A Wideband Wearable Antenna for ISM and WLAN Applications

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Abstract - *A wideband slotted patch antenna with a partial ground for wearable applications is presented in this article. The dimensions have been optimized to obtain a compact structure of 30x20x0.8* mm^3 *on FR4 epoxy substrate. A triple band operation with resonant frequencies at 2.4 GHz, 3.8 GHz and 5.8 GHz is observed. A peak gain of 3.7 dB is found for the center frequency of 5.8 GHz with 97% efficiency. The average value of SAR simulated on a three-layer human body phantom for an input power of 1 mW is 0.0175 W/kg. The antenna is appropriate for implementation in Wireless Body Area Networks.*

Key Words*:* Wearable, Complementary split ring resonator, Return loss, SAR

1.INTRODUCTION

The world of wearables has gained a tremendous increase in the last decade owing to their relevance in the areas of health monitoring, diagnosis, tracking and location sensing [1]. Wearable antennas are most commonly developed for operation at specific frequencies keeping in view the area of application. These antennas are most widely used in Wireless Body Area Networks (WBAN) due to their promise in various healthcare applications. A set of frequency bands are designated to commercial WBAN systems including frequencies in the range of 402 MHz to 10.6 GHz [2]. The realization of wearable antennas has strong dependence on the lossy nature of body tissues. The close proximity of human body, structural deformation, robustness and wearer's comfort are the crucial aspects in wearable antenna configuration. These antennas also tend to suffer from frequency detuning [1]. As these antennas form a part of on body communication system, they need to be light weight, compact and water resistant.

Microstrip patch antennas form a viable solution for wearable antenna design as they produce omnidirectional radiation pattern and can be miniaturized by the choice of suitable substrates. The ease of fabrication and low cost add to the advantages of microstrip patch antennas [3].

In [2] authors have presented a photopaper based flexible antenna operating in 2.5GHz and 5.8 GHz frequency bands. Though photopaper is flexible and low cost but it is prone to degradation. In [4] an antenna fabricated on a felt substrate with dual band operation is proposed for on/off body wearable applications. The antenna spans the ISM and WLAN frequencies. In reference [5] authors have presented a triband electronic bandgap array antenna operating in WLAN and WiMAX bands. In [6] three forms of dual band (2.45 GHz and 5.2 GHz) antennas with electronic bandgap structure have been discussed. Though the use of EBG structure beneath the antenna makes them bulky. The authors of [7] have presented a semi flexible hybrid Moore fractal antenna operating in 1.38-1.8 GHz and 2.45-4.88 GHz bands. The proposed antenna has a compact geometry and lower values of SAR. A meander line patch antenna spanning frequencies between 2.36-2.46 GHz is discussed in [8]. In [9] the authors have proposed an antenna incorporating a foam spacer operating at 2.45 GHz. A wideband minkowski fractal geometry-based antenna is presented in [10] with operation in frequency range of 700 MHz to 4.71 GHz. The authors of [11] have presented an IDE bandgap unit cell-based antenna for use in MBAN applications. In [12] a 2.45 GHz ISM band antenna with double flexible substrates is discussed. In [13] an ISM band antenna with denim as a substate is presented. However, textile antennas are susceptible to water and moisture content.

This work presents a triple band compact wearable antenna with an acceptable value of SAR. The antenna shows a wideband operation and is suitable for WBAN applications. The comparatively simple design and smaller size as compared to previous works makes it a good alternative for wearable applications. Free space and on body analysis have been performed for the proposed antenna. The reflection coefficient, acceptable gain and on body SAR simulations also show the feasibility of the proposed work.

2. GEOMETRY

The antenna is structured on a FR-4 epoxy substrate with a relative permittivity of 4.4 and a dissipation factor of 0.02. A high dielectric constant substrate was utilized to bring down the measurements of the proposed antenna [14]. The resulting geometry has compact dimensions of 30mm x 20mm x 0.8mm. The design process started with the modelling of a square shaped patch and a partial ground. The limited size of ground plane helps in broadening the bandwidth of antenna [15]. Four square shaped slots at the corners of the patch and a 0.5 mm wide single complimentary split ring resonator were incorporated to achieve resonances at the desired frequencies. The dimensions of slots have been optimized to obtain the desired operation. In order to improve the return loss, three slots of equal size were etched from the lateral extremities of the patch. An upturned S shaped groove was etched to refine the operation of the antenna. The S shaped slot also helped in achieving operation in 3.8 GHz band. A microstrip line feed of 50 Ω is applied to the antenna. Fig. 1 shows the layout of the planned antenna.

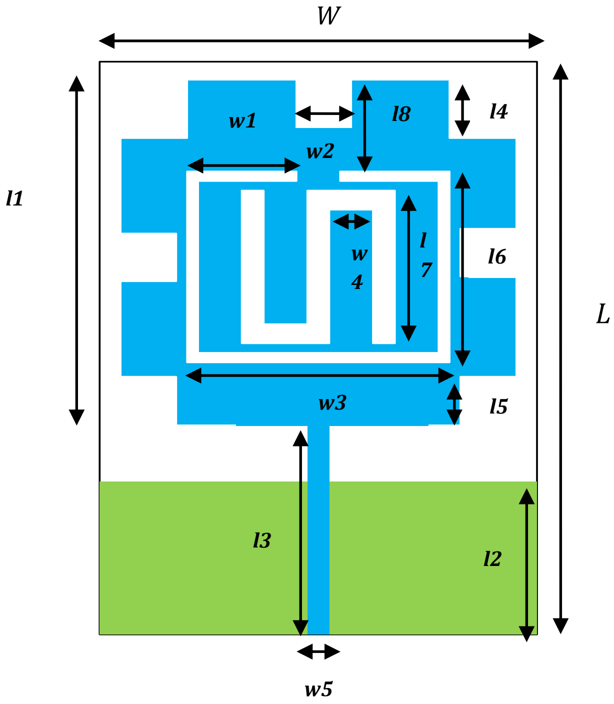


Fig -1: Proposed Antenna layout

Table -1: Parametric Values

Parameter	Value (mm)	Parameter	Value (mm)
L	30	*W*	20
l1	18	*w1*	5
l2	8	*w2*	2.5
l3	11	*w3*	12
l4	3	*w4*	2
l5	2.5	*w5*	1
l6	10	*l7*	8
l8	5		

3. RESULTS

A computational analysis has been performed to determine the return loss of the intended antenna. The simulated S_{11} findings reveal the triband operation of the antenna. Resonance is achieved at the frequencies of 2.4 GHz, 3.8 GHz and 5.8 GHz. The related return loss figures are -16.18 dB, -13.03 dB and -34.93 dB respectively. The antenna shows a wideband operation from 4.5 GHz-6.4 GHz. Fig.2 depicts the reflection coefficient curve of the planned antenna. The monitored E plane and H plane radiation patterns for the resonant frequencies are displayed in Fig.3.

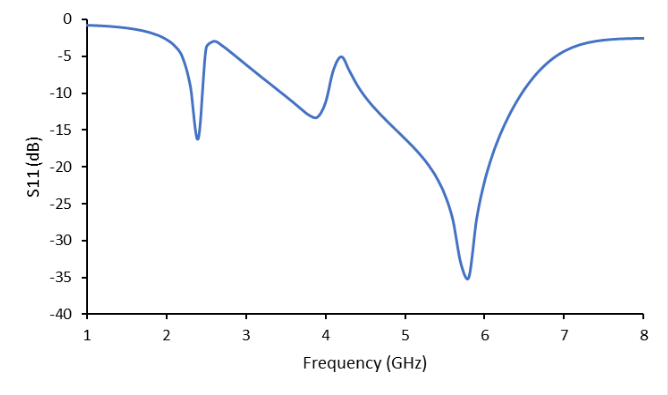


Fig -2: Simulated Free Space Reflection Coefficient

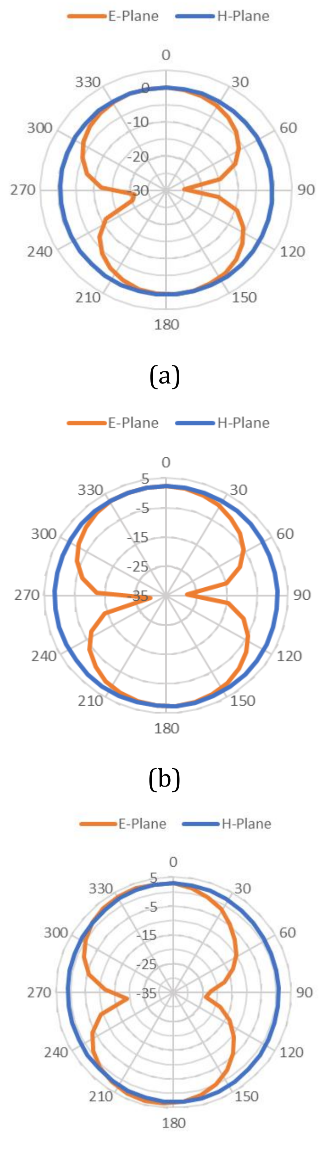


Fig -3: Simulated Radiation Pattern in Polar Coordinates (a) 2.4 GHz (b) 3.8 GHz (c) 5.8 GHz

The observed gain at frequencies of 2.4 GHz, 3.8 GHz and 5.8 GHz are 0.6155 dB, 2.7226 dB and 3.7205 dB respectively. The VSWR characteristics represented in Fig. 4 exhibit fair levels of impedance matching of the antenna.

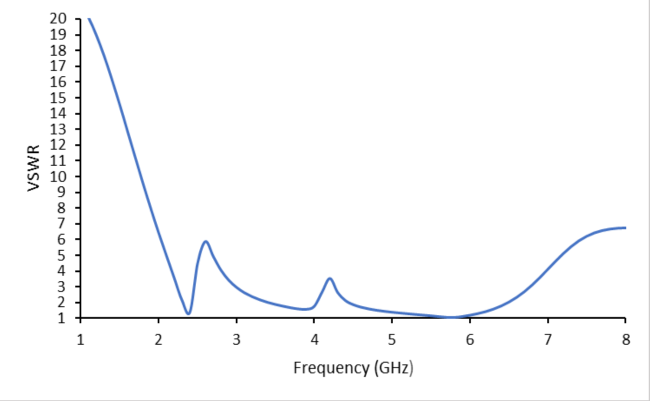


Fig -4: VSWR curve

4. ON BODY ANALYSIS

Wearable antennas function in propinquity of human body therefore the antenna behavior is dependent on the dielectric properties of body tissues. The varying electrical properties of different layers of tissues require the antenna to be optimized with a human body phantom in the design process. A human body phantom comprising three layers of tissues was utilized to study the impact of human body reciprocity with the antenna. The dimensions of the phantom are 50 mm x 50mm x 33 mm. The three-layered phantom is made up of skin, fat and muscle tissues of thickness 2 mm, 8 mm and 23 mm respectively. The relative permittivity, conductivity and loss tangent at frequencies 2.4 GHz and 5.8 GHz have been specified in table 2.

The antenna reflection coefficient characteristics when placed on the phantom are shown in fig.6. The results show a slight detuning at the frequencies of resonance. The S_{11} results show operation in the desired bands. The radiation pattern for on body simulations have been depicted in figure 7.

Table-2: Electrical Properties of Tissues

Tissue	Frequency (GHz)	Conductivity σ (S/m)	Permittivity ε	Loss tangent
Skin	2.4	8.013	31.29	0.2835
	5.8	3.717	35.114	0.3280
Fat	2.4	0.585	4.602	0.1938
	5.8	0.293	4.954	0.1833
Muscle	2.4	1.705	52.79	0.2419
	5.8	4.961	48.48	0.3171

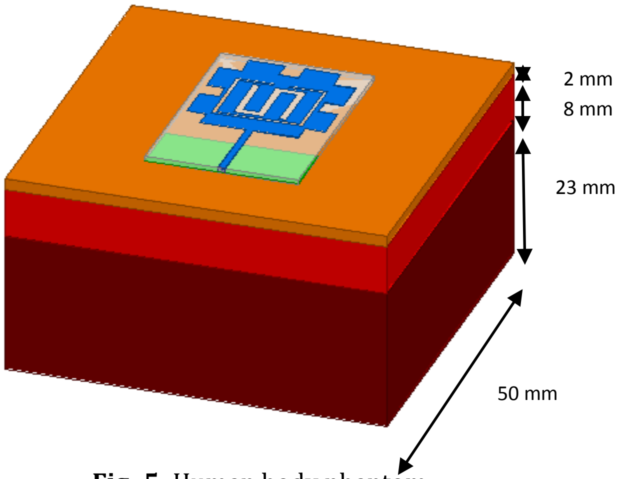


Fig -5: Human body phantom

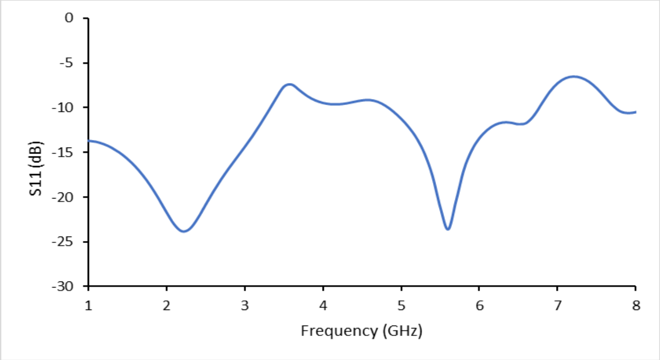
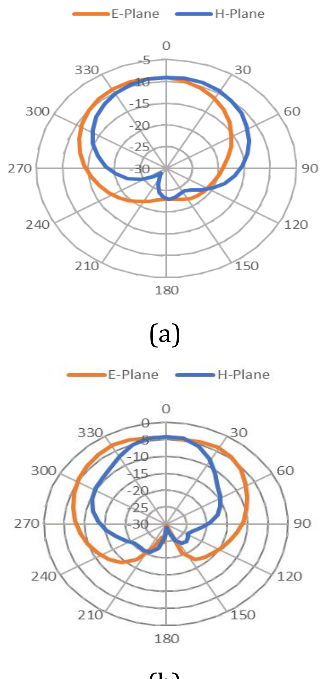


Fig -6: Simulated return loss on phantom



(a)

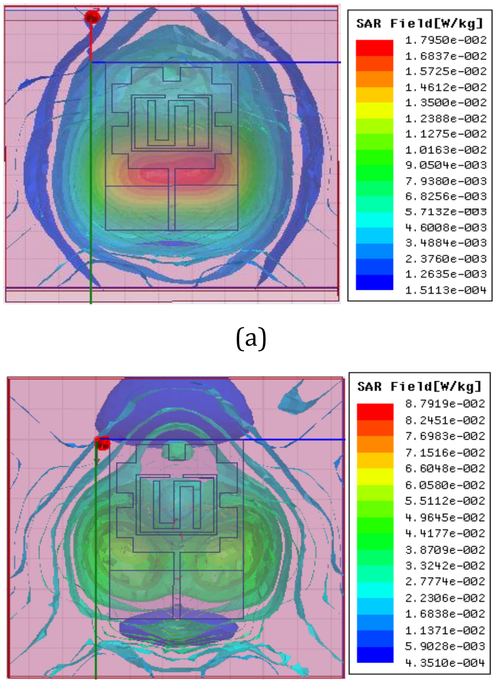
(b)

Fig -7: Simulated Radiation Pattern on body phantom in Polar Coordinates (a) 2.2 GHz (b) 5.6 GHz

5. SAR ANALYSIS

The magnitude of radiation that can be sustained per unit mass of human body is called SAR. According to International Standards the stipulated values of SAR are 1.6 W/kg aggregated over 1 gm of tissue and 2 W/kg over 10 gm of tissue respectively [1]. The amount of SAR was measured for the frequencies of 2.4 GHz and 5.8 GHz. Radiation pattern analysis of on body measurements reveal the reduced amount of back lobe radiations when antenna is emplaced on phantom. The reduced back lobe radiations correspond to lesser amount of SAR.

The measured SAR for 1 mW input power normalized over 1 gm of tissue at 2.4 GHz is 0.0175 W/kg and at 5.8 GHz is 0.0879 W/kg. The SAR analysis also reveals that the penetration depth of electromagnetic waves is lesser at higher frequencies.



(a)

(b)

Fig -8: SAR Analysis

6. CONCLUSIONS

The proposed antenna has a tri band operation in ISM, WiMAX and WLAN frequency bands. The impedance bandwidths measured across the three bands are 4.61%, 13.33% and 34.86% respectively. The range of operation shows that the proposed work is acceptable for WBAN applications. The on-body reflection coefficient and radiation pattern results also show the efficacy of the proposed design. The antenna has fair values of gain and SAR measurement which make it suitable for on body communication.

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