Measurements of Effective, Apparent and Actual Diversity Gain of Two Parallel Dipoles close to a lossy Cylinder in a Reverberation Chamber

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ABSTRACTS

We use a reverberation chamber to measure diversity gain of two parallel dipoles close to a lossy cylinder at 900 MHz. We define an actual diversity gain as the diversity gain of the dipole pair by comparison with a single separate dipole in the same location and orientation. We observe a significant actual diversity gain of 6 dB for this case, when the dipoles are 2 cm from the lossy cylinder and two cm apart. This value is very inspiring for making use of diversity on small handheld terminals even at 900 MHz.

INTRODUCTION

The performance of mobile and wireless terminals can be significantly improved by making use of two or more separated antennas for spatial, polarization or pattern diversity by combining the signals received by the antennas in a desirable way. Diversity studies are normally done by moving antennas and equipment around in an urban or indoor environment, which is expensive both in terms of cost and time. In addition, the result may or not be repeatable in other environments. We will in the present paper describe how to measure diversity gain in a small reverberation chamber, without the need of moving neither the phone nor the measurement equipment away from the laboratory. We will also give values for the diversity gain for antennas located close to a cylinder filled with the same brain equivalent liquid used for SAR measurements.

In previous published articles, measurements and theory does not agree so well [1][2]. Even for a simple test case of two parallel dipoles the agreement between measurement and theory is not so good [1]. The reason is that the radiation efficiency due to the mutual coupling, between the two coupled dipoles, is not included. From our measurements we have found that when we include the radiation efficiency, the agreement between measurement and theory is good [3]. Due to the mutual coupling we have to consider the two dipoles as an antenna system and not as separated dipoles. The induced current in the neighbouring dipole will not only dissipate in the 50Ω but also make the dipole radiating. The additional radiation is added to the radiation from the active dipole. This will deform the ideal dipole radiation pattern so that the pattern correlation between the two dipoles becomes lower.

We have defined an **effective diversity gain** relative to a single lossless reference antenna [4]. The measured effective diversity gain turns out to be very close to theoretical maximum calculated without considering neither efficiency nor mutual coupling. Thus, the physical limitation due to reduced efficiency and coupling through the radiation patterns are strongly related, which we know also from other types of antennas.

The effective diversity gain accounts for the case of reduction in radiation efficiency due to the mutual coupling between the antennas. When we consider a real scenario where diversity is applied to a handheld terminal close to a lossy object, such as a mobile phone at a head in talk position, we also need to account for the losses in the head. Therefore, the reference case is taken to be a lossless single and separate antenna in the same position at the lossy object as for the antennas used for diversity. The diversity gain with this reference is called an **actual diversity gain**.

In the present paper we will show experimental results for two parallel dipoles in free space and 2 cm away from a lossy cylinder, all measured in a small reverberation chamber of 0.8m x 1m x 1.6m size. We also show theoretical results for the effective diversity gain of two dipoles in free space, obtained from [3]. This has been calculated from the equivalent circuit of two parallel dipoles including mismatch and mutual coupling.

HOW TO ACHIEVE DIVERSITY

The concept of diversity combining means that we make use of two antennas to receive a signal, and that we can combine the replicas of the received signal in a desirable fashion to improve performance. There should be low coupling between the antennas, otherwise the diversity gain will be low. This can be achieved by using orthogonally polarized antennas (polarization diversity), by locating the antennas away from each other (spatial diversity), or by using antennas with different radiation patterns such as antennas radiating in different directions (pattern diversity). Two parallel dipoles is an example of spatial diversity.

Each antenna is connected to a separate receiver, and the outputs of the receivers are combined in such a way that the signal-to-noise ratio S/N of the combined signal is larger than the S_1/N_1 and S_2/N_2 of the signals in each of the two antennas. This is possible if the fading characteristics of the signals S_1 and S_2 are uncorrelated in the two antennas. To ensure this, we have to require low coupling between the antennas. The simplest diversity algorithm is to select at all times the S_1+N_1 or S_2+N_2 with the highest level, referred to as selection combining [5, Sec.10]. Another approach that gives slightly higher diversity gain is maximal ratio combining [5, Sec.10]. The diversity gain represents a relative increase in signal-to-noise-ratio, S/N. Therefore, it is important to know how the S/N of each antenna is affected by the presence of the neighbouring antenna.

The diversity gain G_{div} relative to antenna 1, i.e. the apparent diversity gain, and the effective diversity gain G_{diveff}, both defined in [4], are

$$G_{div} = \frac{S/N}{S_1/N_1} \quad \text{and} \qquad G_{diveff} = \frac{S/N}{S_1/N_1} e_{rad1} \tag{1}$$

where e_{rad1} is the radiation efficiency of antenna 1. Note that this formula is valid only if the noise signals N_1 and N_2 are independent of the radiation efficiency. This is the case if the system noise is dominated by that of the receivers, or if the antenna noise temperature is the same as the ambient temperature. This is evident from the equations (2.110), (2.112) and (2.118) in [10, Sec. 2.5.4]. The latter condition is often close to being satisfied in mobile systems because the antenna is rather omni-directional and picks up thermal noise mainly from the environment (ground, buildings, trees, humans) around the antenna, and less from the low temperature sky.

RESULTS

We have used two calibrated reference dipoles located parallel to each other and with different distances between them. They have been measured in both free space and 2 cm away from a lossy cylinder in a reverberation chamber of 0.8m x 1m x 1.6m size. The reverberation chamber uses platform stirring [6] and polarization stirring [7] to improve the field uniformity [8] and the accuracy of the measurement. The setup of the parallel dipoles is shown both in Figure 1 and 2 and we measure two cases. In the first case we connect one of the dipoles, the active dipole, and terminate the other in 50Ω. In the second case we simply swap the connections of the dipoles so that the active dipole in case one is terminated in 50Ω and the other is active. A network analyser is used to acquire transmission data S_{12} between the active dipole and one of the monopoles on the chamber wall, see Figure 1. S_{12} is measured over a frequency range centred at 900 MHz. The transmission measurement is repeated but with another monopole by switching the switch in Figure 1. After the three measurements between the active dipole and the three monopoles, we move the plate stirrers along the walls and rotate the rotatable turntable, at the bottom of the chamber, in a controlled way with a computer. The transmission measurements are repeated again and in this way, we collect typically 3750 transmission samples. When the first case is done, we swap the connections of the two dipoles and relocate the plate stirrers and platform at exactly the same starting position as for the first case. The stirrer sequence is then exactly repeated for the second measurement case, and the transmission samples are collected. In this way we have controlled the stirrer positions so that they are the same in both measurement cases and henc we obtain the same multipath environment.

Parallel dipoles in free space. From the transmission samples we can extract the return loss [9] and also the radiation efficiency when it is compared to an ideal reference case. For the parallel dipoles in free space, we have both measured and calculated the reflection losses (due to mutual coupling between the dipoles) and the absorbsion in the 50Ω termination of the inactive dipole. We then have the radiation efficiency as the sum of both these losses and we see the measured and calculated losses and radiation efficiency in Figure 3. The calculations have been performed with an equivalent circuit of two parallel dipoles, in free space, [9][10] and we see in Figure 3 that the calculations agree well with the measurements. The diversity gain for the dipoles in free space is calculated at 1% probability that the transmission samples are under the abscissa. Figure 4 show both calculations and measurements of diversity gain and effective diversity gain and they compare well.

Parallel dipoles close to lossy cylinder. Next, let us consider the two parallel dipoles 2 cm away from a lossy cylinder. The radiation efficiency is then decreased due to that some power is absorbed in the cylinder. The measurements are performed in the reverberation chamber as described above but with a lossy cylinder in the proximity of the two dipoles instead of free space. In Figure 5 we see the transmission samples plotted in a cumulative plot (left most “diversity branches”). As references we have located a single separate matched dipole both in free space and 2 cm away from the cylinder. The dipole in free space is used as a reference for the effective diversity gain. This is shown in figure 5 as the cumulative distribution curve “ideal reference”. However, when the two parallel dipoles are close to a lossy cylinder, the effective diversity gain will not be a representative quality measure of the diversity antenna. In this case, the improvements are better characterized in terms of the diversity gain relative to a single lossless matched dipole in the same position relative to the lossy cylinder. This is the case when the reference dipole is located 2 cm away from the lossy cylinder and can be seen in Figure 5 as the cumulative distribution curve marked “reference 2 cm close to lossy cylinder”.

We see in Figure 5 that the cumulative distribution curve for the reference dipole 2 cm away from the lossy cylinder is shifted to the left relative to the reference dipole in free space (ideal reference). The shift is around 2.5dB along relative power level axis and this is the reduction in radiation efficiency, i.e. the power absorbed in the lossy cylinder.

The combined signal is obtained by selection combining [5] and also shown in Figure 5. The diversity gain is the difference between the combined signal and the reference dipole (which can be either the dipole 2 cm away from the lossy cylinder or the dipole in free space) along the relative power level axis at some cumulative probability level. In figure 5 we have chosen a 1% cumulative probability level, which can be seen as a thin line at the cumulative probability value 0.01.

We have plotted the different diversity gains as a function of the distance between the dipoles in Figure 6. The distances between the dipoles are 2 cm (0.06λ), 4 cm ($0.12\ \lambda$) and 6 cm ($0.18\ \lambda$). We see that the actual diversity gain is around 2.5dB higher than the effective diversity gain. This is the reduction of the radiation efficiency due to absorption in the lossy cylinder. However, if we compare Figures 6 and 4 we see that the effective diversity gain in Fig.4 compares well with the actual diversity gain in Fig.6.

CONCLUSION

We have shown that it is very important to choose an appropriate reference case when measuring diversity gain. Otherwise, the results may be misleading. For antennas close to human tissue it is possible to define three different diversity gains, depending on the reference. These are apparent diversity gain, effective diversity gain and actual diversity gain. The latter is the most appropriate when evaluating diversity antennas for mobile phones. We have shown by measurements in a reverberation chamber that the actual diversity gain may be as large as 6 dB at a 1% cumulative probability level for parallel dipoles located only 2 cm apart and 2 cm from a lossy cylinder, at 900 MHz. For orthogonal antennas the actual diversity gain should be even larger.

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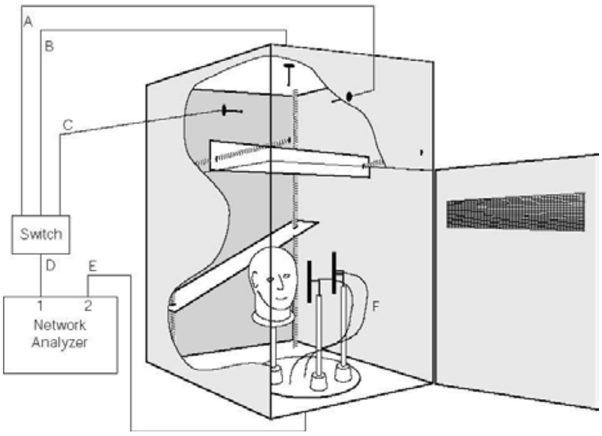

Figure 1. Illustration of the measurement setup in the reverberation chamber.

Figure 2. Two parallel dipoles 2 cm from lossy cylinder.

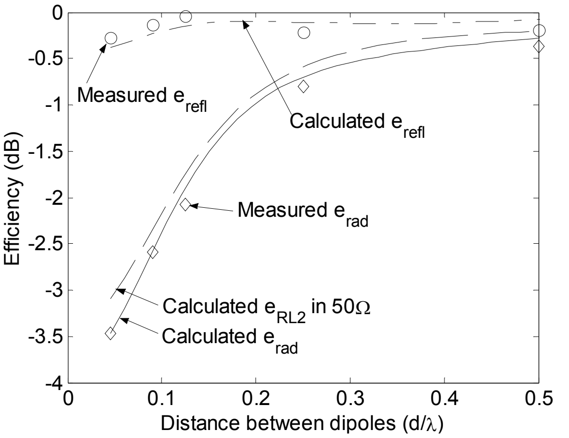

Figure 3. Results for measured and calculated efficiencies of the parallel dipoles in free space, for 50Ω termination.

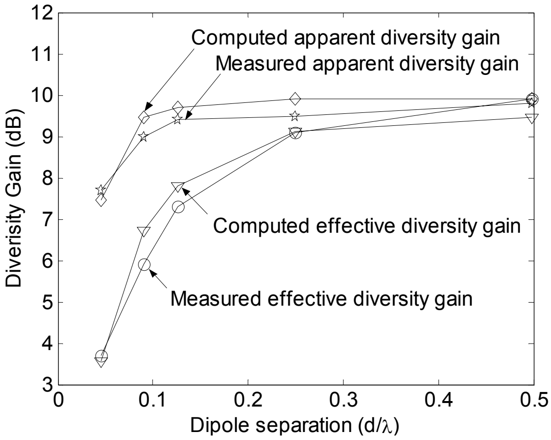

Figure 4. Computed and measured diversity gain and effective diversity gain for the dipoles in free space, from [3].

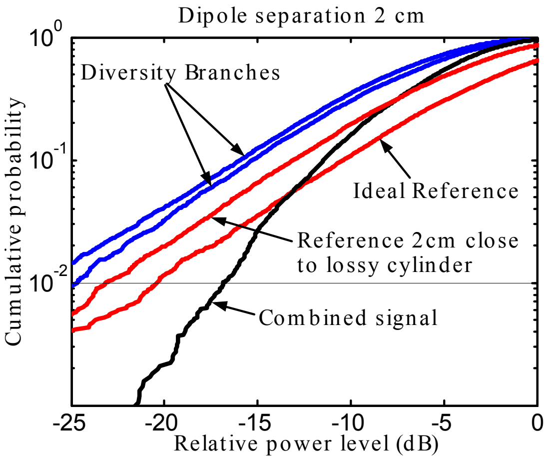

Figure 5. Cumulative probability plot of the transmission samples obtained from the two parallel dipoles when they are located 2 cm from a lossy cylinder. There are two single separate antenna reference cases, one in free space and one 2 cm from the lossy cylinder.

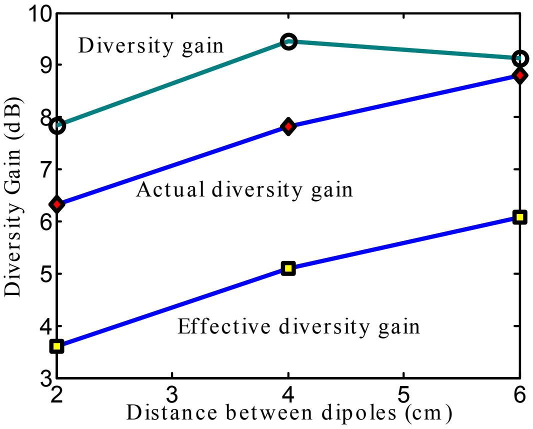

Figure 6. Results for actual, effective and apparent diversity gain of two close dipoles close to a lossy cylinder, at 1% cumulative probability level.