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1. Introduction

A considerable effort has been made in 3GPP towards the development of standardized MIMO OTA test methods. One method currently considered for standardization, the reverberation chamber, has already been found to fulfil the ABCD criteria set for IL/IT test results consistency, and has also recently been found to be harmonized with Anechoic Chamber Multiprobe method as it provides the same decision of what is a “good” or “bad” device from the radiated receiver performance perspective.

Some previous contributions in 3GPP and CTIA [1] have concluded that “*MIMO antenna systems can have different results in different test methodologies due its fundamental limitations, i.e. lack of antenna polarization discrimination*” when testing some antennas in an ETS-Lindgren AMS8700 anechoic chamber and an ETS-Lindgren AMS-7000 Reverberation Chamber.

The objective of this contribution is to present some test results of Polarization Diversity at the user terminal using a reverberation chamber and its ability to discriminate polarization in antennas, in view of the future requirements to be set for MIMO OTA test equipment, and to conclude that the conclusions in [1] and [2] cannot be generalized to all anechoic or reverberation chambers, and have to be limited to the tested equipment in [1] and [2].

This contribution was made in co-operation with EMITE, a manufacturer of mode-stirred reverberation chambers.

2. Preliminary considerations

In the contributions [1] and [2], some experiments were carried out in a single-cavity reverberation chamber (RC) with two transmit antennas of different orientations and the analysis of the data made the authors conclude that “*MIMO antenna systems can have different results in different test methodologies due its fundamental limitations, i.e. lack of antenna polarization discrimination*”, based only on the measurements performed at the specific ETS-Lindgren AMS8700 anechoic chamber and an ETS-Lindgren AMS-7000 Reverberation Chamber and using only correlation results.

While the contributors of [1] and [2] set different polarization diversity schemes at the user terminal (UE) to be measured, yet made their conclusions over the polarization diversity of a fading environment. It is important to remember that there are substantial differences between polarization diversity of a fading environment, typically characterized by its cross-polarization ratio (XPR), and the polarization diversity inherent within an angular antenna diversity system, both of which have different applications, as explained in [3]. It is also important to remember that the cross-polarization ratio (XPR) indicates how much the polarization of the paths change, whereas the co-polarization ratio (CPR) shows the degree of vertical polarization with respect to the horizontal polarization [4]. Different conditions for the cross polarization ratio (XPR) between the outdoor and indoor environments can be found [5]. Adopting both space diversity and polarization diversity as the transmit diversity configuration for base stations will also lead to a variation in the XPR [6]. XPR is in the range from -9 to 0 dB outdoor environment where space diversity configurations is employed for the base station [7], whereas the absolute XPR will be low in an environment where a polarization diversity configuration is employed or in an indoor environment [5].

Similarly, in the contributions [1] and [2] it is claimed that “... *the same antennas can't be discriminated in the statistically uniform MIMO OTA test environment where by definition XPR = 0dB*”, but whether these detected differences resemble a behaviour that can be observed in real propagation scenarios or are the consequence of the emulation artefacts inherent to a 2D SCME channel model emulated in an anechoic chamber with specific transmit antenna polarizations remain unknown. In fact, from [4], measurements in a small urban macrocell of the behaviour of polarization ratios with respect to delay, and to direction, shown that they are affected by elevation AoA, whereas “*delay and azimuth AoA do not show any significant impact on polarization ratios*”. This indicates that the lack of elevation AoA in [1] and [2] when the terminals were measured in the anechoic chamber system may be the source of the encountered differences, which could not correspond to values encountered in the field.

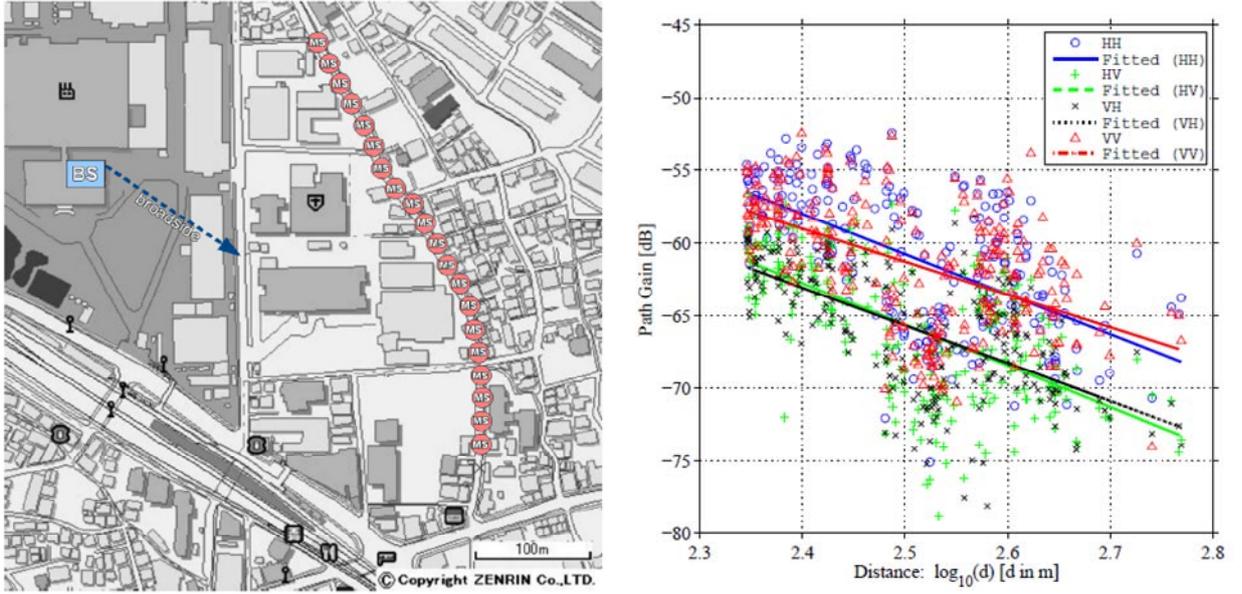


Figure 1. Polarization path differences measured in [4].

Before considering the ability of reverberation chambers to discriminate polarization, it is important to remember how the spatial correlation is evaluated in an urban fading environment at the mobile. This depends on the three-dimensional angle of arrival characteristics, and the distance between the two points which will cause a phase delay. It is assumed that, since the antennas are close together in a terminal, the local mean power levels available at the two branches are the same. Hence, to evaluate the diversity gain only correlation has to be considered [9]. Complex correlation can be evaluated using the closed form expression

$$\rho_{12} = \frac{\int_0^\pi \int_0^{2\pi} (XPR \cdot E_{\theta 1}(\theta, \phi) E_{\theta 2}^*(\theta, \phi) p_\theta(\theta, \phi) + E_{\phi 1}(\theta, \phi) E_{\phi 2}^*(\theta, \phi) p_\phi(\theta, \phi)) \sin\theta d\phi d\theta}{\sqrt{\sigma_1^2 \sigma_2^2}}$$

where

$$\sigma_n^2 = \int_0^\pi \int_0^{2\pi} (XPR \cdot |E_{\theta n}(\theta, \phi)|^2 p_\theta(\theta, \phi) + |E_{\phi n}(\theta, \phi)|^2 p_\phi(\theta, \phi)) \sin\theta d\phi d\theta$$

and it can be seen that correlation depends on cross-polar ratio (XPR), vertical and horizontal fields and the angle of arrival (AoA) statistics. As stated in [9], in the case of spatial diversity, only vertical E fields have to be considered, which causes the correlation to become independent of XPR. When evaluating spatial correlation, it has often be the case that only the azimuth angle of arrival has been taken into account, which is assumed to be uniform [10]. Yet, when considering angular correlation, for practical measurements or simulations several azimuth and elevation cuts are needed [9], and angular correlation is found dependent on

XPR [9]. A 6 dB value is found for typical urban environments [11]. Therefore, being able to measure angular correlation implies the detection of an XPR-dependence, and consequently XPR effects. Moreover, it has been shown that angular correlation has an effect on reducing the efficiency of the antennas when compared to the isolated units [9]. In order to find how the efficiency is reduced, the Mean Effective Gain (MEG) has to be evaluated [9]. Consequently, in order to evaluate the MIMO performance of antennas which are not closely separated, correlation and diversity gain are parameters of importance. Angular correlation, however, does not give an indication per se as to what polarisation the antennas have, for which the concept of source stirring could be helpful, as it will be explained further on.

In consequence, **when two antennas are no longer considered to be closely spaced**, as in the experiments in [1] and [2], then **correlation alone cannot be used to evaluate diversity**. In fact, for the specific antenna orientation studied in the contributions [1] and [2], in which one antenna had its angular spacing varied respect to the other but with different orientations in space, it was clearly stated in [3] that *“changing the polarizations between two dipoles is creating an angular diversity system with some inherent polarization diversity as well and that the polarization diversity of two polarizations in space is a completely separate matter that is not related to that of the antennas”*, and that a measurement of the diversity gain is needed to properly evaluate the apparent diversity gain of such a system with two polarization diversity antennas at different polarizations.

3. Reverberation Chamber for testing Polarization Diversity with different orientations at the UE

3.1 Polarization diversity with closely spaced antennas

Most polarization diversity situations that can occur at real terminals employ antennas that show some correlation, therefore cannot be considered to be uncorrelated. This is because the available space is limited, and therefore the antennas at the use equipment, a handset, USB dongle, smartphone or Tablet, can be considered as closely spaced.

The correlation properties of closely spaced dipoles which are simultaneously separated a spatial and an angular distance, therefore with both spatial and polarization diversity, have been studied in [12] and [13]. In [14] and [15], a reverberation chamber was used to discriminate polarization diversity in these closely spaced terminals. When evaluating the different 2-element polarization diversity schemes, depicted in figure 2, it was clearly shown that for these antenna arrays polarization diversity was equivalent to spatial diversity, as also illustrated in figure 2, with the limitation of the angular 360° rotation, and that for more than 2 elements the combination of both spatial and angular separation was optimum for diversity schemes.

The diversity gain and MIMO capacity of linear and circular antenna arrays exploiting both spatial and polarization diversity was evaluated using a reverberation chamber in [15]. For 3x6 circular arrays, specific angular separation distances between elements was found to provide optimum gains and capacity, showing the capabilities of the generalised polarization diversity for MIMO performance enhancement and the capabilities of reverberation chambers to evaluate those enhancements when the antennas had different orientations.

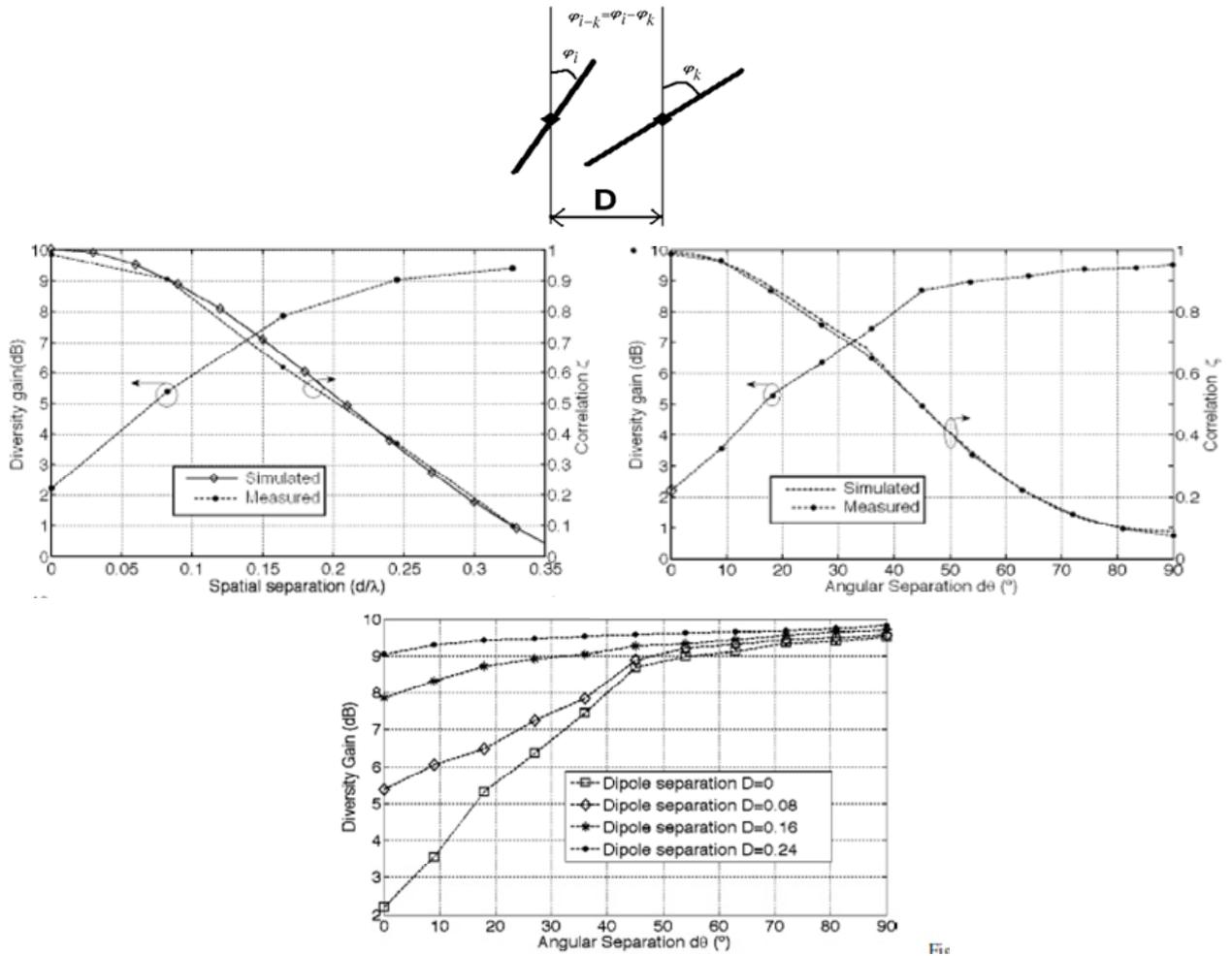


Figure 2. Polarization diversity discrimination of closely-spaced 2 antenna elements using a reverberation chamber [14].

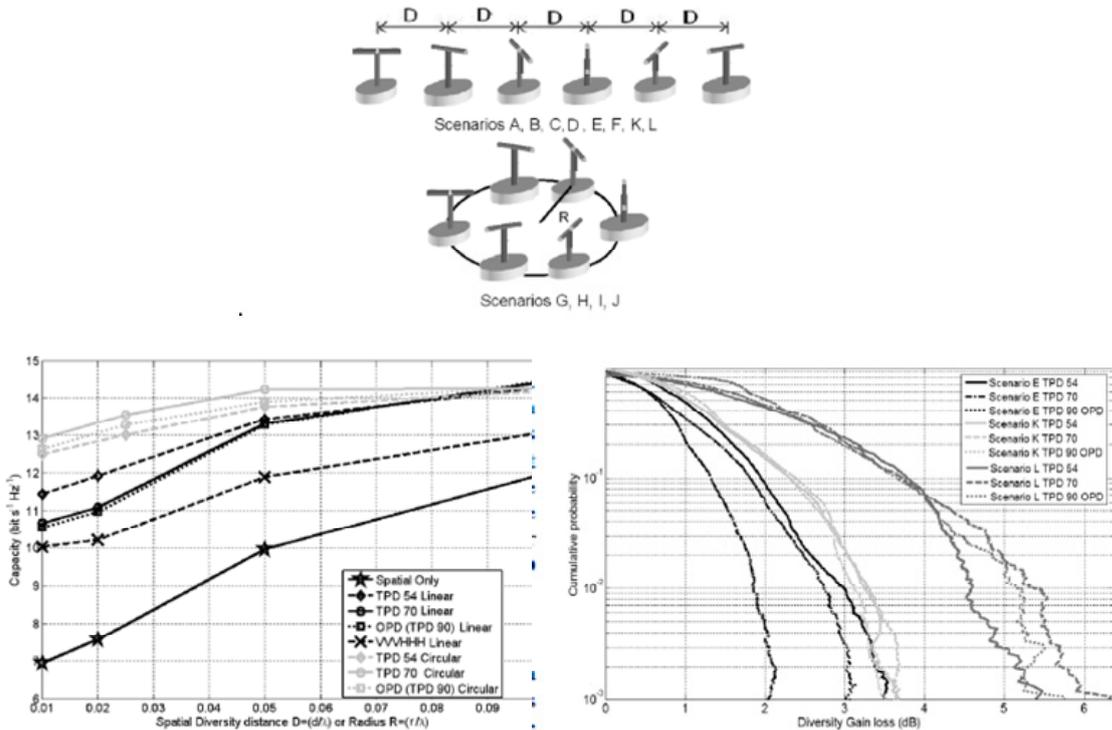


Figure 3. Diversity gain and MIMO capacity for linear and circular antenna arrays with both spatial and polarization diversity evaluated using a reverberation chamber in [15].

Another example of studying closely-spaced three-axis orthogonal polarization diversity terminal systems using a reverberation chamber and eigenvalues can be found in [16]. Two compact antenna sets with very low mutual coupling were studied, one of them was a three orthogonal polarization unit whereas the other was a cube-six-port antenna which has both polarization and space diversities. The eigenvalues in the 3×6 MIMO were found to be greater than those in 3×3 , demonstrating that the proposed antennas are very much suitable for MIMO systems working in multi-path rich environments and that their performance increase respect to other designs without three-orthogonal polarization diversity can be studied using a reverberation chamber.

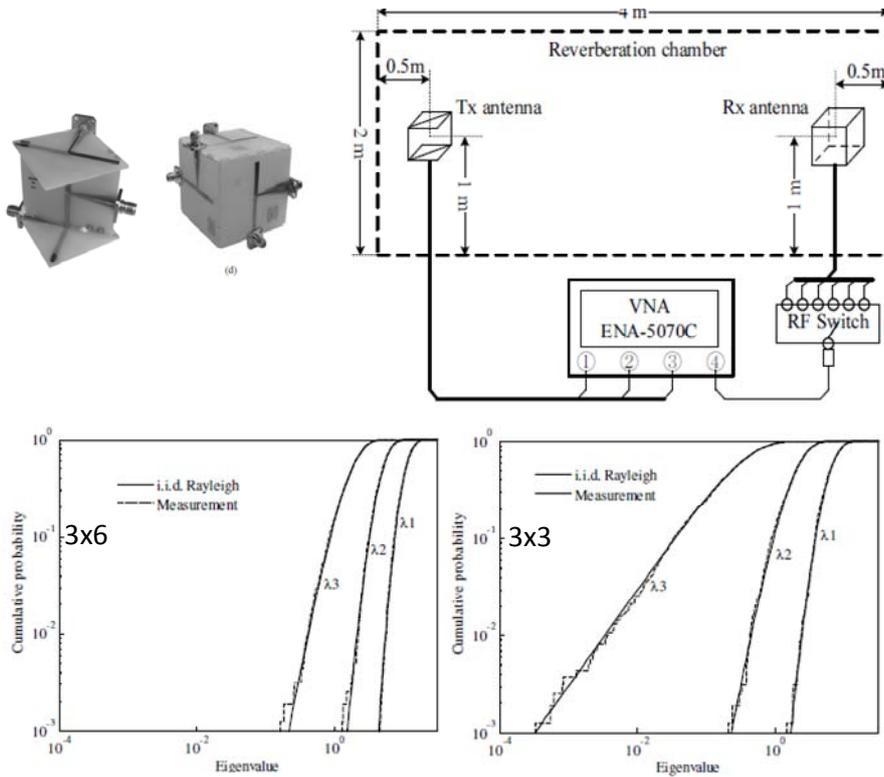


Figure 4. Three-orthogonal polarization plus spatial diversity studies using a reverberation chamber in [16].

Therefore, reverberation chambers have already shown their ability to discriminate polarization diversity in commonly-used closely spaced MIMO systems.

Typical closely-spaced terminals, however, was not the case studied in [1] and [2], in which the elements are uncorrelated and cannot be considered a typical user equipment of closely-spaced antenna elements.

3.2 Polarization diversity with largely spaced antennas

As it has been mentioned, the polarization diversity schemes employed in the [1] and [2] documents are uncorrelated antennas corresponding to largely spaced devices.

Several examples can be found in the literature that characterized polarization diversity schemes similar to the ones employed in the [1] and [2] contributions using reverberation chambers.

In [17], for example, tri-polarized MIMO systems, in which the second and third antenna take a different orientation (and orthogonal) to the first antenna, were characterized through the measurement of their eigenvalues in a multipath-rich chamber, as illustrated below, which were compared to those of single and dual schemes. The median value of the eigenvalues for tri-polarization MIMO system was found 4dB greater than that for dual polarization system. This result proves that the third antenna with a different orientation to the other two was actively working in a multipath environment and that the increased MIMO performance can be characterized in a reverberation chamber.

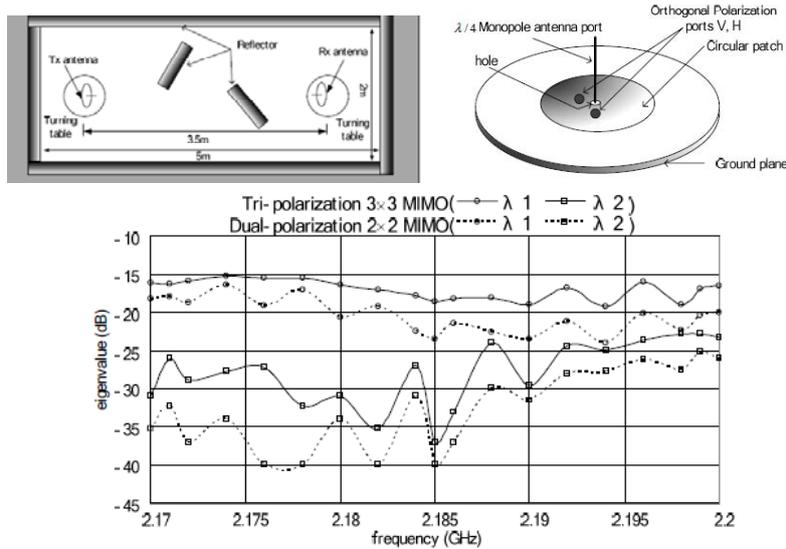


Figure 5. Tri-polarized schemes tested in a multipath-rich chamber.

Another example can be found in [18], in which a scattered field chamber was used to evaluate the effects on XPR on the system diversity of a terminal with two different set of antennas with very low correlation coefficient but different polarization diversity schemes, concluding that “*The results indicate that the three dimensional isotropic incident field is a good reference case to evaluate diversity performance in a multi-antenna application*”. By the introduction of the diversity system gain, the antenna efficiency including reflection loss, ohmic loss and mutual coupling loss were taken into account, and not only correlation was considered. While results were different for diversity gain between different XPR scenarios, system diversity gain results were very similar, resulting in the reverberation chamber to be a good candidate for a complete evaluation of the diversity performance of the UE.

In order to verify the above, a set of measurements was arranged in a reverberation chamber with source-stirring.

4. Measurements

In order to reproduce the experiments in [1] and [2], two different combinations of a set of two-antenna elements with a large spatial separation were prepared. The sets are illustrated in figure 6 and it consists of a discone antenna and a dipole antenna which are separated 20 cm. The dipole operates at a centre frequency of 1500 MHz, which is also covered by the discone. In set 1, the dipole was placed horizontal, while in set 2, the dipole was placed vertical. The sets are therefore reproducing a MIMO array of largely separated antennas with different polarization diversity schemes. Measurements were performed in the EMITE E400 MIMO Analyzer mode-stirred reverberation chamber. The E400 RC is a multicavity with 8 transmitting antennas, with both source- and mode-stirring capabilities.



Figure 6. Set of tested antennas with dipole in horizontal (left) and vertical (right) positions.

As expected, the correlation results showed little differences between the two sets, as they are very low correlated due to the spatial separation, but when evaluating the apparent diversity gain (ADG), results obtained with the two sets were different depending upon the selected source antennas. Measured ADG results with source-selection are depicted in figure 7. Table 1 summarizes ADG results at 1500 MHz center frequency. When the source antennas selected were those with vertical polarization, higher diversity gain values were observed when the dipole was placed vertical. Similarly, when the selected source antennas were those in horizontal position, higher diversity gain values were observed when the dipole was placed horizontally. While the absolute values of these source-selected measurements cannot be used for overall assessment, they can certainly be used for discriminating polarization diversity in a largely-separated MIMO antenna array.

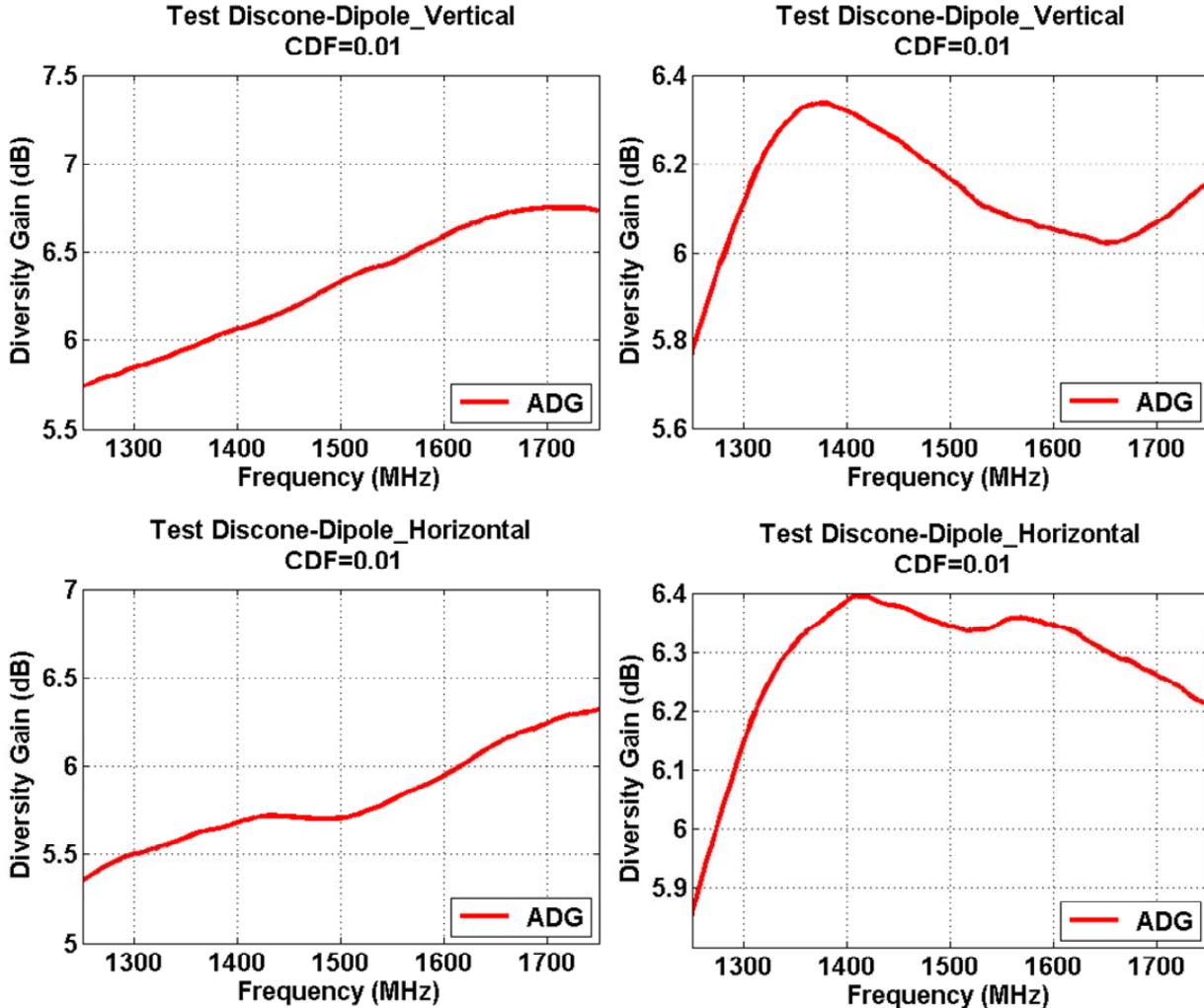


Figure 8. ADG for the tested sets with vertically-polarized selected sources (left) and horizontally-polarized selected sources (right).

Table 1. ADG (dB) @ 1500 MHz.

	Sources V	Sources H
Set 1 (Dipole H)	6.16	6.34
Set 2 (Dipole V)	6.34	5.71

It has been demonstrated that a reverberation chamber can discriminate polarization diversity also in largely-separated MIMO antenna arrays with low correlation.

5. Conclusions

It was demonstrated that Reverberation Chambers can clearly discriminate polarization using a uniform MIMO OTA test environment, for both closely- and largely-spaced antenna elements, and that this can be done using different measured parameters.

It is therefore concluded that the conclusions in [1] and [2], i.e. a general disability of the statistically uniform MIMO OTA test environment to discriminate polarization, cannot be obtained from some few measurements in a particular set of equipment, and has to be limited to the tested equipment in [1] and [2], the ETS-Lindgren AMS-7000 Reverberation Chamber.

6. References

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