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On User Effect Compensation of MIMO Terminals with Adaptive Impedance Matching

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***Abstract*—Proximity of user has been established as a major cause of performance degradation in multiple-input multiple-output (MIMO) terminals. Here, we investigate the potential of adaptive impedance matching (AIM) to improve the performance of two MIMO terminals in a free space (FS) and a two-hand (TH) user scenario, assuming uniform 3D angular power spectrum for the incoming signal. The results show that lossless uncoupled AIM circuits can enhance the MIMO capacity of the terminals by up to 43% relative to standard 50 ohm terminations. In particular, the largest capacity gain is obtained in the terminal with good matching but narrower antenna bandwidth and worse isolation performance, for the TH scenario. On the other hand, the terminal with poorer matching but higher isolation and significantly larger bandwidth has lower average capacity in FS. However, it is more robust to user proximity, and hence it achieves only 8% capacity gain with AIM in the TH scenario. Therefore, antenna design parameters can significantly influence potential benefits of AIM in practice.**

I. INTRODUCTION

The performance degradation of multiple-input multiple-output (MIMO) terminals from user proximity is an issue of growing importance, due to the ever increasing demand for higher throughput as well as the many relevant user scenarios to consider (see [1] and references therein).

To compensate for user effects in MIMO terminals, adaptive impedance matching (AIM) was studied in [2] for a realistic dual-antenna terminal prototype using measured data in an indoor office environment. For a two-hand scenario, the results show that AIM can provide capacity gains of 44% and 22% in the 0.8 GHz and 2.3 GHz bands, respectively, relative to the conventional 50 ohm match. Nevertheless, the study focused on assessing the potential application of AIM using real measurements, and it considered only one terminal. In [3], the tuning range and user influence on a reconfigurable planar inverted-F antenna (PIFA) with a fixed capacitor are presented. A relatively wide tuning range was shown, but the matching network used had only a few achievable states. Moreover, the study focused on comparing user-induced mismatch and absorption losses between high-Q and low-Q antennas.

In this work, we present a study on the potential of AIM in the 0.8 GHz band based on two fabricated MIMO terminals of significantly different antenna properties. In particular, two MIMO terminal prototypes were considered: one that has good impedance matching but poor isolation and narrowband behavior, and another one that has poorer matching but higher isolation and larger bandwidth. The main motivation is to gain insight into the antenna parameters that give rise to performance gains from AIM in MIMO terminals. In this paper, we focus only on a two-hand scenario, similar to [2]. To obtain the capacity performance, measured antenna parameters from fabricated prototypes (with and without phantom hands) were combined with a simulated propagation environment characterized by uniform 3D angular power spectrum (APS), which corresponds to a multipath-rich indoor environment.

Even though the results confirm previous findings in [2] that significant capacity gain can be achieved using AIM, they point to significantly different performance characteristics for the two terminals, when AIM capabilities are considered. In particular, due to the different influences of user proximity on matching, isolation and bandwidth, the MIMO terminals will benefit from AIM in different ways, and to different extents. With this in mind, antenna design parameters of matching, isolation and bandwidth remain critical considerations even when AIM can be realized to give additional design flexibility.

II. METHODS AND RESULTS

The effect of a lossless uncoupled matching network (of a given matching state) on measured antenna scattering parameters and 3D radiation patterns obtained with 50 ohm termination on the unexcited antenna port, was calculated using the method in [4]. The capacity calculation using post-matching total efficiencies and correlation is described in [5]. In these calculations, we assumed an environment with uniform 3D APS, 1000 channel realizations using the Kronecker model, and a total of 96 matching states covering the entire Smith chart were used to evaluate the AIM performance.

This study is carried out on two dual-antenna terminals with fundamentally different antenna designs. Both mobile terminals had been fabricated and measured in an anechoic chamber. As in [2], the two user scenarios measured were free space (FS) and two hands (TH). The dual-antenna prototypes cover both LTE Band 18 (0.815 – 0.875 GHz) and LTE Band 9 (1.75-1.88 GHz) with a maximum reflection coefficient of -6 dB. In this study, we only consider the low band performance. Each of the two terminals is fully enclosed in a volume of $130 \times 66 \times 9$ mm^3. Prototype A is similar in design to the dual-antenna terminal in [2]. In FS, it features a 6 dB impedance bandwidth of 85 MHz and antenna isolation of 5.3 dB at the frequency of operation (0.860 GHz). In contrast, Prototype B is a coupled-fed dual-antenna design [6] that offers a significantly larger bandwidth of 200 MHz and improved isolation of 6.3 dB at 0.860 GHz in FS. The two antenna elements of Prototype A are located at the two short edges of the chassis, whereas those of Prototype B are co-located at one of the two short edges.

TABLE I. AVERAGE CAPACITY AND CAPACITY GAIN [BITS/S/HZ]

	Prototype A		**Prototype B**	
	FS	TH	FS	TH
Capacity without AIM	8.4	5.8	7.6	7.5
Capacity with AIM	8.5	8.3	8.3	8.1
% capacity gain	0.4	43	10	8

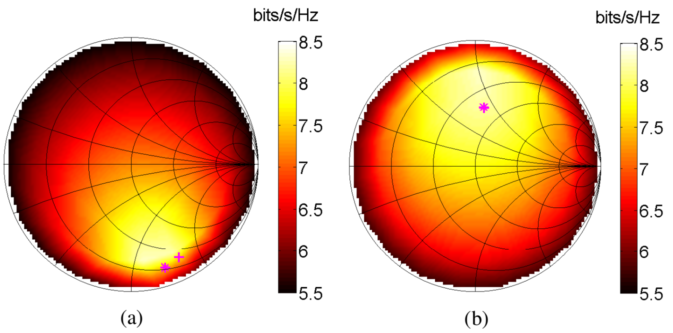

Fig. 1. (a) Prototype A capacity in TH and (b) Prototype B capacity in FS. Markers indicate conjugate of antenna impedances at port 1 (+) and port 2 (*).

Table 1 presents the average capacity performance without AIM (i.e., 50 ohm terminations) and with AIM at the center frequency, as well as the percentage capacity gain from AIM. All numbers are rounded to one decimal place. A reference SNR of 20 dB was assumed. The capacity gain for Prototype A is as high as 43% in the TH case, as compared to 0.4% in FS. This suggests that AIM can significantly improve the capacity performance in cases where there is severe antenna mismatch (see the complex conjugate of the antenna input impedance in Fig. 1(a)). This observation is further supported by the results for Prototype B, where the antenna is not well matched by initial design (see Fig. 1(b)), so that it can give a larger bandwidth. Therefore the FS scenario results in a more significant impedance mismatch than the TH scenario. Hence, for Prototype B the gain in FS (10%) is higher than the gain in the TH scenario (8%). Antenna mismatch is one of the main contributors to performance degradation due to user influence.

Besides conjugate of antenna impedances, Fig. 1 also presents capacity contours over matching states on the Smith chart for one antenna port (port 2), assuming that the other port (port 1) has been optimized for the highest capacity. It can be seen in Fig. 1 that the maximum capacity is achieved in these cases when the matching state is close to the conjugate of the antenna input impedances.

The results in Table I and Fig. 1 indicate significant differences in the performance characteristics between the two prototypes. This is due to the differences in matching, antenna bandwidth and isolation. Concerning bandwidth, the presence of a user is known to decrease the resonant (or matched) frequency of an antenna element [7]. Therefore, Prototype B, which offers 135% more antenna bandwidth than Prototype A (85 MHz for Prototype A and 200 MHz for Prototype B), is less likely to be detuned as severely by the user at the frequency of operation, and hence is more robust to user influence. This phenomenon can be observed from Table I, where the user hands cause very small capacity degradation of 0.1 bits/s/Hz in Prototype B, relative to the drop of 2.6 bits/s/Hz in Prototype A. This phenomenon of less severe detuning by the user hands due to larger bandwidth also results in a smaller capacity gain from AIM for Prototype B than Prototype A (i.e., a smaller mismatch to compensate for).

Apart from bandwidth, antenna isolation also heavily influences achievable capacity gain from AIM. As can be seen in Table 1, Prototype A that has lower FS isolation than Prototype B yields higher capacity gain when using AIM in the TH scenario. This can be attributed to the proximity of the user hand that disturbs the coupling mechanism, which effectively increases isolation. The effect of improved isolation is more beneficial for Prototype A than Prototype B, due to the lower FS isolation of Prototype A causing more severe degradation in the FS capacity. Since AIM with uncoupled matching circuits is effective in compensating for mismatch loss at the frequency of operation, without significantly changing the isolation, the more critical improvement in isolation in Prototype A due to user proximity is translated to a larger capacity gain with AIM.

III. CONCLUSIONS

In this work, we show how AIM can be used to compensate for the degradations introduced by a TH user grip on two MIMO terminals with drastically different antenna designs. Significant improvement has been observed for Prototype A, where a capacity gain of up 43% was obtained in simulation based on measured scattering parameters and antenna radiation patterns. In contrast, Prototype B shows only a moderate improvement of up to 10%. This was attributed to the differences in antenna design between Prototypes A and B. Impedance matching, bandwidth and isolation have been identified as key factors that determine the capacity performance of MIMO terminals in the presence of user. It was established that a relatively large bandwidth prototype with moderate isolation and impedance matching is robust to user influence and hence not a promising candidate for large capacity gains from AIM. On the other hand, MIMO antennas with narrow bandwidth and low isolation in FS can potentially offer larger gains from AIM.

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