

Emulation of Realistic Multi-Path Propagation Channels inside an Anechoic Chamber for Antenna Diversity Measurements

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Abstract

As antennas are inherently included recommended in Over-The-Air (OTA) testing, it is important to also consider realistic channel models for the multiple-input multiple-output (MIMO) device performance evaluation. This paper aims to emulate realistic multi-Path propagation channels in terms of angles of arrivals (AoA) and cross-polarization ratio (XPR) with Rayleigh fading, inside an anechoic chamber, for antenna diversity measurements. In this purpose, a practical multi-probe anechoic chamber measurement system (MPAC) with 24 probe antennas (SATIMO SG24) has been used. However, the actual configuration of this system is not able to reproduce realistic channels. Therefore, a new method based on the control of the SG24 probes has been developed. At first time, this method has been validated numerically through the comparison of simulated and analytical AoA probability density distributions. At the second time, the performance of an antenna diversity system inside the SG24 has been performed in terms of the correlation coefficient and diversity gain (DG) using an antenna reference system. Simulated and measurements results have shown a good agreement.

Keywords

Channel Emulation, Multi-Path OTA Measurements, Antenna Diversity Measurements, MIMO, Correlation Coefficient, Diversity Gain

1. Introduction

Generally, the multiple antennas configuration has been adopted in wireless

communication systems in order to improve the capacity of data transmission and mitigate the effects of multipath fading. Due to constraints on the physical dimensions of the wireless terminals, the distances between the multiple antennas are usually small. These distances induce a high mutual coupling between the antennas [1] [2]. Therefore, the antenna placement in the terminal has to be considered carefully. In multi-antenna communication systems, antennas and multi-path fading environment have a significant impact on system performances [3] [4] [5]. For this reason, the evaluation of antenna diversity performances in realistic environments is now mandatory in order to elaborate efficient multi-antenna terminals.

Recently, many methodologies Multiple-Input Multiple-Output (MIMO) Over The Air (OTA) have been discussed in 3GPP and COST2100 [4] [6] [7]. This discussion focuses on the establishment of a standardized testing approach for verifying the overall performance of the multi-antenna terminals. Some fading emulators have been proposed for OTA testing for assessing the performance of antenna diversity terminals in realistic multipath channel [3] [5]. These emulators are based on an anechoic chamber, antenna array and a channel emulator. However, a channel emulator is very expensive, and its cost increases with the number of antennas.

In this paper, we present a new test method, considerably, less complex than other emulators proposed in the literature, in terms of cost-effectiveness. It consists to replace the channel emulator by a switch in order to generate a realistic Rayleigh channel in terms of AoA and XPR, based on the ignition probabilities of emitting antennas. This method allows evaluating the performance of antenna diversity systems. Two types of propagation models, such as Uniform and selective in terms of AoA, are used for OTA testing in terms of correlation coefficient and diversity gain (DG). These parameters have been computed from the signals received at the different branches of the antenna systems.

2. Measurement System

An illustration of the MPAC measurement system developed for this contribution is shown in **Figure 1**. It is consisting of an anechoic chamber in order to

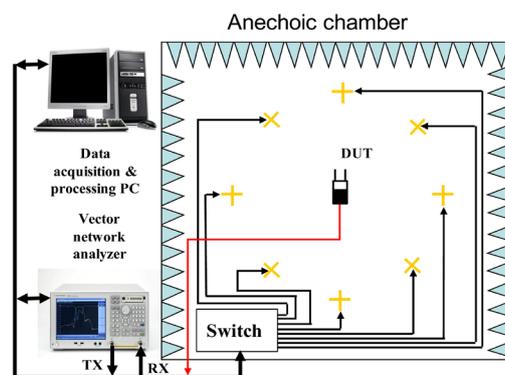


Figure 1. Channel emulation in MPAC measurement system.

generate multi-path environments free from undesired reflection inside the chamber and unwanted external interferences, an antenna array for emulating realistic channel models around a device under test (DUT) and a switch related to the emitting antennas.

In this work, the SATIMO SG24 measurement system [8] has been retained where it meets the requirements in terms of flexibility. However, this system is not designed for emulating multi-path channels. Therefore, a specific control method of the SG24 probes (emitting way) has been developed.

A Nakagami channel is obtained when the DUT is placed at the probes center during the control. And, that is due to the same amplitude and the same shift phase values introduced on the different received paths, where the Euclidean distances between the emitting antennas and the DUT are equals. As the material configuration of the SG24 is not able to modify the amplitude and the shift phase of the paths for generating a multi-path channel with Rayleigh fading, a solution consists to displace the DUT horizontally has been proposed.

3. Probes Control for Channel Emulation

This method consists in generating a desired multipath propagation channel in terms of angles of arrivals (AoA) at a DUT. It is based on the ignition probabilities of probes, used in emitting way, of the SG24 measurement system.

In this method, we consider that at each rotation step of the device under test (centered or displaced) a new group of probes is created artificially. So, after a U turn of the DUT an artificial spherical probes distribution is obtained as illustrated in **Figure 2**.

The SATIMO SG24 has a finite number of probes distributed discretely on an arch. Therefore, in this method the space surrounding the device under test is decomposed in many cells in azimuth (φ) and elevation (θ) by a discretization step of k° (**Figure 3**). This step has been calculated by seeking the minimum resolution in such a way that each cell can be illuminated. It should be noted, that each cell can be illuminated by more than a probe. Therefore, we have to take this fact into account in order to calculate the probabilities of ignition probes.

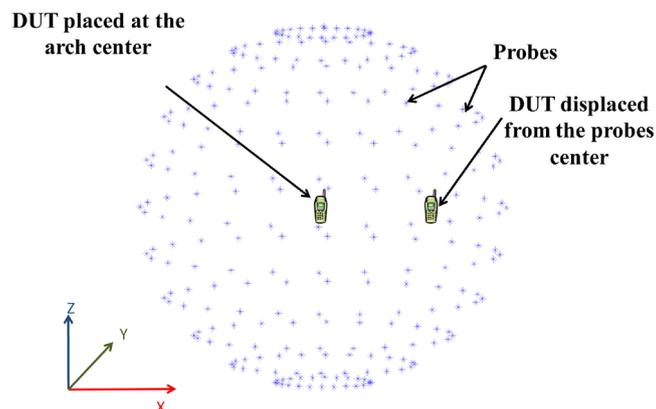


Figure 2. Block diagram of the proposed measurement system.

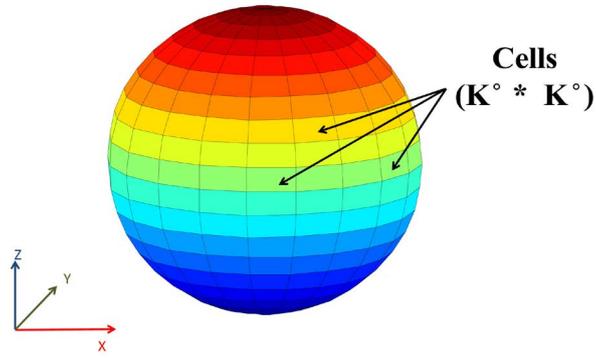


Figure 3. Discretization of space surrounding the DUT in many cells.

In this method we compute the ignition probabilities of each probe to manage the angles of arrivals (AoA) at the DUT in order to obtain a desired multi-path propagation channel. These probabilities are obtained using the law of total probability [9] and considering that the illuminated cells and probes are two family events.

We consider here that the probes number of the artificial sphere equal to J and the cells number equal to M. So, the probability to illuminate the cell number 1 is computed from the equation as listed below:

$$\begin{aligned}
 P(\text{cell}_1) = P(\theta_1, \varphi_1) &= P(\text{cell}_1 | \text{probe}_1) * P(\text{probe}_1) \\
 &+ \dots + P(\text{cell}_1 | \text{probe}_j) * P(\text{probe}_j) \\
 &+ \dots + P(\text{cell}_1 | \text{probe}_j) * P(\text{probe}_j)
 \end{aligned} \tag{1}$$

where,

- $P(\text{cell}_1 | \text{probe}_j)$ is the probability that the cell number 1 is illuminated given the probe number j is switched on and the others are switched off.
- $P(\text{probe}_j)$ is the ignition probability of the probe number j .

The procedure of the cell number 1 is repeated for all the cells. The obtained equations of all the cells can be written in matrix form as illustrated in (2).

$$A = \begin{bmatrix} P_{\text{cell}_1} \\ \vdots \\ P_{\text{cell}_m} \\ \vdots \\ P_{\text{cell}_M} \end{bmatrix} = \begin{bmatrix} P(\theta_1, \varphi_1) \\ \vdots \\ P(\theta_m, \varphi_m) \\ \vdots \\ P(\theta_M, \varphi_M) \end{bmatrix} = H \cdot B = H \cdot \begin{bmatrix} P(\text{Probe}_1) \\ \vdots \\ P(\text{Probe}_j) \\ \vdots \\ P(\text{Probe}_j) \end{bmatrix} \tag{2}$$

With:

$$H = \begin{bmatrix} P(\text{cell}_1 | \text{Probe}_1) & \dots & P(\text{cell}_1 | \text{Probe}_j) & \dots & P(\text{cell}_1 | \text{Probe}_j) \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & P(\text{cell}_m | \text{Probe}_j) & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ P(\text{cell}_M | \text{Probe}_1) & \vdots & \vdots & \vdots & P(\text{cell}_M | \text{Probe}_j) \end{bmatrix} \tag{3}$$

The angles of arrival of a given cell (θ_m, φ_m) are computed for every cell as

illustrated in (4).

$$\begin{aligned}\theta_m &= \theta_m^{\min} + k^\circ/2 \\ \varphi_m &= \varphi_m^{\min} + k^\circ/2\end{aligned}\quad (4)$$

where, $\theta_m^{\min}, \varphi_m^{\min}$ are the minimum AoA of a given cell in elevation and in azimuth respectively. And, k is the discretization step of cells.

Finally, the ignition probabilities of the SG24 probes are obtained in resolving the system of linear equations mentioned in (2) according to the QR factorization method with column pivoting.

In order to validate the developed method numerically, two propagations models are used. The first model is characterized by a uniform distribution of the AoA in elevation and azimuth with a XPR equal to 0 dB. The second model is defined as selective in terms of AoA where it is characterized by a Gaussian distribution in elevation ($\bar{\theta} = 0^\circ, \sigma_\theta = 20^\circ$) and in azimuth ($\bar{\varphi} = 180^\circ, \sigma_\varphi = 20^\circ$) with a XPR equal to 3 dB.

On the other hand, these models are also adopted in this paper with the purpose of evaluating the performance of an antenna diversity system using an antenna reference system.

4. Numerical Validation of the Control Method

In order to generate a multi-path propagation channel with Rayleigh Fading, the DUT has been displaced of 0.7 meters from the arch center, where the Euclidian distances between probes and antennas are different. The DUT has been rotated from 0° to 175° at 5° step in azimuth and from -7° to 7° at 1° step in elevation. In addition, at each position of the DUT 500 samples have been captured for statistical needs.

As the AoA estimation of the received paths on the DUT is impossible to be achieved using the SG24 system, a program based on the ray tracing method that models this system has been developed. The numerical validation of the developed method is done through the comparison between the analytical and simulated probability density distribution of the angles of arrivals (AoA). A discretization step of 18° has been computed in order to illuminate all cells. In **Table 1**, we can see that the obtained results using the propagation models mentioned in 3 have a good agreement.

After validating the developed method numerically, the performances of an antenna diversity system will be evaluated through the ray tracing program and measurements using the SATIMO SG24 system.

5. Diversity Measurements

In this paragraph, we characterize an antenna diversity system at a frequency of 3.5 GHz using the propagation models mentioned previously in the section 3. The reference antenna (**Figure 4(a)**) consists of a linear monopole integrated on a small PCB. The actual diversity system (**Figure 4(b)**) consists of two identical monopoles spaced by $d = 0.14\lambda$.

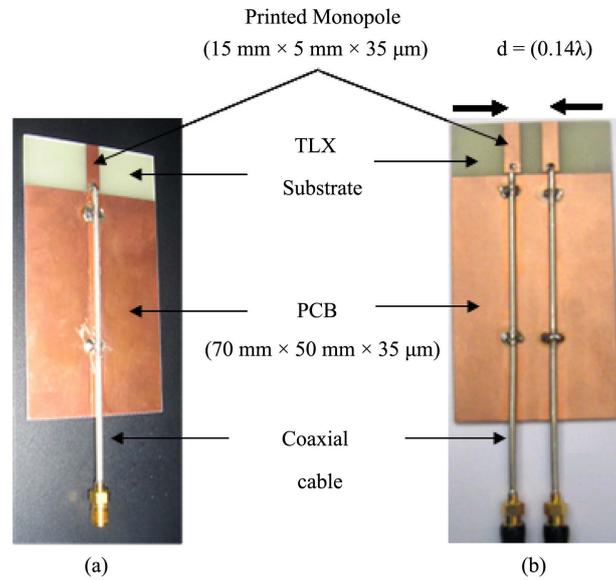
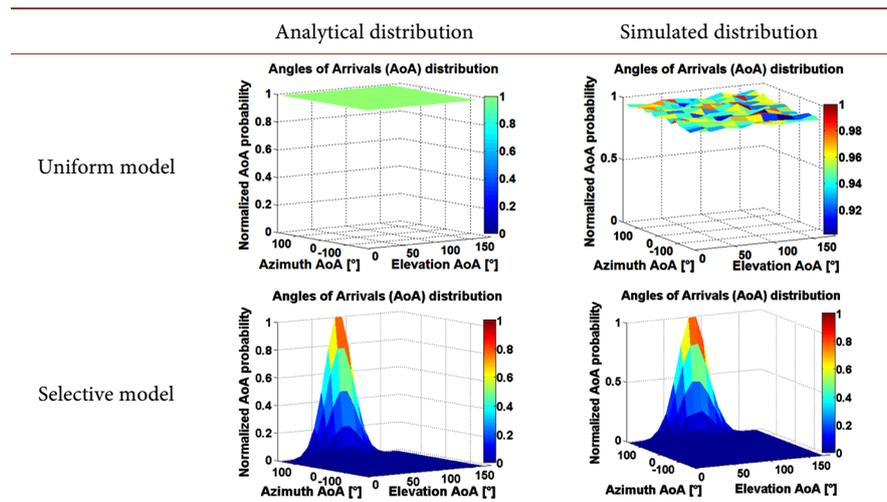


Figure 4. Reference (a) and diversity system (b).

Table 1. Comparison between analytical and simulated models.



5.1. Measurement Setup

In these measurements (Figure 5), the configuration mentioned in the paragraph 4 has been used in order to have a good ratio between the angles of arrivals resolution and measurements time. In addition, a vector network analyzer of 2 ports has been used, where the RX port is connected to the probes and the TX port is related to the DUT.

In post processing, the received signals at each position of the antenna systems in elevation have been summed. This procedure has been performed in order to represent a 3D multi-path propagation channel. The obtained signals at each branch of the diversity system are used to evaluate its performance in terms of the correlation coefficient and DG using the signal collected by the reference antenna system.

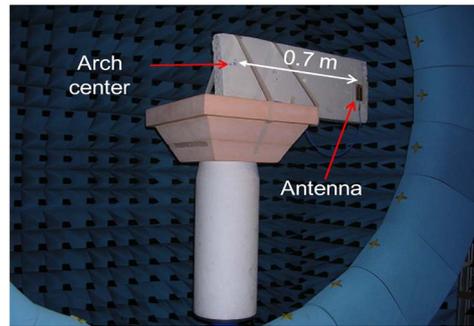


Figure 5. Measurements setup using SATIMO SG24 system.

5.2. Diversity Measurement Results

In this section, the propagation models mentioned in the paragraph 3 are used to evaluate the performances of the antenna diversity system in terms of correlation coefficient and diversity gain (DG) using an antenna reference system. The correlation coefficient is computed through the signals collected on the antenna diversity branches [10]. The DG is deduced from the cumulative distribution function (CDF) plot of the received signals and after a combining according to the diversity combining methods [11]: Equal Gain Combining (EGC) and Maximum Ratio combining (MRC).

5.2.1. Diversity Measurement Results

As mentioned before, the angles of arrivals in this model are uniform in elevation and in azimuth, and the XPR is equal to 0 dB. Measurements and simulations have been done. In order to validate the diversity measurements using this model, measurements have been performed also in a reverberation chamber [11] [12] which is considered as a proper isotropic Rayleigh fading channel [13].

The obtained fading amplitude distribution of the normalized received signal (power = 0 dB) using the SATIMO SG24, depicted in **Figure 6**, shows a good agreement with both the reverberation chamber (RC) results and theoretical Rayleigh distribution. In addition, we see that the standard deviations (σ) are very close to each other.

The correlation coefficient has been computed as illustrated in **Table 2**. The cumulative distributed function (CDF) plot of the signals is a good indicator to show the diversity gain performance in fading environment as depicted in **Figure 7** (Simulation), **Figure 8** (SATIMO measurements) and **Figure 9** (RC measurements). These figures reflect the probability of having a power below a given threshold (normalized).

In the previous figures, we see that the CDF's of the received signals show a good agreement with the theoretical Rayleigh distribution. However, we denote that there is a small difference between these CDF's. It is due to the radiation patterns of the antennas systems.

A consolidated summary of the different simulated and measurement diversity parameters is depicted in **Table 2** where we see that they have a good agreement.

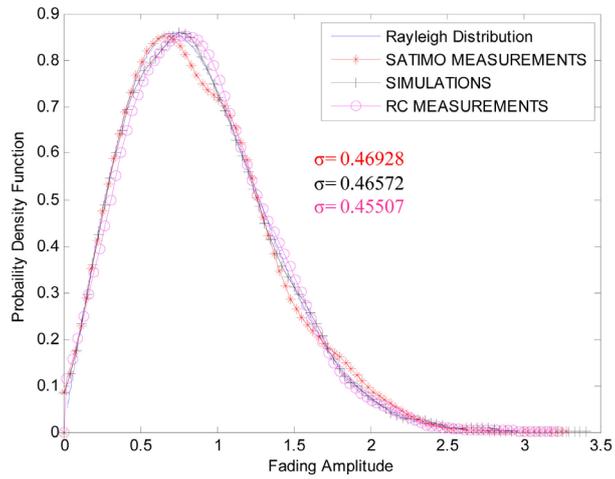


Figure 6. Fading amplitudes of the received signals using the uniform model.

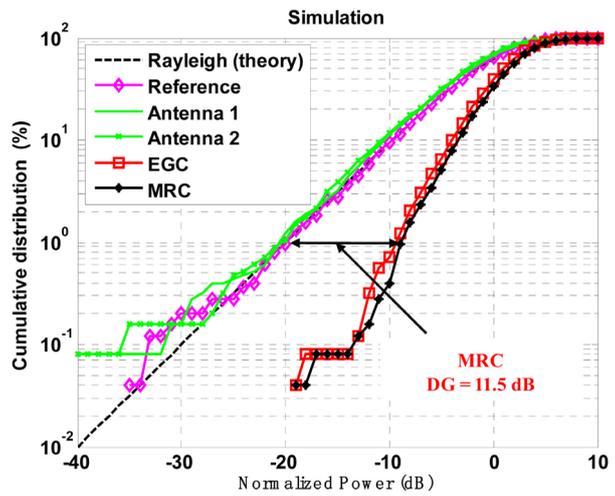


Figure 7. CDF of the simulated signal powers, and after diversity combining: EGC and MRC.

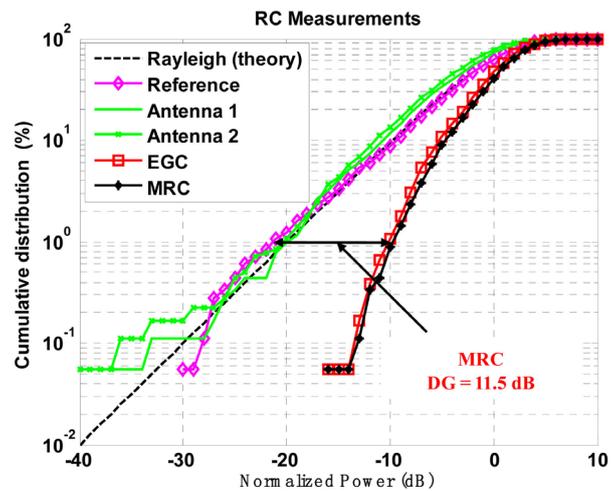


Figure 8. CDF of the measured signal powers using the RC measurement system, and after diversity combining: EGC and MRC.

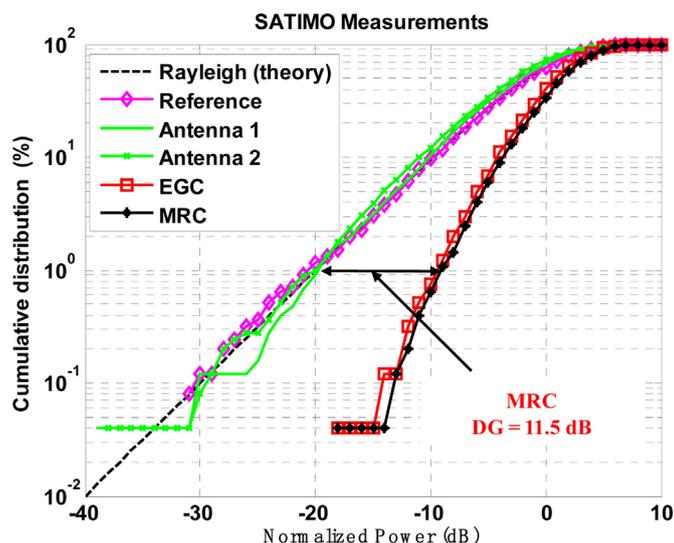


Figure 9. CDF of the measured signal powers using SATIMO SG24 measurement system, and after diversity combining: EGC and MRC.

Table 2. The diversity parameters results using the uniform model.

	Envelope Correlation coefficient	DG at 1% probability (dB)/ EGC	DG at 1% probability (dB)/MRC
Simulations	1.6×10^{-1}	11	11.5
SG24 measurements	6×10^{-3}	11	11.5
RC measurements	8.8×10^{-2}	11	11.5

5.2.2. Selective Model Results

Using this model, we have proved also that the emulated environment is characterized by Rayleigh fading as illustrated in **Figure 10**.

The CDF curves have been computed in order to deduce the diversity gains as depicted in **Figure 11** (Simulation) and **Figure 12** (SATIMO measurements).

The previous figures show that the CDF's of the signals received by the reference system and the branch 1 (Antenna 1) of diversity system have a good similarity with the theoretical Rayleigh distribution. However, the CDF of the signal collected by the branch 2 (Antenna 2) is different due to the sensitivity of the radiation patterns using a selective model in terms of AoA.

The simulated and measured diversity parameters have been shown in **Table 3**. In this table we see that the correlation coefficients have a good agreement. However, we denote that there is a difference of 1 dB between simulated and measurement diversity gains according to the EGC and MRC combining methods. This difference is due to the antenna positioning during the measurements compared to simulations. Since a small rotation of the antenna system, using a selective model in terms of AoA, may change the received power level and consequently it affects the diversity gain.

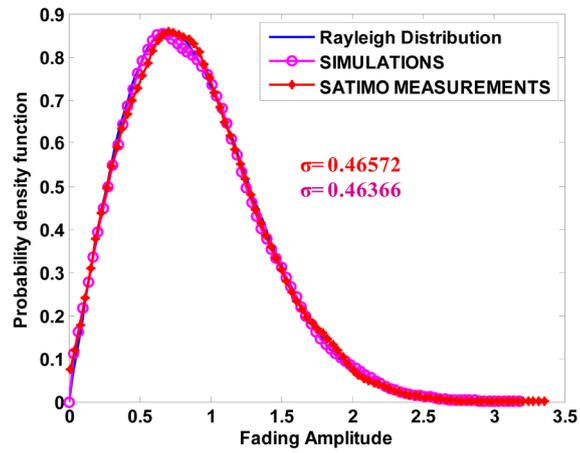


Figure 10. Fading amplitudes of the received signals using the selective model in terms of angles of arrivals.

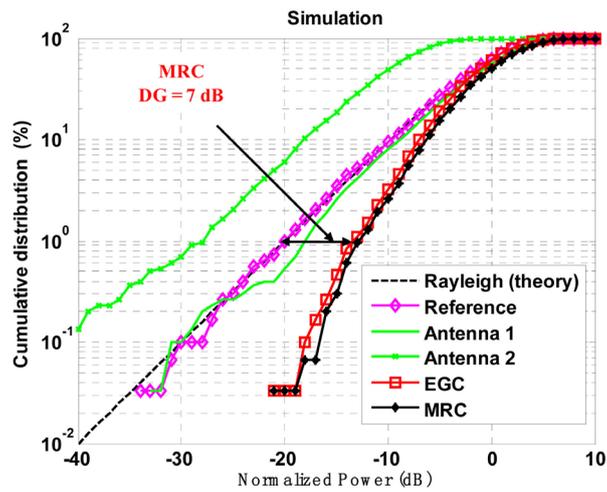


Figure 11. CDF of the simulated signal powers, and after diversity combining: EGC and MRC.

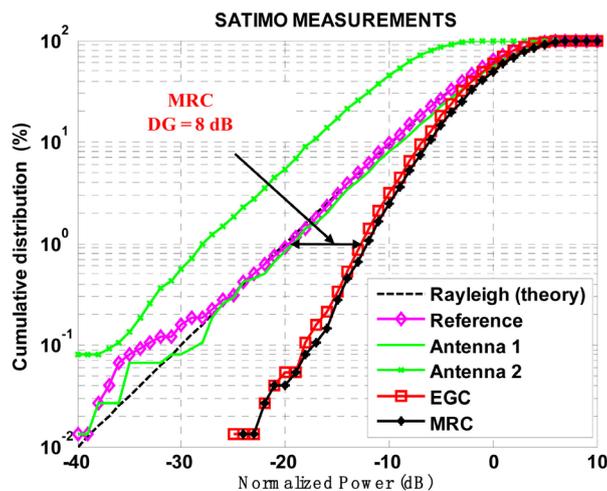


Figure 12. CDF of the measured signal powers using SATIMO SG24 measurement system, and after diversity combining: EGC and MRC.

Table 3. The diversity parameters results using the selective model.

	Envelope correlation coefficient	DG at 1% probability (dB)/EGC	DG at 1% probability (dB)/MRC
Simulation	23×10^{-2}	6.5	7
SG24 measurements	28×10^{-2}	7.5	8

6. Conclusion

In this paper, realistic multi-path propagation channels in terms of angles of arrivals (AoA) and cross polarization ratio (XPR) with Rayleigh fading have been emulated with the purpose of diversity measurements using the SATIMO SG24 measurement system. Two propagation models such as Uniform and selective in terms of AoA have been used. The performances of a diversity system, using these models, have been evaluated in terms of correlation coefficient and diversity gain using an antenna reference system. Simulation and measurement results have shown a good agreement.

The future work of this paper consists on one hand, in evaluating the performance of diversity antennas systems in realistic environment using MPAC such as out-door and in-door propagation channel models in order to save time and equipments in comparison with measurements on the land. And, on the other hand, taking into account the delay spread on the interfering rays, in order to assess the overall MIMO performances including the antennas characteristics and the RF transmitter.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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