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Research Article

Differences in User Influence on MIMO Handset Antenna Performance in Reverberation Chamber

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User influence on multiple-input multiple-output (MIMO) performance is studied for different dual antenna handsets specially designed to have good and bad MIMO performance. The study reveals that user influence can cause either improvement or degradation for different test objects, including a spread effect over the parameters. Differences in performance between good and bad handsets can be clear when they are measured without user influence, but become small under real person influence. This result illustrates the particular importance of user influence to characterize MIMO handsets.

1. Introduction

User influence on multiple antenna device performance has been a topic for research in the last few years, since it is well known that a user in the vicinity of a wireless device affects the propagation conditions that the device is experiencing. This effect is well known for single-input single-output (SISO) communications, consisting of a degradation of radiation performance due to the losses introduced by the user. This effect is usually quantified by the changes in radiation efficiency and absorbed power [1].

In spite of this knowledge, it is still not clear what the consequences are when it comes to multiple antenna devices, since they base their enhanced capabilities on a rich field distribution in terms of signal paths. Numerous studies have been performed over the last years, agreeing to the fact that the effect of the human body is more complex in MIMO terminals than in traditional ones [1–5]. The presence of the user has been demonstrated to have immediate influence on radiation patterns, input impedances and therefore on the correlation matrix, yet the effects are not fully understood and contradictory findings are commonplace. In [3], the envelope correlation coefficients were significant when the user was present. These changes showed a more important dependence to antenna orientation in [1]. In contrast, an increment of the correlation coefficients is also available in the literature [6]. Contradictory findings can also be found for the effects on diversity gain [7].

In this paper, the performance of different handsets has been analyzed. All the handsets used within this study consist of two antennas, in order to implement diversity at the receiving terminal end of the link (SIMO: Single Input Multiple Output). This SIMO configuration is relevant for this study since it is one of the normal over-the-air (OTA) test cases for the new communication standards (HSDPA and LTE).

2. Measurements

2.1. Test Objects. Four different handsets are used for this study. Two of them work at low frequency (700–780 MHz) and the other two work at a higher frequency (2620–2690 MHz). For each band, there is one handset with a good

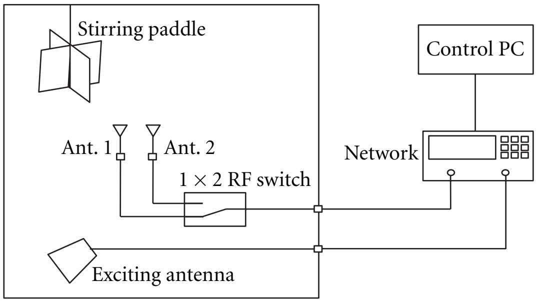

FIGURE 1: Scheme of the reverberation chamber measurement setup.

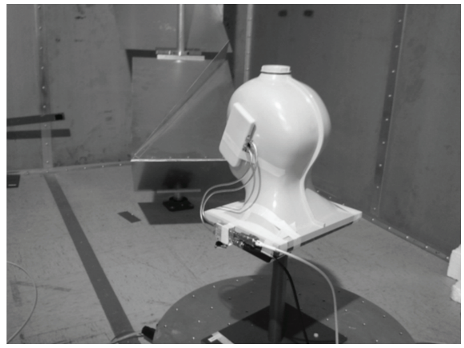

FIGURE 2: Measurement setup with the presence of the head phantom and the device placed in talk position.

antenna solution and the other one has been designed on purpose to have bad MIMO performance.

2.1.1. 700 MHz Test Objects. Two samples of the same handset model are used with dimensions 115 mm × 65 mm. The two test objects are referred to as Prototype A and Prototype B. Prototype A has two monopole antennas located at each short side of the handset. The two monopoles excite the chassis in the same way, so high correlation is expected. Prototype B includes one monopole located at one of the short sides of the handset and a notch antenna located along the long side of it. These two antennas have different radiation patterns which cause a low correlation with each other.

2.1.2. 2600 MHz Test Objects. Two terminal antenna models are used with dimensions 100 mm × 40 mm. The two test objects are referred to as Prototype C and Prototype D. Both Prototype C and Prototype D consist of a ground plane and two Planar Inverted *F* Antennas (PIFA) fed by coaxial cables. Prototype C is designed to have high correlation on purpose, by slightly connecting the patches of the two single PIFA antennas; however, Prototype D has low correlation.

2.2. Measurement Setup. Measurements were carried out using a reverberation chamber (RC) (length 3 m, width 2.45 m, and height 2.45 m) located at SP Technical Research Institute of Sweden, Borås, Sweden. The RC comprises an electronically controlled turn table, as well as a rotational zig-zag stirrer placed in a corner of the metallic cavity. The shielding effectiveness of this RC is 100 dB. Figure 1 showed a basic scheme of the setup used for the measurements performed during this study.

Three different scenarios (No User, Head Phantom, and Real Person) are used to simulate different effects of the user on the radiation performance of the antennas. No User scenario is the classical scenario generated in a reverberation chamber, with an isotropic and Rayleigh distributed field strength at the device. In this scenario, the antennas under test were placed over a low loss dielectric foam piece, in order to avoid as much as possible the effect of the holder. Head Phantom is the commonly used scenario to estimate the behavior of a device including user influence, that is, device attached to the cheek of the phantom and aligned between the ear point and the mouth point (Figure 2). Real Person scenario is performed with the introduction of a real person inside the chamber, holding the device with the hand simulating talk position, in the same way as in the Head Phantom scenario. The person is sitting on a chair placed in the center of the chamber, in order to have the antenna in a similar place as in the other scenarios.

No User is used as a reference case. This scenario, although useful, is not intended to be realistic. With the introduction of a head phantom, the effect of the user head on the antenna is included. The head phantom affects the close environment of the antenna, but it is still an intermediate approach to a real user influence simulation, since a head phantom does not block all the incident waves that a real person would. This is the motivation of the Real Person scenario.

3. User Influence on Antenna Parameters

3.1. Correlation. Antenna correlation is the figure-of-merit which has been commonly accepted to be a good indicator of the MIMO performance of an antenna pair. As showed in [8], correlation affects MIMO capacity, which is clearly decreased when antennas at the receiver are highly correlated. The complex correlation coefficient of two antennas can be calculated from the complex transmission coefficients (S_{21}) between the exciting antenna of the RC and the antenna pair under test, by [9]

$$\begin{aligned}\rho &= \left|\rho_{\text{complex}}\right| \\ &= \left|\frac{\sum_{k=1}^{N}\left(S_{21,1}(k)-\langle S_{21,1}\rangle\right)\left(S_{21,2}(k)-\langle S_{21,2}\rangle\right)^{*}}{\sqrt{\sum_{k=1}^{N}\left|S_{21,1}(k)-\langle S_{21,1}\rangle\right|^{2}\sum_{k=1}^{N}\left|S_{21,2}(k)-\langle S_{21,2}\rangle\right|^{2}}}\right|, \end{aligned} \tag{1}$$

where k stands for the current stirrer position, and

$$\langle S_{21}\rangle = \frac{1}{N}\sum_{k=1}^{N} S_{21}(k) \tag{2}$$

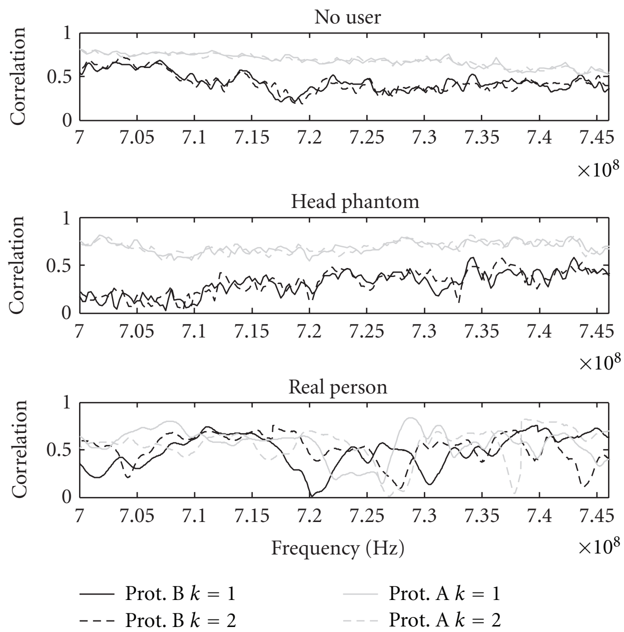

Figure 3: Correlation of the 700 MHz band devices for the three different scenarios.

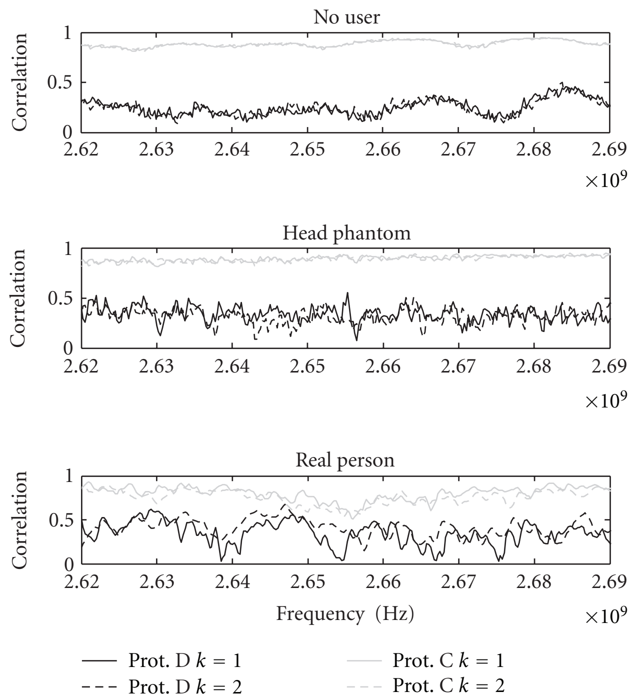

Figure 4: Correlation of the 2600 MHz band devices for the three different scenarios.

(i) N is the total number of stirrer positions over a whole sequence of stirring movement.

(ii) $S_{21,1}$ is the S_{21} parameter between the transmission antenna and receiving antenna 1.

(iii) $S_{21,1}$ is the S_{21} parameter between the transmission antenna and receiving antenna 2.

For the purpose of these measurements, 400 different positions are selected (100 stirrer position × 4 turn table positions), and the number of points of the vector network analyzer used to perform the S_{21} measurements is set to 401.

Two repetitions ($k = 1, k = 2$) of each measurement were performed. The measurement of each of the scenarios took about 40 minutes, for each dual antenna. Some problems were detected due to the decorrelation introduced by the cables connected to the antennas. In order to avoid those problems, an RF switch is introduced between one of the connectors of the vector network analyzer and the antennas under test, so the S_{21} can be measured for the two receiving antennas without changing the position of the cables.

Figures 3 and 4 show the different correlation values obtained under the three different user influence scenarios, for antennas at both bands. Tables 1 and 2 show the values of mean and standard deviation of the measured correlation values.

Correlation is clearly affected by the presence of the user. Normally when an object is close to the antenna, the object produces two different effects. The first effect is to create new reflection points for the signal thus producing new clusters and increasing the richness of multipath propagation, which means that it decreases the correlation between antennas. On the other hand, when an object is positioned near an antenna, this object blocks the signal incoming from other cluster which impoverishes multipath propagation of the signal causing an increase of the correlation.

These two opposed effects, as they are combined, cause the a randomization of the measured correlation. That is, when an object is inserted in the vicinity of a wireless device, the device can either increase or decrease its correlation. In other words, we can say that the effect of introducing objects near the antenna makes these antenna lose their inherent properties and their correlation depend more on the propagation environment. While the handsets present a well-recognized low and high correlation behavior in the No User scenario, this difference becomes smaller as the presence of the user is more significant. In fact, in the Real Person case, where there exist the influences of both the head and the hand of the person, the random effect on the results is much greater than when it is the head phantom only.

It is also worth noticing the different impact depending on the frequency. Even though the effect is important at the higher frequency, it has a dramatic impact at the 700 MHz band, where correlation becomes very similar in both test objects, and with large variations over the band. This is because in terms of (d/λ), the distance over which the objects are placed (phantom or real person) is much smaller at 700 MHz compared to 2600 MHz, which means that an object placed closer has a greater influence.

Another factor is that the real person has a physiognomy much rougher than a phantom which is the average of many users (being the average of many users tends to round the shape). This rougher shape of individual persons, when compared to phantoms, creates more scattering effects and therefore some differences can be appreciated.

Table 1: Correlation results (mean).

Band	Prototype	k	No User	Head Phantom	Real Person
700 MHz	A	1	0.689	0.676	0.570
		2	0.687	0.676	0.526
	B	1	0.313	0.389	0.506
		2	0.310	0.390	0.492
2600 MHz	C	1	0.885	0.889	0.813
		2	0.886	0.886	0.760
	D	1	0.257	0.354	0.336
		2	0.255	0.340	0.375

Table 2: Correlation results (standard deviation).

Band	Prototype	k	No User	Head Phantom	Real Person
700 MHz	A	1	0.099	0.055	0.151
		2	0.098	0.057	0.168
	B	1	0.155	0.129	0.164
		2	0.156	0.130	0.169
2600 MHz	C	1	0.026	0.032	0.079
		2	0.027	0.035	0.074
	D	1	0.071	0.077	0.126
		2	0.073	0.083	0.115

Finally, it should be noted that the standard deviation of the correlation (Table 2) is always higher for the scenario of real person in all the prototypes. This is also observable in Figures 3 and 4, where we can see that variations in correlation are much larger with the frequency. Also the difference between the two measurement repetitions is much higher for the real person case. This is due to abrupt changes in the appearance of the real person, together with the uncertainty on the position of the prototypes introduced when a real person is holding them. Both phantoms and holders are designed so they represent the average of human shape. However, in order to detect minimums and maximums in performance, average shapes are not as useful as particular cases are. Therefore, it is advisable to perform these tests with real people because the results of these tests may differ from the results obtained using a phantom.

3.2. Diversity Gain. Diversity gain (DG) is one of the most recognized figures-of-merit when evaluating multiple antenna terminals. DG quantifies the improvement created by the existence of more than one antenna over a reference case. In this study, the reference case chosen is the average power of both antennas operating separately.

Several schemes can be used to combine the signals coming from the two antennas. Since the prototypes and antennas used in this study are intended to be part of complex wireless devices, the maximum ratio combining (MRC) [10–12] scheme is used, which is common for these kind of devices. Table 3 shows the measured DG (in dB) of the devices for a signal reliability of 1 %. Efficiency of antennas is not taken in account for the DG calculations, which means that apparent diversity gain (ADG) is calculated [13, 14].

Table 3: Apparent diversity gain results (decibels).

Band	Prototype	No User	Head Phantom	Real Person
700 MHz	A	6.38	6.98	6.71
	B	8.21	8.40	7.35
2600 MHz	C	5.52	5.75	7.28
	D	8.76	8.10	8.38

Low correlation handsets present a reduction in diversity gain when the user influence becomes more important. The effect is the opposite for the high correlated handsets.

This effect is in line with the correlation that both devices present under the three different scenarios. As we have seen before, the correlation between antennas is decreased in high correlated devices when they are under user influence. This effect can actually lead to a better MIMO performance of the device under user influence, compared to the performance the device has under No User scenario. Even more so, we can see how the DG results become very similar for both bad and good devices, in the case of a real person influence. It then seems that the real effect of a user on DG is the equalization of device performance, and not necessarily deterioration.

4. Conclusion

In this paper, user influence over correlation and diversity gain is evaluated for some different scenarios including a real person. This is the first time that measurements using a real person in a reverberation chamber are reported. Results show that user influence equalizes MIMO performance of devices which have very different behavior when analyzed without user influence. Furthermore, the user influence on correlation does not seem to be a linear constant offset but a spread effect.

The different behavior of different user calls for detailed studies with different body phantoms in order to define the effect of the user influence over the antenna. It is important to study standard deviations from different body phantoms. Finally, it is necessary to deepen the shadowing effect that actually changes the propagation environment where the antenna is being measured.

Further research includes the development of a theoretical model for the user influence on MIMO devices, as well as the repetition of this study including realistic propagation channel models (including delay and angular properties).

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