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The effect of antenna position and environment on MIMO channel capacity for a 4 element array mounted on a PDA.

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Abstract: The properties of a four element slot antenna array mounted on a PDA for a MIMO system are investigated by means of a Finite Difference Time Domain analysis and a multipath channel model. The effects of changing the positions of the antenna elements on the PDA box and the effect of the box being held in a human hand are investigated.

I. INTRODUCTION

In Multiple Input Multiple Output (MIMO) systems, multiple antennas are used on both the transmitter and the receiver to increase the capacity of the channel. Such multi-antenna systems have several advantages including high data rates without need for extra bandwidth. Many communication systems, however, require small sized mobile units which force the antennas to be placed close to each other. This leads to significant mutual coupling, increased envelope correlation and "super-directive" effects which affect the practical performance of the system.

In this work a realistic system is considered such that 4 slot antennas are placed on a PDA box [1]. In this situation, spacing is a dominant parameter that restricts the capacity. Another important effect is that of the user's body being close to one or more of the antennas. In this contribution, the effect of the positions of the antennas on the box and the close proximity of a human hand on the overall channel H matrix, the envelope correlation coefficients and the capacity is investigated. For this purpose, a multipath model is used to synthesise the channel using similar techniques to those used in [2]. All of the antenna simulations were done using the Finite Difference Time Domain technique.

II. ANTENNA MODEL

A cavity-backed stripline-fed linear slot antenna was designed to operate at 5.2 GHz with a -10dB input bandwidth better than the 120MHz [3] at Bristol University and this was used as the element for a four element array mounted on a PDA box. Measurements of the radiation patterns, directivity and envelope correlation are already available for this array in a free space environment and these were used to validate the model. Figure 1 shows the geometry of the slot antenna. The antenna dimensions are 40x14x3.15 mm, the cavity is filled with material having ϵ_r=2.2 and the length of the stripline is 11mm.

This antenna is simulated using an enhanced FDTD method with software developed by Bristol University CEM Group. Four cavity-backed linear slots were mounted on a PDA box of 63x113x14 mm [1] as seen in Figure 2. This figure also shows the human hand model, based on [4], which was used to investigate the effect of the close proximity of the human body to the box.

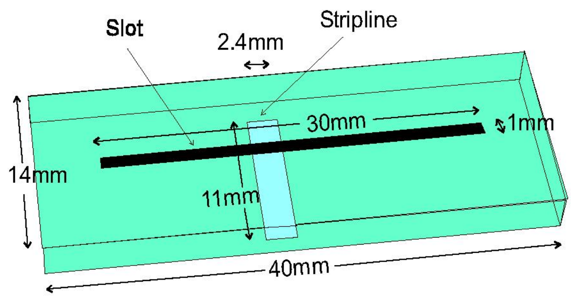

Figure 1 - **Geometry of the slot antenna**

III. CHANNEL MODEL

A simple path based channel was modelled using Maple 9.1 to calculate the H matrix for the purpose of comparing the different antenna configurations. Each of the *n* paths making up the channel is characterised by elevation and azimuth angles of departure, (θ_n^T, ϕ_n^T), elevation and azimuth angles of arrival, (θ_n^R, ϕ_n^R) and a complex path gain, β_n. Also the effects of the polarisation of the departing and incoming rays were included. The H matrix elements were calculated using equation (1).

$$H_{ij} = \sum_n E_i^R(\theta_n^R, \phi_n^R)\beta_n E_j^T(\theta_n^T, \phi_n^T) \quad (1)$$

where $E_i^R(\theta,\phi)$ is the radiation pattern of the i[th] slot on the PDA and $E_j^T(\theta,\phi)$ is the radiation pattern of the j[th] transmit antenna. These are obtained from 3D FDTD simulations.

The values of (θ,ϕ,β) are calculated randomly to fit a specified statistical distribution which in turn would depend on the expected environment for the system. In the work described in this contribution, 100 paths were considered. The angular distribution was uniform and the path length was taken as having a Gaussian distribution.

Once the channel matrix is found, the maximum capacity is calculated using the formula:

$$C = \log_2\left(\det\left(\underline{\underline{I}} + \frac{\underline{\underline{H}}\,\underline{\underline{H}}^H}{\sigma^2}\right)\right) \quad (2)$$

Where $\underline{\underline{I}}$ is the unit matrix and σ is the receiver noise amplitude and is assumed to be the same for each antenna element.

IV. SIMULATIONS AND RESULTS

In order to verify the correctness of the model, calculations were first done which could be compared to the existing measured results. An FDTD model of the PDA box with the four slot antennas mounted on it in the same configuration as that which was measured in [1] was made. The geometry is shown in Figure 2 where h1=14mm and h2=15mm but without the hand being present. The envelope correlation was calculated using both the radiation pattern and the S matrix [5]. The results are shown in Tables 1-3 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. These all confirm that the antenna elements are well decorrelated

Table 1 - Measured envelope correlation [1]

	E 1	E2	E 3	E 4
E 1	1.000	**0.022**	**0.056**	**0.015**
E 2	0.652	1.000	**0.020**	**0.017**
E 3	0.532	0.789	1.000	**0.013**
E 4	0.728	0.551	0.611	1.000

Table 2 - Calculated envelope correlation using radiation pattern (this research)

	E 1	E 2	E 3	E 4
E 1	1.000	**0.059**	**0.013**	**0.004**
E 2	0.420	1.000	**0.071**	**0.011**
E 3	0.380	0.880	1.000	**0.027**
E 4	0.820	0.330	0.310	1.000

Table 3 - Calculated envelope correlation using S matrix (this research)

	E 1	E 2	E 3	E 4
E 1	1.000	**0.053**	**0.023**	**0.043**
E 2		1.000	**0.059**	**0.005**
E 3			1.000	**0.03**
E 4				1.000

Table 4 - Calculated envelope correlation with human hand present

	E 1	E 2	E 3	E 4
E 1	1.000	**0.041**	**0.073**	**0.043**
E 2	0.386	1.000	**0.021**	**0.073**
E 3	0.433	0.849	1.000	**0.008**
E 4	0.846	0.346	0.440	1.000

To see the effect of placing the antennas in different positions on the box, calculations of the envelope correlations and the overall capacity were done first using h1=7mm, h2=7.5mm and again using h1=21mm and 22.5mm. In addition, calculations were done with the original spacings of h1=14mm and h2=15mm but with the human hand in place. Results for the calculated capacity are given in Figure 3 for a range of signal-to-noise ratios. It can be seen that the placing of the antennas on the PDA has very little effect on the overall capacity but that placing the hand around the PDA causes a noticeable reduction. The envelope correlation coefficients for this situation are shown in **Table 4** where it can be seen that the elements are still well decorrelated. It has been found from these investigations that the reduction in capacity is caused by the lowering of the efficiency due to the hand covering one of the elements. This is confirmed by calculating the capacity while ignoring the loss caused by the hand. The capacity is slightly reduced when the hand is present but when losses are included the reduction is much greater. The effect can also be seen by examining the radiation patterns of each element when the hand is absent and when it is present. These patterns are shown in Figure 4 and Figure 5 respectively. It can be seen that the gain of element 3 is reduced by more than 20dB when the hand is present.

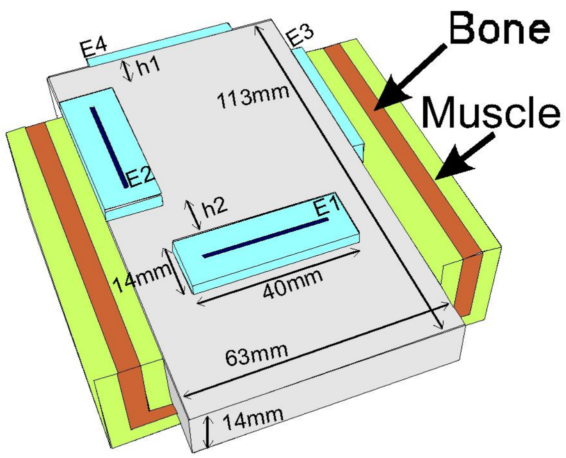

Figure 2 - PDA with 4 element array with human hand present

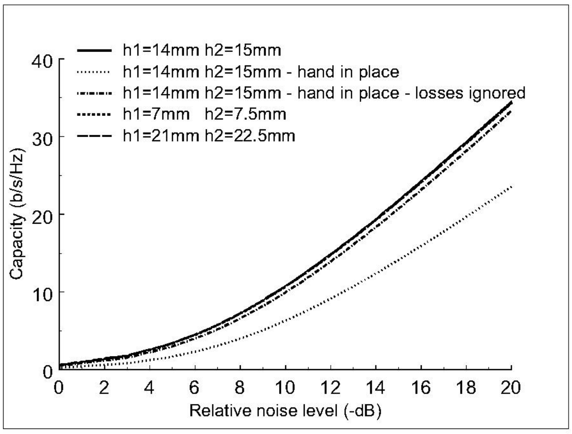

Figure 3 - Calculated capacities of the channel for various antenna configurations

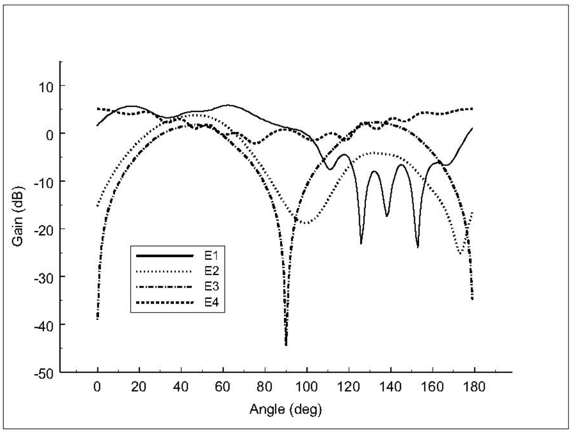

Figure 4 - Radiation pattern along principal plane for the four slots

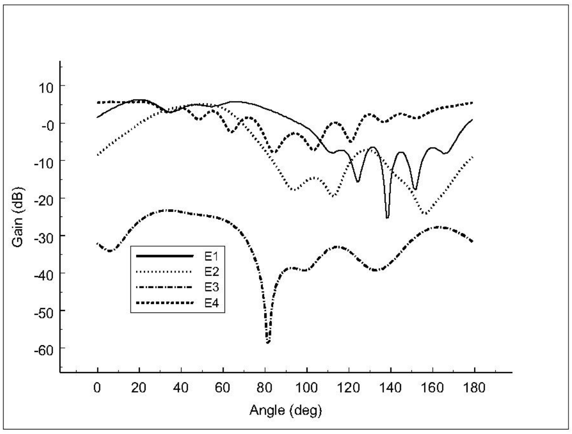

Figure 5 - Radiation pattern along principal plane for the four slots in the presence of a hand

V. ALTERNATIVE LAYOUT

Guided by the results obtained for the configuration shown in Figure 2, an alternative layout for the slots, shown in Figure 6 was modelled. In this case, the likely correlation between elements 1 and 3 will be greater due to closer proximity and more similar orientation but element 3 will be less affected by the presence of the human hand. Overall it is expected that the performance will be improved. The envelope correlation matrix of the array was calculated and is given in **Table 5** for the case where the hand is not present and in **Table 6** for the case where the hand is in place. The radiation patterns of this arrangement, with and without the hand present, are shown in Figure 8 and Figure 9. It can be seen that the effect of the hand in this case is small.

Without the hand present, the correlation between elements 2 and 3 is 0.194 for the alternative layout compared to just 0.071 for the original layout. A similar, expected, increase is seen when the hand is in place. There is no significant change to the correlation between other pairs of elements. Despite this, however, it can be seen from Figure 7 that the calculated capacity is not significantly different for the two layouts. When the hand is present, the alternative layout shows little reduction in capacity while the original layout does show a substantial reduction. This indicates that better performance of the system might be obtained using a slightly different arrangement of the antennas.

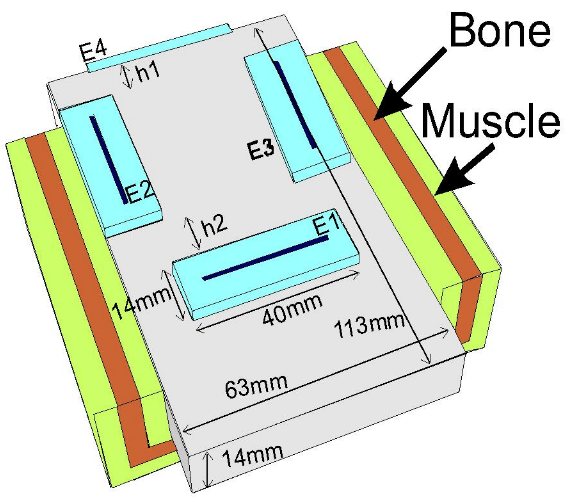

Figure 6 - PDA with 4 element array with human hand present

Table 5 - Calculated envelope correlation using radiation pattern for alternative layout.

	E 1	E 2	E 3	E 4
E 1	1.000	**0.078**	**0.019**	**0.007**
E 2	0.42	1.000	**0.194**	**0.012**
E 3	0.417	0.94	1.000	**0.019**
E 4	0.81	0.33	0.33	1.000

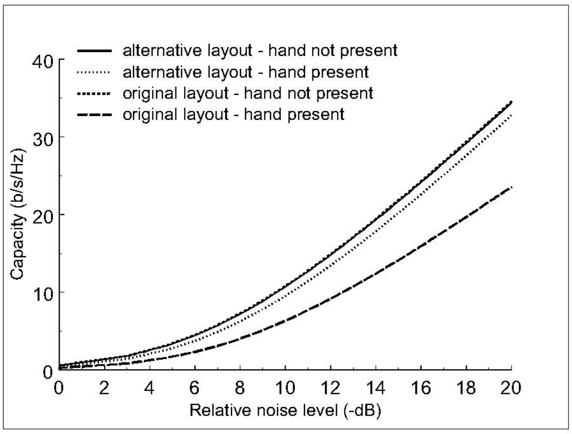

Figure 7 - Calculated capacities of the channel for the original and alternative layouts

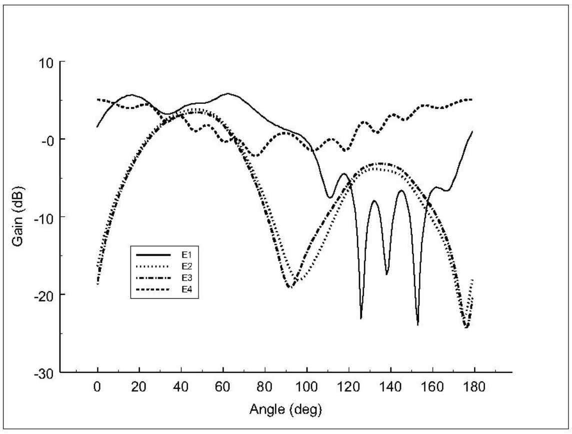

Figure 8 - Radiation pattern along principal plane for the four slots for alternative layout

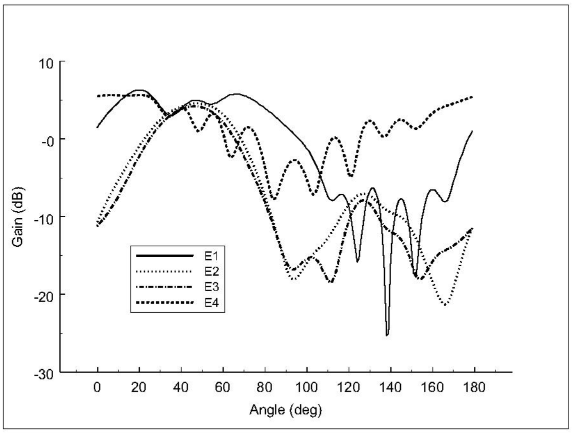

Figure 9 - Radiation pattern along principal plane for the four slots in the presence of a hand for alternative layout

Table 6 - Calculated envelope correlation with human hand present for alternative layout

	E 1	E 2	E 3	E 4
E 1	1.000	**0.026**	**0.041**	**0.008**
E 2	0.38	1.000	**0.216**	**0.052**
E 3	0.387	0.97	1.000	**0.041**
E 4	0.846	0.346	0.330	1.000

VI. CONCLUSIONS

In this contribution an investigation into the effect of antenna placement on a PDA and the proximity of the human hand on the MIMO capacity of a representative channel has been done using an FDTD analysis of the antennas and a multi-path model of the MIMO channel. It has been shown that the placement of the antennas is not critical so long as the PDA is away from other objects but that the presence of the hand reduces the capacity due to a reduction in efficiency of the antenna. By comparing two different element layouts, it has been shown that in this case the effect of losses is more of a limitation than the effect of correlation between antenna elements and that the choice of antenna placement is best made accordingly. The method used is general and can be equally applied to different antenna types and configurations and to different MIMO environments.

VII. REFERENCES

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