MIMO Requirements and Capabilities with Modern Communication Terminals

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1. Introduction

To enhance the throughput and channel capacity in modern communication systems, like WiMAX or LTE, they make use of new MIMO (multiple input multiple output) technologies. As the essential part of MIMO, the communication over uncorrelated channels is arbitrary for the gain in data throughput or communication robustness. Based on modern coding schemes, at least several independent and separated physical channels are necessary. This requires in the same way additional efforts regarding hardware components, i.e. antennas and rf-systems for the base station as well as for the mobile terminal. Due to the limited size of a terminal and due to environmental influences (hand held position, body influence, etc.) sophisticated antenna designs and technologies have to be used to achieve best results. This paper now presents investigations on small mobile terminal antenna arrays and their capabilities for MIMO systems.

2. Wide band / multi band antennas

Future terminal devices have to be multifunctional, so they should be compatible to all common communication standards (e.g. GSM, 3G, LTE, WiMAX, etc.). Therefore a multitude of single band antennas would be necessary. Due to the limited space in a terminal it is more feasible to use multi/wide band antennas. Fig. 1 shows such a design of two multi band / wide band antennas, based on the principle of a printed monopole with additional parasitic structures on the backside of the PCB. These structures are implemented to achieve the wide bandwidth, as well as to reduce the mutual coupling. Simulated and measured return loss of one antenna is shown in Figure 1 (right). Over a wide frequency range from 1.65 GHz up to 6 GHz it provides an extremely good impedance matching. Therefore, such an antenna can be used for 3G, LTE, WLAN and WiMAX. Fig. 2 shows the pattern of both antennas for different frequencies.

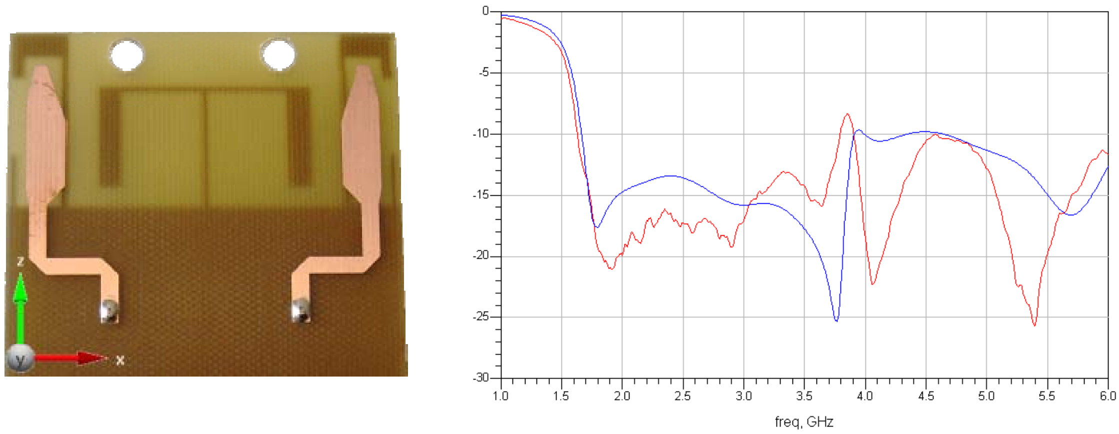
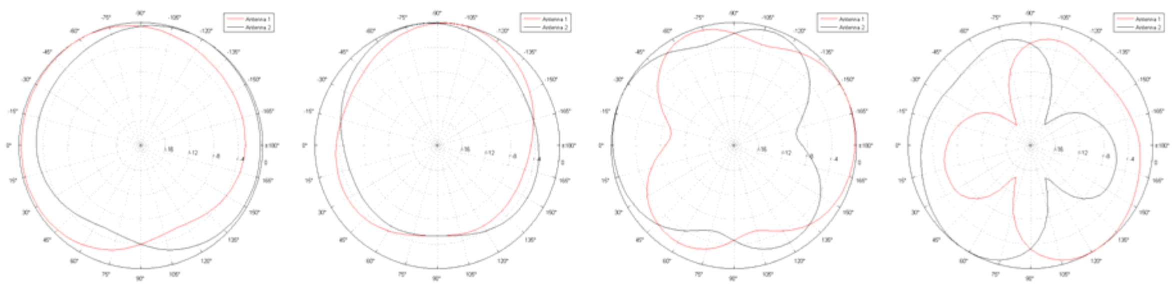


Figure 1: 2-element MIMO wide band antenna system with simulated return loss in dB (blue line) and measured (red line) of one antenna

3. Diversity and Digital Beam forming (DBF)

Mobile communication systems always suffer from signal fading which often leads to a communication breakdown. Therefore, in many modern radio systems diversity is used to reduce this effect. It works either, in such a way, that the antenna with the strongest signal is used or by means of a combination of all antenna signals (this is very similar to DBF). When using switching diversity, it is important that the complete azimuth range (or better: the complete sphere) around the terminal is fully covered by the radiation pattern of all the individual antenna elements. In contrast to the radiation characteristic the correlation between the antennas is an important parameter, too. Only these conditions allow successful and effective diversity operation.

In Fig. 2 the pattern of both antennas of the 2-element system are displayed. As required, the antennas mostly provide different patterns. The main radiation of each antenna is always directed to one side only. This has been achieved by means of an additional parasitic element in the middle of the structure (see Fig. 1). There is of course a change in the characteristics over the entire frequency range but the desired main functional principle of the inner parasitic element keeps working.



1.78 GHz　　2.5 GHz　　3.5 GHz　　5.35 GHz

Figure 2: Antenna patterns of both antennas of the 2-element system on different frequencies

One big problem with closely spaced antennas is that mutual coupling often reduces diversity and radiation efficiency [1]. This problem has to be considered in the design process of a terminal antenna system as follows. The radiation pattern and the mutual coupling of the antennas are either simulated or measured. With N antennas this leads to N+1 quadratic matrix, consisting of a N x N impedance and coupling matrix and one additional column resp. row, which contains the complex radiation pattern. This allows the calculation of the gain function resp. the pattern of the terminal antenna system. In a further pattern optimisation step the required excitation and matching network loading impedances or the decoupling network has to be found. Fig. 3 shows a comparison of two monopoles which are decoupled by such a parasitic element in the middle of the structure. This additional element works like the reflector of a Yagi-Uda antenna and deflects the radiated power to the opposite direction. The antennas are separated by a distance of $\lambda/8$ and antenna no. 2 is loaded with variable impedance to the ground. As it is shown in Fig. 3, the mutual coupling between Antenna 1 and Antenna 3 is reduced significantly from -13 dB at 3.5 GHz (with 50 Ω load) to less

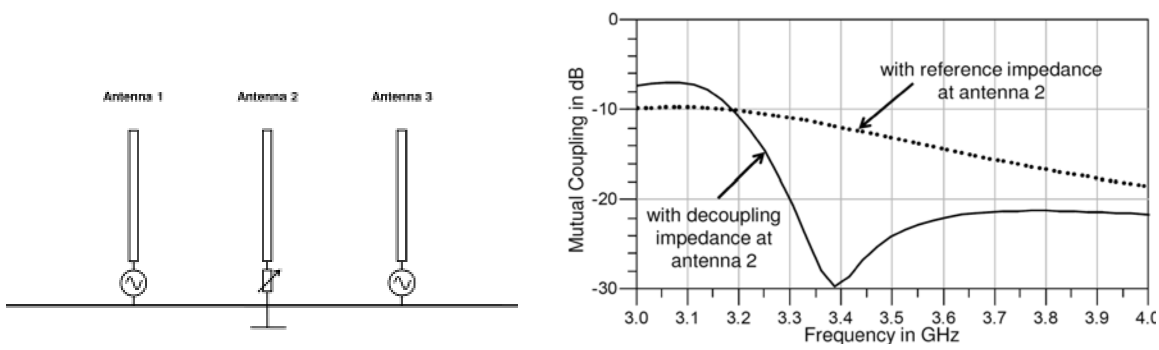


Figure 3: Reduction of mutual coupling with passively loaded antenna element

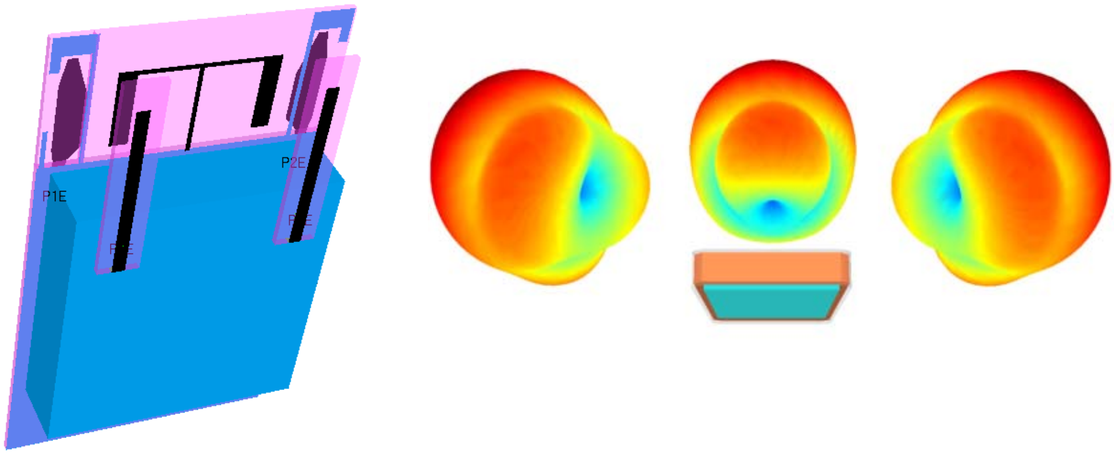


Figure 4: Beamforming capabilities with a small terminal antenna system

than -20 dB for WIMAX frequencies between 3.3 GHz and 3.8 GHz. Unlike additional matching networks, which can also reduce mutual coupling, the use of passively loaded elements is more feasible for higher bandwidth.
By means of adaptive beam forming, the radiation characteristics of an antenna array can be influenced and controlled and signals can be tracked [2]. This technique has been widely and successfully used with modern radar technology. With multi terminal antennas for MIMO, which can be regarded as a small version of an antenna array, beam forming is possible in a limited way. In contrast to radar systems, the main lobe will be of course much wider and the directivity respectively the gain of such an array will be much lower. First simulations and measurements have shown, that 3 - 4 terminal antennas allow a main beam, which can be directed almost in the whole azimuth range (see Fig. 4). The typical beam width is between 60 and 120 degrees and the achievable gain compared to a single antenna is between 3 - 5 dB. This also allows the tracking of the base station, even if the mobile station is moving. In weak signal scenarios, the gain improvement of 3 - 5 dB may be important to keep communication. Additionally, nulls in the radiation pattern can be created. This allows efficient interference reduction to unwanted signals, i.e. from a very close other mobile stations. To achieve good results with digital beam forming (DBF), the terminal antennas have to be optimized regarding single pattern characteristics, coupling and overall characteristics.

4. MIMO Effectiveness

To validate the above results, extended simulations have been performed. The extended spatial channel model (SCME) [4], which is related to the 3GPP TR 25.996 [3], is used to simulate the behavior of the channel capacity regarding the channel environment and antenna behavior. To obtain simulation results like the throughput of the more complex LTE system, in the next step the correlation matrices and power delay profiles of the Matlab® channel simulations containing the channel and antennas properties are included into a full LTE link level simulator, based on Synopsys System Studio.
Fig. 5 shows the mean channel capacity of several antenna constellations as a function of antenna separation. It can be seen that in the decoupled case (marked with arrows) the capacity increases by 2% to 10%. With closely spaced antennas the benefit is higher due to the stronger coupling. At distances larger than 0.3 λ decoupling has only small benefits. Furthermore, additional networks can be used to affect beam forming, correlation and coupling. Channel simulations have shown that both techniques (parasitic elements and networks) can be applied to improve the system performance. Therefore, they should be considered in the terminal antenna design.

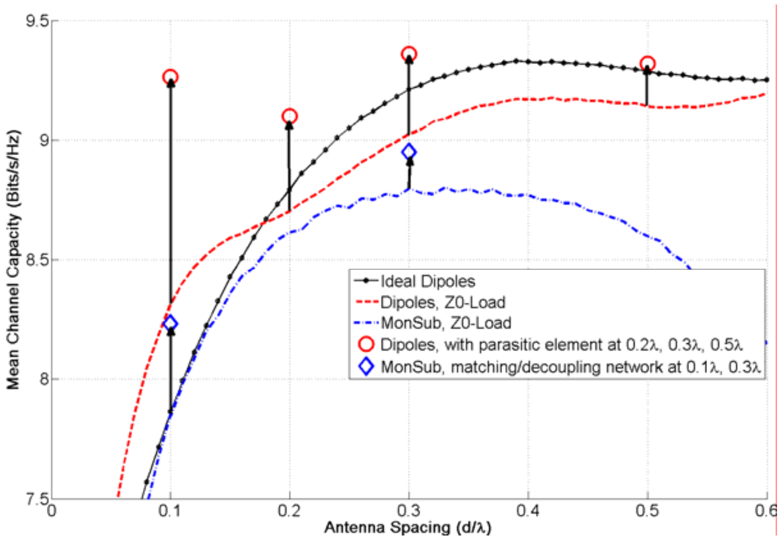


Figure 5: 2 x 2 MIMO-channel capacity for antennas with matching networks and/or parasitic elements for selected antenna distances on the receiver side.

5. Conclusions

The overall challenge with the MIMO terminal antenna design is to realize very small and compact antennas which fulfil individually the specific demands of the standard and which additionally operate effectively in combination to achieve optimum MIMO performance. By using sophisticated decoupling techniques, highly efficient terminal systems can be achieved, which allow beamforming and/or diversity operation. To proof the efficiency of such systems careful and extended simulations are necessary which include the full antenna parameters with environment.

Acknowledgments

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