A Novel MIMO Antenna System for Small Handsets

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Abstract - In this paper we propose a novel compact MIMO antennas system for use in modern small handsets. The proposed system is based on two different types of antennas; a small loop and the MB antenna. The MB is an electrical antenna with characteristics similar to those of the conventional dipole, and the small loop antenna is a magnetic antenna. It is shown that using the proposed antennas, it is possible to create a compact MIMO system with small mutual coupling between the antennas, even when the distance between them is much smaller than λ/3. A new solution for the low radiation efficiency of small loop antennas at frequencies exceeding 470MHz is also proposed. The simulation results show that the mutual coupling between the MB and small loop antennas is low. This solution can be practically applied for use in compact mobile handsets using MIMO technology.

Keywords - MIMO, LTE, cellular handset, MB antenna, small loop antenna.

I. INTRODUCTION

Cellular phone systems have evolved rapidly over the past several decades [1]. Next generation wireless devices will require multiple antennas to coexist in a small area while maintaining their low coupling to support multipath channel de-correlation [2].

LTE is the next generation cellular phone technology that is intended to achieve a high peak data rate, low latency, and high radio efficiency in addition to low cost and sufficiently high mobility characteristics [1, 2]. One important characteristic of the LTE standard is the requirement for implementing MIMO architecture. The LTE standard refers to various frequency bands.

In this paper we consider the lowest LTE band, i.e. the 698-798MHz band. At these low frequencies, implementing multiple antennas in a handheld device poses significant challenge in terms of high antenna radiation efficiency, high isolation, and low mutual coupling between the antennas.

We present a novel MIMO antenna system for use in compact mobile handsets, when the maximal distance between the antennas is less than λ/3 and the operating frequency is about 730MHz. In order to reduce the mutual coupling between the antennas we propose to use antennas of different types- electrical and magnetic, where the former is MB antenna [3], and the latter is a small loop antenna.

In addition, we propose a solution for the low radiation efficiency of loop antennas at frequencies higher than 470MHz.

Simulation results show that it is possible to obtain a low mutual coupling between the antennas of the proposed MIMO system, even when the distance between them is much smaller than λ/3.

II. MB ANTENNA

The MB antenna is a modified version of the monopole antenna that allows for the radiating element to be mounted in parallel to the ground plane [3].

The main idea behind the MB antenna is to introduce a phase shift of 180° in the feed path of the radiating trace (relative to the ground) so that the two currents become in-phase and flow in the same direction. In this way, the fields emanating from the monopole and the ground plane will be in-phase and hence add up, resulting in high radiation efficiency similar to that of conventional monopole antennas [3].

The PCB of the handset, used for the electronic hardware of the cellular phone, may act as the substrate and ground plane for the antenna. That means, the radiating trace and the delay line, either one or both of them, can be printed on a certain area of the PCB.

III. SMALL LOOP ANTENNA

Loop antennas are usually classified into two categories; electrically small and electrically large. The small loop threshold is normally defined by the circumference of the loop, and is usually somewhere between one-tenth and one-third of a wavelength [5, 6, 7].

The planar shape of the small loop antenna makes it ideal for use as a compact antenna. However, like most other compact antennas, the electrically small loop suffers from poor radiation efficiency. Because of this poor radiation efficiency, its use has been traditionally limited to applications that are low-range, low data-rate communications or receive only systems [4, 5].

Figure 1 shows an equivalent circuit of a small loop antenna [8].

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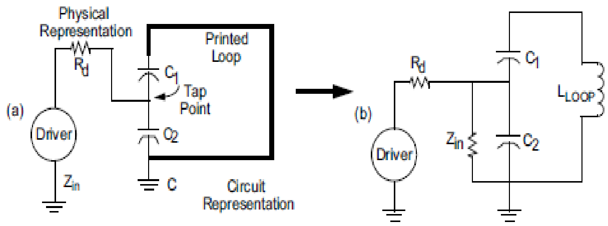

Fig. 1 – (a) Loop antenna physical implementation, (b) the standard loop antenna model.

In this circuit, C_1 tunes the resonant frequency, while C_2 independently tunes the antenna impedance. Typically $C_2 >> C_1$.

IV. SOLUTION FOR LOW RADIATION EFFICIENCY OF THE SMALL LOOP ANTENNA

In order to increase the resonant frequency of the loop, one must reduce the C_1 value. In practice, it is difficult to realize an antenna with capacitance smaller than 2-3pF. The reason for this is the parasitic capacitance, which begins to affect the performance of the antenna. Capacitance increasing can be obtained by reducing the antenna inductance, but it directly affects the antenna's effective area. As a result, the antenna will have a very poor radiation efficiency, and cannot be used as a transmit antenna.

The low radiation efficiency problem of a small loop antenna can be solved by an additional antenna, connected to the same source, as shown in Figure 2. In this structure, each antenna is still classified as a small loop, with circumference smaller than 0.1λ-0.33λ.

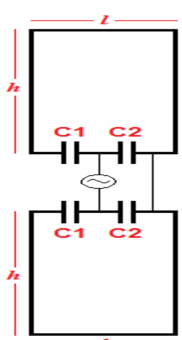

Fig. 2 –The proposed solution for enhancing the radiation efficiency.

V. ANTENNA DESIGN

In order to achieve a MIMO system of high spectral efficiency, the radiation efficiency for each antenna element in the array must be maximized while minimizing their far-field envelope correlation numbers [2]. These two key challenges along with fitting two low frequency 698-798MHz LTE MIMO antennas in a compact handset form factor are summarized by the following three factors:

1. Each antenna's radiation efficiency over the operating bandwidth (698-796MHz) must exceed 40%.
2. The isolation between two adjacent antennas of the MIMO system must be less than -10dB.
3. The physical size of each antenna must fit the small board size of a smart phone device (typically around 50x100mm).

VI. SIMULATION RESULTS

The design and simulation of the proposed MIMO antenna system was carried out using the CST Microwave Studio 2010. The MB and the small loop antennas were designed for central frequency 730MHz.

A. SMALL LOOP ANTENNA

Figures 3 and 4 show the far-field simulation results of the conventional and the enhanced small loop antennas, respectively. As it can be seen in these figures the total radiation efficiency of the enhanced small loop antenna is 95%, which is much higher compared to the conventional small loop's total efficiency of 12%. In addition to its higher efficiency, the enhanced small loop antenna has an E-field of 6.707V/m, much larger compared to that of the conventional small loop antenna, 2.295V/m.

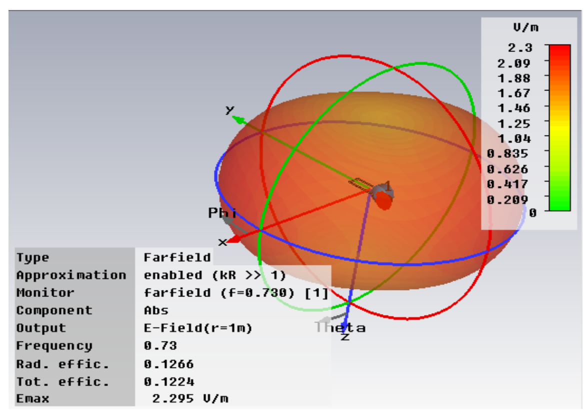

Fig. 3 – Simulation results for conventional small loop antenna.

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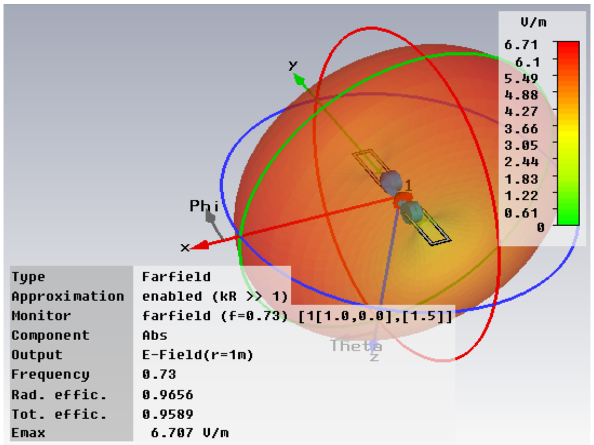

Fig. 4 – Simulation results for the proposed enhanced small loop antenna.

Figure 5 shows the simulation results of the S11 characteristics for the enhanced small loop antenna. This figure shows a S11 of -21.58dB at the resonance frequency (730MHz).

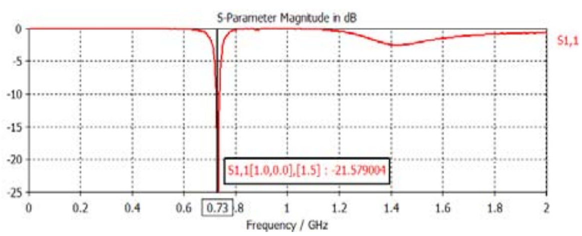

Fig. 5 – S11 simulation results of the enhanced small loop antenna.

B. MB ANTENNA

Simulation results of the far field performance of the MB antenna are shown in Figures 6, 7 and 8. In this simulations the 180˚ phase shift is implemented by a typical spiral, but in the real MB antenna it can be implemented by a compact electronic component, such as the CDM-Type LTCC Chip Delay Line.

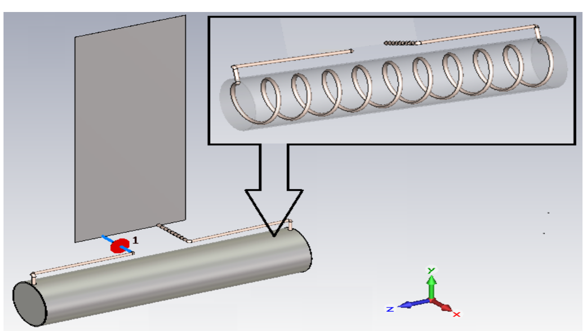

Fig. 6 – MB antenna with 180˚ phase shifter implemented by a typical spiral.

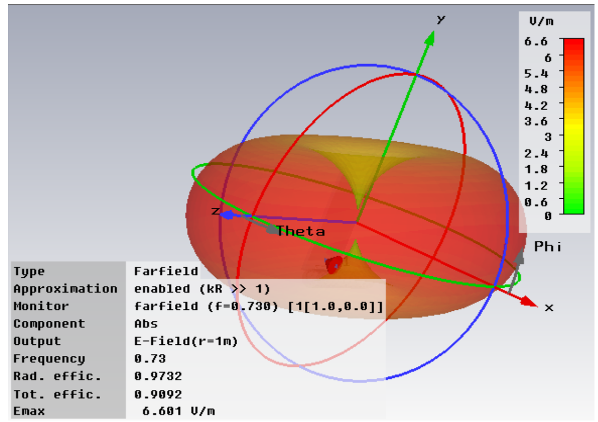

Fig. 7 – Simulation of the MB antenna at 730MHz.

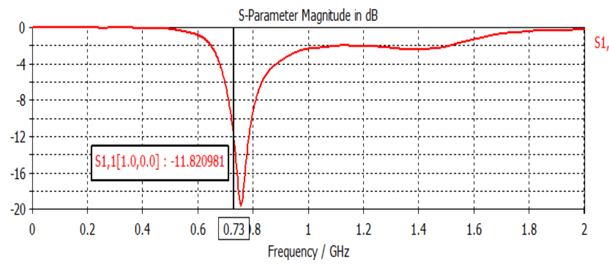

Fig. 8 – S11 simulation results of the MB antenna.

As it can be seen in Figures 13 and 14, total radiation efficiency of the MB antenna at 730MHz is 90%.

In addition to its higher efficiency, the MB antenna has an E-field of 6.707V/m and a good isolation level (-11.83dB).

C. SMALL LOOP AND MB ANTENNA SYSTEM

After simulating each antenna (small loop and MB) separately, now we proceed with simulations of the MIMO system based on the MB-loop antennas, as shown in Figure 9. The distance between the antennas can be much smaller than λ/3, for example 4mm. That is, the MIMO system is small enough to fit into the handset device.

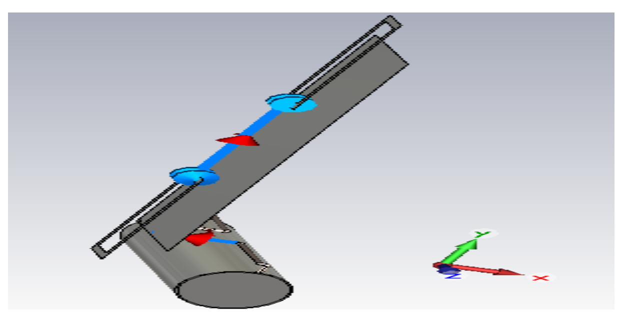

Fig. 9 – The MB- small loop antenna system. The distance between the antennas is 4mm.

From the far-field simulation results (Figures 10 and 11) of this MIMO system, it can be seen that the total radiation efficiency of the small loop and MB antenna is 41% and 60%, respectively. Also, the E-fields of the

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antennas are approximately the same, 4.991V/m for the small loop, and 5.529V/m for the MB.

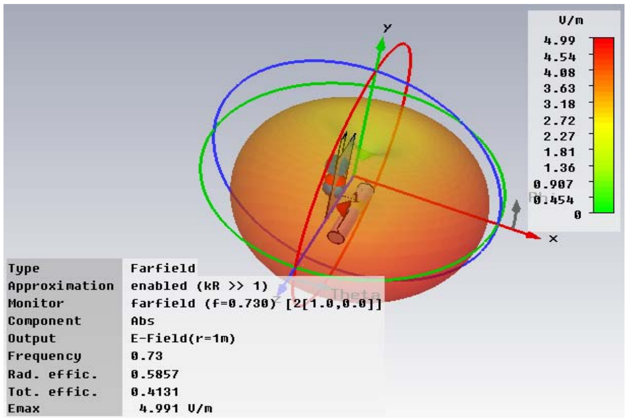

Fig. 10 – Simulation of the small loop antenna placed near the MB antenna.

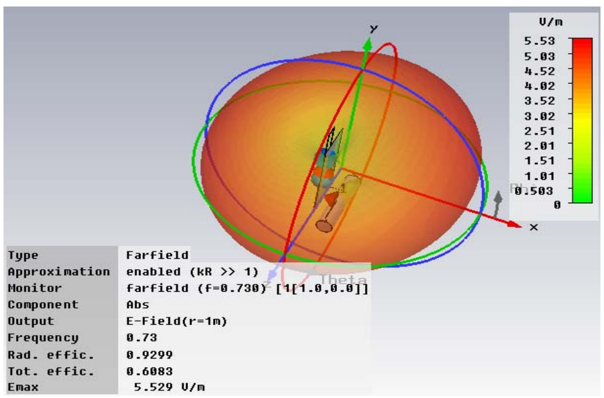

Fig. 11 – Simulation of the MB antenna placed near the small loop antenna.

Figure 12 shows the S11 parameter of the antennas. It can be seen that the isolation of each one of them is better than -10dB.

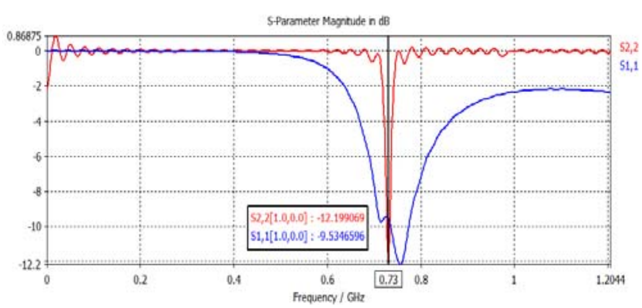

Fig. 12 – S11 simulation results of the small loop (red) and MB antenna (blue) placed near each other.

VII. CONCLUSIONS

In conclusion, we have investigated the feasibility of a novel compact MIMO antenna system for small mobile handsets. The proposed antenna system is based on small loop and MB antennas. Despite the close vicinity between the antennas (antennas spacing less than $\lambda/3$), the mutual coupling between them is low and does not degrade their performance significantly

The presented simulations were carried out at 730MHz as the operating frequency of the antennas. It is shown, that each antenna radiation efficiency is higher than 40%, and the isolation of each one is lower than -10dB. The dimensions of the investigated MIMO system are 4x40x98mm, thus it is small enough to fit into compact handset devices.

We've also proposed a solution for the low radiation efficiency of small loop antennas at frequencies higher than 470MHz. It is shown that it is possible to obtain high radiation efficiency by an additional loop antenna, connected to the same source.

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