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# Comparison of Channel Emulation Techniques in Multiprobe Anechoic Chamber Setups

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***Abstract*—This paper compares two different techniques for channel emulation in multiprobe anechoic chamber based setups, which is a candidate solution for the standardization of MIMO OTA performance testing of mobile devices. The comparison is performed via simulations of the field distribution, temporal correlation, and spatial correlation emulated by these methods for different number of probes. Results show that the emulation accuracy of the field distribution and temporal correlation are degraded when the emulation technique uses a single sinusoid per probe antenna, while the emulation accuracy of the spatial correlation depends on the power weights applied to the antenna and the number of probes employed.**

***Index Terms*—MIMO OTA, multiprobe anechoic chamber, spatial channel emulator, prefaded signals synthesis.**

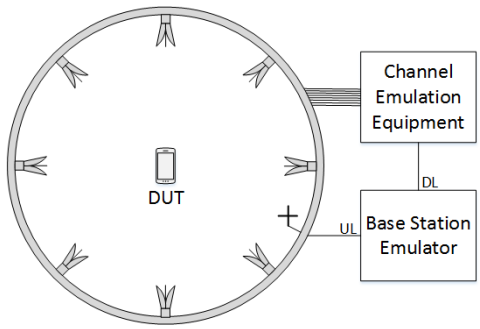



Fig. 1. Setup for the Multiprobe Anechoic Chamber based method.

## I. Introduction

The increasing demand for higher data rates in wireless mobile communications is moving the focus towards technologies and devices that use Multiple Input Multiple Output (MIMO) techniques, which utilize multiple antennas both at the terminal and at the base station sides. MIMO techniques benefit from the multipath nature of the mobile environment to improve communication performance. Single Input Single Output (SISO) Over the Air (OTA) performance testing focus on evaluating antenna parameters, such as the Total Radiated Power (TRP) or the Total Isotropic Sensitivity (TIS) [1], which become insufficient when assessing the performance of MIMO devices. In order to accurately measure the performance of MIMO capable devices, such devices need to be tested under realistic radio channel conditions. Moreover, the spatial correlation between the antennas plays a key role in MIMO performance.

Standardization forums, such as the 3rd Generation Partnership Project (3GPP) [2], have ongoing discussions regarding the methodologies for the standardization of the receiver performance testing of MIMO devices. One of the main requirements is that the devices must be tested OTA to include the performance of the antennas. One of the several solutions described in [2] is the multiprobe anechoic chamber test methodology, which employs a number of spatially separated antennas to emulate the channel characteristics in a controlled, flexible, and repeatable manner. In addition, all critical parts of the device are assessed at once, enabling true evaluation of the performance of MIMO devices [3].

Different techniques have been proposed to emulate realistic channel conditions using the multiprobe anechoic chamber methodology. The goal is to transmit specific signals from the probe antennas so that the desired channel conditions are emulated within the test area where the Device Under Test (DUT) is placed. Reference [3] describes the Prefaded Signals Synthesis (PFS) technique, where prefaded signals are transmitted from each probe with a certain power weighting to emulate the target channel characteristics. On the other hand, [4] proposes a simpler solution, in which each probe transmits a single sinusoid with a certain amplitude and random initial phase. This technique appears as a cost-effective alternative to the previous one, yet its associated emulation accuracy has been solely studied for Clarke's model [5]. In the following, the technique proposed in [4] will be referred to as reference method or technique.

This paper compares the emulation accuracy of the Prefaded Signals Synthesis and the reference technique for two simple channel models: Clarke's model and a single spatial cluster model. Nevertheless, the conclusions extracted from the results are, in theory, applicable to other spatial channel models. Section II describes the setup and introduces the channel emulation techniques in more depth. The results from the simulations in terms of the field distribution, temporal correlation, and spatial correlation accuracy are given in Section III. Finally, Section IV summarizes and concludes the paper.

## II. Setup and Techniques

The following subsections describe the simulation setup and the channel emulation techniques, with focus on how to emulate the desired channel parameters.

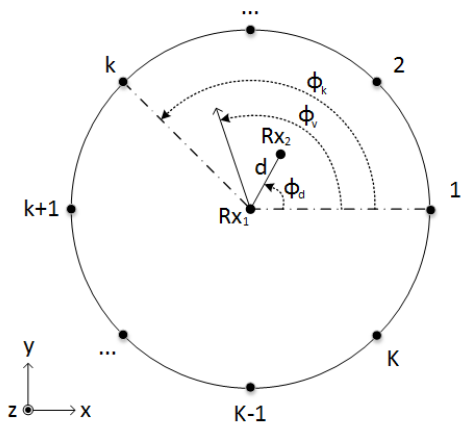



Fig. 2. Geometry definition of the simulation setup. [4]

### A. Simulation Setup

The general setup for the multiprobe anechoic chamber method is depicted in Fig. 1, where a number of equally spaced probe antennas are placed on a circumference surrounding the DUT. A base station emulator is connected to the channel emulation equipment, which is in turn connected to the antenna probes. An extra antenna is placed inside the chamber for the uplink transmission. The test area is defined as the area surrounding the DUT in which the desired spatial characteristics of the channel model can be accomplished.

An example of the specific setups for the PFS and the reference technique can be in found in [3] and [4] respectively. The former employs a commercial channel emulator as channel emulation equipment, while the latter uses a power splitter, phase shifters and attenuators.

For this work, we assume that the equipment connected to the probes is capable of generating the target signals to feed the probe antennas. Fig. 2 shows the simplified setup used in this study, where $K$ probe antennas are placed over a circumference of radius $r$. All angles are defined from probe number 1, with $\phi_k$ being the angle of the kth probe, and $\phi_v$ the Direction of Travel (DoT) of the mobile device. For the calculation of the spatial correlation it is assumed that there are two receivers ($Rx_1$ and $Rx_2$), one of them placed in the centre of the circumference and the other one separated by a distance $d$ at an angle $\phi_d$.

### B. Channel Emulation Techniques

The purpose of the channel emulation techniques is to emulate a spatial channel with specific channel characteristics such as fast fading, Doppler spectrum, Power Delay Profile (PDP), Cross Polarization Ratio (XPR) or Power Angular Spectrum (PAS) within the test zone. The Doppler spectrum and the PAS are usually evaluated using their Fourier transform pairs instead, the Temporal Correlation Function (TCF) and the Spatial Correlation Function (SCF), which provide a more meaningful comparison [3].

As previously mentioned, this paper focuses on the emulation accuracy achieved by the PFS and the reference technique for the field distribution, TCF, and SCF. Other parameters such as the PDP or the XPR are straight forward to create using, for example, a commercial channel emulator and dual-polarized probes. For this reason, the emulation of these parameters is omitted from the study.

The radius of the ring where the probe antennas are placed is assumed to be sufficiently large so that a signal transmitted from any of the probes is seen as a plane wave within the test area. In addition, reflections from the anechoic chamber and coupling between probe antennas are assumed to be negligible. These effects would have a negative impact on the emulation accuracy in practical setups, which has been studied in [9], [10], for example.

*1) Reference Channel Emulation Technique:* With this method, each probe antenna transmits a single sinusoid with a certain amplitude, Doppler shift, and initial independent random phase. The sinusoids transmitted from all probes are summed in the test area, creating a Rayleigh distribution if the number of probes is sufficiently large.

The power of the $k$th probe antenna, $g_k$, is calculated by sampling the target continuous PAS, $p(\phi)$, at the probes positions, $\phi_k$:

$$g_k = \frac{p(\phi_k)}{\sum_{n=1}^{K} p(\phi_n)} \tag{1}$$

On the other hand, the temporal phase evolution for the $k$th probe, $\Phi_k$, is calculated according to [4] as:

$$\Phi_k = 2\pi f_d t \cos(\phi_k - \phi_v) + \alpha_k \tag{2}$$

where $\phi_k$ and $\phi_v$ are the angle of the $k$th probe antenna and the DoT of the device respectively, defined as in Fig. 1, $f_d$ is the maximum Doppler shift given by $f_d = v/\lambda$, with $v$ being the speed of the device and $\lambda$ the wavelength of the carrier wave. The initial phase for the kth antenna, $\alpha_k$, is independently generated for each probe from an uniform distribution $\sim U[-\pi,\pi]$.

The expression of the SCF, assuming that the radius, $r$, is sufficiently large, can be defined as:

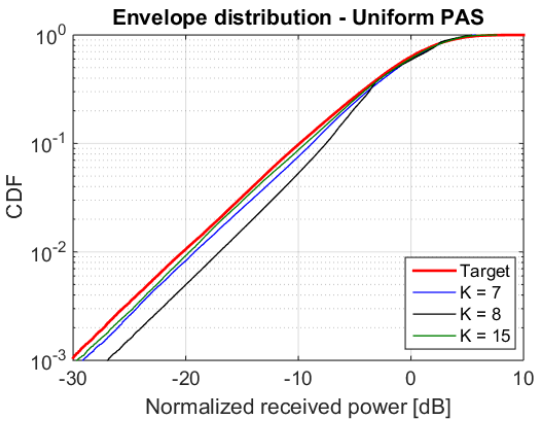
$$\hat{\rho}_d = \sum_{k=1}^{K} g_k \exp\left(j\frac{2\pi}{\lambda} d \cos(\phi_k - \phi_d)\right) \tag{3}$$

where $d$ is the distance between the two receiving antennas, and $\phi_d$ is the angle of the secondary receiver as shown in Fig. 1.

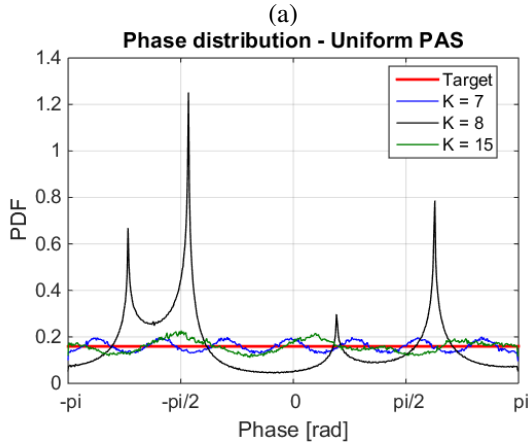
The TCF can be expressed as:

$$\hat{\rho}_\tau = \sum_{k=1}^{K} g_k \exp\left(j\frac{2\pi}{\lambda} v\tau \cos(\phi_k - \phi_v)\right) \tag{4}$$

where $\tau$ is the time lag, and $\phi_v$ is the DoT as defined in Fig. 1. It is important to note that the SCF and the TCF obtained with this technique will provide the same results when they are evaluated for the same angle, i.e. $\phi_d = \phi_v$.

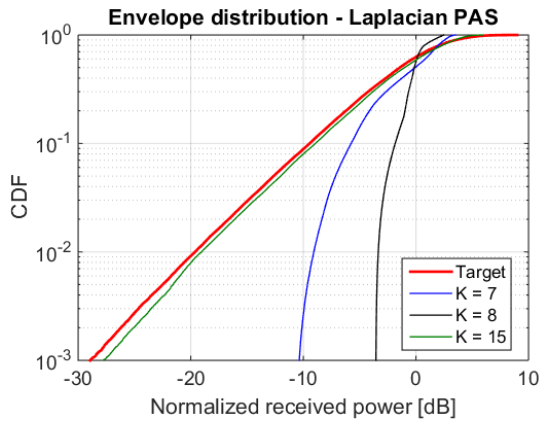



(a)

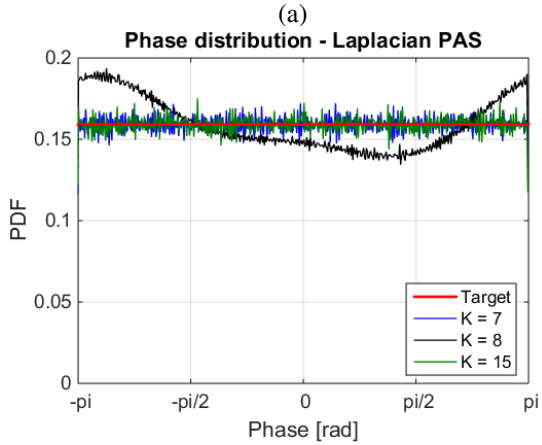



(b)

Fig. 3. Field distributions emulated using the reference technique for Clarke's model (uniform PAS). (a) Envelope distribution. (b) Phase distribution.




(a)




(b)

Fig. 4. Field distributions emulated using the reference technique for a single cluster model with Laplacian PAS. (a) Envelope distribution. (b) Phase distribution.

*2) Prefaded Signals Synthesis:* The idea of the PFS is to transmit prefaded signals with specific statistics from a number of probe antennas so that they approximate one cluster. The antennas used for representing one cluster are chosen depending on the setup geometry and the target PAS.

The main difference with the previous method is that, in this case, each probe antenna transmits a fading sequence calculated as a sum of sinusoids with the target statistics. The fading sequences are independent between clusters and i.i.d. within a cluster. This means that the emulated field distribution and Doppler spectrum will always match the target independently of the number of probes used, since the statistics of the fading sequences are created to be the same [3].

In [3], the test area is spatially sampled and the antenna power weights are calculated so that the Mean Squared Error (MSE) between the target continuous SCF and the spatial correlation obtained from a discrete PAS is minimized. Other optimization techniques have been proposed for example in [8].

## III. Simulation Results

In this section the performance of the proposed techniques is compared for the following channel models:

*1) Clarke's model:* This model is characterized by a uniform PAS [5]:

$$p(\phi) = \begin{cases} \frac{1}{2\pi} & -\pi \leq \phi \leq \pi \\ 0 & \text{otherwise} \end{cases} \tag{5}$$

The SCF and the TCF can be expressed respectively as [5]:

$$\rho_d = J_0\left(kd\right) \tag{6}$$

$$\rho_\tau = J_0\left(kv\tau\right) \tag{7}$$

where $J_0(\cdot)$ is the first kind zero order Bessel function.

*2) Single Cluster model:* Clusters are typically modeled using a Laplacian PAS [6]:

$$p(\phi) = \frac{\sqrt{2}}{2\sigma} \exp\left(-\sqrt{2}\frac{|\phi - \bar{\phi}|}{\sigma}\right) \tag{8}$$

where $\sigma$ is the Angle Spread of Arrival (ASA), and $\bar{\phi}$ is the mean Angle of Arrival (AoA). There are no close form solutions for the target SCF and TCF correlations for a Laplacian shaped PAS [7]. However, they could be approximated by using a sufficiently large number of probes in (3) and (4).

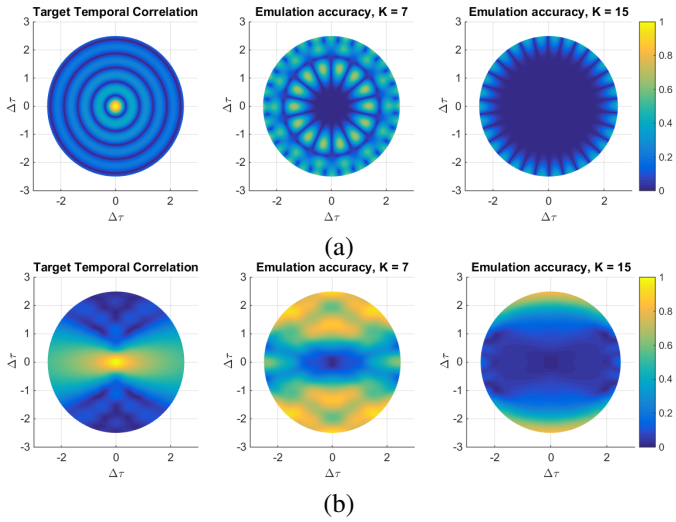



Fig. 5. From left to right: target TCF, emulation accuracy using $K = 7$ probes, and emulation accuracy for $K = 15$ probes. (a) Uniform PAS. (b) Laplacian PAS with AoA=0 [deg], and ASA = 35 [deg].

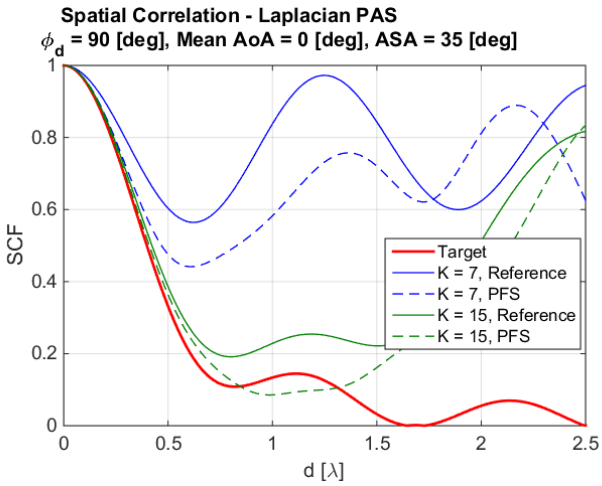



Fig. 6. SCF for a single cluster model with Laplacian PAS for different number of probes $K$. Solid line is used for the reference technique, while dashed line is used for the PFS technique.

### A. Field Distribution

In [4], it is mentioned that the effective number of incident waves is reduced to half when an even number of probes is used for the reference method. To verify this, the envelope and phase distributions are calculated for different number of probes.

Fig. 3 shows the results obtained using 7, 8, and 15 probes to emulate Clarke's model. It can be seen that the envelope and phase distribution follow the target ones for an odd probe number, but are degraded when an even number of probes is used. Fig. 4 shows the results obtained using 7, 8 and 15 probes to emulate a Laplacian PAS. In this case, the envelope follows no longer a Rayleigh distribution for a low number of probes, but resembles a Rician distribution instead. The Rician distribution is commonly used to model Line of Sight (LOS) scenarios where there is a dominant component. Since the discrete PAS is obtained by sampling the continuous PAS at the probes positions, a dominant component appears for a relatively low number of probes, which modifies the envelope distribution.

The results indicate that field distribution achievable using the reference method depends on the number of probes, its parity, and the spatial characteristics of the target channel model. This comes as a consequence of transmitting a single sinusoid from each probe. On the other hand, the PFS technique does not suffer from any of these limitations, since each probe transmits a fading sequence composed by a sum of sinusoids with the target statistics. Consequently, the field distribution will always match the target one, independently of the spatial characteristics of the target channel model or the number of probes used. For this reason, the results for the PFS technique are not included in this paper.

### B. Temporal Correlation Function

As for the field distribution, the temporal correlation achieved using the PFS technique will be equal to the target one, thus it is not included in the results.

The emulation accuracy is defined as the absolute value of the difference between the target correlation and the emulated one. Fig. 5 shows the target temporal correlation and the emulation accuracy obtained with 7 and 15 probes using the reference method to emulate the target models. $\Delta\tau$ is the delay component $\tau$, normalized to the maximum Doppler shift $f_d$, while the DoT of the mobile device is represented in the $\phi$ direction. The figure shows that the emulation accuracy of the TCF depends on the DoT of the device, i.e. the emulation accuracy is not uniform in $\phi$. In addition, the emulation accuracy improves for a higher number of probes. This result is expected, since higher number of probes means higher number of sinusoids used in the emulation, which results in better approximation of the target temporal correlation.

### C. Spatial Correlation Function

The spatial correlations emulated using 7, and 15 probe antennas for the PFS and the reference technique are compared with the target SCF. Fig. 6 shows the emulated SCF for a Laplacian PAS with AoA = 0 degrees and ASA = 35 degrees. The second receiver is placed perpendicular to the first probe, i.e. $\phi_d = 90$ degrees. It can be seen that the accuracy achieved by the PFS technique is higher than for the reference technique. In fact, this is a consequence of the optimization technique used to calculate the power weights of the probe antennas. If the same power weights were used for both methods, the PFS and the reference technique would provide the same results. Additionally, the emulation accuracy is improved for a higher number of probes.

In Clarke's model, all incoming rays are assumed to have the same amplitude, thus the antenna weights calculated using

TABLE I
SUMMARY OF THE EMULATION ACCURACY CHARACTERISTICS

| | **PFS technique** | **Reference technique** |
|---|---|---|
| **Field distribution** | $K$ independent<br>Channel model independent | $K$ dependent<br>Channel model dependent |
| **Doppler/ TCF** | $K$ independent<br>DoT independent | $K$ dependent<br>DoT dependent |
| **SCF** | $K$ dependent<br>Optimization technique | $K$ dependent<br>Direct sampling |

the PFS and the reference technique are the same, i.e. the transmission from all probe antennas is weighted with the same value. Consequently, the emulated SCFs are the same for both emulation techniques and are not included in the paper.

## IV. CONCLUSION

The emulation accuracy of two different channel emulation techniques for multiprobe anechoic chamber setups have been compared throughout this paper. The discussion of the results focuses on two different channel models: Clarke's model with uniform PAS, and a single cluster model with Laplacian PAS. Yet again, the conclusions extracted are theoretically valid for other spatial channel models. A summary of the results is shown in Table I.

In the technique referred as the reference method, each probe antenna transmits a single sinusoid with a certain amplitude, time variation, and random initial phase. The sinusoids from all probes are added in the test area, emulating the target channel characteristics under certain conditions. It has been shown that the field distribution achievable by the reference technique follows more accurately the target one for a higher and odd number of antennas. Furthermore, the target envelope distribution cannot be emulated when the number of probes is relatively low for a non-uniform PAS. In addition, the temporal correlation achieved using the reference technique depends on the DoT of the device as well as on the number of probes.

In the Prefaded Signals Synthesis each probe sends a fading sequence, which statistics correspond to the target ones. Therefore, this method suffers from none of the previous limitations. The target field distribution and temporal correlation are perfectly matched independently of the number of antennas or the spatial characteristics of the channel model.

Finally, the spatial correlation emulated using both techniques has been compared, showing that the PFS matches the target SCF for a bigger test area. However, this comes as a consequence of the power weights applied to the probe antennas. The SCF was calculated using direct sampling of the target PAS for the reference method and an optimization technique for the PFS. For the same power weights, both techniques would obtain the same test area size.

From the results it can be concluded that the reference method becomes insufficient, especially for non-uniform PAS, since the target field distribution and temporal correlation can only be matched for a high number of probe antennas.


## ACKNOWLEDGMENT

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