Two element folded meander line MIMO antenna for Wireless applications

Sanjay Chouhan and Leeladhar Malviya

Abstract— **Compact antenna, appropriate gain, high efficiency, wide bandwidth, minimum envelope correlation coefficient (ECC), large total active reflection coefficient (TARC) bandwidth, and low specific absorption rate (SAR) are certain conditions set on the present/future generations of wireless communication antennas with the lowest cost of implementation. A compact low profile folded MIMO antenna has been designed using CST tool to cover application at 5.2 GHz. The reported folded MIMO antenna has bandwidth of 600 MHz (5.0-5.6 GHz) and has fractional bandwidth of 11.32 % along with the compact size of 37.5 × 17.0 mm^2. The reported MIMO antenna has ECC of < 10^{-2}. The proposed folded MIMO antenna resonates at 5.2 GHz and has return loss of -44.0 dB. The inter-port isolation in antenna ports is > 11.50 dB in the defined frequency band. The response of TARC shows > 580 MHz of bandwidth with pair of excitation angles at antenna ports. The gain of antenna is > 3.0 dBi in the operating band. The reported radiating geometry makes the design very compact. To check the radiation effect on human body in different positions, the SAR is evaluated for indoor environment.**

***Index Terms*— MIMO, ECC, TARC, WLAN, SAR.**

Original Research Paper
DOI: 10.7251/ELS1923011C

I. Introduction

VARIETIES of wireless communicating devices are presently available in market and the continuous research work is also carried out in different parts of the world for fastest communication to reduce the delay and loss of signaling using multiple input multiple output (MIMO) antennas. Various MIMO radiators are offered for WLAN applications. Previously, an antenna system based on single-input-single-output (SISO) was used in wireless communication, which had low data/bit rate, low capacity and average quality of transmission and reception of signals. MIMO antenna has high data rate, high channel capacity, medium latency, and good connection reliability over the slow/fast fading [1]. Various MIMO antenna factor like, gain efficiency, dimension of antenna and radiation distribution are decided according to the length of antenna [2]. A defected ground structure and metamaterial (MTM) plays important role in MIMO antenna design system. It limits the objectionable port coupling effects and surface wave [3].

Sometimes multi-layered substrate like Polydimethylesiloxane (PDMS) used to produce the effects like the defected ground and MTM in MIMO antenna system [4]. Some square shaped antenna produced >15 dB of isolation without supporting decoupling element [5]. A virtually touched element like parasitic element (PE) provides frequency shifts by inductive effect and produces in-band mutual coupling from 5.8 GHz frequency band to some undesired bands [6].

Various types of meander line antenna have been designed in last few years. Sometimes miniaturization is achieved in travelling wave tube using meander line structures, and it increases the bandwidth about 53.5% [7]. The ultra wideband (UWB) application is fulfilled by monopole antenna using two-dimensional meander line structures [8]. The low profile meander line with defected ground structure (DGS) was used to miniaturize the design structure by 23.8% [9]. Some other meander line based antenna with meandered feeding lines [10], MIMO antenna with dual band meander line [11], and meander line frequency selective surface [12] etc., are used with folding for compactness. Some UWB [13], circularly polarized [14], offset planner antenna [15], and terahertz antenna [16] are used for isolation enhancement.

The paper covers 0.66λ x 0.3λ mm^2 substrate size for 2-element folded MIMO antenna for wireless application. The proposed antenna has return loss of -44.0 dB at resonant. The good isolation between ports is achieved in reported frequency band. The compactness in design is achieved by partial ground.

The initial part of paper covers proposed antenna geometry, then simulation and measured results are discussed. The detailed MIMO antenna parameters with SAR are presented and analyzed in further sections.

II. Meander Line Mimo Antenna Design

The folded MIMO antenna design parameters are optimized using CST version 15.0. The FR-4 dielectric substrate has thickness, permittivity, and loss tangent of 1.524 mm, 4.4, and 0.025 respectively. The proposed antenna takes complete size of 37.5 x 17.0 mm^2. The compactness in the design is achieved by overlapping of meander lines and small ground. The limited ground plane is considered for proposed antenna to contribute in size reduction and return loss. For the same frequency of operation full ground takes large size as compared to presented antenna ground. The optimized parameters are specified in Table 1. The schematic and fabricated folded MIMO antenna views are shown in Fig. 1 and Fig. 2.

Manuscript received 19 October 2018. Received in revised form 11 January and 7 February 2019. Accepted for publication 8 February 2019.

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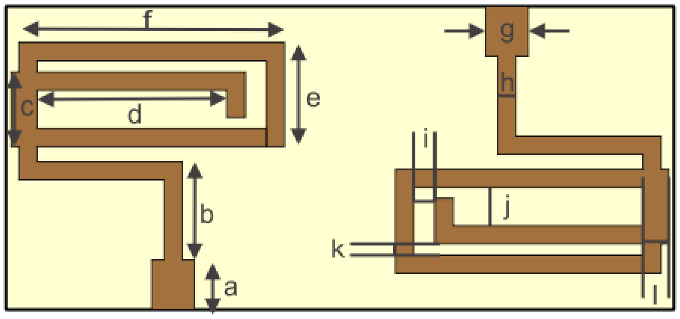

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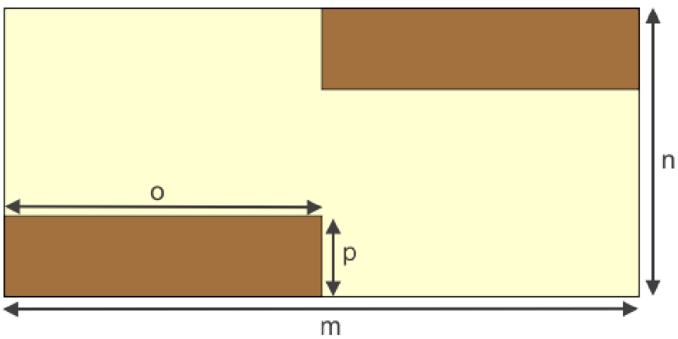

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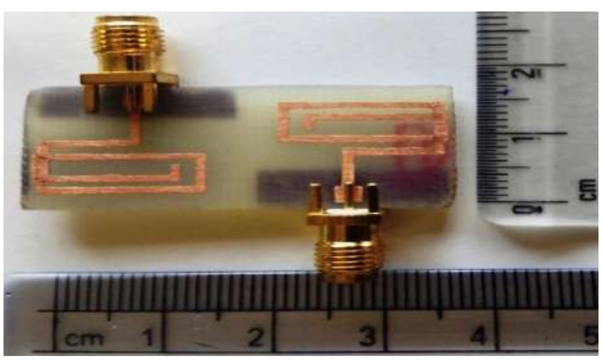
Fig. 1. Schematic views (a) Folded MIMO Front (b) Folded MIMO Back

Table 1. Optimized Design Parameters

Design parameter	a	b	c	d	e	f	g	h
Size (mm)	2.8	5.5	4.2	10.6	5.8	14.8	2.4	1.0
Design parameter	i	j	k	l	m	n	o	p
Size (mm)	1.1	2.1	0.6	1.5	37.5	17	18.7	4.8



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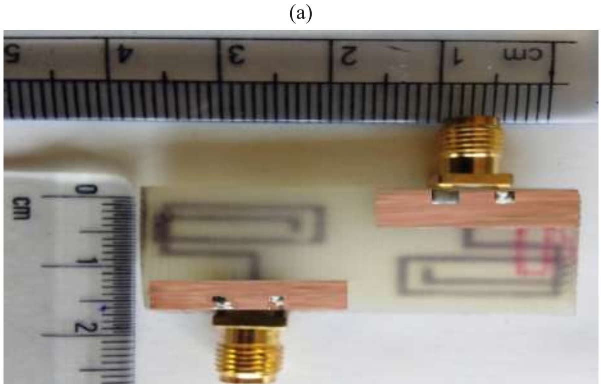


(b)

Fig. 2. Fabricated views of proposed design (a) Front, (b) Back

III. Simulated And Measured Results

The proposed two port antenna with microstrip feed is 180^0 upturned to control the field and surface current accountable for mutual coupling. As the entire antenna elements are equal in size and identical, therefore only S_{11}, and S_{12} parameters are considered. The proposed folded MIMO antenna with limited antenna ground has band of 5.0-5.6 GHz. The total bandwidth is 600 MHz. The designed folded antenna has return loss and inter-port isolation of -44.0 dB and 11.9 dB at 5.2 GHz frequency. In the working band, the inter-port isolation is > 11.5 dB. The results are presented in Fig. 3 for simulated and measured S-parameters. The fabricated folded antenna resonates at 5.27 GHz. The minor mismatch in results is due to coupling in port or may be due to fabrication errors.

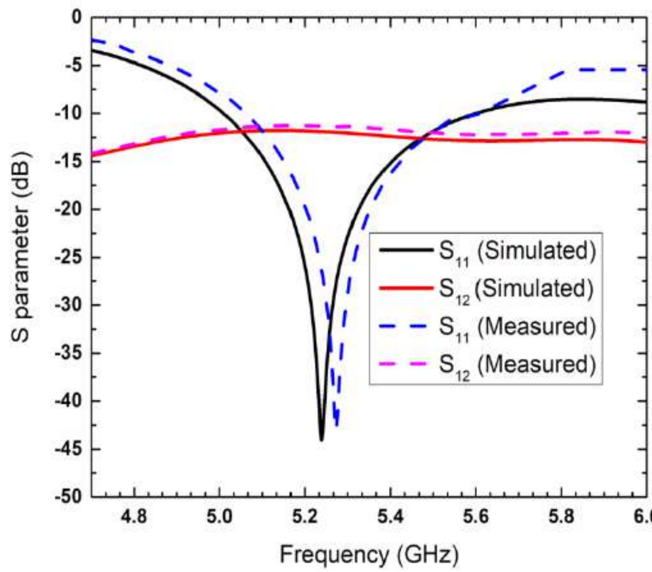


Fig. 3. S-parameters of proposed MIMO antenna.

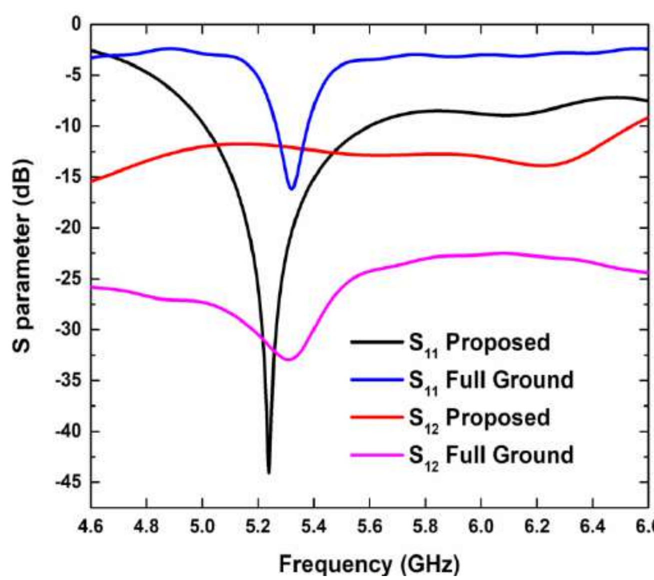
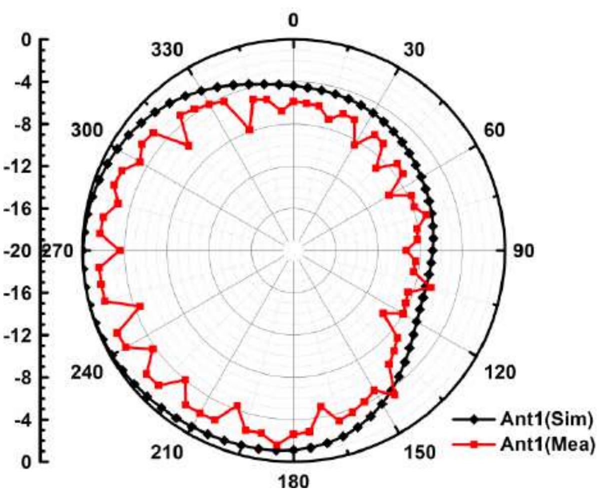


Fig. 4. S-parameter with partial ground and full ground.

In Fig. 4, results of proposed MIMO S-parameters are compared with full ground. The full ground shows the band of 5.26-5.38 GHz which has bandwidth of 114 MHz and resonates at 5.3 GHz. It is therefore evident that the full ground has very less bandwidth and very less return loss.

The E-field and H-field patterns are discussed to show the radiation behavior of the designed folded antenna. Fig. 5 (a) shows the radiation field (E-field for $\phi=0^0$) for port 1 at 5.2 GHz resonant frequency. The other port has the same field pattern. The results show that 259^0 and 12.8 dBV/m main lobe direction and magnitude respectively at port 1. The 3 dB angular width of proposed MIMO antenna at port 1 is 184^0. Similarly, Fig. 5 (b) gives the radiation field (H-field for $\phi=90^0$) at 5.2 GHz frequency. The H-field magnitude of MIMO antenna at port 1 is 33.9 dBA/m with direction of 261^0.



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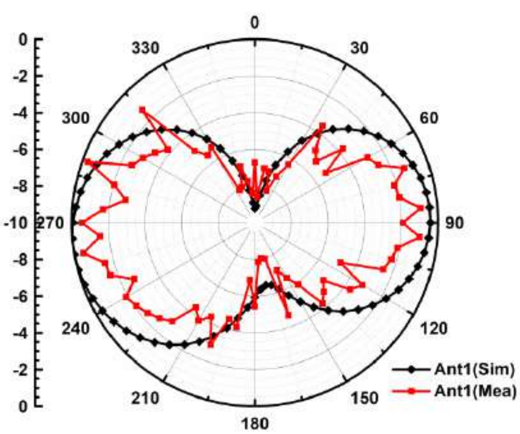


(b)

Fig. 5. Far-field (a) E-Field (b) H-Field (Sim: Simulated, and Mea: Measured)

The distribution of current sharing on the patch surfaces reveal the idea of isolation. The lower mutual coupling indicates higher isolation among antenna ports. For the proper analysis of surface current, port 1 is energized and port 2 is terminated with 50 ohm load. The current distribution in patch is shown in Fig. 6. The effect of surface current is very less at other ports on the corresponding antenna arms. The port 2 has equal current values due to same antenna geometry. The distribution of surface current at port 1 is in the range of 0 to 97.4 Ampere/meter.

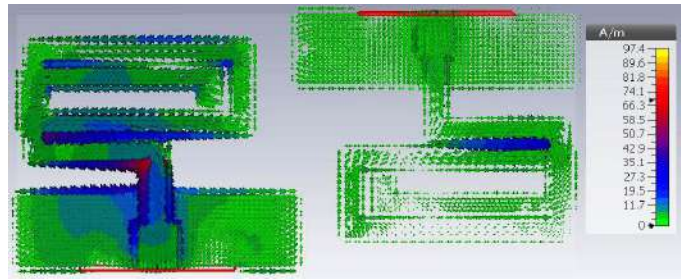


Fig. 6. Surface current distribution (SCD) of MIMO antenna.

The gain of antenna is typically the power ratio produced by the antenna from a far-field source on the antenna's beam axis to the power produced by a hypothetical lossless isotropic antenna. Generally this ratio is expressed in decibels, and these units are referred to as "decibels-isotropic" (dBi). The measurement of gain of the proposed design is obtained in an anechoic chamber using substitution method. The proposed antenna is used as a receiver and pyramidal horn antenna as transmitter. The measured value of gain is > 3 dBi in presented band, and is 4.0 dBi at resonant. The simulated-measured results of gain are presented in Fig. 7. The radiation efficiency and total efficiency are > 80 % and > 65 % in proposed operating band.

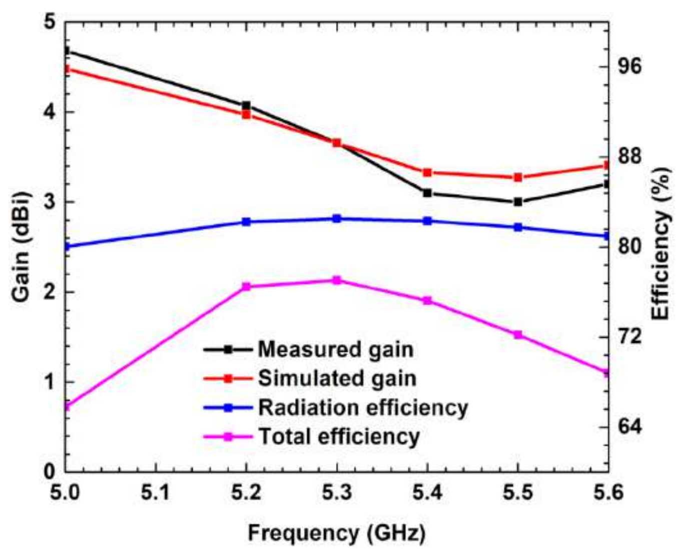


Fig. 7. Proposed MIMO antenna gain and efficiency.

The overall mutual coupling of MIMO antenna is evaluated by ECC. The ECC is calculated using all S-parameter coefficients, and it shows the correlation between ports 1and 2. The individual isolation coefficient is unable to give all the diversity information, thus ECC plays a very important role for the same. It is calculated by using (1) [17]:

$$|\rho_e(i,j,N)| = \frac{|\sum_{n=1}^{N} S_{i,n}^{*} S_{n,j}|}{\sqrt{|\prod_{k(=i,j)}[1-\sum_{n=1}^{N} S_{i,n}^{*} S_{n,k}]|}} \quad (1)$$

where N is the number of antennas and i, j are the antenna elements.

The two port correlation (ρ_{e12}) can be calculated by equation (2):

$$\rho_{e12} = \frac{\left|S_{11}^{*}S_{12}+S_{21}^{*}S_{22}\right|^2}{\left(1-|S_{11}|^2-|S_{21}|^2\right)\left(1-|S_{22}|^2-|S_{12}|^2\right)} \tag{2}$$

where S_{11}, S_{22} are return loss coefficients and S_{12}, S_{21} is isolation coefficients.

The simulated-measured results of ECC are presented in Fig. 8. The simulated result of ECC for the ports (1, 2) is given as 0.01 at 5.2 GHz. The ECC result shows minute difference between simulated and measured one. Therefore, the proposed folded antenna is appropriate for WLAN application in the given frequency band. The simulated and measured ECCs in the whole frequency band are < 10^{-2}.

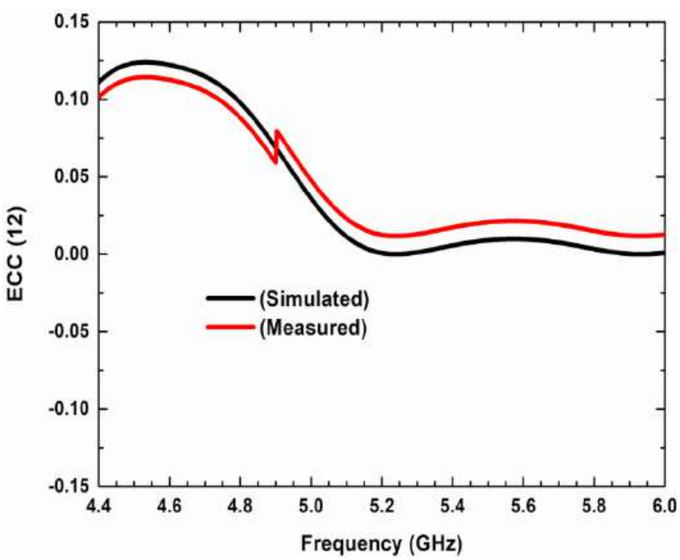


Fig. 8. Simulated-measured results of ECC.

The frequency response description of MIMO antenna with the random signals and their excitation angles can be analyzed using the parameter TARC. The TARC is defined in terms of square root of total reflected power to total incident power. The TARC is expressed in (3) and (4) [18]:

$$\Gamma = \sqrt{\frac{Available\ Power - Radiated\ Power}{Available\ power}} \tag{3}$$

$$\Gamma_a^t = \frac{\sqrt{\sum_{i=1}^{N}|b_i|^2}}{\sqrt{\sum_{i=1}^{N}|a_i|^2}} \tag{4}$$

where [b]=[S][a], [b], [s] and [a] is the scattering vector, scattering matrix, and excitation vector respectively.

The TARC value of 1 represents total reflection in the defined frequency band, while 0 for no reflection. Fig. 9 shows the TARC results for the two port MIMO antenna for various excitation angles. The TARC bandwidth is 580 MHz. From the TARC graph, the best condition for the excitation angle combination of 45^0, 45^0 is obtained.

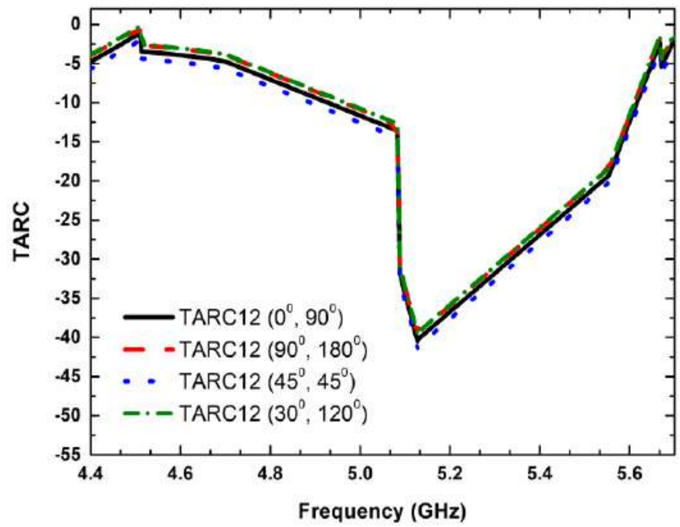


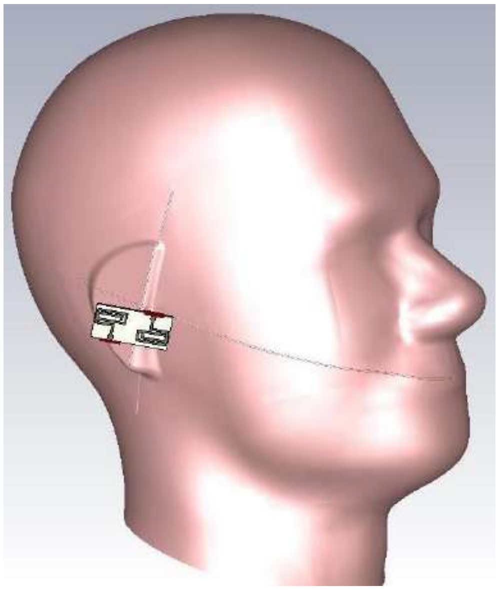
Fig. 9. Proposed MIMO antenna TARC.

The effect of radiation on the human body is analyzed using SAR. The SAR is a sign of electromagnetic energy absorbed by the biological tissues, mainly in the human head/body/palm. Fig. 10 presents the CST simulated SAR results by the IEEE/ICE 62704-1 averaging method. The results of SAR are calculated by placing antenna 140 mm away from human head. The maximum SAR for 1g is 0.283 W/Kg and SAR for 10 g is 0.144 W/Kg near the human head and ear. The obtained SAR values of proposed antenna satisfy the standard safety limit over 1 g of tissue.

The SAR performance near palm and fingers are calculated in Fig. 11. The maximum SAR values near palm and fingers are 0.264 W/Kg and 0.137 W/Kg for 1g and 10g tissues respectively. The SAR calculation near body parts are given in Table 2.

Table 2. SAR Calculation Near Human Body Parts

SAR near	SAR	
	At 5.2 GHz	
	1 (g) W/Kg	10 (g) W/Kg
Head	0.12	0.07
Ear	0.28	0.14
Palm	0.13	0.10
Finger	0.26	0.13
Wrist	0.08	0.07



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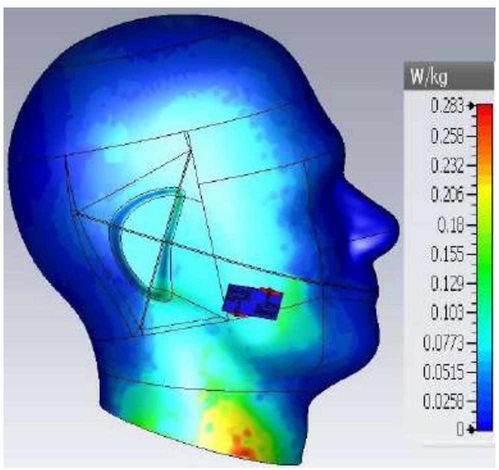

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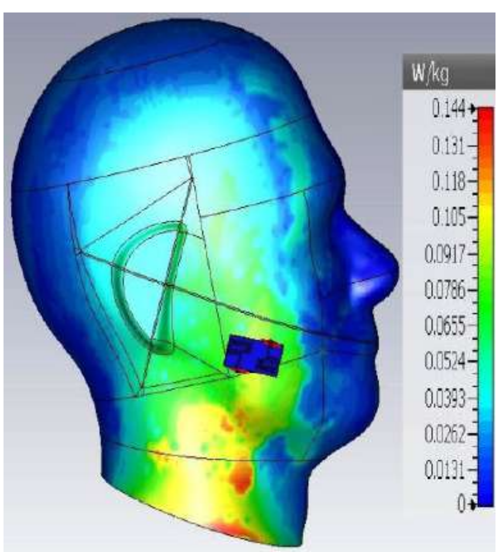

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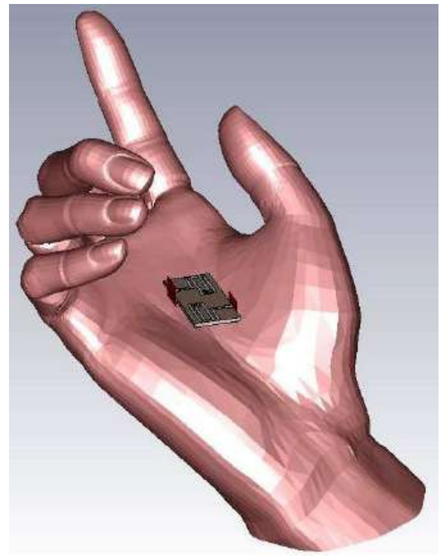
Fig. 10. SAR Results near human head at 5.2 GHz (a) antenna positioned near head (b) SAR 1 g (c) SAR 10 g.



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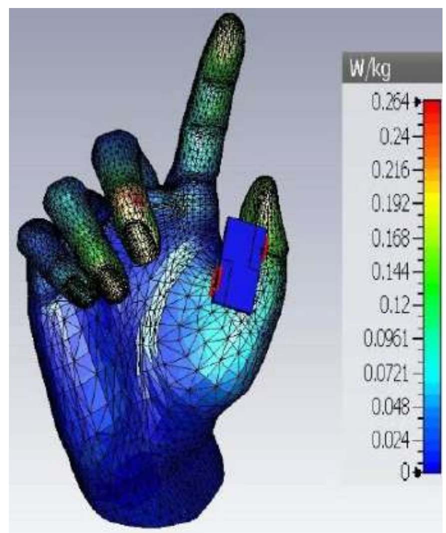

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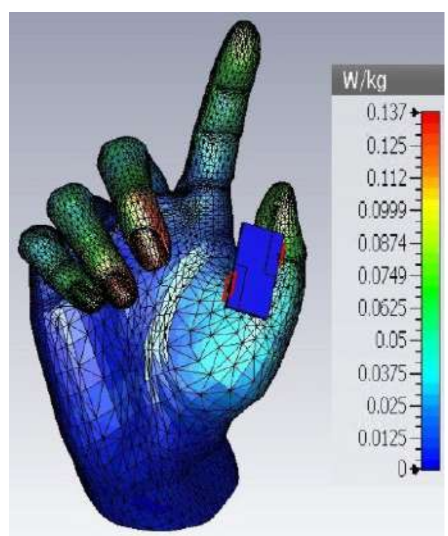

(c)

Fig. 11. SAR Results near palm and fingers (a) antenna positioned near palm (b) SAR 1 g near palm (c) SAR 10 g near palm.

Similarly, the input power and radiated power are given in Fig. 12. The MIMO antenna is simulated for 0.5 watt of power and radiates in the range of 0.34-0.38 watt, which shows good performance. The 0.16 [W] of power is absorbed, returned and lost.

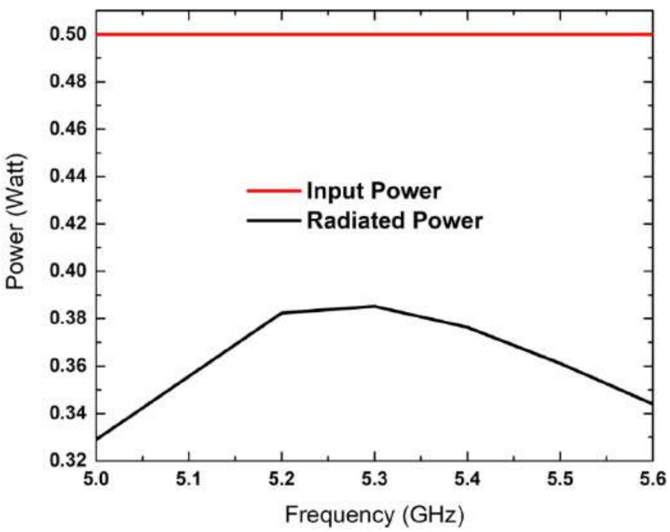

Fig. 12. Proposed MIMO antenna power distribution.

Some existing designs are compared with the proposed folded MIMO antenna, given in Table 3. The given references except [3] have bigger sizes in comparison with proposed MIMO antenna. The size reduction factor has also been given and compared. The radiation effect on human body also gives results below the safety limits.

IV. Conclusion

The folded antenna elements placed in opposite direction to each other produces good isolation. Good radiation performance is achieved with low mutual coupling. The surface current distribution of MIMO antenna showed the low correlation among the antenna elements. The proposed folded MIMO structure showed the suitability for IEEE 802.11 for 5.2 GHz. Also, it has very low value of SAR for different modes of operation/handling and is as per the standard set by the ITU. The presented results in the paper showed meaningful research contribution for wireless technology.

Table 3. Comparison of Proposed Work with earlier Reported Works

S. No.	Ref.	f_H(GHz)	f_L(GHz)	Size (mm^2)	Size reduction (%)	Isolation (dB)	ECC	Gain (dBi)	TARC (GHz)	SAR (W/Kg)
1.	[3]	5.75	5.84	0.5 λ x 0.45 λ	-4	55	-	-3.0	-	-
2.	[4]	5.7	6.1	2.5 λ x 1.4 λ	92	31	1 x 10^{-6}	11.5	-	-
3.	[5]	5.5	6.2	0.57 λ x 0.94 λ	54	15	1x 10^{-2}	4.7	1.0	-
4.	[6]	5.75	5.85	0.7 λ x 0.6 λ	41	42	-	4.9	-	-
5.	[19]	5.49	6.024	0.53 λ x 1.85 λ	76	33	5 x 10^{-4}	5.3	-	-
6.	[20]	5.3	6.7	0.76 λ x 0.76 λ	56	13	4 x 10^{-4}	5.43	1.24	-
7.	Proposed	5.0	5.6	0.66 λ x 0.3 λ	-	11.8	1x 10^{-2}	4.0	0.58	0.28

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