Dual-Polarized Textile Antenna for Full-Duplex Wearable Applications

Neha Dalakoti and Priyanka Jain

Abstract In this article, an ultra-wideband, dual-port, textile antenna on jeans substrate has been designed and simulated for wearable and MIMO applications. The antenna consists of a partial ground plane on which a square shape has been cut out from the corner. It gives very wide bandwidth ranging from 1.58 GHz to 10.08 GHz and achieves isolation at least −11 dB throughout the operating band. The design has been done on 1.8 mm jeans substrate having dielectric constant 1.67. When ports are excited individually for both the polarizations, the gain of 2.73 dBi, 3.52 dBi, and 5.27 dBi is obtained at 3.5 GHz, 6 GHz, and 10 GHz, respectively. In addition to isolation between the ports, envelope correlation coefficient (ECC) and diversity gain have been calculated. The antenna is made out of a textile material, and as a result, it has a high level of structural flexibility and manufacturing precision. Using the Finite Integral Technique (FIT) numerical method, the provided two-port antenna structure is examined, investigated, and optimized.

Keywords Dual polarization · Textile antenna · Ultra-wide bandwidth · Wearable applications

1 Introduction

An important part of any wireless communication is the antenna, which is available in variety of shapes and sizes. Some of them are microstrip patch antenna, slot antenna, horn antenna, Vivaldi antenna, etc. Planar shape patch antenna is very much compatiple and suitable in wearable devices applications (Sanjaria et al. 2013). Microstrip patch antenna has been an area of interest for both the academia and industries for over more than seven decades. In recent years, the application of microstrip patch antenna in the Personal Area Network (PAN), or more specifically, the Wireless Body Area Network (WBAN), has received a lot of attention. Apart

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from this, microstrip patch antenna is highly useful in wearable biosensors, cameras, computers, healthcare, military, and a range of other wearable technologies. Such advancements arouse our interest in the creation and evolution of wearable antennas that are embedded in our clothing (Sundarsingh et al. 2014). Textile antennas are latest research interest because of its easy fabrication and good integration with planar circuits. These antennas are flexible, robust, highly efficient and possess low specific absorption ratio (SAR) (Mao et al. 2020). It is hugely desirable to have a transmitting and receiving antenna in a single antenna system for the most effective use of duplexing systems (Mao et al. 2020). In order to develop such antenna system, multiple-input multiple-output (MIMO) is used at both transmitter and receiver sides. MIMO antennas are better than single-input single-output (SISO) antennas in terms of channel capacity and transmitted power (Jensen and Wallace 2004; Choi et al. 2014). Channel capacity is directly proportional to the bandwidth of the system and it is improved with the use of ultra-wideband (UWB) antennas (Siddiqui et al. 2019). MIMO antennas sometimes use polarization diversity to double the channel capacity. Since these antennas use one radiating element and two ports, the isolation between the ports is very important to study. Multiple attempts have been made to design such antennas focusing bandwidth enhancement (Mao et al. 2020; Saxena et al. 2020), isolation improvement (Moradikordalivand et al. 2014; Chung and Yoon 2007; Luo et al. 2015), and gain improvement (Saxena et al. 2020). It has been reported that coupling degrades due to increased signal correlation between multiple radio signals (Singh et al. 2021). Numerous structures such as parasitic ring element (Moradikordalivand et al. 2014), extra ground wall (Chung and Yoon 2007), and approach for neutralization techniques on the ground plane (Luo et al. 2015) have been used between the ports to improve the isolation further.

In this paper, a dual-polarized, ultra-wideband, low profile, wearable, MIMO antenna has been designed and simulated in CST v.19. It has been designed on a general jeans substrate of dielectric constant 1.67 and height 1.8. Parameters like ECC and diversity gain have also been calculated to study isolation between the ports. The outline of the paper is as follows, Sect. 2 deals with antenna design, Sect. 3 includes results and discussion, and the last section summarizes the conclusion.

2 Antenna Design

2.1 Configuration

The design consists of a patch antenna on a jeans substrate of height 1.8 mm and dielectric constant 1.67 having one edge cut in the fashion of stairs. It has been feed from two orthogonal sides to have dual polarization in both the orthogonal planes. A partial ground has been used on the other side. The designed antenna has been shown in Fig. 1a with all the dimensions marked. Figure 1a shows the top view of the design which is very compact and uses no extra circuit for bandwidth

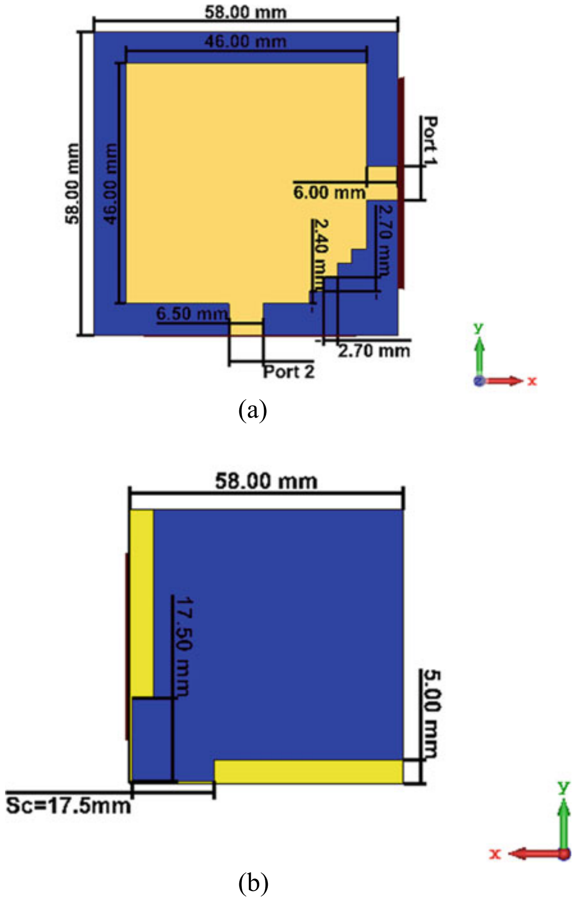


Fig. 1 Proposed design **a** top view and, **b** bottom view

enhancement. Figure 1b, on the other hand, shows the ground plane. Through a 6 mm long, 6.5 mm (50 Ω) broad microstrip line, the square shape patch is fed. The square patch has 58 mm side length. A square shape of sides 17.5 mm has been cut out from ground plane in order to enhance the bandwidth and improve the isolation between the ports. The antenna design and optimization are performed using the CST—Computer Simulation Technology based upon Finite Integration in Technique (FIT)

3 Results and Discussion

Ultra-wide bandwidth (UWB) of 145.8% ranging from 1.58 to 10.08 GHz has been obtained. Return losses (S11 and S22) are well below −10 dB, and also, the coupling coefficients (S12 and S21) are less than −11 dB throughout the bandwidth. The

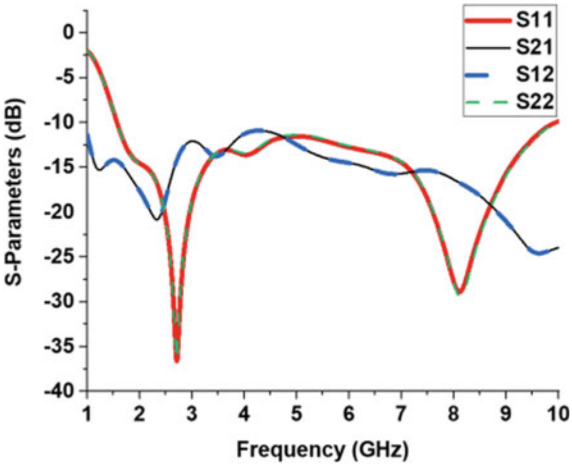


Fig. 2 S-parameters of the proposed antenna

design possesses good isolation in lower and upper bands which is less than -15 dB in frequencies ranging from 1.7 to 2.7 GHz and 6.4 to 10 GHz. Since the design is physically symmetrical, the value of S11 with S22 and S21 with S12 is almost identical. The parameter 'Sc' (square cut) has been optimized and simulated for 17, 17.5, 18, and 19 mm and the return loss less than 10 dB and isolation less than 11 dB come at 17.5 mm as shown in Fi 3.

The radiation efficiency of the proposed antenna is shown in this Fig. 4a. The proposed antenna has an average radiation efficiency of 65%. The gain of the proposed antenna is shown in Fig. 4b. The proposed antenna has an average peak gain of 5.2dBi. Simulated gain for this antenna varies from 0.08 to 5.2 dBi as shown in Fig. 4b. Surface current is measured and plotted at 3.5 GHz as shown in Fig. 5.

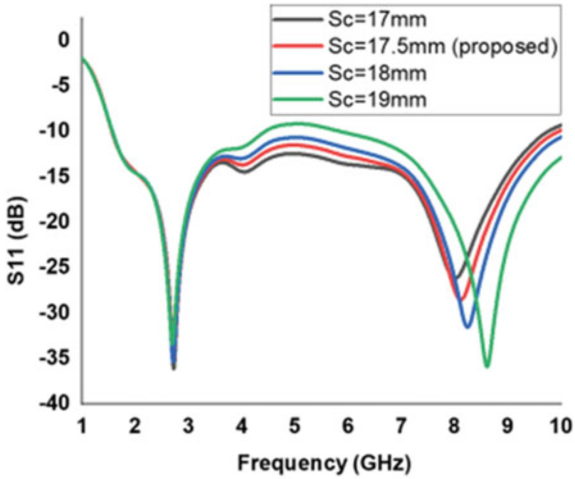
ECC is a measure of isolation between the ports in a multiport MIMO antenna. It is desirable to have ECC as minimum as possible to minimize the isolation between the ports (Singh et al. 2021). ECC is calculated either using far-field pattern or using s-parameters of the system as given in Eq. 1 (Saxena et al. 2020). It is less than 0.02 throughout the band of operation.

Another term is diversity gain which conveys same information about the isolation of the ports and it is related to ECC as given in Eq. 2 (Saxena et al. 2020). Diversity gain is 9.95 or above throughout the band of operation for this design (Fig. 6).

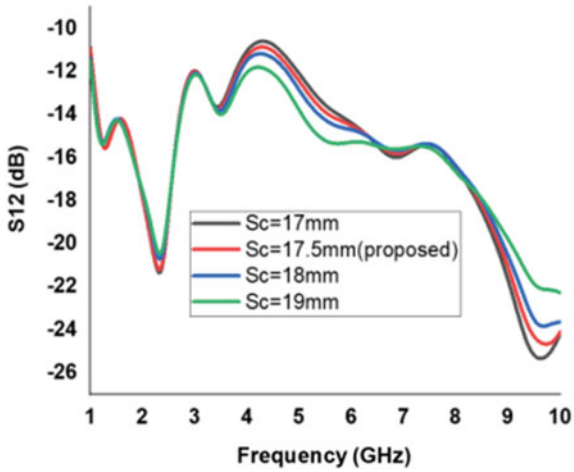
$$\mathrm{ECC} = \frac{\left|S_{11}^{*}S_{12} + S_{21}^{*}S_{22}\right|^{2}}{\left(1 - |S_{11}|^{2} - |S_{21}|^{2}\right)\left(1 - |S_{22}|^{2} - |S_{12}|^{2}\right)} \tag{1}$$

$$\mathrm{DG} = 10\sqrt{1 - \mathrm{ECC}^{2}}. \tag{2}$$

Fig. 3 Parametric analysis **a** S11 and, **b** S21



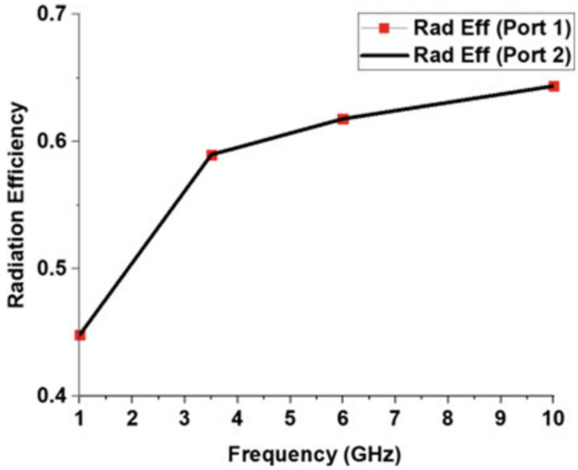
(a) Parametric S11 analysis



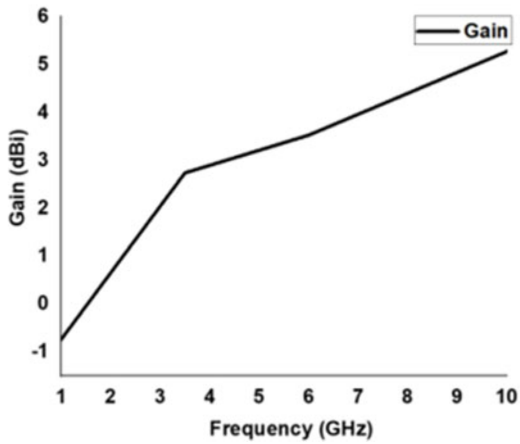
(b) Parametric S12 analysis

The proposed design has physical size of 58 × 58 mm^2 which is smaller as compared to (Sundarsingh et al. 2014; Moradikordalivand et al. 2014; Rais et al. 2013). The design has 1.58–10.08 GHz and 145.8% of fractional bandwidth which is better as compared to (Sundarsingh et al. 2014; Mao et al. 2020; Ononchimeg et al. 2010; Rais et al. 2013) as shown in (Table 1).

Fig. 4 Radiation efficiency and antenna gain with frequency



(a) Radiation efficiency vs. frequency



(b) Antenna gain vs. frequency

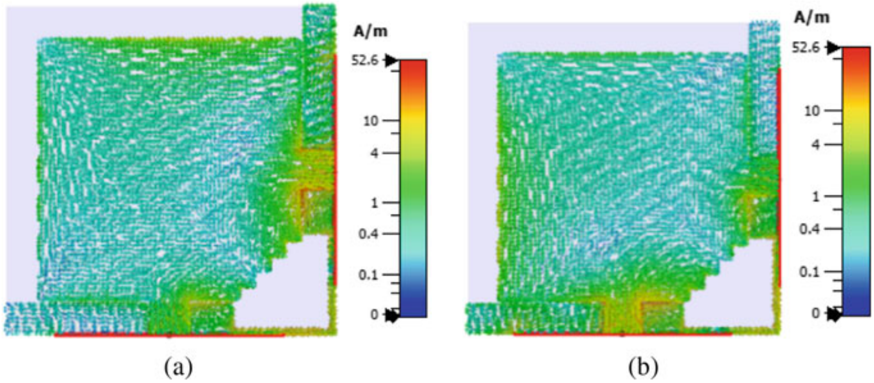
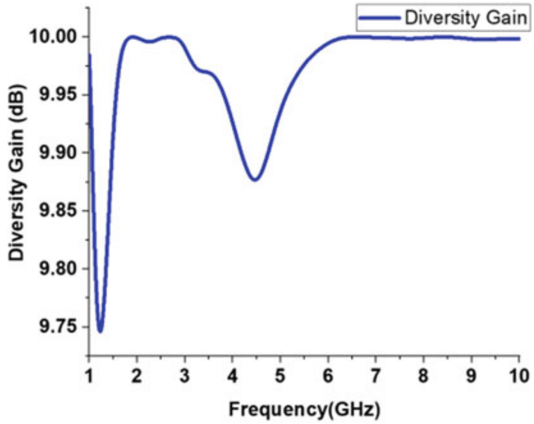
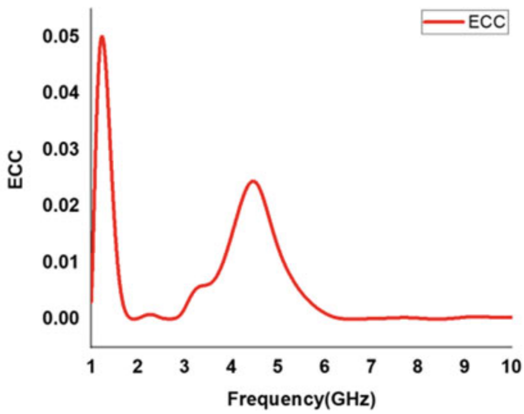


Fig. 5 Surface current of the proposed antenna when **a** Port-1 is excited and **b** Port-2 is excited

Fig. 6 Diversity gain and ECC



(a) Diversity gain versus frequency



(b) ECC versus frequency

Table 1 Comparison table

References	Material	Size (mm^2)	Bandwidth (GHz)	Isolation (dB)	Radiation efficiency (%)	Peak gain (dBi)
Sundarsingh et al. (2014)	Jeans	120 × 120	900 MHz,1800 MHz	NA	20	NA
Mao et al. (2020)	Evolon	NA	2.35–2.5	>15	90	7.5
Ononchimeg et al. (2010)	NA	45.0 × 40.0	14.5–15.2	>30	NA	6.2
Fallahzadeh et al. (2010)	Taconic RF35	30.2 × 38.8	2.6	>20	NA	4.5
Moradikordalivand et al. (2014)	FR-4	130 × 110	1–2.7	15	68–72	5.6
Upadhyay and Tripathi (2017)	Rogers RT/ Duroid 5880	96 × 96	25%	>11	NA	8
Hussein et al. (2019)	FR-4	70 × 70	3.2–3.3	−36	75	4.4
Rais et al. (2013)	Polyurethane foam	80 × 60	(2.22–2.48 GHz), (4.95–5.80 GHz)	NA	67–89	8.33
Proposed	Jeans	58 × 58	1.58 to 10.08	>15 at 1.7–2.7 and 6.4–10	65	5.2

4 Conclusion

A compact, dual-port, dual-polarized, ultra-wideband antenna for full-duplexing wearable application has been designed and simulated. The design consists of a stair cut patch antenna placed on jeans substrate backed by a partial ground with a square cut on the edge. The simulation result shows good reflection coefficients, isolation between the ports, and radiation characteristics throughout the band. Designed antenna is suitable for wearable and/or full-duplex applications such as health care, defense, and IoT. Isolation 15 dB has been achieved in the frequency range 1.7–2.7 GHz and 6.4–10 GHz. The efficiency of up to 65% is obtained in the required frequency band. Diversity gain of approximately 9.95 dB and envelope correlation coefficient below 0.02 have been obtained for diversity applications.

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