Measurement Results of Compact MIMO Terminal Antennas

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Abstract

This paper is concerned with the integration of compact antenna arrays for MIMO into hand-held devices, where the antenna properties are influenced by the housing of the device and the user's head and hand. It is shown by measurements, that the performance of compact antenna arrays is strongly influenced by a reduced efficiency, rather than by the correlation properties of the signals.

1 Introduction

Transmission systems with several antennas at both the transmitter and the receiver (MIMO systems) lead to very high capacities or spectral efficiencies respectively as recent research results have shown, see [4]. The capacity of a MIMO system depends on the number of antennas, the signal to noise ratio (SNR), and the correlation properties of the channel matrix H, which contains the channel impulse responses among the transmit and receive antennas. If the channel impulse responses or, in the flat fading case, the channel coefficients are uncorrelated, MIMO systems can transmit several datastreams in parallel at the same time and frequency, which leads to increased capacities. It has been shown, that it is possible to reach low correlations among the transmit or receive signals even for small hand-held devices by exploiting the combination of different diversities such as polarization, pattern, and spatial diversity, see [9]. Besides a low correlation a high efficiency in terms of power of the antennas is required, since many small hand-held devices are battery-driven. For a fair comparison of the performance of arrays for MIMO both aspects have to be considered, the correlation properties and the power transmission gain of the MIMO system. Mutual coupling among the antennas, which are always closely spaced in a hand-held device, strongly influences the correlation properties and the power efficiency of the arrays, see [6]. To take mutual coupling into account, the whole transmission channel including transmitter, transmit antennas, physical channel, receive antennas and the receiver has to be considered, as shown in [10].

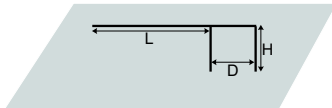


Fig. 1. Inverted-F antenna.

In this paper, measurement results of a MIMO system are shown. Different antenna arrays are integrated into a small housing of a hand-held device to allow for the investigation of compact antenna arrays in MIMO systems.

2 MIMO System Configuration

The MIMO system measurements presented in this paper are link level investigations, thus no interference occurs. The MIMO transmission link consists of a hand-held device with Inverted-F antennas and a base station with dipoles for an indoor environment. Two different hand-held devices are compared. The whole system operates at a frequency of 2 GHz.

2.1 Hand-held Device Setup

For the hand-held device Inverted-F antennas were used. An Inverted-F antenna (IFA) is characterized by three geometrical parameters D, H, and L, as shown in figure 1. In this paper, the

height H equals 10 mm. The distance D can be used to match the input impedance of the antenna to $50\,\Omega$. In this case it equals 7 mm. The length L is determined so, that $L + H \approx \frac{\lambda}{4}$, where λ is the wavelength. The thickness of the wire segments is 0.8 mm. Three or four IFAs respectively are integrated in the hand-held device, see figure 2.

The aim of the antenna configuration was to combine different diversity techniques i.e. pattern and spatial diversity. To overcome polarization mismatching effects polarization diversity is exploited. The simulation model of the small hand-held device consists of a metallic block, representing the battery and the display of the device, and a PVC housing with a wall thickness of 2 mm. The permittivity of the PVC material equals $\varepsilon_r = 3$, the loss factor $\tan\delta = 1 \cdot 10^{-4}$. The size of the housing is $54 \times 114 \times 24$mm. The metallic block is $40 \times 80 \times 10$mm large. The antennas were mounted onto the metallic block spatially separated and with different orientations to exploit different diversity techniques. Usually Inverted-F antennas require an infinite ground plane, which is not given in the small hand-held device. Thus the metallic block, representing the ground plane, acts as a part of the antennas and influences the shape of the patterns and the mutual coupling impedances.

In the first hand-held device three Inverted-F antennas were mounted onto the metallic block. The other hand-held device uses four Inverted-F antennas. The positioning parameters for the two hand-held devices are given in table 1.

	Model 1	Model 2
A	13 mm	20 mm
B	13 mm	50 mm
C	13 mm	10 mm
E	–	30 mm
h	5 mm	5 mm

Table 1: Parameters for the two hand-held models.

Both devices were simulated with FEKO, see [3], a standard EM code based on method of moments. FEKO allows to calculate the pattern of the coupled antenna system as well as the mutual coupling and self impedances of the antennas, which serve as an input for the model of the MIMO transmission link mentioned in section 3.4.

2.2 Base Station Setup

For the indoor measurements an antenna array setup, consisting of three half-wavelength dipole antennas, which were arranged like a triangle, was used. This antenna array setup is a very compact antenna solution, that leads to capable MIMO systems, as shown in [12]. This antenna array exploits a combination of polarization and spatial diversity. Due to its rotational symmetry it is robust against polarization mismatching.

3 Quality Measures for MIMO antennas

3.1 Capacity and Power Considerations

The instantaneous channel capacity of a MIMO system in the presence of spatially uncorrelated Gaussian distributed noise can be calculated by

$$C = \log_2(\det(I + \frac{\mathrm{SNR}}{m} H H^\dagger)) \qquad (1)$$

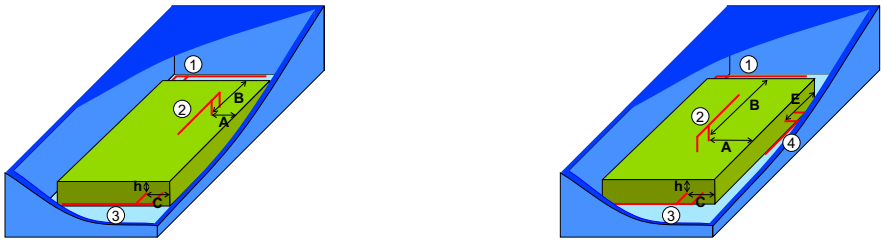
where I is the identity matrix and m the number of transmit antennas (here the transmitter is always the base station). In order to assess a MIMO transmission system by the capacity usually a fixed SNR and a channel matrix, which is normalized by the Frobenius norm, is used. With this normalization, the influence of the correlation properties of the channel matrix on the capacity becomes visible, but any interrelation between the SNR and the correlation properties of H is neglected. If H is not normalized, that means the path loss and the gain of the single antenna elements are included in H, (1) can be written as

$$C = \log_2(\det(I + \frac{P_T}{\sigma^2 m} H H^\dagger)) \qquad (2)$$

P_T is the transmit power, which is equally distributed among the transmit antennas if no channel state information is available at the transmitter. σ^2 is the noise power. This formula allows for a comparison of different MIMO systems, including the influence of the transmission gain and therewith of the SNR.

3.2 Correlation

The correlation properties of H influence the capacity. The number of correlation coefficients between all elements h_{ij} in H is n^2m^2, thus it is difficult to assess the correlation properties. It is also difficult to show the direct relationship between the capacity distribution and the correlation properties. In [5] a measure to describe the



(a) Model 1 with 3 IFAs (b) Model 2 with 4 IFAs

Fig. 2. Models for hand-held devices with three and four Inverted-F antennas.

correlation among all elements h_{ij} is defined, and it is shown, that the ergodic capacity of a MIMO system without channel state information increases with decreasing correlation. A simple way to assess, whether the correlation is high or low, is to consider only the transmit and receive correlation. The complex transmit and receive correlation coefficients of two zero-mean elements h are defined as

$$\rho_{Tx} = \frac{E\{h_{ki}h_{kj}^*\}}{\sqrt{E\{|h_{ki}|^2\}E\{|h_{kj}|^2\}}} \quad (3)$$

$$\rho_{Rx} = \frac{E\{h_{ik}h_{jk}^*\}}{\sqrt{E\{|h_{ik}|^2\}E\{|h_{jk}|^2\}}} \quad (4)$$

thus only the correlation among signals transmitted or received from different antennas is considered. The power correlation coefficient is $\rho_P = |\rho_{Tx/Rx}|^2$, given in [8].

3.3 Power Considerations

Since most hand-held devices are battery-driven, the efficiency of the antennas is an important topic. Mutual coupling among closely spaced antennas does not only influence the signal flow and the correlation properties, it can also strongly reduce the efficiency of an array. Due to the fact that the efficiency of an array depends on its excitation, it is not reasonable to use the efficiency as a quality measure for arrays in MIMO systems. The power transmission gain is the ratio of the power received at the signal drain to the power fed into the transmit antennas. The latter is not equal to the power which is radiated from the transmit antennas, if the efficiency of the transmit array is not 100%. By comparing the power transmission gain of MIMO systems with different arrays in the same channel, conclusions on the performance of the arrays in terms of power can be easily drawn. To assess single antennas in an array the mean effective gain (MEG) can be used, which was introduced in [1]. The MEG is the ratio of the mean receive power of an antenna under test to the mean receive power of a reference antenna, when both antennas are used in the same channel with the same transmit antenna. This definition can be extended to assess arrays. The mean effective array gain (MEAG) is the ratio of the mean received power of an array to the mean received power of a reference antenna.

3.4 Measurement Results

The measurement system consists of a two channel network analyzer, amplifiers and fast switches. The channel coefficients were measured one by one. All measurements were done during night, in order to reduce the time variance of the channel. The measurements were performed in an office building, with concrete ceilings and concrete and wood covered walls. The average office size is 4×5 m, see figure 4. The parameter set of the indoor channel model was obtained from ray-tracing simulations of the building, where the measurements were done in. The receive array was placed at the same position for all measurements. The transmitter was moved along a route, shown in figure 4. Along the route measurements at 300 different positions were performed. In order to keep the measuring time for each channel matrix short, the network analyzer was used in an uncalibrated mode and the calibration was done off-line. The measured data were normalized to obtain a constant mean SNR of each channel matrix of 10 dB. There was no user near the hand-held devices.

The measured power correlation coefficients for both hand-held devices are given in table 2. As in the simulations, the correlation coefficients are low.

In table 3 the measured mean effective gains are shown.

In figure 3 the cdfs of the simulated and measured capacity are given for both models. For the

model	ρ_{12}	ρ_{13}	ρ_{23}	ρ_{14}	ρ_{24}	ρ_{34}
1	0.13	≤ 0.1	0.17	–	–	–
2	≤ 0.1	≤ 0.1	≤ 0.1	≤ 0.1	≤ 0.1	≤ 0.1

Table 2: Measured power correlation coefficients for each pair of antennas in model 1 and 2.

antenna number	1	2	3	4
model 1	−2	−3	−4	–
model 2	−4	−2	−4	−3.5

Table 3: Measured mean effective gain for all antennas in model 1 and 2 in dB. A half-wavelength dipole is used as reference antenna.

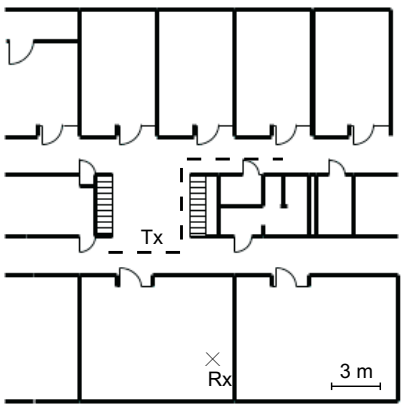


Fig. 4. Scenario for the measurements

simulations the model described in [10] was used.

4 Conclusion

The results show, that it is possible to integrate several antennas into small hand-held devices. To assess compact arrays in small hand-held devices a complete study of the correlation properties and the power characteristics has to be performed. It is shown, that the performance is strongly influenced by a reduced efficiency of the arrays, rather than by the correlation properties of the signals.

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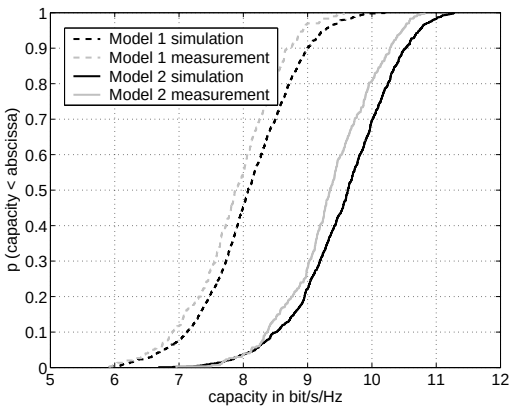

Fig. 3. CDFs of the simulated and measured capacity. The channel matrices are normalized to a constant mean SNR of 10 dB.