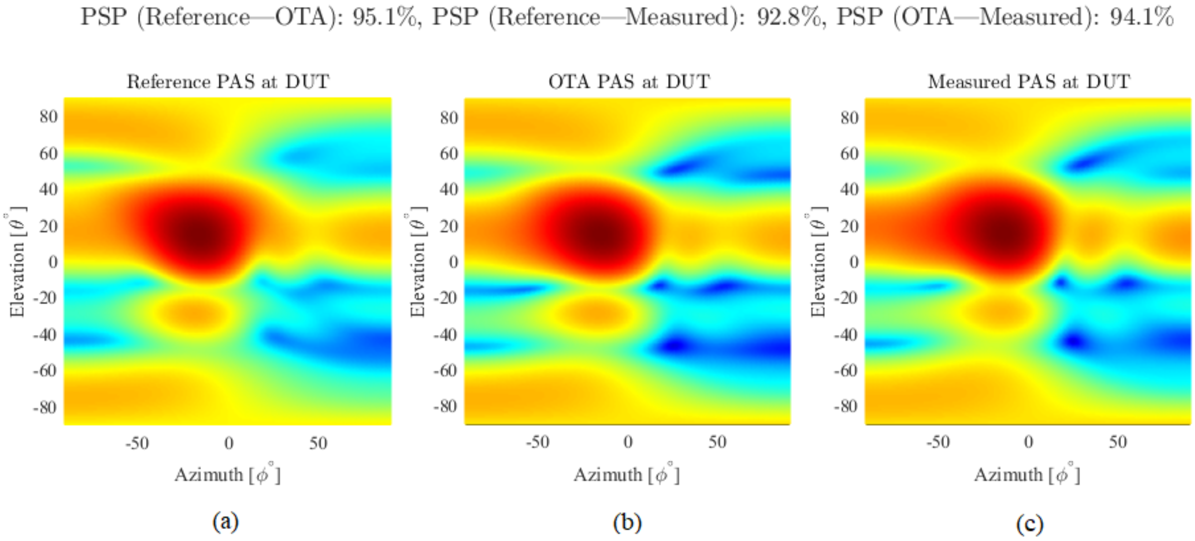

Fig. 5. PAS for CDL-C UMi model, (a) theoretical reference, (b) simulated OTA , and (c) measured.

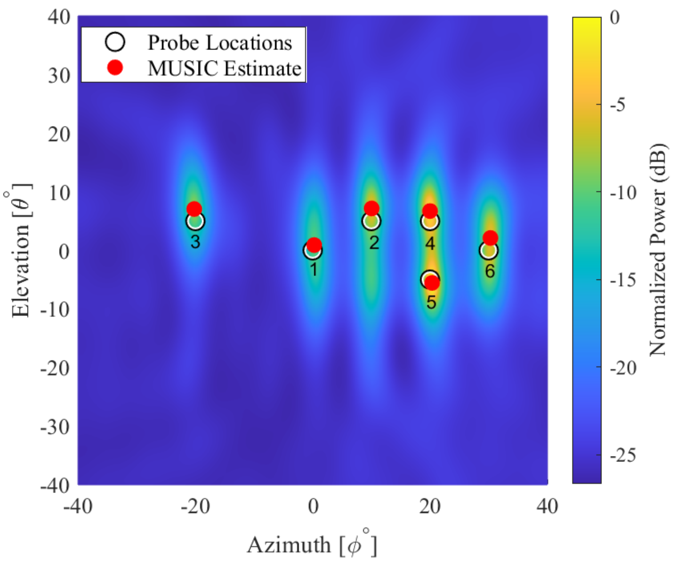

Fig. 6. Probe location (angle) estimation using Music algorithm.

3. In the final step, the angle and power estimates, i.e. the discrete PAS of six probe azimuth and elevation directions and power values are used for a 4×4 DUT sampling array for beamforming with the conventional Bartlett beamformer in order to estimate the "measured PAS at DUT" for the PSP calculations.

Either the theoretical or simulated OTA PAS can serve as a reference, however, the standard [6] specifies OTA PAS as a reference. For further details on the signal processing aspects of this evaluation, readers are referred to [7]. To evaluate PSP, total variation distance (D_{p}) is calculated from the reference and measured PAS, as follows [4].

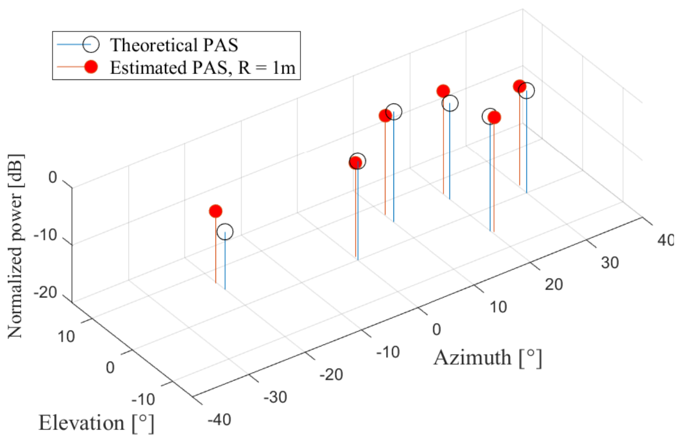

Fig. 7. Estimated probe powers.

$$D_{\mathrm{p}} = \frac{1}{2} \int \left| \frac{P_{\mathrm{r}}(\beta)}{\int P_{\mathrm{r}}(\beta')d\beta'} - \frac{P_{\mathrm{o}}(\beta)}{\int P_{\mathrm{o}}(\beta')d\beta'} \right| d\beta \qquad (2)$$

Where $P_{\mathrm{r}}(\beta)$ and $P_{\mathrm{o}}(\beta)$ refers to the measured and reference PAS, respectively. The PSP is subsequently calculated as PSP $= (1 - D_{\mathrm{p}})\%$. The resulting PSP values are shown in Figure 5, i.e., measured vs. theoretical reference is 92.8%, simulated OTA vs. measured is 94.1%, and theoretical reference vs. simulated OTA is 95.1%.

IV. Conclusion

For mobile device performance test systems, the verification of test environment is pivotal to make sure the target channel model conditions are accurately reproduced in the test zone. This necessitates the validation of channel models according to 3GPP specified criterion. This paper presents FR2 CDL-C UMi MIMO OTA channel model validation in 3D MPAC. The measurements are performed based on the procedure defined

TABLE I
PROBE LOCATIONS ESTIMATED WITH MUSIC ALGORITHM AND RESULTING ERRORS

Actual ($\phi_{\rm a}^{\circ}, \theta_{\rm a}^{\circ}$)	**Estimated** ($\phi_{\rm e}^{\circ}, \theta_{\rm e}^{\circ}$)	**Difference** ($\Delta\phi, \Delta\theta$)	Δ PAS (dB)
(0.0,0.0)	(0.3, 0.9)	(-0.3, -0.9)	0.9
(10, 5.0)	(10, 7.1)	(0.0, -2.1)	1.9
(-20, 5.0)	(-20.2, 7.0)	(0.2, -2.0)	-2.5
(20, 5.0)	(20, 6.7)	(0.0, -1.7)	-1.2
(20, -5.0)	(20.3, -5.5)	(-0.3, 0.5)	0.0
(30, 0.0)	(30.3, 2.1)	(-0.3, -2.1)	0.5

in 3GPP TR 38.827 [6]. The two most relevant validation metrics, i.e., power-delay profile (PDP) and power-angular spectrum (PAS) similarity percentage (PSP) are evaluated. Some key observations are as follows.

- The specified virtual array and the MUSIC algorthim based estimation with range length information are sufficient for identifying directions-of-arrival (DoA) (probe direction), on the accuracy level of about $2°$.
- The virtual array, measured channel responses, and the directional power estimation method are sufficient for identifying the received power distribution over the estimated DoA with accuracy level of a few decibels.
- PSP, the final figure of merit, can be measured with an accuracy of 92.8% if the considered reference is purely theoretical or 94.1% if the reference is considered to be the simulated OTA.

The measurement results following the theoretical and simulated references indicate the suitability of the FR2 channel model validation procedure adopted by 3GPP. The validation process will be continued for other metrics of FR2 channel models as part of the future work.

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