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Performance of a Multiband Diversity Antenna with Hand Effects

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1. Introduction

The implementation of multiband diversity antennas in compact mobile handsets, for the purpose of increasing transmission quality, is a topic of current interest in the mobile phone industry. In order to achieve the expected performance improvement in typical operating conditions, we not only have to contend with the challenges of designing multiple multiband antennas, which are closely spaced within the compact handset and thus strongly interacting with one another electromagnetically [1], we also need to keep in check the electromagnetic interaction between the whole antenna system (i.e., the handset) and the user.

Previous studies have concluded that the presence of a user degrades the mean effective gain (MEG) of the diversity antennas significantly [1]-[3]. Different results have been presented on the effect of the user on the correlation coefficient, no effect [1] and a significant increase of the correlation [2], [3], have been pointed out. However, these studies have been performed on simple single band antennas in talk position. In this paper a more realistic approach is presented by choosing the diversity antenna system to comprise compact versions of PIFA and monopole antennas which cover three WCDMA bands: WCDMA850, WCDMA1800 and UMTS [4]. Such compact antennas are easily conformable for small mobile phone products [4]. The choice of the bands, as well as the evaluation of the diversity performance for the data mode position, is derived from the increasing demand on HSDPA applications in the mobile phone market.

The investigation of user interaction presented in this paper focuses on the comparison between the free space and data mode diversity performance of a tri-band “stick” phone size prototype in the uniform 3D propagation environment. A state-of-the-art phantom hand from IndexSAR [5] is used to hold the diversity prototype in the data mode position.

2. Theory

The metrics used to evaluate the diversity performance of the tri-band antennas are: *mean effective gain* (MEG) [6], *envelope correlation coefficient* [7], *diversity gain* (DG) for selection combining at 1% probability [8-9] and *diversity system gain* (DSG) [10] or equivalently, effective diversity gain [11]. The metrics are calculated in Matlab using formulas from [6-10] and 3D far field antenna gain patterns from simulations and measurements, under the assumption of uniform 3D propagation model.

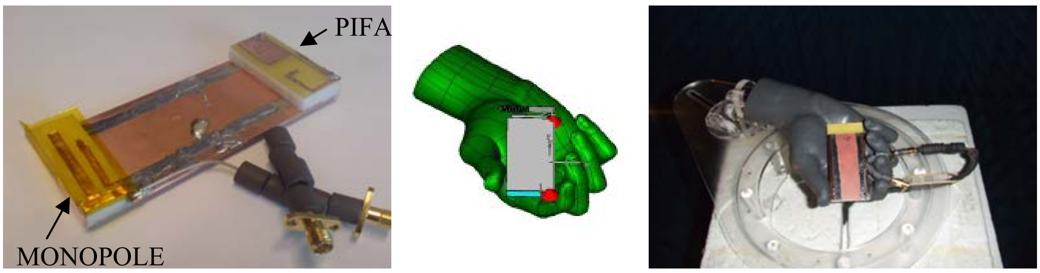
Since DG is relative to the antenna branch with the highest efficiency when in presence of the other antenna, the metric DSG has been formulated [10]. DSG is defined as

$$\mathrm{DSG} = \mathrm{DG} \cdot e_{div}, \qquad (1)$$

where the total efficiency e_{div} takes into account the mismatch, dielectric and conductive losses, as well as mutual coupling losses for the antenna branch with the highest efficiency. DSG is therefore a metrics relative to an ideal antenna with unit radiation efficiency.

3. Multiband diversity antenna prototype

The prototype used for this investigation, comprising two multiband antennas on a ground plane, has the size of 100×40×2 mm [4]. The main antenna is a monopole based antenna with one of the branches forming a patch with dense meandering end for the WCDMA850 band. The diversity antenna is a PIFA based antenna with shorted parasitic branch for the UMTS band (see Figure 1(a)). The volume of each multiband antenna does not exceed 40×20×8 mm and the spacing between the feed points is 84 mm, or 0.24λ for the WCDMA850, where λ is the signal wavelength. Each of the antennas cover the entire receive bands of 869-894, 1805-1842.5 and 2110-2170 MHz at 6dB impedance bandwidth (see Figure 2). The monopole antenna, being the main antenna covers also the transmit frequencies of the aforementioned bands.



(a) (b) (c)

Figure 1: (a) Antenna prototype; (b) Simulated and (c) measured antenna prototype held in data mode.

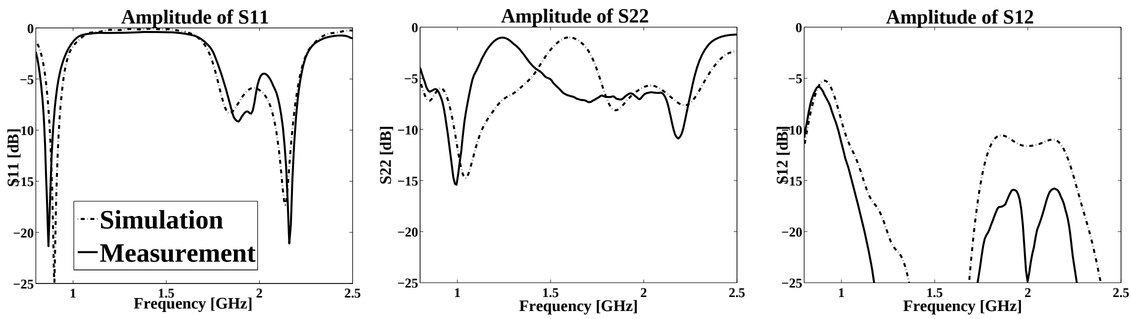


Figure 2: Simulated and measured scattering parameters.

4. Performance evaluation

4.1 Simulations and measurements

The simulations have been performed with the time domain simulator CST Microwave Studio [12]. For the data mode simulation case, a user hand CAD model from IndexSAR was used (see Figure 1(b)). The CAD model has equivalent dielectric properties to those of muscle tissue. For the data mode measurements performed in the Satimo Stargate 64 system [13], the phantom hand that was used was produced by IndexSAR (see Figure 1(c)) with the same specifications as the CAD model.

The farfield antenna gain patterns data, efficiencies and S-parameters were simulated and measured for 9 frequencies, corresponding to the frequencies at the lower edge, midpoint and higher edge of each of the three receive WCDMA bands mentioned earlier.

4.2 Results and discussion

The complexity of the antenna prototype makes it harder to obtain a good agreement for the MEG performance of the antennas for the built and measured case as compared to the simulated one. However, if we focus on the data mode investigation, as is the purpose of this paper, it can be visualized in Figure 3(a) that for the PIFA antenna, the user hand model induces a drop of 7 dB in MEG performance in the lowest band and 3 dB in the two higher bands. The monopole, with similar original MEG performance as compared to the PIFA, is affected by a 5 dB drop in MEG over all bands (see Figure 3(b)). This is the case for both simulation and measurement.

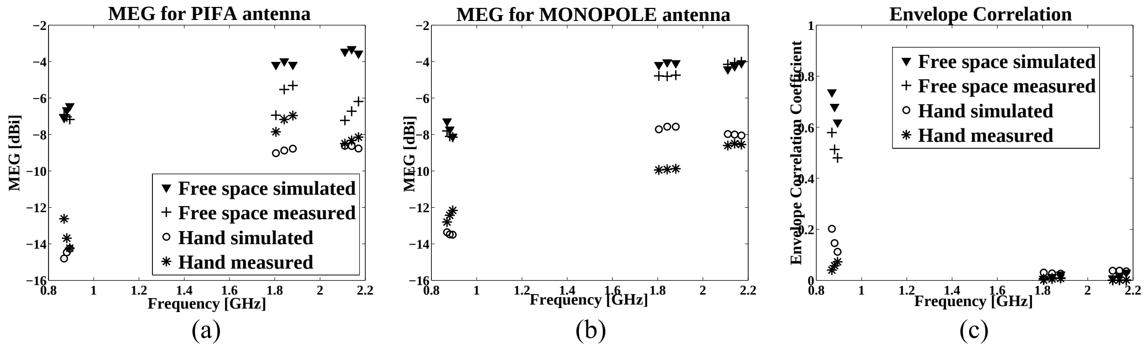


Figure 3: MEG from simulation and measurement for free space and hand for (a) PIFA antenna and (b) monopole antenna; (c) Envelope correlation coefficient from simulation and measurement for free space and hand.

On the other hand, the correlation decreases for the lowest band when the user hand model is present. This can be explained by the difference in simulated gain patterns for the two antennas for the case of free space vs. data mode as shown in Figure 4. The gain patterns for the antennas in the data mode position are more directive and more orthogonal to each other than in free space position, which facilitates a greater statistical independence of the received signals. Due to the lack of space, we omit the corresponding plot of the measured antenna patterns. However, we note that the directivity of the simulated and measured patterns is similar.

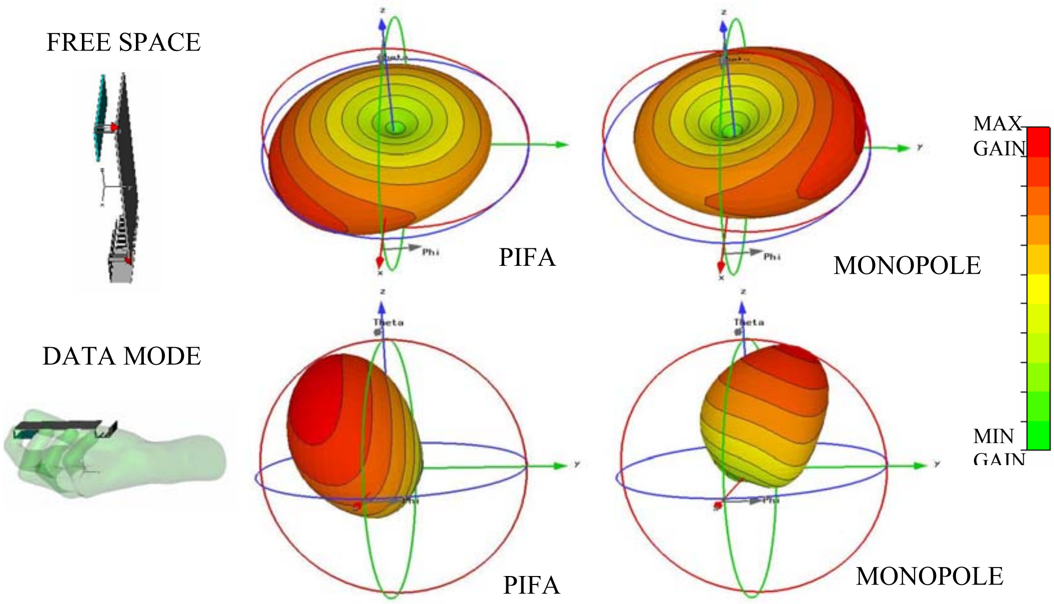
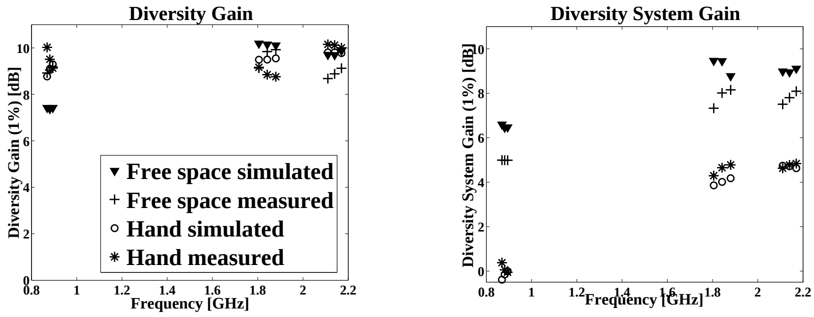


Figure 4: 3D gain patterns for 881.5 MHz frequency simulated for free space and data mode positions. The first two pictures show the placement of the prototype in relation the coordinate systems for the patterns. Note that the gain patterns (in dB) are individually scaled by their respective maximum gains.

With the highest envelope correlation at just above 0.7 and MEG fairly equal for the two branches, the diversity gain with and without user hand model is very good (see Figure 5(a)), as can be expected [14]. However, the more realistic diversity performance is seen in the diversity system gain results (see Figure 5(b)). These show acceptable benefits of diversity (5dB) for the two higher bands, but only a small benefit of diversity is obtained for the lowest band, when the hand is present. Despite the low correlation of the branches, the diversity performance for the lowest band is mainly affected by the large degradation in MEG. The radiation performance, with and without the hand, is much worse than for the two higher bands due to high mutual coupling.



(a) (b)

Figure 5: (a) Diversity gain and (b) diversity system gain at 1% probability

5. Conclusions

For the multiband antenna prototype presented in this paper, approximately 5dB of diversity system gains (DSGs) can be obtained for the higher frequency bands of WCDMA1800 and UMTS when held in data mode position. For the lowest band, WCDMA850, the hand degrades the radiation performance severely, which leads to small or negligible DSGs, despite having uncorrelated branches. However, we emphasize that by definition DSG is calculated with respect to the reference case of an ideal antenna in free space with 100% efficiency. Evaluations with respect to other reference cases, such as a single antenna with hand effects, are left for future work.

In contrast to previous studies [1]-[3], which consider user effects in talk position, we find that in data mode position the correlation is relatively unaffected, and it is even reduced for the WCDMA850 band. The hand model affects the antenna patterns, making them more directive and orthogonal to each other for the lower band. Other evaluated performance metrics for the lowest band are, due to high coupling, much worse than those for the two higher bands. This is the consequence of restricting the size of the prototype considered to that of a typical mobile handset.

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