

DECORRELATION OF A CLOSELY SPACED ANTENNA ARRAY AND ITS INFLUENCE ON MIMO CHANNEL CAPACITY

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Abstract

The effect of correlation between four closely spaced slot antennas on the capacity of a MIMO system is demonstrated for several different channel scenarios and a practical decorrelation network consisting of a rat-race hybrid is proposed. The effectiveness of this network is independent of the element type or spacing. The properties of the array and decorrelation network are investigated by means of a Finite Difference Time Domain (FDTD) analysis. The decorrelation network is shown to reduce the envelope correlation and give improved capacity when the elements are close.

1 Introduction

It has been shown recently that multiple-input multiple-output (MIMO) systems have several advantages including high data rates without need for extra bandwidth. An important issue is the effect of envelope correlation (which is increased due to closely placed antennas, particularly with spacing lower than $\lambda/2$), on the practical performance of such MIMO systems. However, in many practical applications such as PDAs and mobile terminals, widely spaced elements are not an option.

It has been shown that a decorrelation network can be used, giving low correlation between closely spaced antennas, e.g. [3], and potentially overcoming this problem, but only simple elements have been treated and no practical results for capacity enhancement have been given.

The configuration of the 5.2GHz slot antennas on the PDA used in [5] has been changed so that all antenna elements are mounted on the same plane and in a symmetrical manner. Two different element spacings have been considered. In addition, the effect of adding a decorrelation network, a 180 degree hybrid, to the two closest elements in the array was investigated.

The system model which consists of antenna model, channel model, proposed decorrelation network and different configurations is described in section 2. In section 3,

radiation pattern plots, correlation coefficient tables, and MIMO channel capacity plots for different scenarios are given which demonstrate the impact of decorrelation network on the performance of compact antenna arrays.

2 System Model

2.1 Antenna Model

An existing cavity backed strip line fed linear slot antenna [1], is optimized to operate at 5.2 GHz, with a -30dB return loss. The optimization process is performed using an enhanced FDTD method with software developed by Bristol University CEM Group. Figure 1 represents the geometry of the antenna.

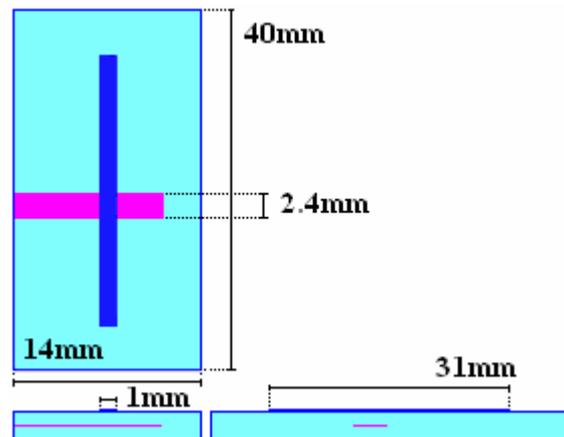


Figure 1 Geometry of the slot antenna

The antenna's overall dimensions are 40x14x3.15mm, the cavity is filled with material having $\epsilon_r=2.2$. This existing antenna was optimised by investigating the effects of slot length, slot width, cavity width, cavity length and feed line length on antenna characteristics and adjusting these to get best performance. The final optimised dimensions are given in figure 1 and the return loss is shown in figure 2.

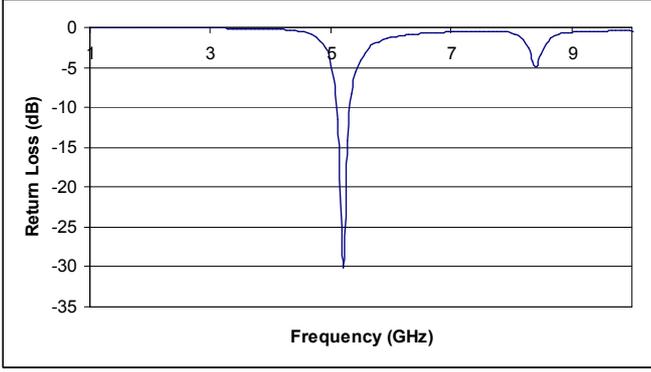


Figure 2 Calculated reflection coefficient of the slot antenna

2.2 Channel Model

A path based channel is modelled to calculate H matrix. Each of the n paths making up the channel is characterised by elevation and azimuth angles of departure, (θ_d, ϕ_d) , elevation and azimuth angles of arrival, (θ_i, ϕ_i) , embedded gain of the element, $G(\theta, \phi)$ and attenuation of the channel, A_k . The H matrix elements are calculated using equation (1).

$$H_{ij} = \sum_k A_k e^{j\psi_k} G_{tx}(\theta_{d_j}, \phi_{d_j}) G_{rx}(\theta_{i_i}, \phi_{i_i}) \quad (1)$$

Once the channel matrix is found, the maximum capacity is calculated using equation (2).

$$C = \log_2(I + \rho^2 H H^T) \quad (2)$$

2.2.1 Artificial Channel

Parameters were generated to fit a specified statistical distribution which in turn would depend on the expected environment for the system. The angular distribution is uniform and path length is taken as having a Gaussian distribution.

2.2.2 Indoor Channel

The data for the channel comes from a ray-tracing simulation of an office environment. Transmit parameters were estimated and the angle of departure was assumed to be uniformly distributed around azimuth plane.

2.2 Proposed Decorrelation Network

In order to decorrelate two closely spaced antennas, two-port antenna system can be connected to an 180° hybrid, which serves as a decoupler [4, 7]. A stripline rat-race hybrid is designed to operate at 5.2 GHz. In order to facilitate connection to the antenna element feeds, two of the ports of the rat race were connected to the inside of the ring instead of the more usual outer connection. The overall dimensions of the hybrid are $40 \times 40 \times 3.15$ mm where length and width are flexible and set according to antenna array in this research. Stripline widths are as labelled in figure 3 and dielectric constant of the filling material is $\epsilon_r = 2.2$.

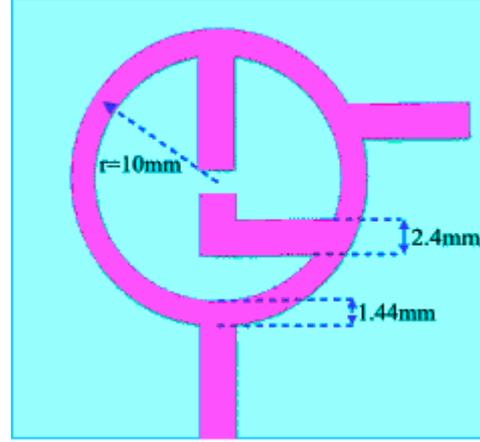


Figure 3 Geometry of 180° hybrid

Hybrid designed to operate at 5.2 GHz and transitions from hybrid to antenna array are combined and simulated together. Figure 4 shows resulting frequency response of whole structure.

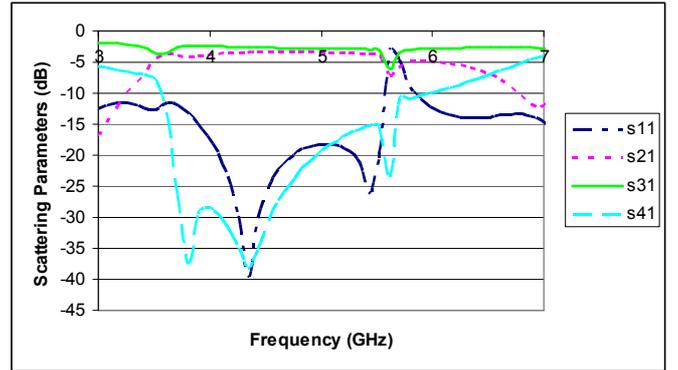


Figure 4 Scattering parameters of decorrelation network

2.3 Different Configurations

To see the effect of placing the antennas in different positions on the box, two different element spacing have been considered as shown in figure 5 and figure 6. In configuration 1, element 1 (E1) and element 4 (E4) are 0.85λ ; E2 and E3 are 1.7λ apart from each other. In configuration 2, antennas are shifted towards each other, such that $h_1 = 0.25\lambda$, $h_2 = \lambda$. Figure 7 shows configuration 3 which is designed to decorrelate E1 and E4 when positioned as in configuration 2. The proposed decorrelation network is connected to the antenna array as a second layer. Whole structure is 6.3 mm in height. Finally, as a last configuration, antennas are matched to hybrid by varying slot width and feed line length of the decorrelated antennas. Table 1 shows all four configurations.

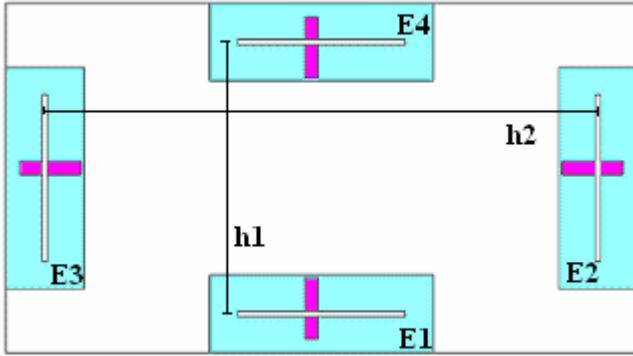


Figure 5 Antenna array on PDA, configuration 1

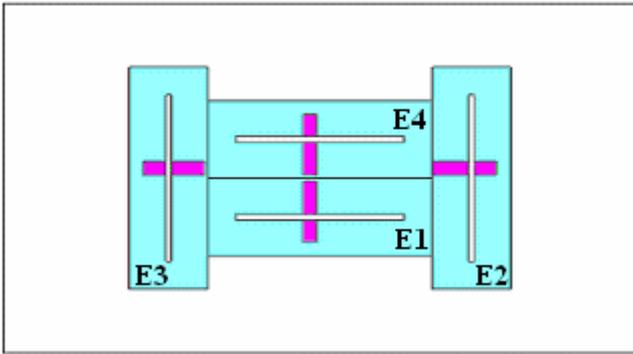


Figure 6 Antenna array on PDA, configuration 2

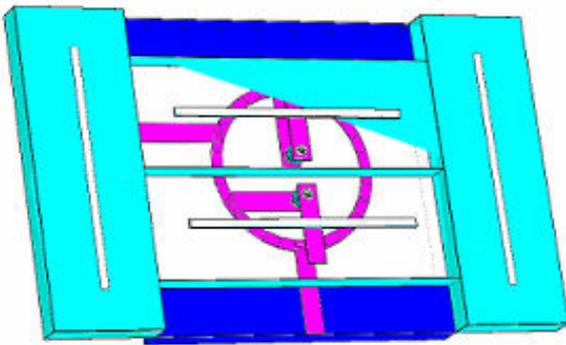


Figure 7 Antenna array with decorrelation network on PDA

	Distance between E1&E4	Distance between E2&E3	Decorrelation Network	Matching between decorrelation network and array
Configuration 1	0.85λ	1.7λ	not connected	not applicable
Configuration 2	0.25λ	λ	not connected	not applicable
Configuration 3	0.25λ	λ	connected	not matched
Configuration 4	0.25λ	λ	connected	matched

Table 1 Topology of the various configurations

3 Simulations and Results

3.1 Radiation Patterns

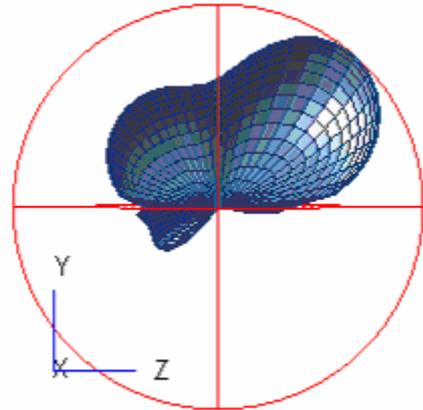


Figure 8 Embedded element pattern of E1 for configuration 1

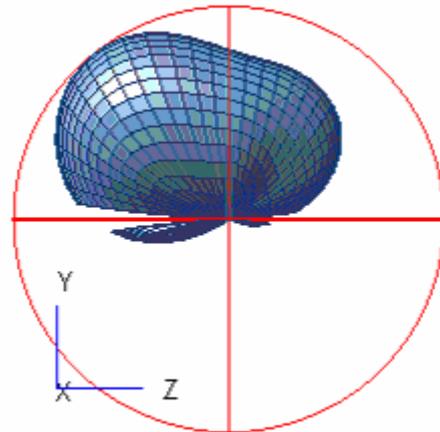


Figure 9 Embedded element pattern of E1 for configuration 2

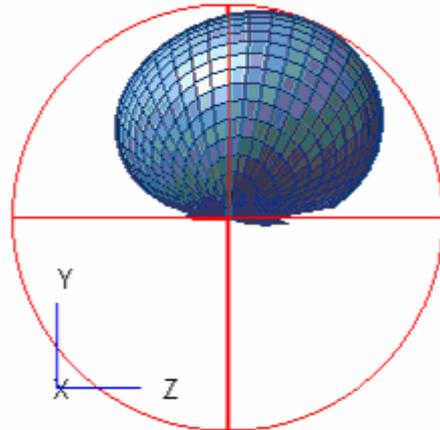


Figure 10 Embedded element pattern of E1 for configuration 3

The embedded element patterns are calculated in the existence of the all elements, one of them is excited but others are terminated with matched loads which stand for source impedance on their ports. Embedded elements patterns appear

to be different from isolated element pattern as mentioned in [6]. Figure 8, 9 and 10 are the embedded element patterns of E1 for configuration 1, 2 and 3 respectively. Figure 11, 12, 13 show the patterns of E4.

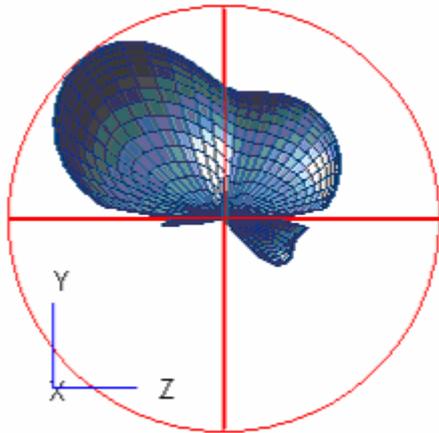


Figure 11 Embedded element pattern of E4 for configuration 1

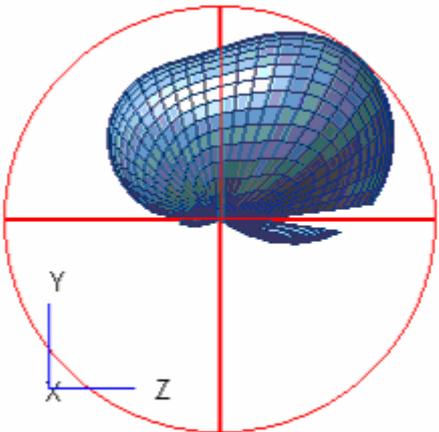


Figure 12 Embedded element pattern of E4 for configuration 2

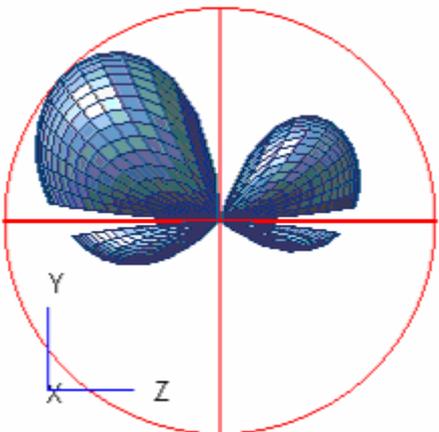


Figure 13 Embedded element pattern of E4 for configuration 3

3.2 Correlation Coefficients

The envelope correlations are calculated using both the radiation pattern and S matrix [2]. The results are shown in Tables 1-6 where the bold figures in the upper right triangle of the tables include the phase of the radiation pattern while the figures in the lower left do not.

	$e1$	$e2$	$e3$	$e4$
$e1$	1	0.024	0.021	0.198
$e2$	0.395	1	0.087	0.024
$e3$	0.393	0.886	1	0.022
$e4$	0.947	0.395	0.393	1

Table 2 Configuration 1, correlation coefficients calculated using radiation pattern

	$e1$	$e2$	$e3$	$e4$
$e1$	1	0.013	0.007	0.112
$e2$		1	0.11	0.021
$e3$			1	0.015
$e4$				1

Table 3 Configuration 1, correlation coefficients calculated using S-parameters

	$e1$	$e2$	$e3$	$e4$
$e1$	1	0.076	0.077	0.376
$e2$	0.3405	1	0.045	0.076
$e3$	0.3407	0.965	1	0.077
$e4$	0.947	0.341	0.342	1

Table 4 Configuration 2, correlation coefficients calculated using radiation pattern

	$e1$	$e2$	$e3$	$e4$
$e1$	1	0.086	0.09	0.344
$e2$		1	0.0067	0.086
$e3$			1	0.09
$e4$				1

Table 5 Configuration 2, correlation coefficients calculated using S parameters

	$e1$	$e2$	$e3$	$e4$
$e1$	1	0.013	0.014	0.209
$e2$	0.339	1	0.047	0.113
$e3$	0.338	0.967	1	0.115
$e4$	0.849	0.34	0.34	1

Table 6 Configuration 3, correlation coefficients calculated using radiation patterns

	$e1$	$e2$	$e3$	$e4$
$e1$	1	0.019	0.02	0.13
$e2$		1	0.002	0.08
$e3$			1	0.085
$e4$				1

Table 7 Configuration 3, correlation coefficients calculated using S parameters

	<i>e1</i>	<i>e2</i>	<i>e3</i>	<i>e4</i>
<i>e1</i>	1	0.0055	0.006	0.068
<i>e2</i>	0.34	1	0.044	0.107
<i>e3</i>	0.34	0.967	1	0.1097
<i>e4</i>	0.847	0.344	0.34	1

Table 8 Configuration 4, correlation coefficients calculated using radiation patterns

	<i>e1</i>	<i>e2</i>	<i>e3</i>	<i>e4</i>
<i>e1</i>	1	0.012	0.014	0.028
<i>e2</i>		1	0.099	0.081
<i>e3</i>			1	0.089
<i>e4</i>				1

Table 9 Configuration 4, correlation coefficients calculated using S parameters

Correlation between element 1 and 4 is plotted vs. configurations in figure 14 which shows that locating the elements close to each other, increases the envelope correlation. The decorrelation network is quite successful in decorrelating these close elements. Also, matching the antennas to the hybrid as in configuration 4 further decreases the envelope correlation

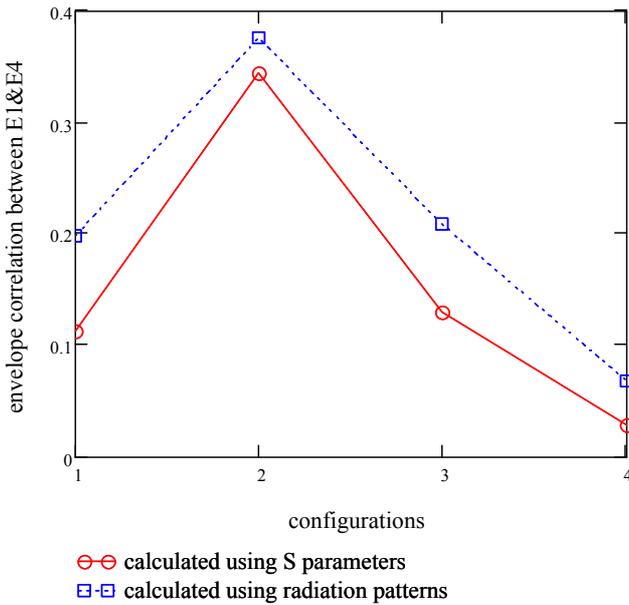


Figure 14 Correlation between E1 and E4 vs. configurations

3.3 Capacity

MIMO capacity of the arrays for artificial and indoor ray-traced channels and for the previously mentioned configurations are calculated with the transmitted power kept constant. Calculated capacities are shown in figure 15 and figure 16 for artificial and indoor ray-traced channels.

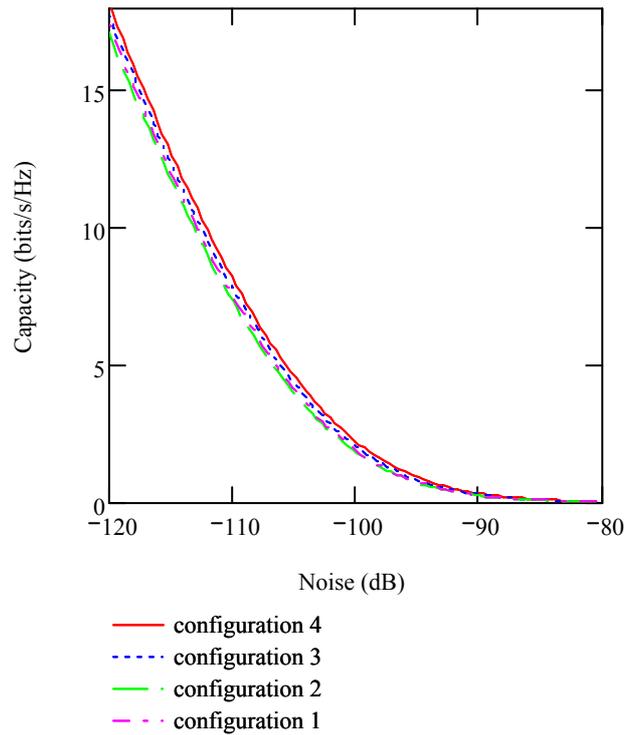


Figure 15 MIMO capacity for artificial channel data

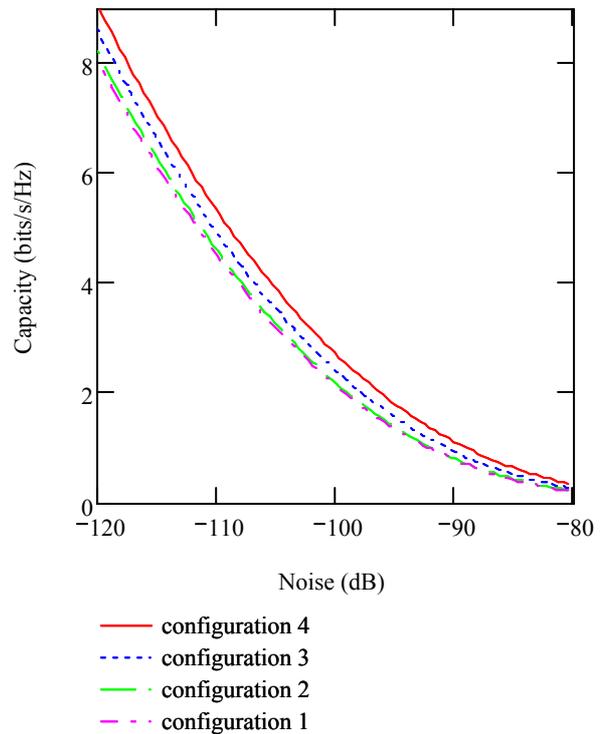


Figure 16 MIMO capacity for indoor ray-traced channel data

The capacity is shown to increase as the correlation decreases as seen in graphs. For artificial channel which is the closest to ideal, configuration 4 has the largest capacity, whereas configuration 2 has the lowest.

4 Conclusion

This paper has presented a study of a decorrelation network. Effect of antenna separation on correlation between MIMO antennas and MIMO channel capacity is investigated. Envelope correlation and MIMO channel capacity are evaluated for four different cases. Comparison of the first two configurations has confirmed that the spacing between the antennas strongly affects the correlation and hence the expected capacity. An FDTD analysis has shown that when the decorrelating network is included, the envelope correlation is greatly reduced. In each case the correlation coefficients between the ports were calculated from the 3D radiation patterns. Capacity calculations have been performed using artificial channel data and indoor ray-traced data based on a specific statistical distribution and results obtained indicate that an improvement can be obtained. It has been demonstrated by simulations that decorrelation of the antenna array elements is crucial to maintain the channel capacity. When the decorrelation network is used, the capacity does not reduce significantly even when the antenna elements are placed close to each other.

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