Split Rectangular Loop Resonator Inspired MIMO Monopoles for GSM/LTE/WLAN Applications

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Abstract —A circular form multiple-input-multiple-output (MIMO) microstrip antenna systems operating in Global system for mobile (GSM), Long Term Evolution (LTE) and Wireless Local Area Network (WLAN) bands (1.2 to 2.7GHz) is presented. The system is comprised of two antennas placed parallel to each other. Initially, a dual band (1.2 and 2GHz) antenna is designed by etching a two rectangular slits on top of the two radiating elements. In order to have a wideband/multiband operations and enhance the isolation between the two antennas a split rectangular loop resonators and a long stub is placed in the space between the two antenna elements. More than 20dB isolation between the array elements is attained at the resonant frequency for the configurations. A sample was constructed to verify the design concept and to validate the simulated results

Index Terms—Rectangular loop resonator, Multiple-Input-Multiple-Output (MIMO), mutual coupling, diversity gain, refractive index

I. Introduction

The recent development of wireless communication systems has encouraged the use of high data rates, high quality, increased capacity and high reliability for different system or applications. Multiple-Input-Multiple-Output (MIMO) systems have been proved to enhance wireless system performance in environment where interference, multipath fading tends to degrade the signal quality and reduce effective data rate [1]-[3]. The use of MIMO antenna is known as diversity. Inter-element spacing can cause strong mutual coupling between the antennas, this greater spacing between the elements increases the size of the antenna, it can also influence an impairment of the performance of the antenna in terms of its radiation pattern and the input impedance, therefore, improvement of isolation between two radiating elements is of great significance. Various innovative methods have been investigated in recent literature for suppression of mutual coupling and improvement of the isolation between the antennas, including Electromagnetic Band Gap (EBG) structures [4]–[5], creating defects in the ground plane known as defected ground structures (DGS) [6]–[8], neutralization line [9] – [10] and parasitic elements [11].

Metamaterial has attracted much interest over the last few years, they introduce interesting possibilities for the improvement of antenna performance [12] – [13], they are mixture materials that is carefully combine to provide properties that are not otherwise achieve with ordinary materials. They can also exhibit negative permittivity or permeability, refractive index of less than one with sub wavelength dimension [14]. Researchers have demonstrated metamaterials to enhance mutual coupling of array antennas which include split ring resonators (SRRs) [15] – [16], a frequency selective surface metamaterial (FSS) [17] and capacitive loaded loop structures (CLLs) [18]. Although, in most of this structures the better controllability of the gap capacitance will not be unveil.

A. Related Works

Motivated by the enhancement in mutual coupling of array antennas, considerable research effort has been invested to analyze the prospects of introducing metamaterial as a means of reducing mutual coupling [12] – [13]. The use of Split Ring Resonators (SRRs) has been researched in [15] in which, the SRR structure was added between the two elements to improve the isolation characteristics of higher than 15dB over the band of interest. Metamaterial inspired resonators was analyzed in [16] where a complementary two-turn split resonators (CSR) unit cells are introduced in the ground between the two antenna elements. The measured isolation is nearly -32dB in the lower band and -18dB in the upper band. The work in [17] use a frequency selective surface metamaterial structure which was also inserted between two radiating elements and the mutual coupling between the two antenna was reduced by about 7.2dB. In [18] the use of Capacitive Loaded Loop Structures (CLLs) was reported in which the isolation levels between adjacent radiating elements are improved by 7.15dB.

B. Contribution

In this article, a split rectangular loop resonator-inspired MIMO antenna system with high port isolation that covers GSM (1.5 and 1.8GHz), LTE (2.3-2.4GHz) and WLAN (2.45GHz) is presented. The performance of

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the MIMO antenna is strongly influenced by the introduction of six split rectangular loop resonators and long stub between the two antenna elements. The design and analysis was carried out using computer simulation software version 2017. The simulated results are confirmed by the experimental measurements. The system framework is presented in section II, while in section III the design of a unit cell split rectangular loop resonator will be analyzed, results and discussion is presented in section IV to validate the proposed analysis and finally, followed by the conclusion in section V.

II. Design and Configuration of the Antenna

The patch array antenna geometry is shown in Fig. 1, which is designed on FR4 substrate $\varepsilon_r = 4.3$, $\tan\delta = 0.025$ with a thickness of 1.6mm. The designed MIMO system is formed by two printed circular patches with two slits etched on top separated by a distance 20mm (top view) and a ground plane with a gap at each center of the plane (bottom view). Four rows of split rectangular loop resonator together with one long stub are placed between the two antenna element. Each rows contains two elements which is quite enough to provide a perfect inductance. Table I is the list of parameters of the proposed MIMO antenna system

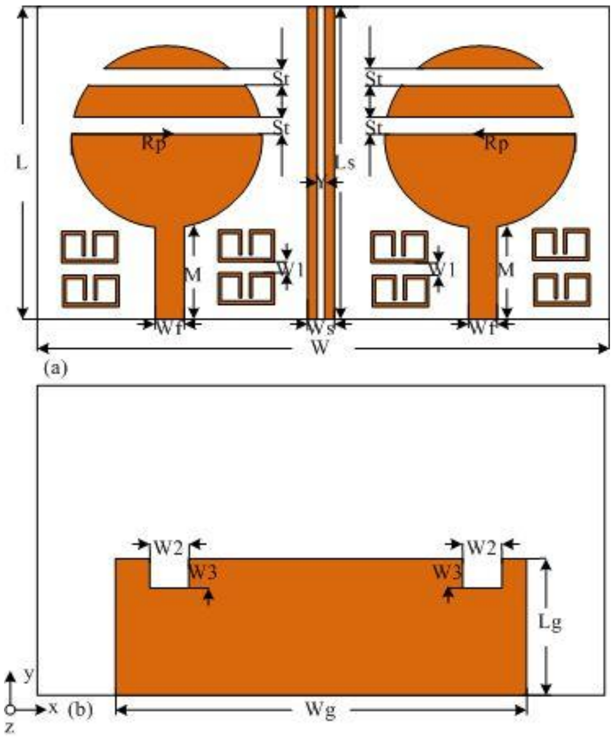


Fig. 1. Antenna geometry; top view (a), bottom view (b).

TABLE I: OPTIMIZED ANTENNA PARAMETERS

Parameter	Value (mm)	Parameter	Value (mm)
L	70	W3	1.4
Lg	17	Wg	86
Ls	70	Wf	3.5
M	20	Ws	2.6
W	120	Rp	16
W1	0.4	St	2
W2	3.5	Y	0.6

Each of the antenna element of MIMO system is fed with 50Ω microstrip feed line to have perfect impedance matching.

III. Rectangular Loop Resonator Design

A unit cell is etched on a 1.6mm thick FR4 epoxy substrate with a dielectric constant = 4.3 at a frequency from 1 – 5GHz. Fig. 2a shows a two dimensional view of the unit cell with dimension A = 13mm, B = 9.5mm, C = 9.75mm, D = 5.5mm, E = 0.85mm, G = 0.7mm, S = 3.65mm, and W = 0.5mm. Fig. 2b shows a unit cell dimension of 13x9.5x1.6 on xyz coordinate, the z-axis will be our negative magnetic permeability for the boundary condition while the x-axis is a two opening where the port will be inserted which propagate wave and the y-axis will be perfectly electric.

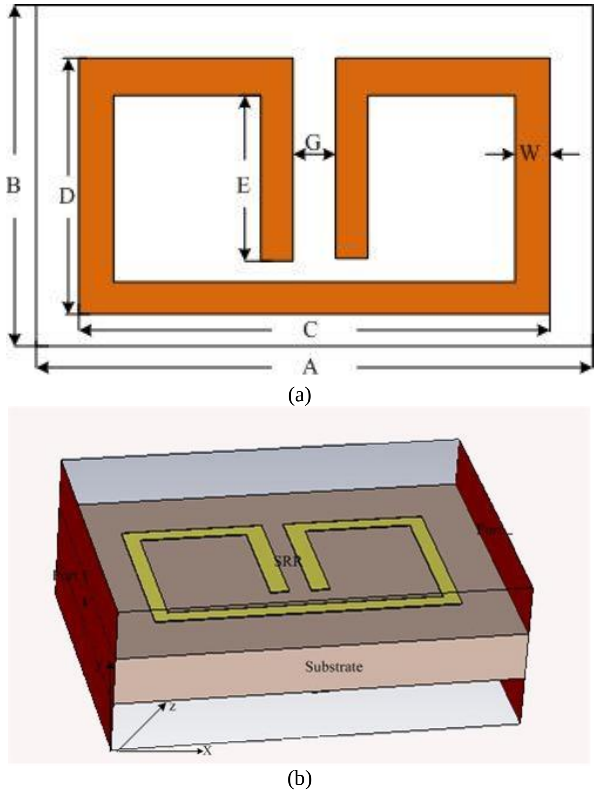
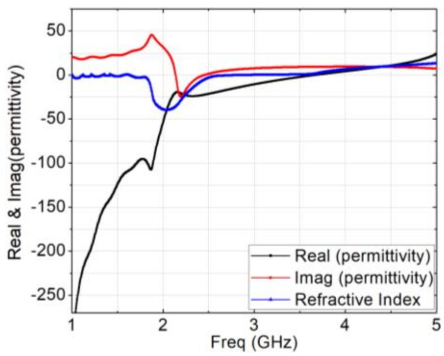
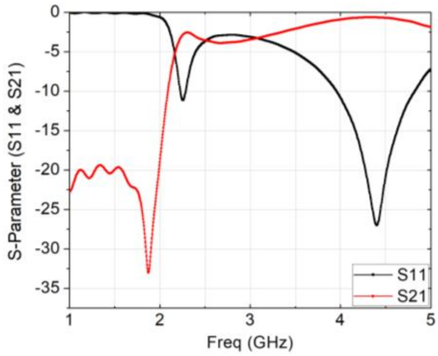


Fig. 2. Metamaterial unit cell; 2D view (a), 3D view (b).



(a)



(b)

Fig. 3. Metamaterial permeability real & imaginary part; (a), Metamaterial S11 & S21; (b).

The electric or magnetic permittivity retrieval is set using the s-parameter retrieval technique. Fig. 3a shows a negative value of permittivity $(\varepsilon)$and the refractive index which is less than one from 1-5GHz. Fig. 3b is the simulated return loss of rectangular loop resonator unit cell.

IV. Experimental Results and Discussion

The remaining dimensions of the rectangular loop resonator are fixed except G which is the gap capacitance that controlled by the length of E, the value of E was chosen to be 0.85mm because the resonant frequency changes correspondingly from 1 - 3GHz.The S11 and the isolation of the proposed MIMO antenna system before the introduction of rectangular loop resonator structure is shown in Fig. 4. The impedance matching characteristics and the mutual coupling of the proposed antenna is enhanced when the metamaterial structure is introduced. The antenna is fabricated as shown in Fig. 5 and measured using PNA-X network analyzer N5244A, demonstrating good agreement, covering the frequency band of GSM (1.5GHz and 1.8GHz), LTE (2.3 – 2.4GHz) and WLAN (2.45GHz). The simulated and measured S11 as well as the voltage standing wave ratio of the proposed antenna is shown in Fig. 6 and 7, with an impedance bandwidth of (1.2 – 2.7GHz) at 10dB return loss.

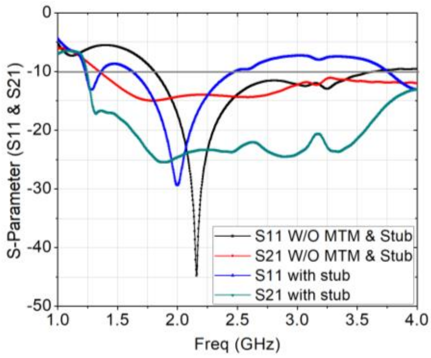
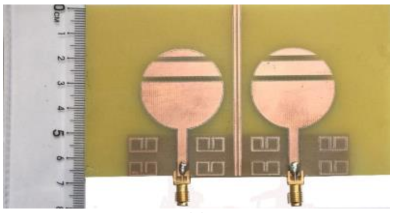
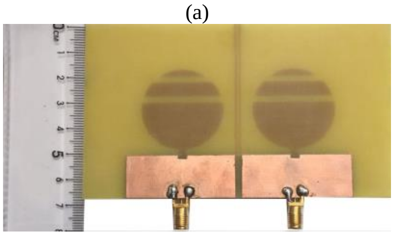


Fig. 4. S-Parameter of the proposed antenna before the introduction of metamaterial structure.

There is a little difference in both the measured and simulated S-parameter of the proposed MIMO antenna which accredited to construction tolerances.

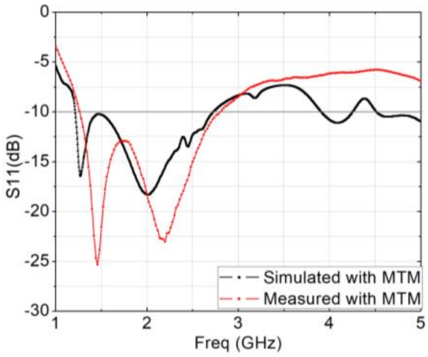


(a)

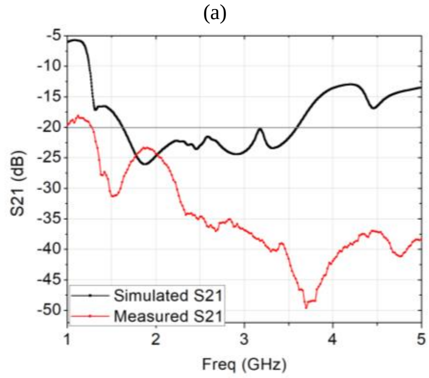


(b)

Fig. 5. Fabricated antenna; top view (a), bottom view (b).



(a)



(b)

Fig. 6. Measured and simulated; S11 (a), S21 (b).

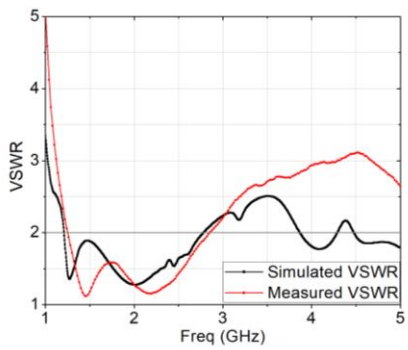


Fig. 7. Measured and simulated VSWR.

A. *Rediation Characteristics*

Simulated radiation pattern for four resonant frequencies when one element was excited has been demonstrated in Fig. 8. One can see that nearly omnidirectional pattern has been achieved at all four frequencies. The 3D radiation pattern together with their respective gains at 1.5GHz, 1.8GHz, 2.3GHz and 2.45GHz is shown in Fig. 9, maximum gain over the entire wideband/multiband frequency is shown in Fig. 10.

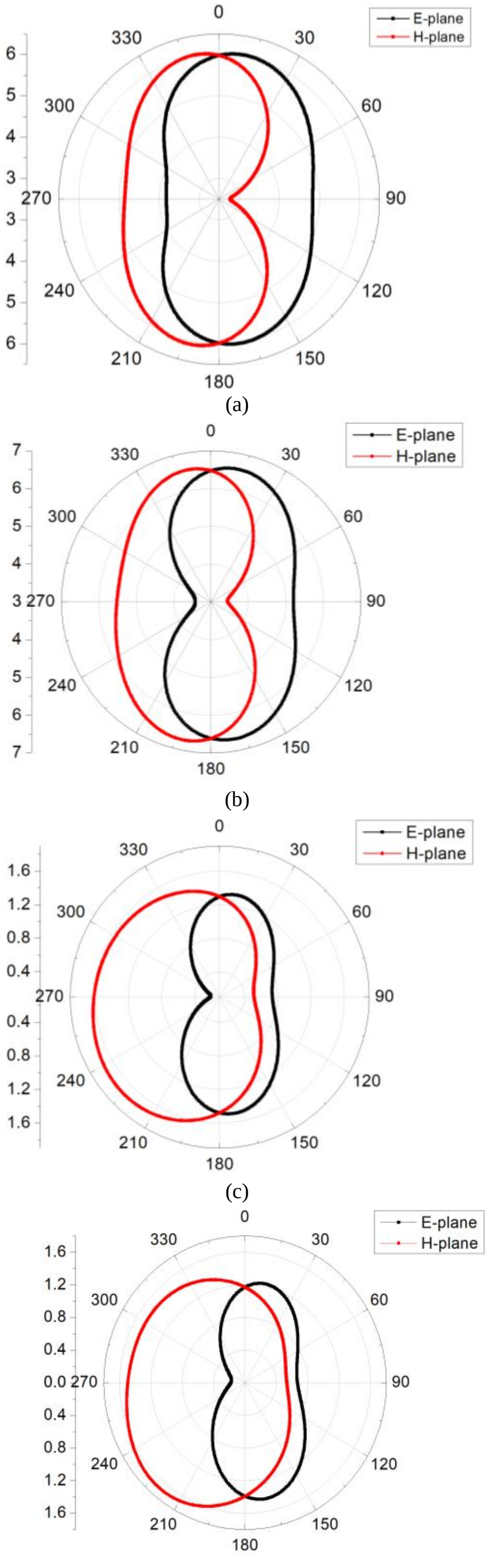


Fig. 8. Radiation pattern; 1.5GHz (a), 1.8GHz (b), 2.3GHz (c), 2.45GHz (d).

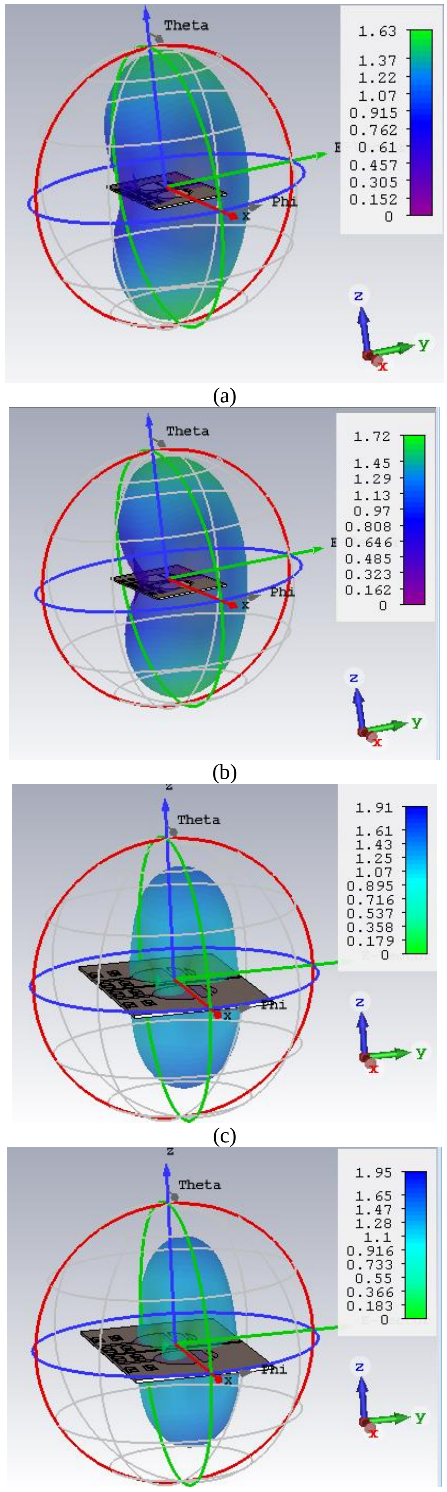


Fig. 9. Simulated 3D radiation pattern; 1.5GHz (a), 1.8GHz (b), 2.3GHz (c), 2.45GHz (d).

B. *Current Distribution*

To gain insight in to the antenna design, the simulated surface current distribution at four frequencies of 1.5GHz, 1.8GHz, 2.3GHz and 2.45GHz is illustrated in Fig. 11. It can be observed that when port 1 is excited, there is a little flow of current on the second element in (a) and (d). When port 2 is excited there is also a little flow of current on the second element in (b) and (c). Split rectangular loop resonator and stubs divert surface current, forcing them to concentrate on one side of the patch.

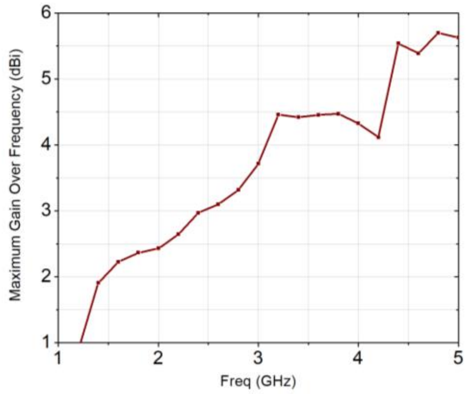


Fig. 10. Maximum gain over frequency.

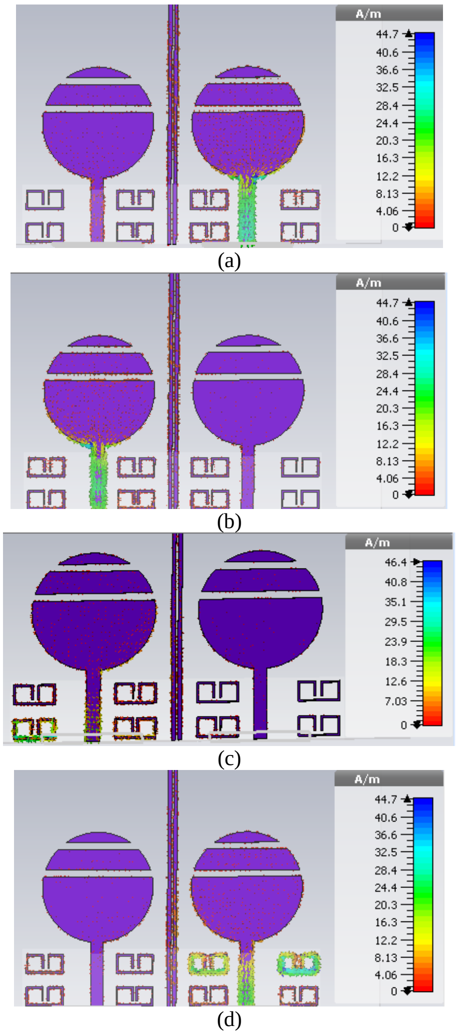


Fig. 11. Current distribution; 1.5GHz (a), 1.8GHz (b), 2.3GHz (c), 2.45GHz (d).

C. Diversity Performance

For MIMO antenna characterization, the envelope correlation coefficient (ECC) and diversity gain (DG) are important parameters to quantify signal interference between channels [19] – [20]. In principle, ECC is a measure of crosstalk among MIMO channels approximately expressed in terms of the S-parameter of the MIMO systems [19]:

$$ECC = \frac{\left|S^*_{11}S_{12} + S^*_{21}S_{22}\right|^2}{\left(1-\left(\left|S_{11}\right|^2 + \left|S_{21}\right|^2\right)\right)\left(1-\left(\left|S_{22}\right|^2 + \left|S_{12}\right|^2\right)\right)} \quad (1)$$

where S11, S12, S21 and S22 is the S-parameter of the 2x2 MIMO array. The diversity gain of MIMO antennas can be calculated from the ECC as

$$DG = 10\sqrt{1-ECC^2} \quad (2)$$

In practical MIMO applications, ECC should be less than 0.3 and DG tends to be 10dB. Fig 12 is the ECC and diversity gain over the entire operating bands. It is noteworthy that the ECC of the proposed MIMO array is exceptionally small, less than 0.005 over the entire operating frequency range, yielding a superior diversity gain of nearly 10dB. Table II is the summary of a comparison between the proposed MIMO array with other antenna presented in the literature in terms of Bandwidth, size and isolation.

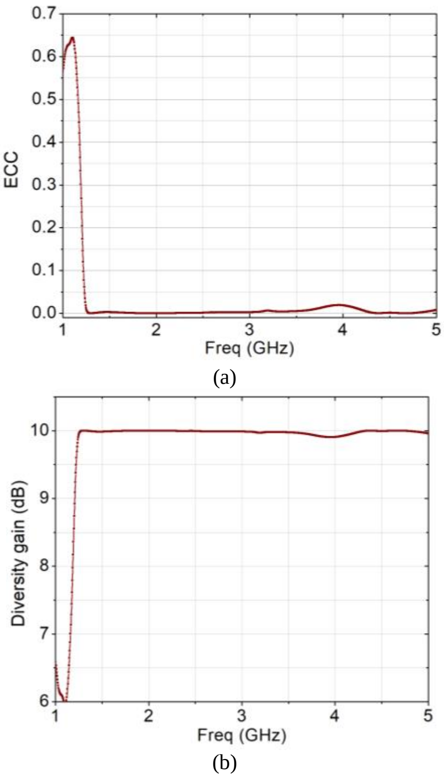


Fig. 12. Envelope correlation coefficient (a), Diversity gain (b).

TABLE II: COMPARISON OF THE ANTENNA WITH PREVIOUS WORK

Preference	B/W (GHz)	Size (mm)	Isolation (dB)
[1]	3.08-10.98	30x30x1.6	≤ -20
[11]	1.8 - 4.0	50x100x1.6	≤ -13
[12]	2.3 - 2.4	45x80x1.2	≤ -16
[17]	2.72 - 12	38.2x26.6x0.4	≤ -15
[20]	2.8 - 11	58x58x1.524	≤ -14
This work	1.2 – 2.7	120x70x1.6	≤ -20

V. CONCLUSIONS

Metamaterial inspired design of MIMO antenna for GSM, LTE and WLAN operation is presented in this letter. The antenna proves a wider impedance bandwidth of 76.9% that covered the wideband/multiband frequencies (1.2 – 2.7GHz). The rectangular loop resonator structure helped in keeping the isolation of the proposed antenna below -20db. This makes the proposed antenna array suitable and can be utilized in wireless system applications.

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