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Metamaterial-Based Highly Isolated MIMO Antenna for Portable Wireless Applications

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Abstract: In this paper, a metamaterial structure is presented to lower the mutual coupling between the closely spaced microstrip patch antenna elements. Two elements Multiple Input Multiple Output (MIMO) antenna is closely placed with each other at edge to edge separation 0f 0.13of wavelength isolation improvement of 9dB is achieved by keeping the metamaterial structure in between the MIMO elements. with the proposed structure, the isolation is achieved by around -24.5dB. Due to low ECC, high gain, low channel capacity loss and very low mutual coupling between elements, the proposed antenna is a good candidate for the MIMO applications. The proposed antenna is fabricated and tested.A reasonable agreement between stimulated and measured results is observed.
KEYWORDS:MIMO; patch antenna; s-parameters; mutual coupling

Currently, MIMO antenna has pulled a lot of attention due to its potential to enhance the capacity and reliability of the wireless communication system. Inspite of its benefits, mutual coupling is a big challenge that need to be overcome. Mutual coupling is typically undesirable since it affects the performance of the MIMO antenna and antenna array system. The interaction between the array elements/MIMO elements degrades the system performance by increasing mutual coupling, increasing envelop correlation coefficient, increasing channel capacity loss, decreasing diversity gain and distorting radiation pattern [1]. This problem may arise when antennas are placed nearby. MIMO antenna contains at least two spaced radiating elements in the aim of achieving good isolation between them. However, the available space is unsuitable for practical portable devices. In this respect, many techniques has been adopted to lower the mutual coupling between MIMO elements. In [2], by introducing F-shaped stubs in between the two radiators, the mutual coupling between the MIMO elements was decreased. Very reduced mutual coupling between the MIMO antennas is accomplished by utilizing neutralization line in [3]. Other approaches have been proposed in the literature to augment isolation between the radiators. Among the adopted approaches we can state the introduction of a meandered line resonator in between the radiating elements of the MIMO antenna [4], the use of different elements for polarization diversity [5], the use of electromagnetic bandgap structures [6–8], U-shaped radiator [9], defective ground structure [10]. Coupling between eye shaped MIMO antenna is reduced by utilizing extended T-shaped stub in between the two resonators [11]. In [12], Artificial Magnetic Conductor (AMC) is used below the V-shaped patches to achieve high gain, lower size and greater isolation. In [13], a novel shaped decoupling structure is inserted between the inverted F shaped radiating elements to lower the coupling. It is in this context that the presented paper can be set with the aim of providing the design, prototyping, and measurement of a small size MIMO antenna. The latter contains two patches fed by a 3 mm wider microstrip lines. In the proposed design, the isolation is achieved by employing a series of metamaterial unit cells between the two antennas. The proposed antenna has a very low mutual coupling ($|S_{21}/S_{12}| < -20$ dB). A comparison between simulated and measured results was inspected in the presented paper for the prototype validation. The proposed MIMO antenna is well-suited for the many wireless applications due to its low ECC, high diversity gain, high peak gain, low channel capacity loss and most of all, the very high isolation.

Antenna Characterization The antenna model geometry is shown in Figure 1. The proposed antenna is printed on a low cost FR-4 substrate having a loss tangent and relative permittivity of 0.02 and 4.4, respectively. The proposed design has two patches excited using a 3 mm wider microstrip lines with

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a 50 Ω characteristic impedance. Edge to edge separation between the radiating elements of the MIMO antenna is kept as 0.135λ0 (7 mm).

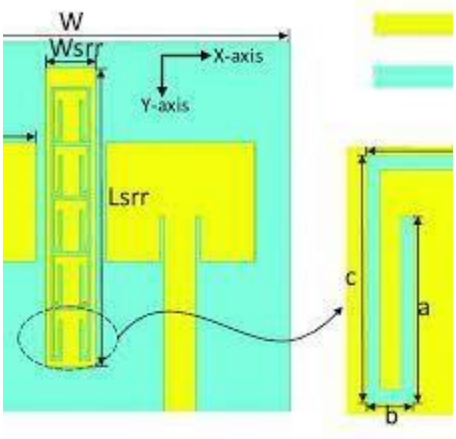

Figure 1. Top view of the proposed Multiple Input Multiple Output (MIMO) Antenna

Par am eters	Dime nsion (mm)	Par am eters	Dime nsion (mm)	Par am eters	Dime nsion (mm)
L	37	W	44	Ws	3
a	4	b	1.1	Lss r	30
W p	15	c	5.3	d	4
Lp	13	Wssr	5	-	-

Table 1. Different Parameters and values of the antenna

The iterative design process of the proposed MIMO antenna that includes three steps is presented in Figure 2. Firstly, a single radiating element patch antenna with microstrip feed is designed and optimized to operate efficiently. Width and length of the optimized antenna were chosen as 15 mm and 13 mm respectively. Secondly, another patch antenna is designed near to the first one as shown in Figure 2 (step 2). The unit cell of the proposed metamaterial structure is shown in Figure 3b is used as decoupling structure. The unit cells are used between the antennas for a good isolation between the two antenna elements (step 3).

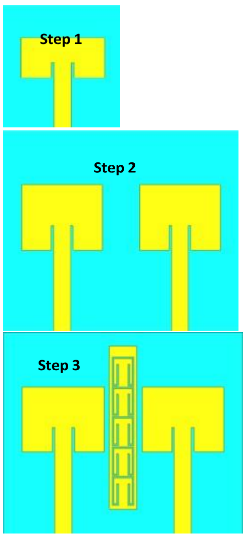

Figure 2. Steps for the design of proposed MIMO antenna.

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Figure 3a presents the simulated reflection coefficient (S_{11}) and the transmission coefficient (S_{21}) of the proposed MIMO antenna with and without using metamaterial. It is clear from the Figure 3a that S_{11} of the MIMO antenna with and without metamaterial is almost same. The resonant frequency of MIMO antenna without metamaterial is observed at 5.7 GHz while the resonant frequency of the proposed MIMO antenna using metamaterial is observed at 5.8 GHz. It is worth highlighting that very low mutual coupling is constantly preferable for efficient MIMO antennas. Figure 3a shows that antenna without having metamaterial has poor isolation in the whole operating band. A very high isolation is achieved by employing metamaterial between the radiating elements.

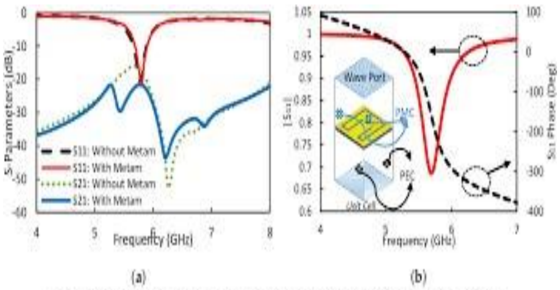

Figure 3. (a) Simulated S-parameter with and without metamaterial, (b) Unit Cell.

The isolation behavior can also be explained through the analysis of the antenna's surface current distribution at the frequency of interest. The current distribution at 5.8 GHz in both cases (with and without using metamaterial) is presented in Figure 4. Upon excitation of port 1 of two port antenna, a high mutual coupling is obtained between the monopoles, because the current is strongly coupled to another radiator. It is obvious from the Figure 4 that mutual coupling is diminished by the insertion of metamaterial unit cells between the two radiating elements. Thus, a very low mutual coupling is achieved.

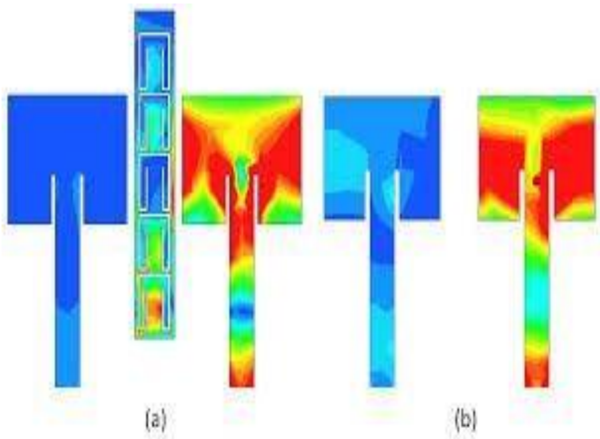

Figure 4. (**a**) Surface current distribution of MIMO antenna with metamaterial, (**b**) Surface current distribution without metamaterial.

To give a profound comprehension of the global configuration, the equivalent circuit model is provided in Figure 5. Three resonating structures are cascaded together. The patches of the proposed antenna are modeled by a resonator structure with Lp1, Cp1, Lp2, and Cp2. The decoupling structure of metamaterial is modeled as LcR, CcR, and RcR. Cc and Lc are coupling structures and help in the coupling of the two patches, which is always undesirable in MIMO antenna. The *S*21 of the proposed antenna is compared with the circuit model in Figure 6.

Table 2 presents the optimized parameters of the proposed circuit model.

The performances of the MIMO antenna are displayed in Table 3 comparing them to other antennas used in the literature.

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Figure 5. Equivalent Circuit Model of the proposed MIMO antenna.

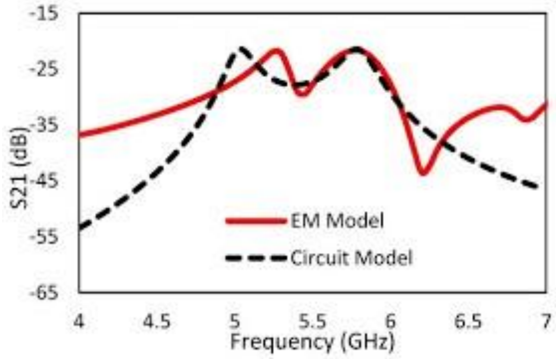


Figure 6. *S*21 comparison of EM model and circuit model of the proposed MIMO antenna.

R1 (Ω)	Cc (pF)	Lc (nH)	Lp1/Lp2 (nH	Cp1/Cp2 (pF	CcR (pF)	LcR (nH)	RcR (Ω)
466.75	1.2	2.1	0.83	1.31	0.01	0.64	0.01

Table 2. Optimized parameters of the circuit model.

Results and Discussions

To validate the proposed design, an antenna prototype is fabricated and measured. The antenna's simulations were conducted using ANSYS High-Frequency Structure Simulator (HFSS) software. Figure 7 shows the antenna as fabricated in conformity with the aforementioned parameters. The antenna's S-parameters were measured using an Agilent Network Analyzer (VNA). The measured S-parameters values are shown in Figure 7 for a comparison with the simulated results. Comparing the simulated and the measured results, we can notice that there is a slight frequency shift. This may be due to several factors which include the SMA connector loss, cable loss, limitation of milling machine as well as radiating boundaries during the measurement process. The measured frequency band.

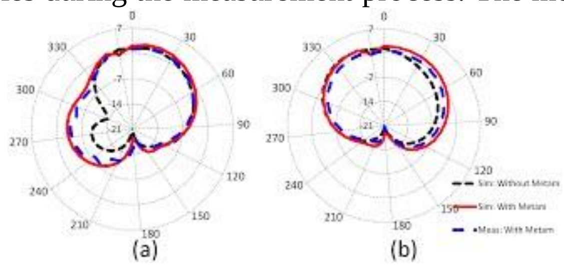
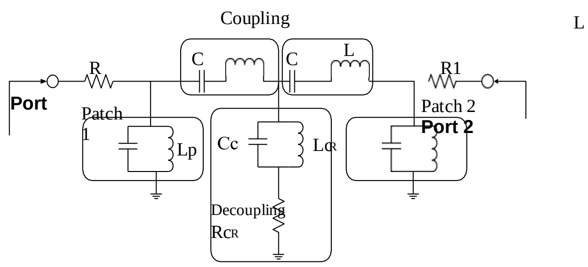


Figure 8. Measured and simulated radiation pattern(with and without metamaterial) at 5.8 GHz (**a**) Phi = 0^0; (**b**) Phi = 90^0



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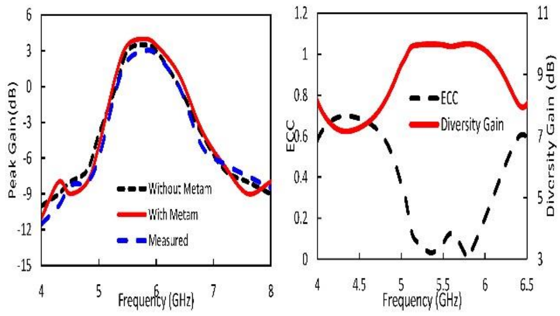

(a) (b)

Conclusions

Throughout the scope of the presented paper, the design, prototyping, and measurement relating to a MIMO antenna, useful for MIMO applications, have been thoroughly depicted. The proposed antenna, operating at 5.8 GHz, has a simple structure with a size of 44 × 37 mm^2. By incorporating metamaterial structure between the radiating patches of the MIMO antenna, a high isolation between the MIMO elements is achieved. The proposed antenna has good performances mainly in terms of Envelop Correlation Coefficient (*ECC* <0.1), Diversity gain (*DG* > 9 dB) and channel loss capacity (*CCL* < 0.05) which make it as a potential candidate for MIMO system.

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