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Near-Field MIMO System Assessment

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1 Introduction

The information flow rate in chips and also on circuit boards is a limiting factor in the development of modern high-performance electronic systems. Wireless ultra-wideband (UWB) multi-input-multi-output (MIMO) chip-to-chip communication has been considered as an option to mitigate these bandwidth limitations. The physical modeling of near-field MIMO systems requires network-oriented modeling accounting for the reciprocity of near-field MIMO antenna configurations [1]. Nanoelectronics-based integrated circuits including also integrated antennas open new prospects for broad-band wireless chip-to-chip and board-to-board data transfer, and could facilitate wireless ultrawideband (UWB) multi-input-multi-output (MIMO) communication [2].

In [3], a compact Hertzian dipole model has been proposed to provide an efficient tool to investigate characteristics such as potential channel gain for near-field MIMO systems under varying conditions for the embedding geometry. We consider a MIMIO configuration consisting of N transmitting/receiving antennas and M scatterers which are modeled by Hertzian dipoles and by terminated Hertzian dipoles, respectively. In a compact description, the feed point currents and voltages of the N MIMO antennas are given in the vectors I_N and V_N. The currents and voltages of the M scattering antennas are contained in the vectors I_M and V_M. An impedance matrix $Z_{tot}(\omega)$ describes the interaction of the MIMO transmitting/receiving antennas and the scatterer antennas. In [4], we investigate MIMO antenna configurations consisting of a set of antennas and scatterers designed and realized.

In this contribution, we combine assessment of MIMO systems by compact network oriented models with experimental assessment, based on correlation analysis [5], for a 2 by 2 near-field MIMO system operating at 2.4 GHz.

2 Near-Field MIMO

The transmitted bit sequences in the MIMO scenario can be considered random sequences for modeling purposes. A characterization of the stochastic electromagnetic (EM) fields emitted by the antennas requires assessment of auto and cross correlation functions of the EM field [6–8]. In addition to the EM field due to the radiated quasi random signals additional noise, i.e. thermal noise and EMI have to be considered. To describe MIMO signal transfers accurately not only a unilateral signal flow should be considered, rather two conjugate variables like voltage and current, electric and magnetic field are needed to consider energy and power flow [9, 10]. MIMO configurations for very near-field communication have been investigated in this context in [3, 11, 12].

For the experimentally realized system, universal software radio peripheral devices drive the transmitting antennas. The channel power gain, the ratio of the received power to the transmit power, is evaluated. Under consideration of a matching network [3], the channel power gain is

$$G = \max \frac{P_\mathrm{R}}{P_\mathrm{T}} = \max_{V_\mathrm{G}} \frac{V_\mathrm{G}^\dagger D^\dagger D V_\mathrm{G}}{V_\mathrm{G}^\dagger V_\mathrm{G}} = \mu_\mathrm{max}\left(D^\dagger D\right), \qquad (1)$$

where $\mu_\mathrm{max}(\cdot)$ denotes the maximum eigenvalue of its argument and D is a matrix mapping voltage at the generator side V_G to the load side of the multiport describing the MIMO system with its matching network. An antenna arrangement for the experimental setup of a 2-inputs and 2-outputs MIMO configuration is shown schematically in Fig. 1. For assessment of the channel capacity, the ratio of

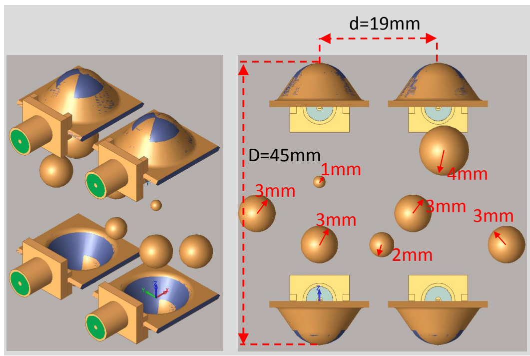

Figure 1. Antenna arrangement with obstacles.

the singular values s_i of D

$$\chi = s_2^2/s_1^2 \leq 1, \qquad (2)$$

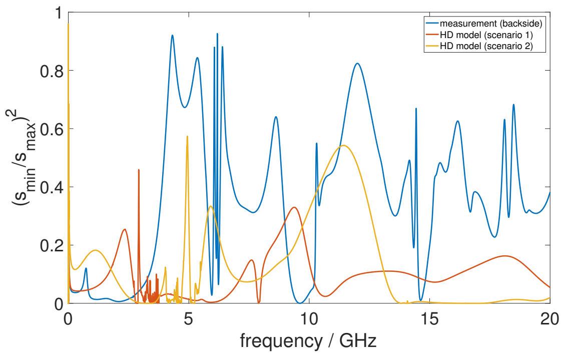

Figure 2. $\chi = s_2^2/s_1^2$ for sample configurations from measurement and Hertzian dipole model.

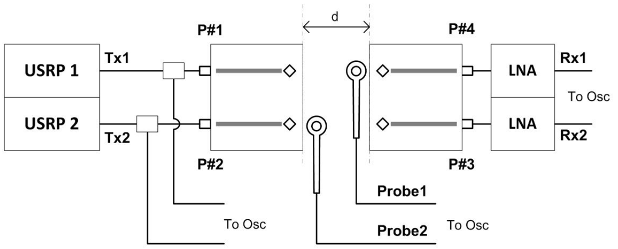

Figure 3. 2×2 MIMO test setup with USRP device driven transmitters T_x facilitating correlation analysis with field probes and receiving antennas R_x connected to the digital oscilloscope.

provides a measure for the multichannel capacity of our 2×2 MIMO link, which is potentially maximized for $\chi = 1$ [11]. Measurement and a compact Hertzian dipole model for the experimental setup shown in Fig. 1 yield a first assessment of the MIMO system as plotted in Fig. 2. Scatterers are placed as shown in Fig. 1 for scenario 1 and are slightly displaced for scenario 2. The setup is expanded according to Fig. 3. The transmitting antennas T_x are driven by universal software radio peripheral (USRP) devices modulating random bit sequences onto the carrier. Field correlations can be observed at the receiver side, where the antennas R_x are connected to a digital oscilloscope and, furthermore, field to field correlations can be determined by sampling the field with magnetic near field probes in the vicinity of the MIMO system.

The transmitted signal frames are 200 Bits wide. The frames consist of a frame header and the data payload. The frame header is formed by a 13 Bit Barker-Code sequence for frame synchronization, transmitted on both, in-phase and quadrature components, accounting for 26 Bits in the header and a 14 Bit frame identifier. The payload is given by a 160 Bit pseudo-random Bernoulli sequence which is independently calculated for each frame, such that the payload of one frame is uncorrelated with the payload data of any other frame. The data frames are then modulated to I/Q symbols by a QPSK (quadrature phase-shift keying) modulation scheme. The modulated symbols are filtered and up-

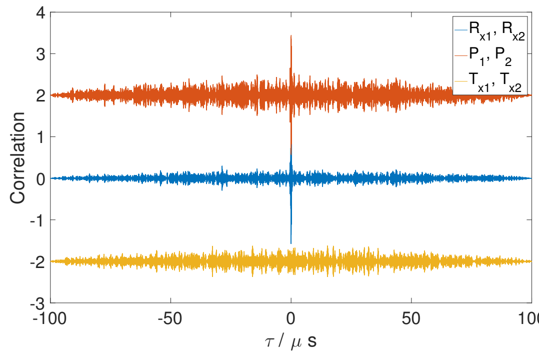

Figure 4. Signal correlations between transmitter T_x, receiver R_x, and near field probe P_i signals. Correlation functions for P_1, P_2 and T_{x1}, T_{x2} are plotted with an offset of ± 2.

sampled by a factor of two with a root-raised-cosine transmit filter with a roll-off factor of 0.5.

The resulting symbols are encoded for MIMO transmission using the diversity scheme given in [13]. Using two USRP devices the resulting I/Q transmit symbols for antenna T_{x1} and T_{x2}, are then upconverted with a 2.4 GHz carrier, respectively. Signal correlations for signals x_i and x_j, given by

$$c_{ij}(\tau) = \lim_{T\to\infty} \frac{1}{2T} \int_{-T}^{+T} x_i(t) x_j(t-\tau) \; dt \,, \qquad (3)$$

are plotted in Fig. 4 for the signals at the transmitting antennas T_{x1}, T_{x2}, for those at the receiving antennas R_{x1}, R_{x2}, and for the two near-field probes P_1, P_2. Since bit sequences of the two transmit signals are uncorrelated, the correlation of T_{x1}, T_{x2} does not show the pronounced peak at $\tau = 0$. Minor peaks indicate correlations due to common carrier signal and symbols for frame synchronization in the QPSK scheme.

3 Conclusion

We presented an approach for to assess near field MIMO systems. Noisy electromagnetic fields require a characterization by their power spectra and energy densities. These are obtained from the second order statistical moments of the electromagnetic field.

An experimental setup for a 2×2 antennas MIMO configuration with conformal antennas has been realized. Based on S-parameter characterization of the antenna link and by a compact Hertzian dipole model, channel gain and multi-streaming potential can be estimated in the design stage.

An extension to this setup is presented using two USRP devices for driving a 2×2 near-field MIMO test case. The USRPs are configured to transmit QPSK modulated random data.

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