Two/Three-element textile Diversity MIMO Antenna for Biomedical and Wearable Applications

Anubhav Kumar [1], Asok De [2], R.K Jain [3]
[1 2 3] Department of Electronics and Communication Engineering
[1 3] Shobhit Institute of Engineering and Technology,(Deemed to be University), Meerut, Uttar Pradesh, India
[2] Delhi Technological University (DTU), New Delhi
[1] rajput.anubhav@gmail.com

Abstract – A compact two/three-port textile antenna with pattern diversity performance for wearable and biomedical communication is proposed. The antenna-1 is placed orthogonally with antenna-2 and antenna-3 on textile jeans material with 30x30x1 mm^3 dimension. The two symmetrical inverted L-shaped open-stubs between antenna-1 and antenna-2 as well as two L-shaped open-stubs behind the antenna-3 with the diagonal strip are used to perturb and mitigate the surface current between elements. The bandwidth of antenna-1 and antenna-2 is covering 5G and WLAN/ISM bands where antenna-3 covers a partial 5G frequency band. The envelope correlation coefficient (ECC) and channel capacity loss (CCL) are analyzed for Multi-input-Multi-output (MIMO) a antenna performance, which represent the diversity performance of the antenna.

Keywords - Three-port antenna, Diversity antenna, Textile antenna, Wearable application, 5G communication

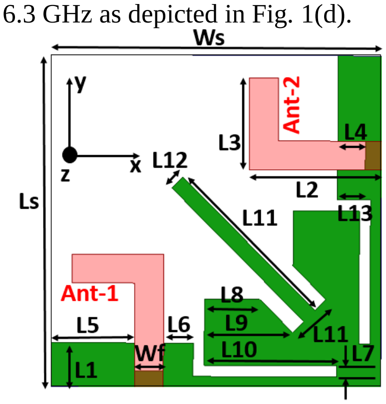
I. Introduction

The requirements of data rates, channel capacity and bandwidth in communication channel increases with the new technology introduced in recent wireless communication. MIMO antenna can meet these demands more easily than a single antenna therefore the focus of researchers has been increased on MIMO antenna designing. In recent times, there has been an increase in demand for wearable antennae in portable, medical and sports applications. The wearable antenna should be flexible and compact for body communication applications so that it can easily accommodate sensors and batteries in external wearable devices. Therefore, the MIMO antenna must be compact and flexible for on-body communication applications for wireless communication [1-5]. In [5], defected ground based isolation enhancement is introduced in two-port circular polarized antenna. In a MIMO antenna, if the antenna elements are close in limited space then it reduces the overall size of the antenna but increases the correlation coefficient between the antenna elements, which also affects the channel capacity [6]. Pattern diversity, defected ground and open stubs in the ground helps to reduce surface current between antenna elements. Many materials are used to design a wearable antenna but the rigid material does not match the agreement of not being flexible for this application, therefore flexible material can make the antenna more comfortable for on-body communication. A study of the wearable antenna in the literature suggests that design of wearable antennae have been emphasized with flexible and compact antenna [1-5, 7-10]. In [7], an s-shaped radiator with co-axial feed is used to obtain a dual-band on jeans material where open stubs in the ground influence the impedance matching of the antenna. In [8], rectangular radiator antenna is modified to an E-shaped radiator antenna with the partial ground on flexible jeans material for medical and wearable applications. In [9], two rectangular radiators are used as a MIMO antenna for wideband and wearable communication accomplished on jeans substrate where dual I-shaped strip in the ground is used to enhance the isolation. In [10], a switch on the resonator is used for reconfigurable application in jeans substrate for wearable wideband applications, where an open-stub and slot in the ground is used for surface current elimination between ports. In [11], circular polarized and CPW-fed antenna is designed where diagonal decoupling structure and open stubs are used to perturb the current and increase the port isolation. In [12], inverted L-shaped microstrip feed is discussed to design 4-element antenna where modified CSRR is used to enhance the IBW of the antenna. In [13], beak-shaped radiators are introduced for sub-6 GHz bands where T-shaped decoupling with slots are accomplished to perturb the surface current. In [14], CPW-fed two port antenna is discussed where H-shaped EBG are used to perturb and mitigate the surface current. In [15], modified open stub with slits in open stub is introduced in the ground in two-port antennas, which improves the port isolation and diminishes the surface current. In [16], microstrip-feed based two-port flexible antenna is designed for WLAN where strip is used as decoupling structure which mitigate the surface current between ports and enhance the port isolation. Keeping in view the requirement of wearable antennas, in this paper, two and three-port antennas are designed in limited size. The 10 dB bandwidth of antenna-1 and antenna-2 varies from 4.4 GHz to 6.8 GHz, which is covered 5G and WLAN / ISM bands. The 10 dB impedance bandwidth (IBW) of antenna-3 varies from

4.55 GHz to 4.8 GHz and can work for a 5G wearable application. Open Stub and diversity placement of antenna elements are used to improve the isolation in present technology where the isolation of antenna-1 with antenna-2 is more than 20 dB and the isolation of antenna-3 with antenna-1 is more than 19.7 dB whereas with antenna-2 is more than 16.7 dB. The ECC and CCL have been computed to analyze the diversity and MIMO characteristics of the antenna, which is under the acceptable limit, and make the antenna helpful for wearable applications with pattern diversity performance.

II. Design of two-element antenna

The prototype and design of the two-port MIMO antenna is illustrated in Fig. 1(a) where both antennas are placed orthogonally to each other. The flexible jeans material (permittivity (εr) = 1.7 with loss tangent (tan δ) = 0.025) is used to design the MIMO antenna with a copper tape of 0.057 mm thickness as a conducting element. The dimensions of two-part antenna are as follows in mm: Ws=30, Ls=30, Wf=2.6, L2=12, L4=2.5, L6=2.7, L8=5, L10=12, L12=1.414, L1=4, L13=3, L3=8.3, L5=7.7, L7=1, L9=8, L11=17, thickness (t) = 1 mm. The antenna evolution steps are divided into four parts as represented in Fig. 1(b), where its s-parameters are illustrated in Fig. 1(c). In the first step, two orthogonally placed inverted L-shaped microstrip feed radiator is accomplished with the partial ground. The IBW of the antenna obtains from 4.5 GHz to 7 GHz with port isolation is more than 15 dB. In step two, conducting part of the ground plane is enhanced with the defected ground below the microstrip feed. It enhances the impedance matching and provides the support to make changes in the ground for next step isolation enhancement. In step three, two symmetric L-shaped open stubs are introduced in the ground, which perturb and diminished the surface current. The IBW of the antenna varies from 4.5 GHz to 6.7 GHz with more than 19.5 dB isolation. In the fourth step, a diagonal strip is placed in the ground between antenna elements, which improves the isolation and maximizes it up to 46 dB. The IBW of the antenna varies from 4.4 GHz to 6.75 GHz where isolation varies from 20 dB to 46 dB. The 3D radiation pattern is analyzed to investigate the pattern diversity of the antenna at 5.1 GHz and 6.3 GHz as depicted in Fig. 1(d).



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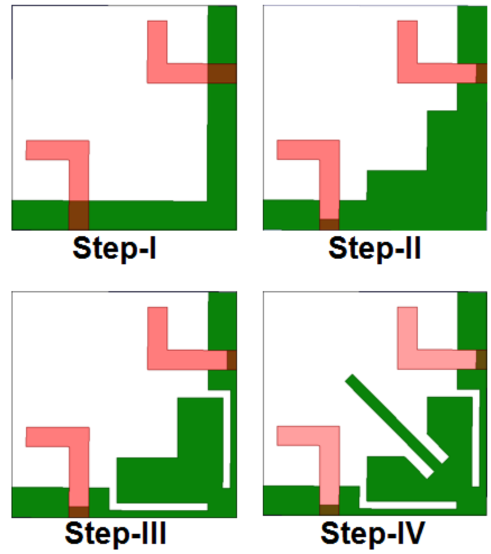

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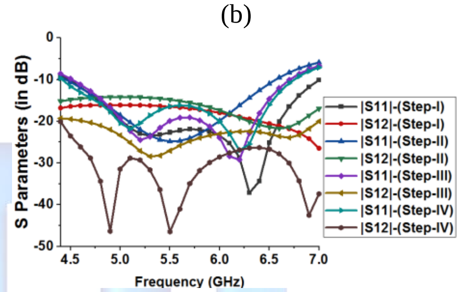

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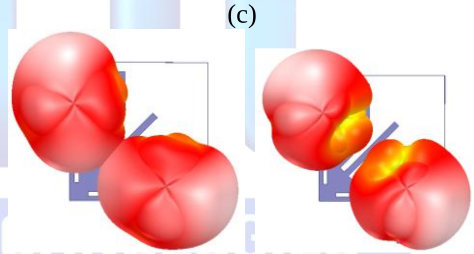


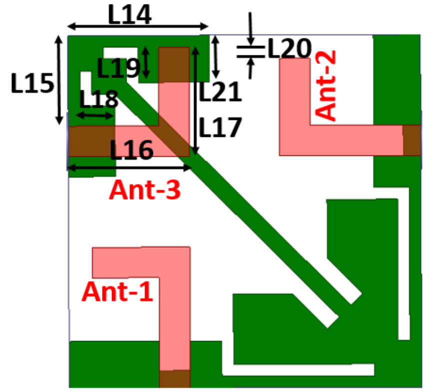
(i) (ii)

(d)

Figure 1. Textile two-element antenna (a) prototype design (b) design steps (c) s-parameters of design steps (d) 3D radiation pattern at (i) 5.1 GHz (ii) 6.3 GHz

III. Design of three-element antenna

In this section, designing of antenna-3 and its results are discussed. The Inverted L-shaped radiator is accomplished in the limited space of a two-port antenna, which is discussed in the previous section with pattern diversity performance. The common ground plane is used in all three-port antenna for keeping in the mind of practical applications as depicted in Fig. 2(a) and Fig. 2(b). The two symmetric L-shaped stubs behind antenna-3 are used for impedance matching and reduced the surface current from antenna-1 and antenna-2. The dimension of the antenna-3 is as follows in mm: L14=12, L16=10.3, L18=3, L20=1, L15=7.7, L17=9.3, L19=3, L21=4. The 10 dB impedance bandwidth (10 dB) of antenna-3 is 4.55 GHz to 4.8 GHz applicable for 5G communication. The isolation of antenna-3 from antenna-1 and antenna-2 is 19.7 dB to 22 dB and 16.7 dB to 25 dB as illustrated in Fig. 2(d). The 3D radiation patterns of all three port antenna is depicted in Fig. 2(c), where patterns are designed of antenna-1 and antenna-2 at 5.1 GHz and of antenna-3 at 4.7 GHz.



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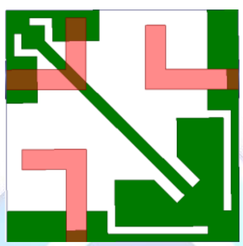

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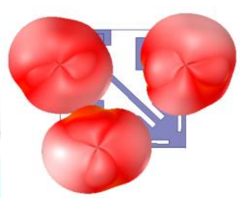

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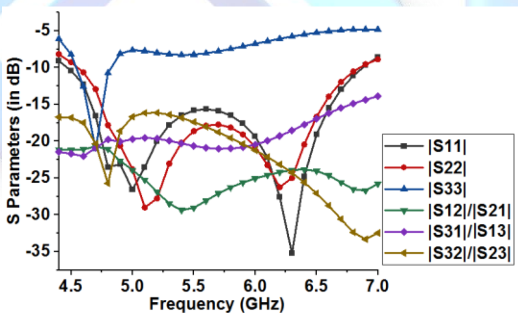


(d)

Figure 2. Textile three-element antenna (a) prototype design with dimensions (b) final design (c) 3D radiation pattern at 5.1 GHz (Ant-1 and Ant-2) and at 4.7 GHz (Ant-3) (d) S-parameters

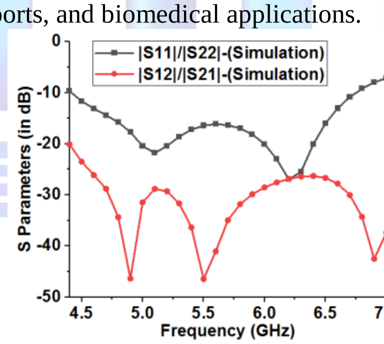
IV. Simulated Results Analysis

The flexible two/three-port textile antenna is simulated in HFSS 13 and HFSS 17 software. The simulation investigation of the two-port antenna and three-port antenna is discussed in Fig. 3 and Fig. 4. The two-port antenna IBW varies from 4.4 GHz to 4.75 GHz with more than 20 dB isolation as described in Fig. 3(a). The realized gain (dB) varies from 2.4 to 5.4 in the entire operating bandwidth as illustrated in Fig. 3(b). The radiation efficiency (%) of the two-port antenna is above 93 in the operating bandwidth. The diversity and MIMO characteristics of the antenna is analyzed with ECC and CCL, which is calculated from equations 1 and equation 2 with simulated s-parameters [6].

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

$$CCL = -log_2 det(\psi^R) \quad (2)$$

The ECC is analyzed and represents the correlation performance between antenna elements where its acceptable values should be less than 0.5. The CCL is extracted from equation 2, where ψ^R is represented the correlation matrix at receiving end. The acceptable value of CCL is 0.4 bits/sec/Hz [6]. The ECC and CCL of the two-port MIMO antenna are less than 0.006 and 0.4 bits/s/Hz and under suitable limits, as depicted in Fig. 3(d) and Fig. 3(e). The s-parameter of the three-port antenna is represented in Fig. 4(a), where |S11| (dB) of antenna-1 and antenna-2 varies from 4.5 GHz to 7.8 GHz and 4.6 GHz to 7.8 GHz. The |S11| (dB) of antenna-3 varies from 4.55 GHz to 4.8 GHz. The port isolation |S12| is more than 20 dB where the port isolation |S13| is more than 19.7 dB and antenna-2 to antenna-3 is more than 16.7 dB. The gain (realized) of antenna-1 and antenna-2 is more than 2.2 dB where it is more than 1.7 dB for antenna-3. The radiation efficiency of all antenna elements is more than 84 % in operating bandwidth as discussed in Fig. 4(c). The ECC and CCL of the antenna-2 to antenna-3 is less than 0.02 and 0.4 bits/sec/Hz respectively and under the satisfactory limit, as depicted in Fig. 4(d) and Fig. 4(e). The radiation pattern (normalized) of antenna-1 at 5.1 GHz and of antenna-3 at 4.7 GHz is depicted in Fig. 5 and Fig. 6 in a different plane (xz and yz) where a stable radiation pattern is achieved. Table-1 is used to analyze different textile and MIMO antenna analysis where the proposed two/three-port antenna is compact with acceptable MIMO parameters and can be used for portable, wearable, sports, and biomedical applications.



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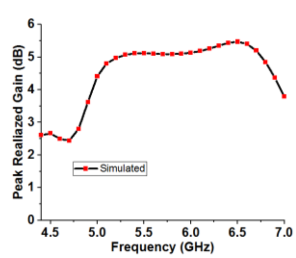

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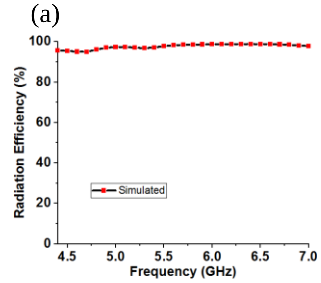

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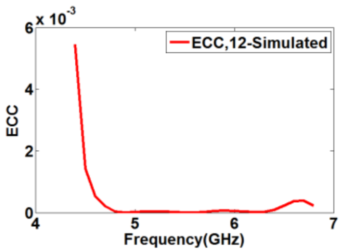

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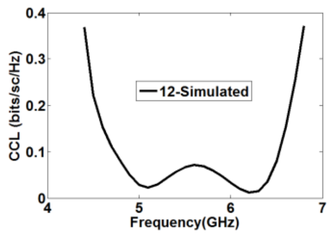

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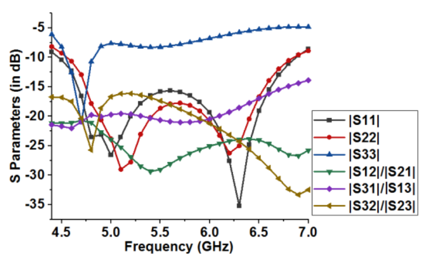
Figure 3. Two-port antenna (a) s-parameters (|S11| and |S12|) (b) realized gain (dB) (c) efficiency in % (radiation) (d) ECC (e) CCL



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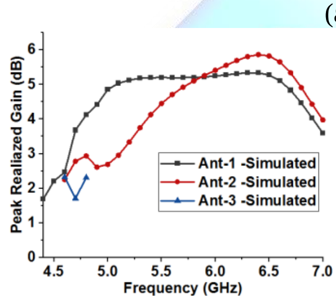

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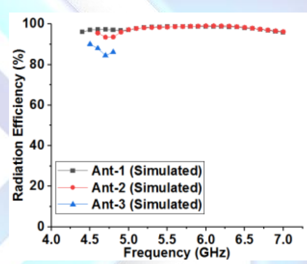

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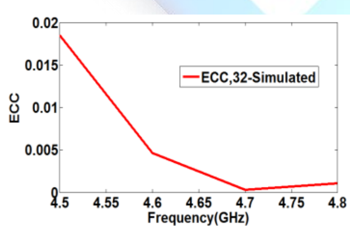

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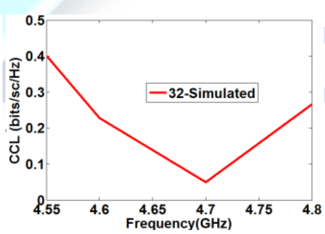

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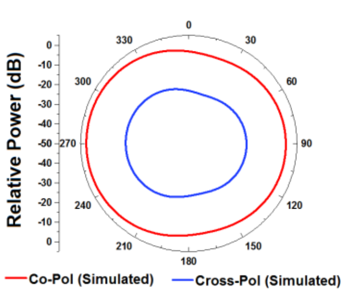
Figure 4. Three-port antenna (a) s-parameters (|S11| and |S12|) (b) realized gain (dB) (c) efficiency in % (radiation) (d) ECC (e) CCL



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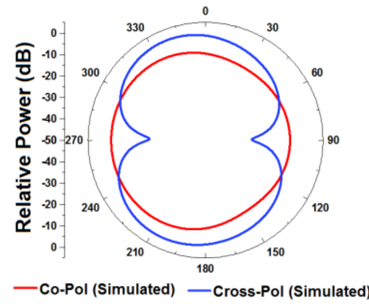

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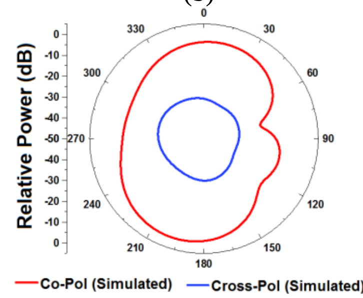
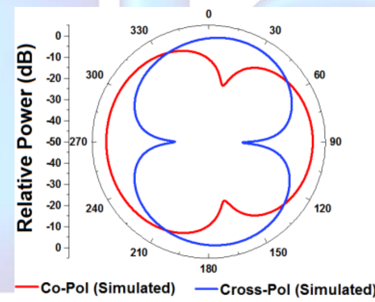


(c)

Figure 5. Normalized radiation pattern of Ant-1 at 5.1 GHz (a) in xz, (b) in yz (c) in xy plane



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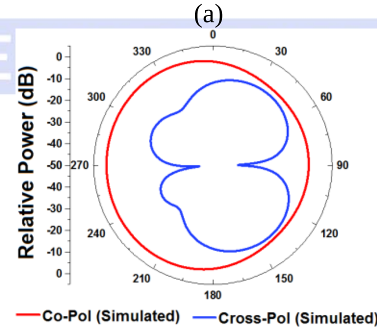

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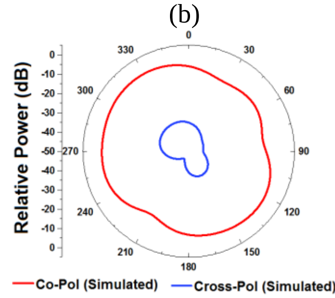

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Figure 6. Normalized radiation pattern of Ant-3 at 4.7 GHz (a) in xz, (b) in yz (c) in xy plane

V. Conclusions

A novel, compact two/three-element textile antenna is presented based on open-stubs and diagonal strip with low-cost flexible jeans material. The antenna-1 and antenna-2 cover 4.6 GHz to 6.8 GHz for 5G and WLAN/ISM bands with isolation of more than 20 dB. The antenna-3 covers 4.55 GHz to 4.8 GHz with isolation more than 19.7 dB from antenna-1 and 16.7 dB from antenna-2. The ECC between antenna-1 and antenna-2 is less than 0.006 and from antenna-2 to antenna-3 is less than 0.02 where CCL is under acceptable limits. The proposed antenna is low-cost, compact size, flexible and good diversity performance can be a good choice for biomedical, sports, portable, and wearable communications.

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Table.1 Comparison analysis of existing textile and MIMO antenna with proposed antenna

Reference	Number of elements	Size (mm x mm)	Material	Bandwidth (GHz)	Isolation	ECC
[5]	2	31x31	Jeans	3.3 to 4.3	>24	<0.2
[7]	1	60×30	felt	2.45 and 5.8	NA	NA
[8]	1	30 × 20	Denim	2.4	NA	NA
[9]	2	40 × 70	Jeans	2.4-8.0	>22	<0.01

[10]	2	35 × 30	Jeans	3.11-5.15, 4.81-7.39	>19.5, 21	< 0.18
[11]	2	30 × 30	FR-4	4.95 to 5.95	>20	<0.005
[12]	4	170 x 80	FR-4	3.40-3.625, 3.90-4.55	>20.1	<0.3
[13]	2	40 × 30	FR-4	2.12–3.85 and 4.95–6	>20	<0.002
[14]	2	35 × 22	FR-4	3.4–10.4	>20	<0.01
[15]	2	30 x 24	FR-4	3.15 to 3.95	>22	<0.004
[16]	2	26x24	Jeans	4.9-6	>27	<0.002
Proposed	**2**	**30x30**	**Jeans**	**4.4 to 6.75**	**>20**	**<0.006**
Proposed	**3**	**30x30**	**Jeans**	**4.6 to 6.8, 4.55 to 4.8**	**>20, 16.7**	**<0.02**