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Alrabadi, Osama; Tsakalaki, Elpiniki; Pelosi, Mauro; Pedersen, Gert Frølund

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Agile and Efficient MIMO System for Smart Phone Terminals

Osama N. Alrabadi*, Elpiniki P. Tsakalaki, Mauro Pelosi, Gert F. Pedersen

Antennas, Propagation & Radio Networking Section, Aalborg University,
Niels Jernes Vej 12 A6-2, 9920 Aalborg, Denmark
Emails: {ona, et, mp, gfp}@es.aau.dk

ABSTRACT: The paper proposes a novel multi-input multi-output (MIMO) system architecture that covers most of the high LTE bands. The system is comprised of four small loop antennas. Each antenna has two ports, one for communication and one for control. The control port is used for tuning the loop antenna where impressive frequency agility using a single capacitor is obtained. A good level of inherent isolation among the four loop antennas is maintained over the different frequency bands. The MIMO performance of the proposed system is evaluated through its spectral efficiency versus frequency. Finally, the information bandwidth of the MIMO system can be defined by comparing its spectral efficiency against the spectral efficiency of three ideal MIMO antennas.

Index Terms --- Agile antennas, MIMO, Spectral efficiency.

SECTION I. INTRODUCTION

Future generations of mobile devices rely on MIMO technology to deliver on the promises of boosted data rates and higher system performance. However, the performance of mobile devices is especially sensitive to the antenna design and a host of other factors that were less significant in single-antenna designs. This places more emphasis on understanding the interrelationship among the handset antennas, the device metallic frame (handset chassis), the user and the far-field scattering channel. MIMO systems may optimally operate as a data-rate multiplier (spatial multiplexer) when the handset antennas and the propagation channel are in good conditions i.e. when the handset antennas are efficient and the channel has enough scattering. While communication engineers are at the mercy of the propagation channel, antenna engineers can have large control over the handset antennas. In this context, antenna engineers aim at guaranteeing a sufficient level of isolation among the handset antennas, not only in free-space, but more importantly in normal user coupling scenarios. In fact, the 'super-antenna' concept goes beyond the device boundaries to further account for the user head and hand. On the other hand, the MIMO antennas should occupy the minimum space over the Ground Plane (GP) as they compete with other mobile components, like the screen and the camera, as well as competing with other communication antennas like GPS, Wi-Fi and Bluetooth antennas.

In this work we propose a novel MIMO architecture where four loop antennas are placed at the four corners of the GP thus maintaining a sufficient bandwidth. We focus on the free-space scenario while user coupling scenarios are left as a future work. Each loop has two ports: an RF communication port and a control port for tuning the antenna. The system shows impressive frequency agility over the frequency range 1600-2200 MHz, while the cross-coupling among the antenna pairs remains acceptable without any antenna or GP modifications. The antennas isolation in the upper part of the high LTE bands is owed to larger *electrical* distance among the antennas while the inherent isolation in the lower part is owed to the higher Quality- (Q-) factor [2]. The MIMO performance over the different frequency bands is evaluated through its spectral efficiency.

The rest of the paper is divided as follows: Section II describes the antenna system while Section III evaluates the MIMO performance of the proposed system. Finally Section IV concludes the paper.

SECTION II. ANTENNA SYSTEM DESCRIPTION

The antenna system is comprised of four loop antennas over a (55 x 110) mm^2 GP representing the typical dimensions of a smart phone tablet. The system dimensions and the dimensions of the loop antennas and their numbering are shown in Fig. 1 where all dimensions are in millimetres (mm). Each loop antenna occupies an area of (15 x 4) mm^2. The MIMO structure made of annealed copper was simulated using the transient time domain solver from CST MICROWAVE STUDIO®.

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The MIMO system can be expressed as a four (active) port network with the following scattering matrix

$$\boldsymbol{S} = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{12} & S_{11} & S_{14} & S_{13} \\ S_{13} & S_{14} & S_{11} & S_{12} \\ S_{14} & S_{13} & S_{12} & S_{11} \end{bmatrix},$$

where the symmetric matrix structure is owed to using identical antenna elements with equal capacitance at their control ports, over a symmetric topology.

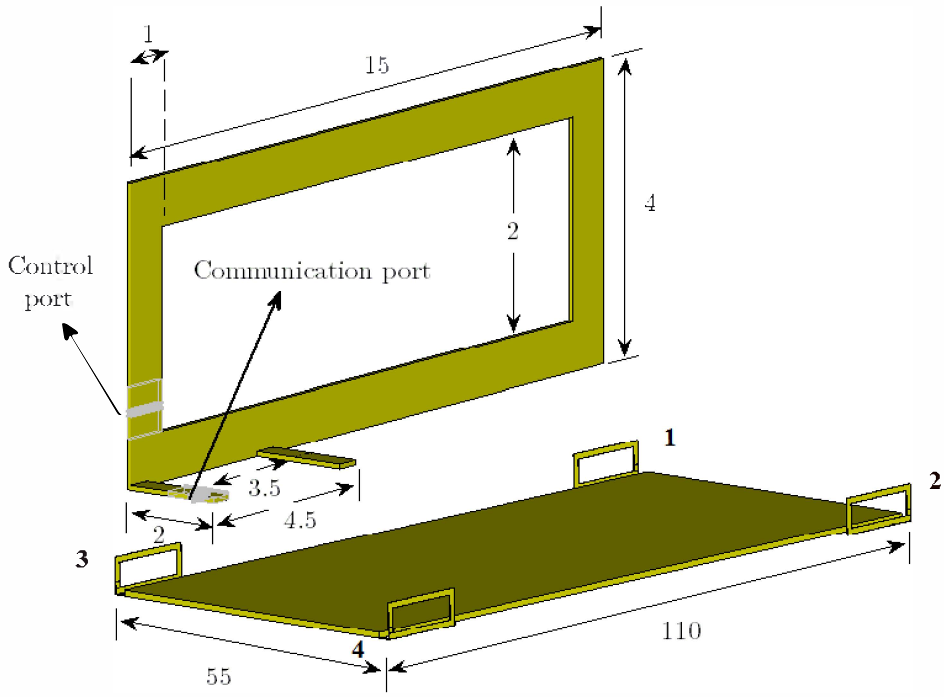

Fig. 1 The numerical model of the antenna system comprised of four loop antennas and the antenna dimensions (in mm)

SECTION III. PERFORMANCE EVALUATION

Fig. 2 shows the frequency response of the MIMO antenna system at the center frequencies f=1600MHz, 1800MHz, 2200MHz and 2400MHz. The control port was tuned between a minimum capacitance of 0.01pF and a maximum capacitance of 1pF. On the other hand, Fig. 3 shows the active loop response at f = 2GHz when exciting the first loop antenna with a unit voltage signal while shortening the remaining three loops with 50Ω at their communication ports and the same capacitance at their control ports. By integrating the active pattern over a sphere, a total efficiency that accounts for the Ohmic losses in the copper can be obtained. A minimum (in absolute terms) total efficiency of -0.5 dB has been obtained across all bands. The coupling mechanism among the MIMO antennas can be observed from the logarithmic contour map of the surface currents shown in Fig. 4. The figure shows the surface currents magnitude (in dB scale) when exciting the first loop antenna with a unit voltage signal while terminating the other ports with their matching impedances (same procedure for obtaining the active element response). The figure clearly shows that the antennas cross-coupling mainly happens through the edges of the GP as is already expected.

On the other hand, the performance of the MIMO system not only depends on the self-matching and cross-coupling among the four loop antennas, but also on the spatial correlation. All the antenna parameters can be taken into consideration by observing the system spectral efficiency versus frequency as explained in [1]. A tight bound on the spectral efficiency of the proposed system assuming a uniform three-dimensional (3D) environment is given by

$$\eta_{\mathrm{UB}} = \log_2 \left| \left(1 + \frac{\mathrm{SNR}}{4}\right)\mathbf{I}_4 - \frac{\mathrm{SNR}}{4}\boldsymbol{S}^{\mathrm{H}}\boldsymbol{S} \right|,$$

where $\mathbf{I}_4$ is an identity matrix of a fourth dimension, $|\mathbf{X}|$ returns the determinant of $\mathbf{X}$, and $(\,.\,)^{\mathbf{H}}$ is the Hermitian operator.

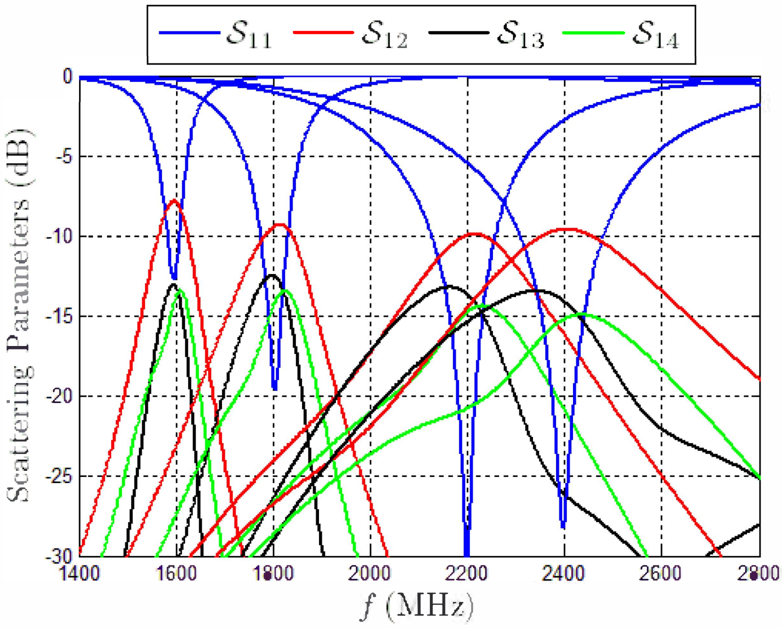

Fig. 2 The frequency response of the proposed MIMO system at f=1600MHz, 1800MHz, 2200MHz and 2400 MHz.

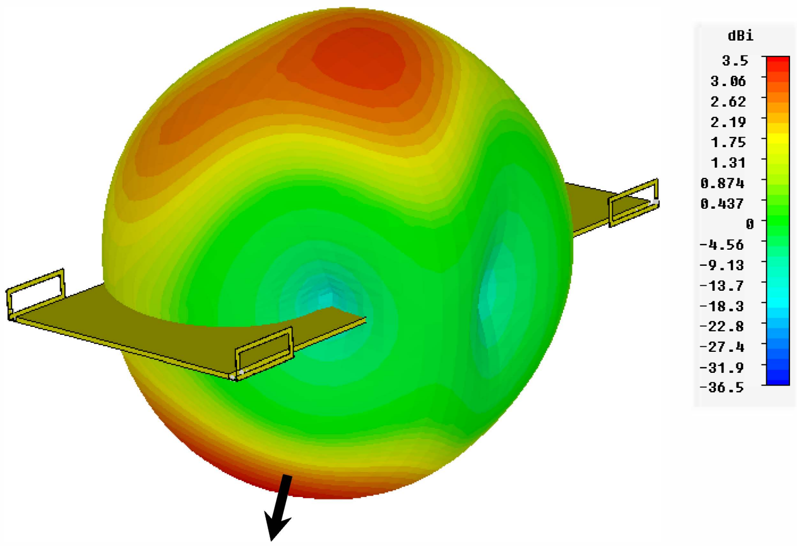

Fig. 3 The active element response of the first loop antenna at f=2000MHz (the arrow shows the direction for maximum radiation).

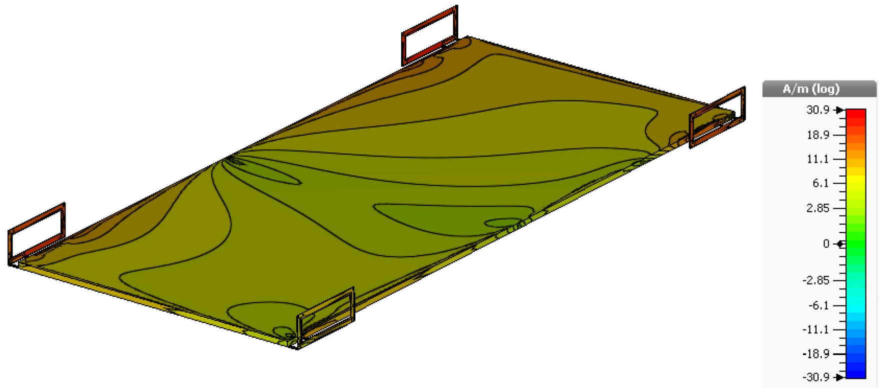

Fig. 4 A logarithmic contour map of the (active) surface currents of the first loop antenna at *f*=2000MHz.

Fig. 5 shows the spectra efficiency versus frequency for the proposed MIMO system (the four loop antennas) as well as the spectral efficiency of *three* and *four* ideal MIMO antennas. The figure clearly illustrates the multiplexing potential of the proposed MIMO system. For example, the proposed MIMO system can be said to have an information bandwidth of 420 MHz (2180MHz-2600MHz) which is the bandwidth over which the system provides a better MIMO performance than *three* ideal MIMO antennas. The MIMO performance of the antenna system is ranked 'good' in view that no decoupling or matching networks networks have been used.

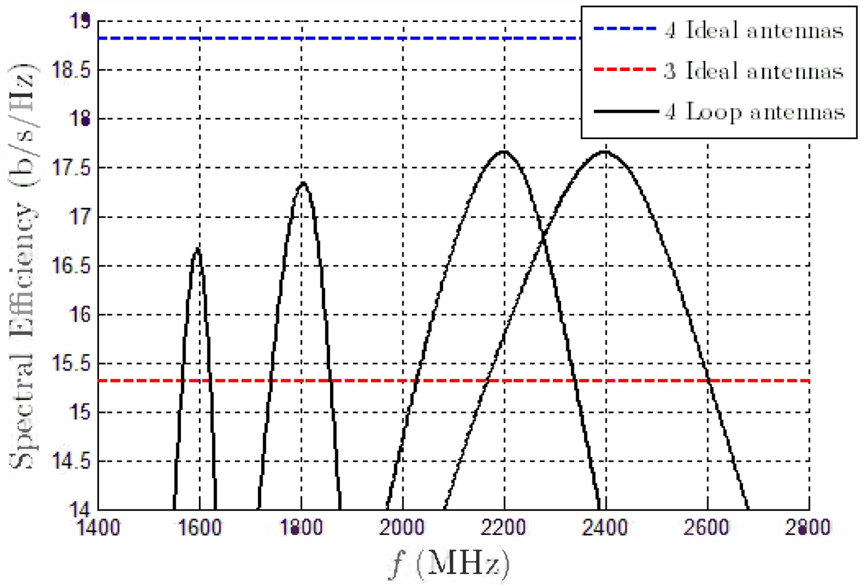

Fig. 5 The spectral efficiency of the proposed MIMO system at SNR=20 dB and at *f*=1600MHz, 1800MHz, 2200MHz and 2400 MHz.

SECTION IV. CONCLUSION

The paper introduced a novel MIMO architecture comprised of agile and efficient loop antennas. The spectral efficiency of the proposed system is compared to *three* and *four* ideal MIMO antennas showing a 'good' MIMO performance without using any decoupling or matching networks.

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