Design of Multiband Wearable Rectangular Slot Antenna for WIMAX and WLAN Applications

R. Darwin, S. Vinodhini

***Abstract:** The design of multiband wearable rectangular slot antenna operating at 2.9 GHz, 3.9 GHz and 5.1 GHz bands is explained in this paper. Wearable antenna requires certain conditions to be fulfilled like miniature size, weightless structure, physical flexibility, less maintenance and also operating with minimal degradation in proximity to the human body. Denim is used as a substrate material and Silver is used as a conducting material to meet the above requirements. The dimensions of the proposed design is 68x60 mm2. The simulated S-Parameter, VSWR, Gain and Directivity of the new design shows better performance. For the multiband operation the proposed antenna has a gain of 5.117 dB, 5.023 dB and 8.462 dB with VSWR of 1.517, 1.816 and 1.173 for 2.9 GHz, 3.9 GHz and 5.1 GHz respectively. The effects of electromagnetic radiation on the human body has also been analysed. The SAR was measured from the antenna by using the Voxel model. SAR values of the proposed design shows 0.8722 W/kg, 1.49 W/kg and1.44 W/kg as average values. It's evident from the measured values that the antenna meets the SAR limits recommended by the ICNIRP, which is 1.6 W/kg averaged over 1 g of tissue. Computer Simulation Technology (CST) Microwave Studio package 2017 has been used for simulation purpose. This antenna design can be used for various applications under WiMAX and WLAN bands.*

***Keywords:** Wearable Antenna, WLAN, WIMAX, Specific Absorption Rate, Multiband, Denim, Silver.*

I. INTRODUCTION

Nowadays, when textile technology is combined with wearable system technology there have been a vast growth in the research area [1]. Steady growth in the application areas which require miniaturization of electronics together with latest technologies enable the use of wearable antenna in textile for various applications including medical treatment and monitoring. By taking into account of the physical flexibility and comfort clothing is the best prospect for the design of wearable antennas [2-4]. A textile antenna must have a flat and planar structure such that it does not affect wearing comfort. The development of wearable system makes more advantages in the monitoring system that includes medical, security and military activities. With the rapid growth in wireless industry this techniques attracts more since it fulfills the increasing demands in the concerned fields like paramedics, firefighting, military etc. [5-7]. Above all wearable antennas can be used for all irrespective of age limit for monitoring. Along with low cost fabrication techniques it should meet the basic requirements like safety standards [11].

Using conductive textile material will satisfy the above said requirements. Growth in technologies with compactness in devices leads to increased interest in the antenna design which is wearable for wireless communication 12] [13]. Several design challenges comes into picture when designing an antenna which is wearable in human body with antenna deformations when worn in the body being the biggest of all and unavoidable. It should be ensured that the performance of the wearable design does not degrade drastically. Another major issue with the design is the coupling between the wearables with the human body which leads to bad health issues to the user. The main aim of this paper is to design and observe the performance of a dual band wearable rectangular slot antenna operating at 2.9 GHz and 5.1 GHz bands 14-15]. Introduction of holes or slots in the conductive element is used in the proposed design [15].

II. ANTENNA DESCRIPTION

Fig.1 shows the geometrical structure of the proposed rectangular slot antenna. The antenna proposed is a patch which is rectangular in shape with lot of changes in it to meet the required specifications. The rectangular radiating patch with stubs and narrow slots and micro strip line fed patch antenna is used for multiband operations. The material used for substrate is denim fabric that has a thickness of 1.6 mm, dielectric constant 1.6, and loss tangent tan Δ=0.016. Table I shows the required design specifications of the required design for the above application.

Design parameter	Specifications
Operating frequency (GHz)	2.9GHz,3.9 GHz 5.1 GHz
Dielectric constant of the substrate	1.6
Thickness of the substrate (mm)	1.6
Loss tangent	0.016

Table I. Proposed Design Specification

The surface wave losses can be reduced due to the low value of loss tangent and low permittivity. They also helps in improving the antenna bandwidth. For making conducting part of the antenna Silver is used.

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Actual length and width of the design are calculated using the formulae below

$$L_p = L_{eff} - 2\Delta L \quad (1)$$

$$w_p = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \quad (2)$$

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_r^{eff}}} \quad (3)$$

$$\Delta L = \frac{0.4}{2h}\frac{(\varepsilon_r^{eff}+0.3)(\frac{w_p}{h}+0.264)}{(\varepsilon_r^{eff}-0.258)(\frac{w_p}{h}+0.8)} \quad (4)$$

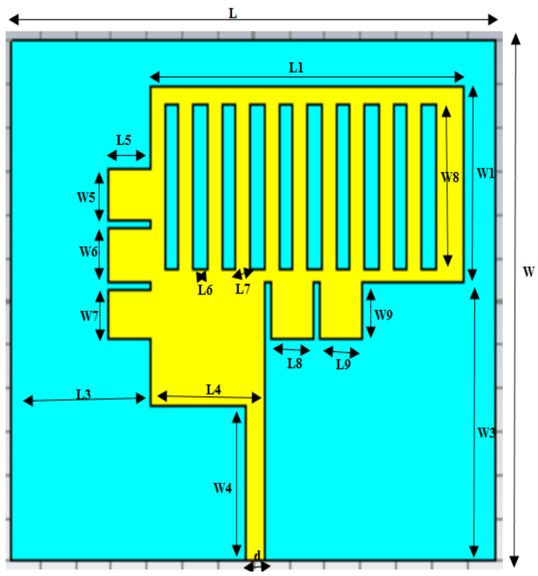
$$\varepsilon_r^{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}[1+12\frac{h}{w_p}]^{\frac{-1}{2}} \quad (5)$$

Substrate length and width are given by

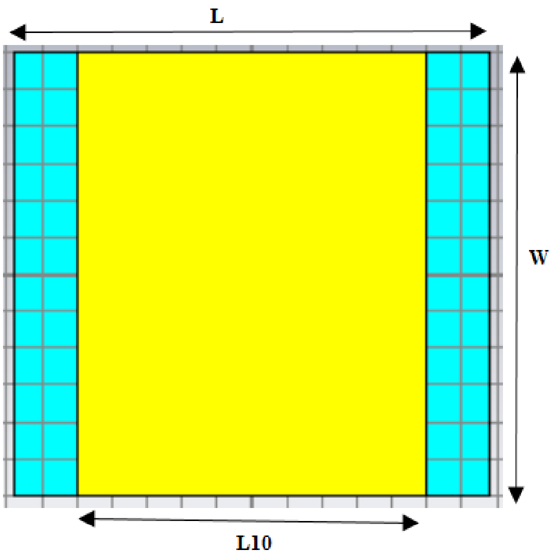
$$L_g = L_p + 6h \quad (6)$$

$$w_g = W_p + 6h \quad (7)$$

The proposed wearable rectangular slot antenna has a compact size of 68x60 mm2. Micro strip line feeding has been used.



(a)



(b)

Fig. 1 Antenna configuration a) Front view b) back view

The design specifications of the design has been mentioned in Table 2.

Antenna parameter	Value (mm)	Antenna parameter	Value (mm)
W	60	L6	2
L	68	W7	6
W1	22.3	L7	2
L1	44	W8	8
W3	32.3	L8	6
L3	19.5	W9	6
W4	17.7	L9	6
L4	16	L10	50
W5	6	d	2.6
L5	6		
W6	6		

Table 2. Antenna Parameters (Optimized)

Fig. 2. Illustrates the schematic of the proposed wearable rectangular slot antenna in CST MWS software environment.

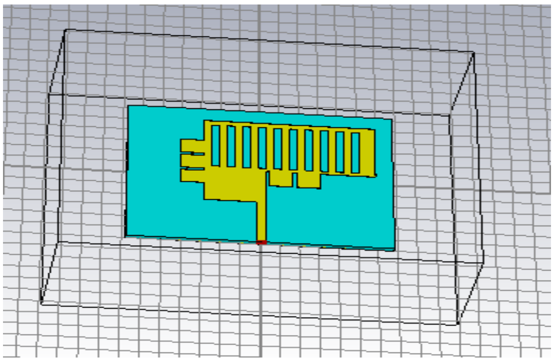


Fig. 2 Proposed antenna design in CST software

III. SIMULATED RESULTS

A. Reflection coefficient (S11)

Fig. 3 shows the simulated result [S11] of the wearable rectangular slot antenna with various slots and stubs in the patch. For the antenna design, -10 dB of VSWR is ideal. Fig. 3 shows the performance of the design in terms of reflection coefficient and VSWR.

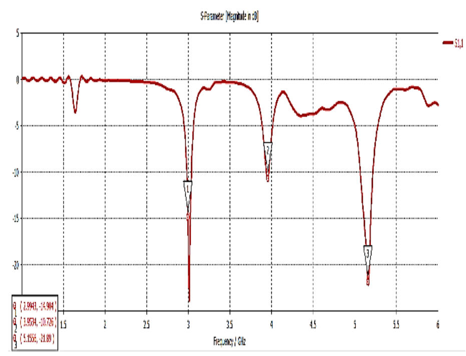


Fig.3 Reflection coefficient (S 11) of the new design

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B. Voltage Standing Wave Ratio (VSWR)

The antenna with less VSWR will perform better. Ideal value of VSWR is unity and it can be a maximum of 2 which is in acceptable range. The proposed design has better VSWR of 1.517, 1.816 and 1.173 for the multiband 2.9 GHz, 3.9 GHz and 5.1 GHz respectively, as shown in Fig. 4.

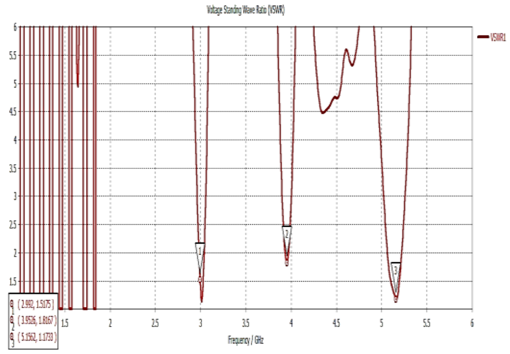


Fig. 4 VSWR Of The Proposed Design

C. Gain

Fig.5 shows the measured antenna gain versus frequency for the design with stubs. For the new design with stubs and slots has the better gain characteristics of 5.117 dB, 5.023 dB and 8.462 dB for the multiband 2.9 GHz, 3.9 GHz and 5.1 GHz respectively.

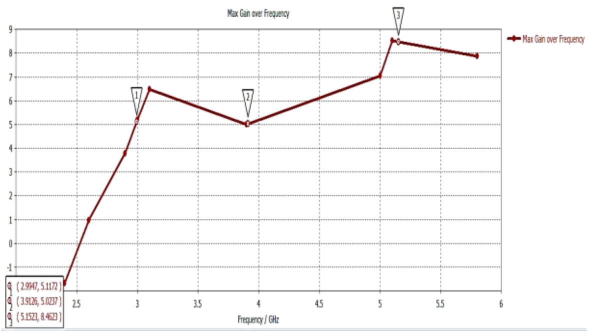
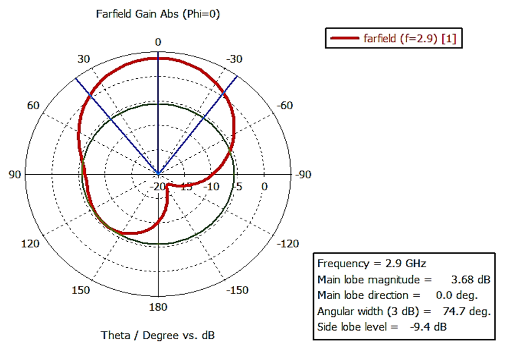


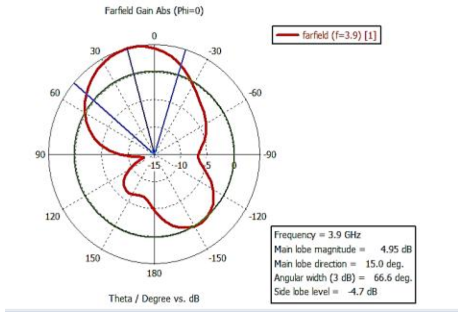
Fig. 5. Gain of the proposed design

D. Directivity

The directivity measured by an antenna should not be less than 5dBi [23]. Far field radiation pattern of the design at 2.9 GHz, 3.9 GHz and 5.1 GHz is shown in Fig.6 a), b) & c).



(a)



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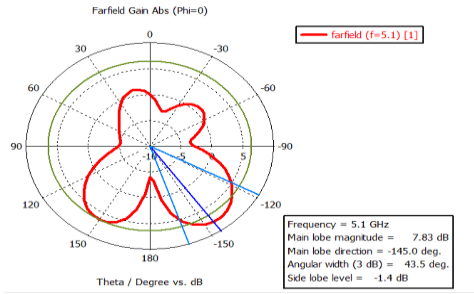


(c)

Fig. 6 Directivity a) 2.9 GHz b) 3.9 GHz c) 5.1 GHz

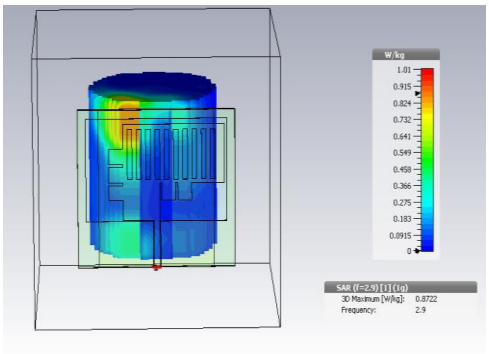
The simulated results of the design such as S11, VSWR, Gain and Directivity are shown in Table 3.

Frequency (GHz)	Reflection Coefficient(S_{11}) (dB)	VSWR	Gain (dB)	Directivity (dB)
2.9	-14.904	1.517	5.117	3.68
3.9	-10.726	1.816	5.023	4.95
5.1	-21.89	1.173	8.462	7.83

Table 3: Proposed Design Simulation Results Frequency

E. SAR Analysis

For better health to be maintained Specific Absorption Rate(SAR) calculation needs to be done since the wearable antennas are in close contact to the human body. CST MWS version 2017 is used for modelling and SAR analysis. Results of SAR average over 1 g for 2.9 GHZ, 3.9 GHz and 5.1 GHz bands are shown graphically in Fig. 7.



(a)

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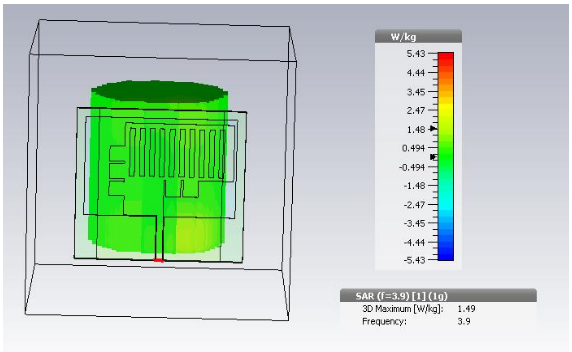

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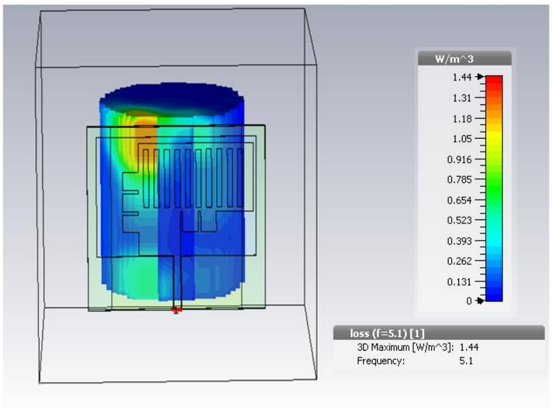

(c)

Fig. 7 : SAR analysis using voxel model a) at 2.9 GHz, b) at 3.9 GHz, c) at 5.1 GHz.

The maximum Specific Absorption Rate (SAR) averaged over 1g of tissue using Voxel model is analyzed for wearable multiband rectangular slot antenna operating in the 2.9 GHZ, 3.9 GHz and 5.1 GHz frequency bands. The SAR over 1 g is about 0.8722, 1.49, 1.44 for 2.9 GHZ, 3.9 GHz and 5.1 GHz bands respectively.

IV. MEASURED RESULTS AFTER FABRICATION

The proposed wearable multiband rectangular slot antenna was validated by simulating the antenna reflection coefficient against frequency. CST is used for measuring S11, VSWR etc., and is also used for calculating the SAR. The obtained results are analyzed using VNA. Fig.8 (a) & (b) shows the front and back side of the fabricated design of the multiband wearable rectangular slot antenna with the denim substrate and SMA connector soldered carefully on conductive silver patch.

(a)

(b)

Fig. 8: Fabricated Textile Antenna. a) Front View b) Back View

A. Experimental Setup

The multiband wearable antenna is tested using the VNA. Fig. 4.8 shows the tested result of antenna in the measuring device of network analyzer with Subminiature Version A (SMA) connector, which has the impedance of 50Ω.

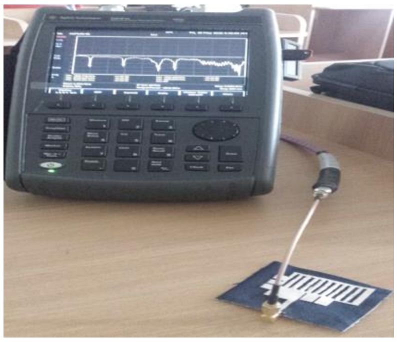

Fig. 9: Experimental Setup.

B. Measured Reflection Coefficient

The wearable multiband rectangular slot antenna resonating at different frequencies having the reflection coefficient of -14.99 dB, -13.22 dB, -17.08 dB, -15.63 dB and -10.12 dB for 1.5 GHz, 2.7 GHz, 3.9 GHZ, 4.5GHz and 5.5 GHz respectively. Fig.10 shows the experimental reflection coefficient plot of antenna with denim substrate.

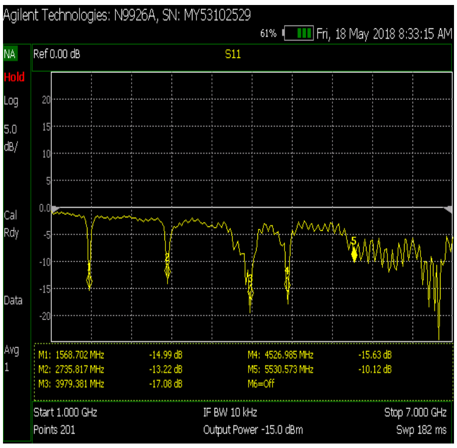

Fig .10: Reflection Coefficient of the Fabricated Textile Antenna

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C. Measured VSWR

Fig. 11 shows the experimental VSWR plot of the fabricated design. The fabricated design have different resonant frequencies and having the VSWR of 1.532, 1.639, 1.383, 1.428 and 1.909 for 1.5 GHz, 2.7 GHz, 3.9 GHz, 4.5 GHz and 5.5 GHz respectively.

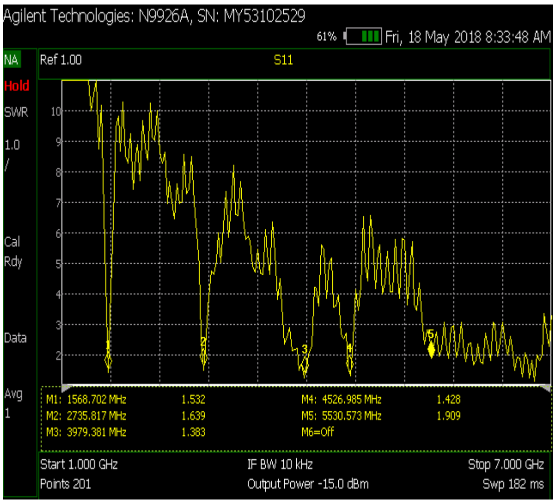

Fig. 11: VSWR of the Fabricated Textile Antenna

The parameters of the fabricated design such as Reflection Coefficient (S11) and VSWR are shown in Table 4.

Frequency	Reflection Coefficient(S_{11})	VSWR
1.5 GHz	-14.99 dB	1.532
2.7 GHz	-13.22 dB	1.639
3.9 GHz	-17.08 dB	1.383
4.5 GHz	-15.63 dB	1.428
5.5 GHz	-10.12 dB	1.909

Table 4: Measured Parameters Of The Fabricated Design.

The slight difference between the simulated and tested results may be due to the material characteristics of the denim substrate and conducting material of silver sheet and also due to flexibility of textile material, fabrication tolerance, humidity, and temperature effect on denim substrate. It has been found that the exists a good correlation between simulated and experimental results.

V. CONCLUSION

A micro strip patch antenna for Wireless LAN and WIMAX applications has been designed and analyzed. The miniaturized multiband rectangular slot antenna with widened tuning stubs and narrow slots was proposed which is operating at the frequency of 2.9 GHz, 3.9 GHz and 5.1GHz for WiMAX and Wireless LAN. The substrate material was denim and conductive Silver was used as the radiating element. The antenna parameters like reflection coefficient, VSWR, gain and directivity have been evaluated in this project. It provides appropriate gain characteristics (5.117 dB, 5.023 dB and 8.462 dB) in the WLAN and WIMAX frequency region for multiband operation. The gain is good and suitable for the intended application. Based on the results obtained its been found that the design is well suited for application on any type of platform. This proposed work also analyzed the effects of EM radiation on the human body. The specific absorption rate (SAR) was measured from the antenna by using the voxel model. The average SAR values of the design are 0.8722 W/kg, 1.44 W/kg and 1.49 W/kg. Because of the low SAR values the new design can be used for communications and wearable applications.

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