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The User's Body Effects on Decoupling Networks for Compact MIMO Handsets

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***Abstract*—Antenna design is very important for the performance of wireless communication. It becomes even more important when multiple antennas are introduced in modern handsets, especially at low frequencies where physical laws impose challenging design constraints.**

In this paper, the impact of the user's proximity to a MIMO antenna for compact hand-held devices designed to operate in the lower bands has been investigated. The implementation contains a decoupling network to reduce the mutual coupling between the elements of the MIMO antenna. A tunable configuration is presented. Partial compensation for the user effect is considered.

I. Introduction

The use of multiple input multiple output (MIMO) systems in mobile communications offers improved robustness, spectral efficiency and data rate by utilizing the spatial and/or polarization properties of the multipath channel. [1].

When MIMO is introduced in compact hand-held terminal, the effects of mutual coupling limit its performance [2]. Because there is a leakage of power from one antenna to the other, efficiency and capacity are reduced. The previously described effects become more severe as the size of the device becomes smaller compared to the wavelength of the operating band [3].

In order to limit the undesired effects of mutual coupling a lumped element decoupling network is used for this paper. Its performance under the influence of the user is considered.

The following section describes the working principle of the investigated methods and how they are evaluated. Here, the simulation results are also presented whereas the last section draws conclusions on the findings.

II. Discussions and Results

In the design process of a MIMO antenna the following parameters must receive special consideration : total system efficiency, near-field coupling and envelope correlation coefficient. The total efficiency can be calculated with equation 1 from [2], where η_{rad} is the radiation efficiency taking into account the conductive, dielectric, coupling losses and absorption losses due to the user's interaction. The mismatch is evaluated through η_m.

$$\eta_{total1} = \eta_{rad1} * \eta_{m1} \tag{1}$$

$$\eta_{m1} = 1 - |S_{11}|^2 \tag{2}$$

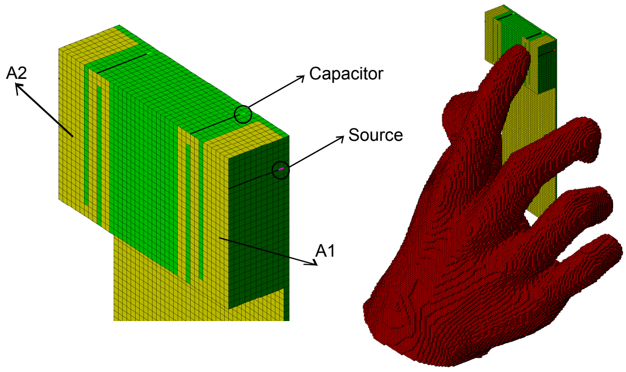

Fig. 1. The numerical model of the structure in free-space and with the hand phantom. The lumped capacitor used for loading and the excitation ports are highlighted as are the two antenna elements.

The antenna used in this paper is shown in figure 1. It has been simulated using the Aalborg University in-house FDTD (Finite-Difference Time-Domain) electromagnetic solver, choosing uniform gridding with a space cell size of 1 mm. It is comprised of two 10 mm high planar inverted F antennas (PIFA) placed on a substrate with $\varepsilon_r = 2.3$ above a 100x40 mm ground plane. The antenna elements are loaded with two capacitors, as highlighted in Fig. 1. The capacitors have been used to lower the resonating frequency from 1.15 GHz to approximately 850 MHz. Furthermore, they have the role of reducing the size of the resonating element and they can be used to tune very easily the resonating frequency. Bandwidth and radiation efficiency are decreased as a result. For values ranging from 1 pF to 1.6 pF, the whole interval from 780 to 890 MHz can be covered. The simulated S parameters are shown in Fig. 2. It can be seen that the level of mutual coupling, which can be evaluated through the S_{21}, is very high due to the close proximity of the two resonating elements. In addition, as the resonant frequency is lowered, the coupling becomes higher.

The influence of the user on the performance of the antenna has been investigated previously. In [6], it has been found that compared to the free space case and depending on the user's grip of the handset, a loss of up to 11 dB in total efficiency can be introduced. The dimensions of the hand phantoms are chosen according to a hand anthropometric study [4], whereas the electric properties of the tissue are the ones presented in [5] for 850 MHz. A part of this extra loss is attributed to the

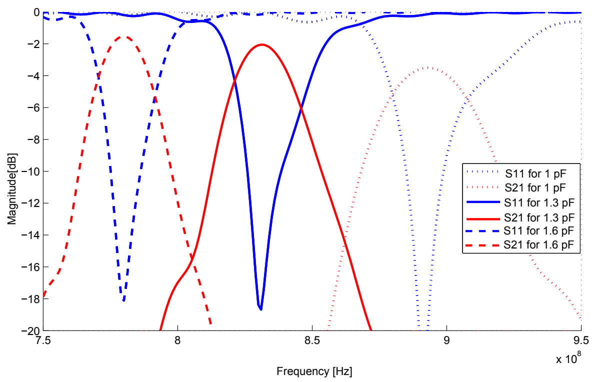

Fig. 2. Simulated S parameters for the free-space antenna with three different values for the loading capacitors in the case without the decoupling network (case H+Tun from table I). S_{11} is equal to S_{22} due to symmetry.

change of the antenna's input impedance, the mismatch loss. The second mechanism responsible for the rest of the losses is the fact that some of the radiated energy is absorbed by the human body, especially when it is placed in the near-field of the antenna, the absorption loss.

For the purpose of this investigation only the absorption and mismatch losses are considered. The rest, ohmic and dielectric losses in the antenna and decoupling network(DN) are not simulated. It has been shown in [6] that the absorption losses can be reduced just by increasing the distance between the PIFA and the index finger. As a result, the optimization focuses only on minimizing the coupling and matching losses. It is considered that the absorption losses can be reduced by optimizing the radiating elements' placement on the printed circuit board (PCB), virtually designing the handset for a certain type of grip. For this study, the position is not changed and the distance between the PIFA element and the finger is kept constant to 1mm. The limit the number of variables, the outer casing of the phone is not simulated.

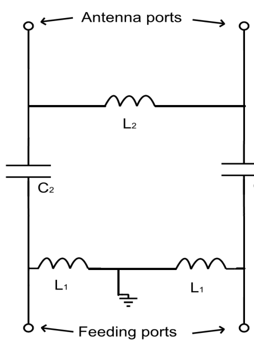

Fig. 3. Schematic of the decoupling network.

In [6], it has been argued that the Specific Anthropomorphic Mannequin (SAM) has a small influence on the PIFA's performance. For this investigation, only the worst case scenario is presented. It is illustrated in the right side of Fig. 1 and it is considered to be the case with index finger covering most of one radiator and with the tip placed at 1 mm distance (the casing width). The results for the left hand models are the same due to the antenna's symmetry.

Because the coupling is very high, a DN has been designed. It has been shown in [7] that symmetric antennas systems can be decoupled by a shunt reactive component and matching network. A similar approach has been used for this paper, a 15 nH inductor placed in between the feeding ports to minimize the transadmittance (Y_{21}), followed by an L matching network stage composed of a 12 nH inductor in parallel and a 2.25 pF series capacitor, as illustrated in Fig. 3.

Table I contains the simulated efficiency results for the different cases. FS and FS+DN represent the free space results without and with the decoupling network. In free space, the DN is robust enough to give reasonable results at the edges of the tuning interval (from 780-890 MHz) if the decoupling network is designed for the middle of the tuning band of interest.

For the simulations including the hand (HA), the efficiency of each antenna is different (the finger is over antenna A1). This is explained by the fact that the index finger (which is the most disruptive part of the hand) is interacting with the radiating elements differently (A1 is more affected than A2), as it can be seen in Fig. 4. Some of the mismatch loss can be reduced and some of the impedance parameters' symmetry can be regained by modifying the values of the loading capacitors independently (the cases HA+Tun), as it can be noticed in Fig. 5.

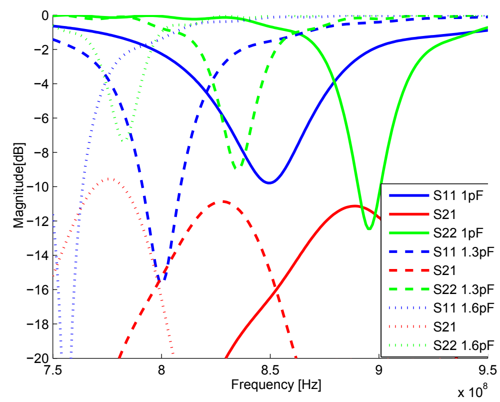

Fig. 4. Simulated S parameters for the case without DN and with the user's hand present for the three tuning values of the loading capacitors (case H from table I).

The capacitor from the most affected antenna is always tuned to a value that is lower than the one of other capacitor in order to counteract for the capacitive coupling to the finger. Thus, the matching efficiency calculated with equation 2 is increased. However, because there is more power radiated into the hand and into the other port, the absorbtion losses increase.

The working principle of this decoupling network is based on the symmetry of the antenna's impedances whereas the user's interaction is anything but symmetric. The reactive component placed in parallel at the feeding ports is calculated for a certain frequency and admittance value. Therefore, when the user's hand is introduced into the simulation, the decoupling is shifted in frequency from the port's self-matching. Even though the resonating frequency is retuned to the free-space one (case HA+Tun), the admittance value for that frequency has changed, thus the DN in not as efficient

TABLE I
SIMULATED EFFICIENCY RESULTS.

Cases	Low band (780 MHz)				Middle band (830 MHz)				High band (890 MHz)			
	$\eta_m(dB)$		η_{rad}(dB)		η_m(dB)		η_{rad}(dB)		η_m(dB)		η_{rad}(dB)	
	A1	A2	A1	A2	A1	A2	A1	A2	A1	A2	A1	A2
FS	-0.1	-0.1	-5.4	-5.4	-0.1	-0.1	-4.3	-4.3	-0.0	-0.0	-2.5	-2.5
FS+DN	-0.1	-0.1	-0.2	-0.2	-0.0	-0.0	-0.1	-0.1	-0.4	-0.4	-0.1	-0.1
H	-5.6	-7.0	-6.9	-1.8	-3.4	-0.9	-7.4	-3.5	-3.5	-0.5	-6.6	-1.1
H+Tun	-0.3	-1.3	-7.5	-4.9	-0.8	-2.1	-7.4	-3.8	-0.9	-1.6	-6.6	-3.0
H+Tun+DN	-4.4	-1.7	-7.7	-4.3	-4.4	-1.9	-6.5	-1.6	-5.1	-1.8	-6.7	-1.2

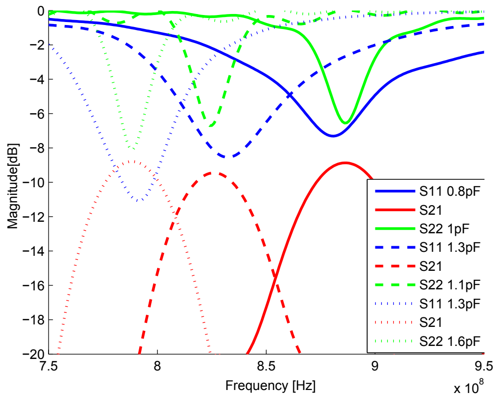

Fig. 5. Simulated S parameters for the case without DN and with the user's hand present for the three adjusted tuning values of the loading capacitors in order to counteract the detuning (case H+Tun from table I).

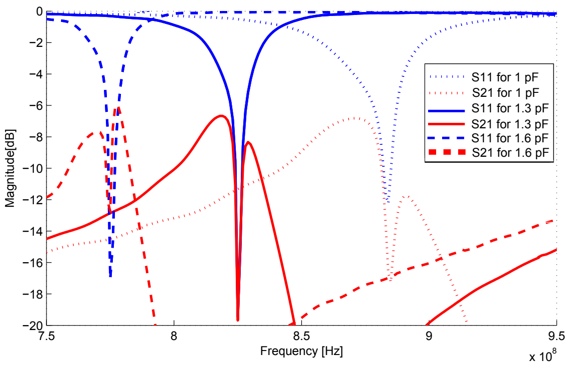

Fig. 6. Simulated S parameters for the free-space complete system, antenna plus decoupling network (case FS+DN from table I). S_{11} is equal to S_{22} due to symmetry.

as in free space (case HA+Tun+DN) which is illustrated by Fig. 6 and Fig. 7.

III. CONCLUSION AND FURTHER WORK

In free-space, the proposed design offers very good isolation even though the antennas are in close proximity of each other. The performance of the antenna with the user interaction has been investigated. As it was expected, it is degraded considerably. The drawback of this implementation is that the DN is limiting the available bandwidth which is consistent with the findings of [2]. This limitation can be overcome by using a tunable antenna configuration. In free space the DN reduces significantly the mutual coupling for a narrow bandwidth.

From the simulation results, one can conclude that the DN is robust enough to give reasonable results at the edges of the tuning interval if the decoupling network is designed for the middle of the tuning band of interest.

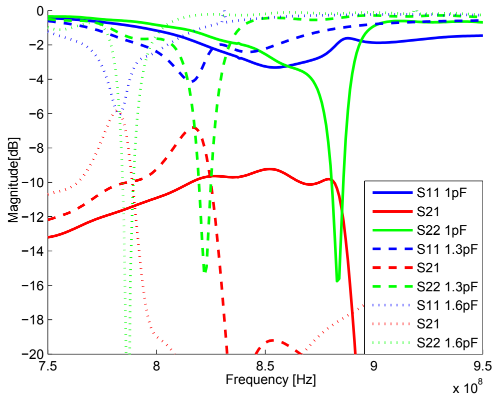

Fig. 7. Simulated S parameters for the complete system with the hand present, antenna plus decoupling network (case HA+Tun+DN from table I).

In this paper, the most detrimental case for the DN has been shown. It is the case where the antenna is affected considerably due to the user's proximity. As a consequence, the DN's performance is degraded considerably. To counteract this degradation, either a tunable DN must be implemented or the antenna placement and distance from the user must be optimized.

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