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On Reduction of Mutual Coupling Effect, for Square Loop Antenna Arrays

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***Abstract*—The purpose of this paper is to present a unique approach for reducing the mutual coupling between two square loop antennas resonating at 26 GHz. In order to achieve this, parasitic elements are employed in the initial design resulting in a very compact Multiple-Input-Multiple-Output (MIMO) array with an overall size of 28.4 x 14 x 0.8 mm3 with a peak of mutual coupling at -49.19 dB.**

***Index Terms*— Mutual coupling, antenna arrays, Multiple-Input-Multiple-Output (MIMO), parasitic elements, square loop antennas.**

I. INTRODUCTION

In recent years, the immense pace and change of technology and its relevant services increased the demand of high data transmission capacity and therefore high data rate. Multiple-input-multiple-output (MIMO) technology (MIMO technology is referred by Foschini [1], Oestges et al. [2] and Sanchez et al. [3]), which is the evolution of the older mobile single-input-single-output (SISO) communication system, was implemented in order to achieve the aforementioned demands. A MIMO system has the ability to send and receive multiple independent channels simultaneously over the same radio channel, which is a satisfying solution in the problem of multipath propagation (isolation regarding multipath propagation is given by Wang et al. in [4]). But despite its benefits, the fact of using multiple antennas within densely proximity can cause mutual coupling between these radiating elements, due to the surface current excited from the ports, or surface waves. The effect of mutual coupling degrades significantly the MIMO system performance, and therefore it needs to be mitigated. This mitigation of mutual coupling can be achieved with several techniques using decoupling networks, such as complementary split ring resonators CSRRs (coupling suppression in microstrip arrays using metamaterial structure is proposed by Shafique et al. in [5], and isolation enhancement in antenna array with complementary split ring resonator is presented by Selvaraju et al. in [6], metamaterial structures and metasurfaces (metamaterial-based isolated MIMO antenna is given by Iqbal et al. in [7], and isolation using metamaterial superstrate is given by Mark et al. in [8]), and neutralisation lines (two-element compact antennas decoupled by a neutralisation line is given by Ou et al. in [9], and MIMO antenna with high isolation is given by Ibrahim et al. in [10]).

In this paper, a unique approach is presented by using parasitic elements inclusions in square loop antennas for isolation improvement of the MIMO system. It is worth to mention that the proposed design offers a significant mutual coupling reduction of -49.19 dB in the frequency of 26 GHz within the very compact size of 28.4 x 14 x 0.8 mm^3.

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II. MUTUAL COUPLING

Mutual coupling can be defined as the energy absorbed by a proximate antenna when another antenna is radiating. Mutual coupling affects drastically and changes antenna's characteristics, such as reflection coefficients, input impedance and radiation pattern. An empirical model of the mutual coupling was given in (mutual coupling equation is presented by Savy and Lesturgie in [11]), as

$$\text{MCmn} = \exp[-\frac{2dmn}{\lambda}(a + j\pi)],\ m \neq n \quad (1)$$

$$\text{MCmn} = 1 - \frac{1}{N}\sum_{m}\sum_{m\neq n} \text{MCmn} \quad (2)$$

where MCmn is the mutual coupling between the mth and the ith antenna elements, dmn is the distance between them, N is the number of array elements and α is a controlling parameter for the coupling level.
Practically, mutual coupling is dependable not only on the array configuration but on the excitations of the other elements, as well. Mutual coupling is calculated, in dB value, as an S-parameter between the mth and nth antenna elements, or as the isolation of -20log10(|Smn|) between them.

III. DESIGN CONCEPTS

The proposed antenna is printed on a Rogers 4003C substrate with ε_r = 3.4. Its size is very compact with dimensions of 14 x 14 x 0.8 mm^3. Figure 1(a) and 1(b) illustrate the top and bottom view of the proposed antenna, respectively, whereas its detailed parameters, after optimisation, are depicted in Table 1.
The design is based on two square loop antennas. The inner loop has a side of r_1= 6.6 mm, while the side of the outer loop is r_2=13.6 mm. As can be seen in Figure 1(a), two branches are added in the structure, as parasitic elements. The whole structure shows a symmetry which can benefit the antenna performance, regarding its radiation pattern. Furthermore, the ground plane is illustrated in Figure 1(b). Parametric study showed improved impedance matching, when slots with optimised dimensions of 0.4 mm x 0.2 mm are etched on it. Also the antenna feeding is achieved through a 2.92 mm K connector, which is suitable for frequencies up to 40 GHz.
A number of simulations were carried out using CST simulation program in order to find an optimum design for our proposed antenna, resulting in the above dimensions for our parameters. First of all, the radiation pattern is given in Figure 2, while the simulated S-parameter of the antenna is depicted in Figure 3, and we can notice that our antenna resonates at the frequency of 26.44 GHz with S_{11}=-20.31 dB. Another resonant frequency is also noticeable at 36.08 GHz.

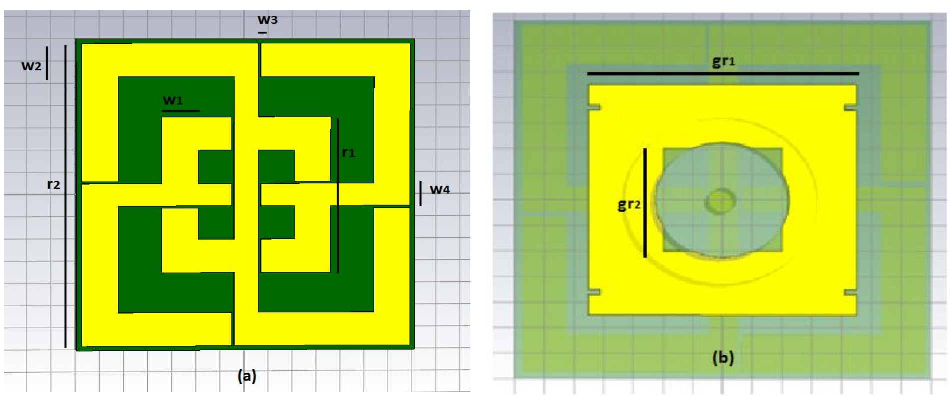

Figure 1. Design of the proposed antenna, (a) Top view, (b) Bottom view

TABLE I. DIMENSIONS OF OPTIMISED PARAMETERS

Parameter	Dimensions (mm)	Parameter	Dimensions (mm)
r_1	6.6	w_3	0.1
r_2	13.6	w_4	1
w_1	1.5	gr_1	9
w_2	1.5	gr_2	4

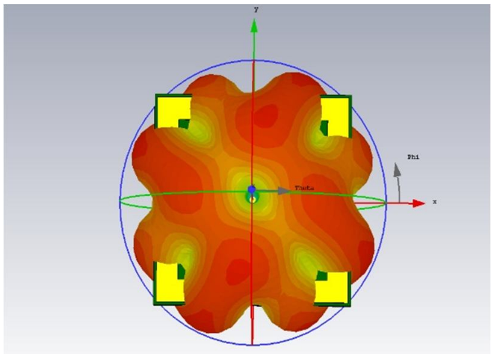

Figure 2. Radiation pattern of the single proposed antenna

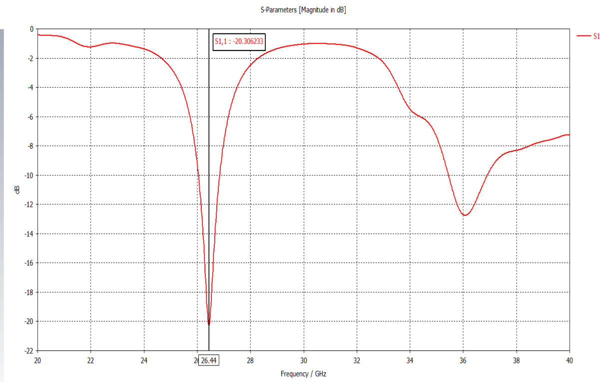

Figure 3. Simulated S-parameters for the single proposed antenna

IV. MIMO ANTENNA DESIGN

In order to investigate the isolation of this specific antenna design in a MIMO array, a second identical antenna element is placed next to the initial one, in the very close proximity of only 0.4 mm. The design itself of the proposed antenna has integrated the decoupling network, which in our case are the branches as parasitic elements, needing no extra decoupling network between the radiating elements, as we can see in Figure 4 (a) and 4 (b). The advantage of this technique is a very compact MIMO antenna array with dimensions 28.4 x 14 x 0.8 mm^3, with a radiation pattern that is depicted in Figure 5.

The simulated S-parameters of the MIMO arrays are presented in Figure 6. The resonance is slightly shifted to 24.32 GHz with the value of S_{21}= - 49.19 dB showing an excellent isolation. This is also verified by the surface current distribution of the proposed MIMO antenna which is illustrated in Fig. 7, where we can clearly see that the current is mainly concentrated in antenna 1, which is fed by port 1, accomplishing the favorable mutual coupling.

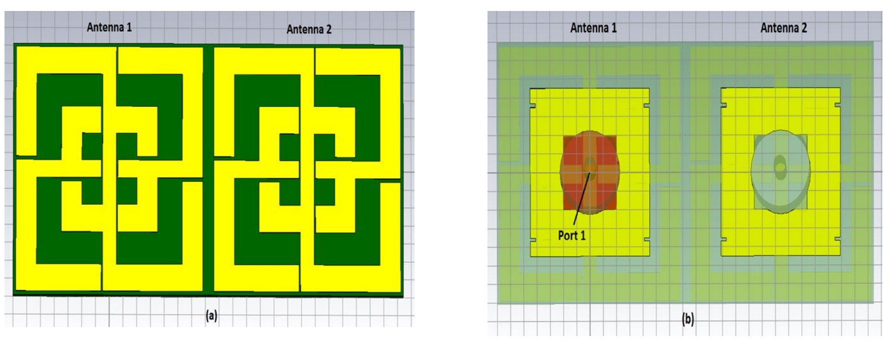

Figure 4. Configuration of the proposed MIMO antenna, (a) Top view, (b) Bottom view

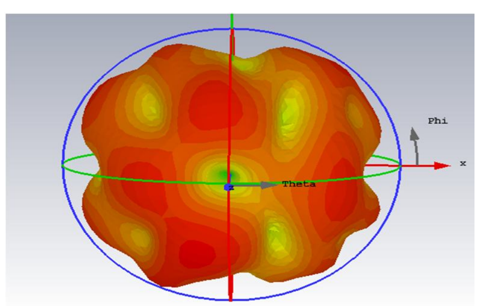

Figure 5. Radiation pattern of the MIMO antenna

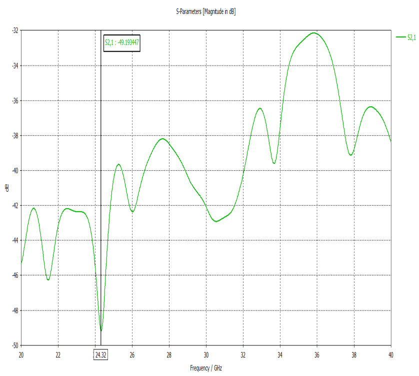

Figure 6. Simulated S-parameters of the proposed MIMO antenna

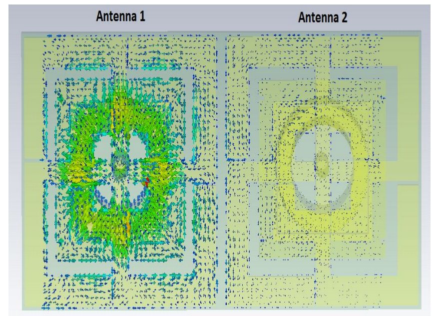

Figure 7. Surface current distribution of the proposed MIMO antenna

V. Conclusion

In this paper, a MIMO antenna with high isolation is proposed and studied. Due to its unique design, this specific structure can achieve high isolation throughout its operating frequency range, in an extremely close proximity between the radiating elements, without using any additional decoupling network. The aforementioned reasons make the proposed antenna an excellent candidate for 5th generation communication applications.

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References

[1] G. J. Foschini, “Layered space-time architecture for wireless communication in a fading environment when using multi-element antennas”, Bell Labs Tech. J., vol. 1, no. 2, pp.41-59 (1996).
[2] C. Oestges, M. Guillaud, and M. Debbah, “Multi-Polarized MIMO Communications: Channel Model, Mutual Information and Array Optimization”, IEEE Wireless Communications and Networking Conference, pp. 1057–1061 (2007).
[3] M. Sanchez-Fernandez, E. Rajo-Iglesias, O. Quevedo-Teruel, and M. L. Pablo-Gonzalez, “Spectral Efficiency in MIMO Systems Using Space and Pattern Diversities Under Compactness Constraints”, IEEE Transactions on Vehicular Technology, vol. 57, no. 3, pp. 1637–1645 (2008).
[4] X. Wang, Z. Feng, and K. M. Luk, “Pattern and Polarization Diversity Antenna with High Isolation for Portable Wireless Devices”, IEEE Antennas and Wireless Propagation Letters, vol. 8, pp. 209–211 (2009).
[5] M. F. Shafique, Z. Qamar, L. Riaz, R Saleem, and S. A. Khan, “Coupling Suppression in Densely Packed Microstrip Arrays Using Metamaterial Structure”, Microwave and Optical Technology Letters, 57(3), 759-763.
[6] R. Selvaraju, M. H. Jamaluddin, M. R. Kamarudin, J. Nasir, and M. H. Dahri, “Complementary Split Ring Resonator for Isolation Enhancement in 5G Communication Antenna Array”, Progress In Electromagnetics Research C, Vol. 83, 217-228 (2018).
[7] A. Iqbal, O. A. Saraereh, A. Bouazizi, and A. Basir, “Metamaterial-Based Highly Isolated MIMO Antenna for Portable Wireless Applications”, Electronics 2018, 7, 267, doi:10.3390/electronics7100267.
[8] R. Mark, N. Rajak, K. Mandal, and S. Das, “Isolation and Gain Enhancement Using Metamaterial Based Superstrate for MIMO Application”, Radioengineering, Vol. 28, No. 4, 689-695 (2019).
[9] Y. Ou, X. Cai, and K. Qian, “Two-Element Compact Antennas Decoupled with a Simple Neutralization Line”, Progress In Electromagnetics Research Letters, Vol. 65, 63–68 (2017).
[10] A. M. Ibrahim, I. M. Ibrahim, and N. A. Shairi, “Compact MIMO Antenna with High Isolation for 5G Smartphone Applications”, Journal of Engineering Science and Technology Review, 12 (6), (2019), 121 – 125, doi:10.25103/jestr.126.15 (2019).
[11] L. Savy and M. Lesturgie, “Coupling effects in MIMO phased array”, IEEE Radar Conference, pp. 1-6 (2016).