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Design of Wearable Multiband Circular Microstrip Textile Antenna for WiFi/WiMAX Communication

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ABSTRACT: In proposed design the wearable circular microstrip antenna of radius of patch is 14 mm and the top of patch consist of two square slits of dimensions 5x5 mm^2 and 10x10mm^2 and the ground structure is made partial of 28mm x 86mm. Due to the properties of jeans fabric as low cost, flexible the antenna is made wearable. In the proposed study, circular microstrip textile based antenna has been designed for the ISM band of resonating frequency of 2.4GHz. The proposed structure provided the triple band as the radiating frequencies of 2.4GHz for WiFi, 6.4GHz for WiMAX and 12GHz for 5G communication applications. The simulated and fabricated results such as return loss, VSWR and gain - directivity etc. are analyzed and compared for the frequencies of 2.38GHz, 6.4GHz and 12GHz. In this proposed antenna, the bandwidths of antenna are obtained of the order 700MHz, 3.43GHz & 2.75GHz and gain of antenna are of the order 1.89 dBi, 3.98 dBi & 4.86 dBi.

KEYWORDS: Circular Microstrip, Multiband, Return Loss, Wi-Fi, WiMAX.

1. INTRODUCTION

Wireless communication technology is progressively passing through everybody life. In the present wireless communication wearable antenna (Microstrip Textile Antenna) plays important role due to their structural and light weight characteristics. The emerging trend in the wireless communication technology and increasing interest in the wearable antenna in the field of applications such as medical, rescue and military etc. In the field of wireless communication the light weight antennas are preferred and in this application the antenna gain & efficiency is kept very high. As antenna theory says the gain and efficiency are proportionally dependent on each other. The fast growth in wearable communication has boosted the need of very small and wide bandwidth antennas. The circular shaped MTA (Microstrip Textile Antenna) well preferred over other structure due to their properties of compact in size, cost effective and ease in fabrication. Nowadays in the wireless communication the multiband antennas are used for mobile applications and Ultra wideband applications.

The frequency range of ISM band is from 2.4GHz to 2.485GHz & used for Wi-Fi communication. The mobile WiMAX is used in three operating frequencies from 2.3-2.4GHz, 2.5- 2.7GHz and 3.4- 3.6GHz. As per the IEEE 802.11 to 16, the WiMAX is used in broadband wireless communication. The frequency band allocated to WiMAX IEEE 802.16a is varying from 10 – 16GHz and for IEEE 802.16d or IEEE802.16-2004 varies from 2- 11GHz. This frequency band is implemented to interface with OFDM or OFDMA for broadband wireless communication.

Nikhil Kumar Singh. et al. (2016) observed that proposed antenna operating at three frequency bands of 3.42GHz, 9.73GHz & 11.17GHz and it has been used for multiband application. The wearable antenna has been designed on jeans material and used for on human body communication [1].

H.K.Bhaldar. et al. (2020) studied the microstrip textile antenna for Wi-Fi communication and antenna has been resonating at frequency of 2.45GHz & provided return loss of -15.76dB with directivity of 8.05. The antenna is designed with rectangular shape & jean as dielectric material to get wide bandwidth [2]. Carlos. et al. (2018) designed on body wearable antenna designed at ISM band of frequency 2.45GHz & radiated at -18dB of return loss & also a robust snap on button textile antenna designed at 2.45GHz and provided return loss of -25dB [3,4]. Pranita Manish et al. (2018) observed and analyzed the microstrip textile antenna simulated at 2.45GHz with different dielectric fabric materials such as Cotton, Polyester, Cordura and Lycra. The values of return losses at 2.45 GHz frequency for respective textile material have studied -32dB, -35dB,-29dB and -31dB [5].

Anurag Saxena. et al. (2018) designed the antenna operating at the multiple frequencies from 5.3GHz to 10.15GHz and provided the bandwidth of 62.78%, return loss of -25dB at 5.44GHz & -24db at 8.05GHz. The author used the moon strip line structure of patch [6]. Idellyse and Rama Reddy. et al.(2018) proposed the circular polarized textile antenna and U slot conical antenna which is designed at ISM band of frequency range 2.4GHz to 2.45GHz, the values of S11 parameter -35dB & -20dB are observed at resonating frequency[7-8].

Sweety Purohit. et al. (2014) simulated the light weight wearable antenna using jeans material at the resonant frequency of 2.45GHz. When antenna used for on body communication, the SAR is very important parameter considered for wearable application and the standard SAR value used is of 1.6 W/kg of tissue [9]. Jiahao Zhang et.al (2017) observed the miniature feeding network for aperture coupled antennas designed at frequency of 2.4GHz – 2.483GHz with gain of 5.6dBi. The author have studied various shapes of coupling aperture such as ring, H-shaped, rectangular, E shaped, cross etc. at various frequencies in ISM band [10].

The Yiye Sun. et al. (2014) designed the circular patch with thin feed line and has rectangular ground plane. The bandwidth of designed antenna has been enhanced due to use of tapered feed line. The proposed antenna used at ultra-wide band application for frequency range of 2.8GHz to 16GHz [11]. Punith S. et al. (2020) studied and the implemented the multiband antenna resonating at 23.9GHz, 35.5GHz and 70.9 GHz and used for 5G communication. The antenna has been analyzed to achieve the return losses of -19.97dB, -22.73dB and -21.96dB for the above mentioned operating frequencies [12]. S. Kumar. et al. (2018) analyzed and implemented the co-planar fed antenna at ISM band for implantable on the body with bio sensor for on body communication. The proposed antenna designed with loop structure and it is radiating with return loss of -37dB [13]. Seyed Mohsen. et al. (2019) designed the multiband CPW fed microstrip wearable antenna for operating frequency of 3.2GHz to 16.3GHz for ultra-wide band application.

The compact antenna is implemented on the body and in the air; the efficiency observed on the body is greater than in the air located antenna [14]. Sandeep Singh Sran. et al. (2020) studied and analyzed the wearable fractal antenna operating at 2.53GHz, 4.9GHz and 7.6GHz for S, C, and X band application. The proposed antenna improved the gain and bandwidth at these resonant frequencies [15]. A. Deviovanni. et al. (2018) proposed the high gradient linacs for hadron therapy for the frequency range of 3 to 5.7GHz. The proton beams are radiated by using hadron therapy with energies 70 and 230Mev [16].

After doing the literature survey, the proposed antenna design focused on the improvement of the gain and bandwidth of antenna.

2. METHODOLOGY

2.1 Microstrip Antenna

Microstrip antenna is most preferred antenna among all printed antenna due to its properties such as light in weight, low cost & ease of installation. In today's era microstrip patch antenna widely used for wireless communication. The geometry of microstrip patch antenna consist of top patch & bottom ground plane separated by dielectric materials such as FR4, Rogger etc. as shown in figure 1. In case of wireless applications, the various structures of microstrip patch antenna are used such as square, rectangular, circular and triangular etc.

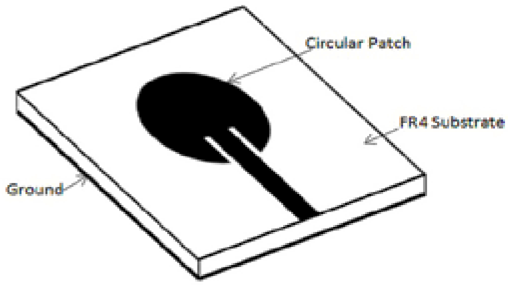


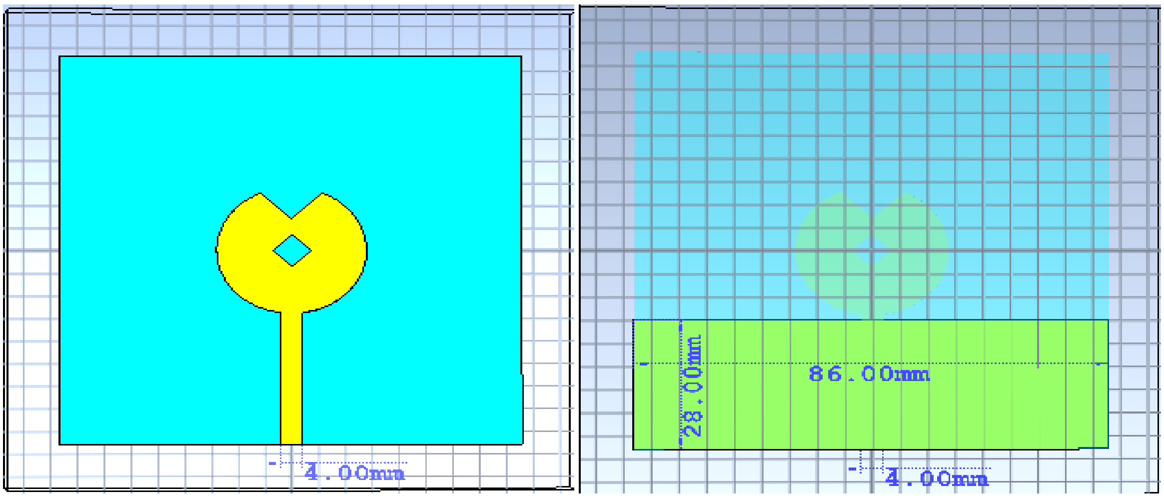
Figure 1: Microstrip Patch Antenna

2.2 Proposed Model

The proposed circular microstrip textile antenna has been designed for Wi-Fi communication at the frequency of 2.4 GHz with radius of patch 14mm is calculated as shown in equation 1.The figure 2a shows geometry of designed circular antenna which consist of top patch with two square slits of dimensions 5mm x5mm and 10mm x10mm provide the extra frequency band. The one more extra frequency band have been achieved by using partial ground of partial ground of 86mm x 28mm which is shown in figure 2b. The circular microstrip textile antenna has made with copper foil of thickness 35micron and the dielectric substrate used as jean material with relative permittivity of 1.7 & height of material 1mm. The designed antenna is excited with voltage source connected to microstrip feed line of impedance 55 ohm. The study of microstrip antenna stated that, the inverse relation between the bandwidth and the dielectric constant ε_r. When the dielectric constant value is decreasing, the bandwidth of antenna is increasing. So this method is implemented proposed study of antenna design.

It has been observed that the proposed geometry of antenna radiating at two extra bands of frequencies 6.4GHz & 12GHz which is used for WiMAX and 5G communication. The 5G communication band can be used from 3.5GHz to 300GHz & the WiMAX frequency band used from 2GHz to 8GHz. So proposed antenna have provided the three frequency bands 2.32GHz, 6.4GHz & 11.95GHz used for Wi-Fi, WiMAX & 5G communication. The designed antenna is compact in size and provided enhanced bandwidth which is requirement of wearable application.

The proposed microstrip textile antenna has been simulated in CST microwave studio software and the various antenna parameters have been analyzed. The figure 3 shows geometry of fabricated microstrip textile antenna and it is tested using VNA of 20GHz frequency.



2a 2b

Figure 2: Proposed antenna 2a: Top patch of proposed antenna & 2b: Ground plane of proposed antenna

Figure 3: Fabricated circular microstrip textile antenna.

The radius of circular patch microstrip antenna is calculated for resonant frequency of 2.4GHz & dielectric constant of 1.7 by using equation 1[2].

$$\mathbf{f_{mn}} = \frac{c}{2\pi a\sqrt{\varepsilon r}}\mathbf{x_{mn}} \qquad \text{eq (1)}$$

Where $\mathbf{c} = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$ speed of light

F_{mn} = Resonating frequency for mn mode

a = Radius of patch

x_{mn}= Constant for mn mode

εr= Relative dielectric constant of substrate

The table 1 shows that the list of antenna parameter used design circular microstrip antenna

Table 1: List of Antenna Parameter

Antenna Parameter	Value
Dielectric constant εr	1.7
Radius of patch a	14mm
Length of slitL1	5mm
Width of slit W1	5mm
Length of slitL2	10mm
Width of slit W2	10mm

Ground plane length Lg	28mm
Ground plane width Wg	86mm
Width of feed line Wf	4mm
Substrate height hs	1mm
Substrate thickness ht	0.035mm

3. **Result & Discussion**: In order to get best analysis & validation, the comparison of simulated and the measured return loss, VSWR and bandwidth values of proposed antenna are discussed.

I) Return Loss: For the perfect radiation the value of return loss must be maintained at minimum -10dB. From figure 4, it has been observed that designed antenna have provided the triple bands & the values of return losses are -31.827dB at a frequency of 2.3268GHz, -20.227dB at a frequency of 6.47GHz and -14.42 dB at a frequency of 11.952GHz. The bandwidths observed at these frequency bands are 0.7GHz, 3.43GHz and 2.75GHz at -10dB of the return loss plot. The above said bandwidths have been enhanced by using low value of dielectric constant of jean and partial ground structure. The simulated and fabricated results are also achieved same which is shown in figure 5 and table no. 3.

The fractional bandwidth also calculated using formula

$$\%\text{Fractional BW} = F_H - F_L / F_c \qquad \text{eq (2)}$$

The results of fractional bandwidths are shown table 2 & 3 of simulated results and fabricated results.

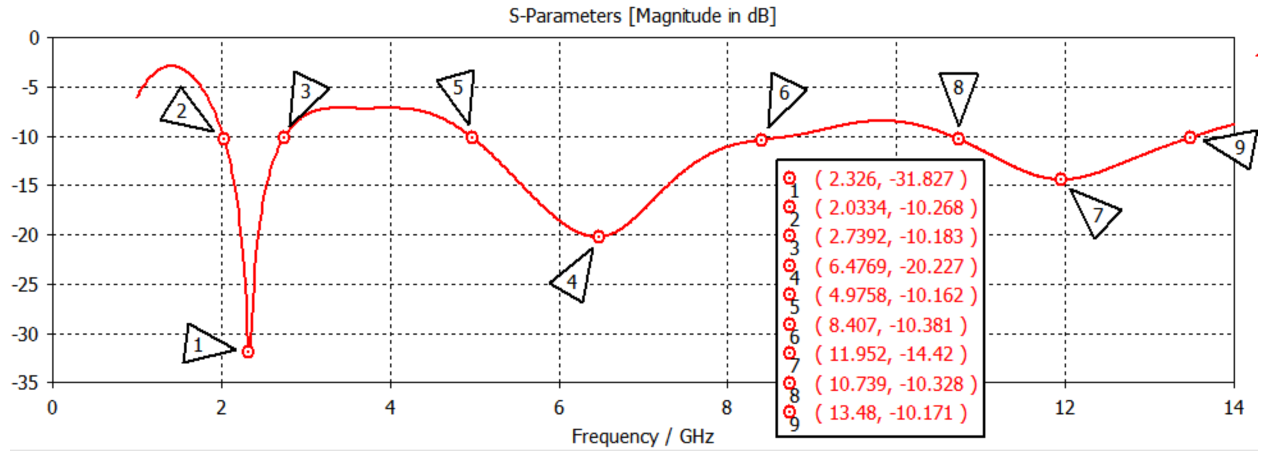


Figure 4: Return Loss in dB at 2.32GHz, 6.47GHz & 11.95GHz

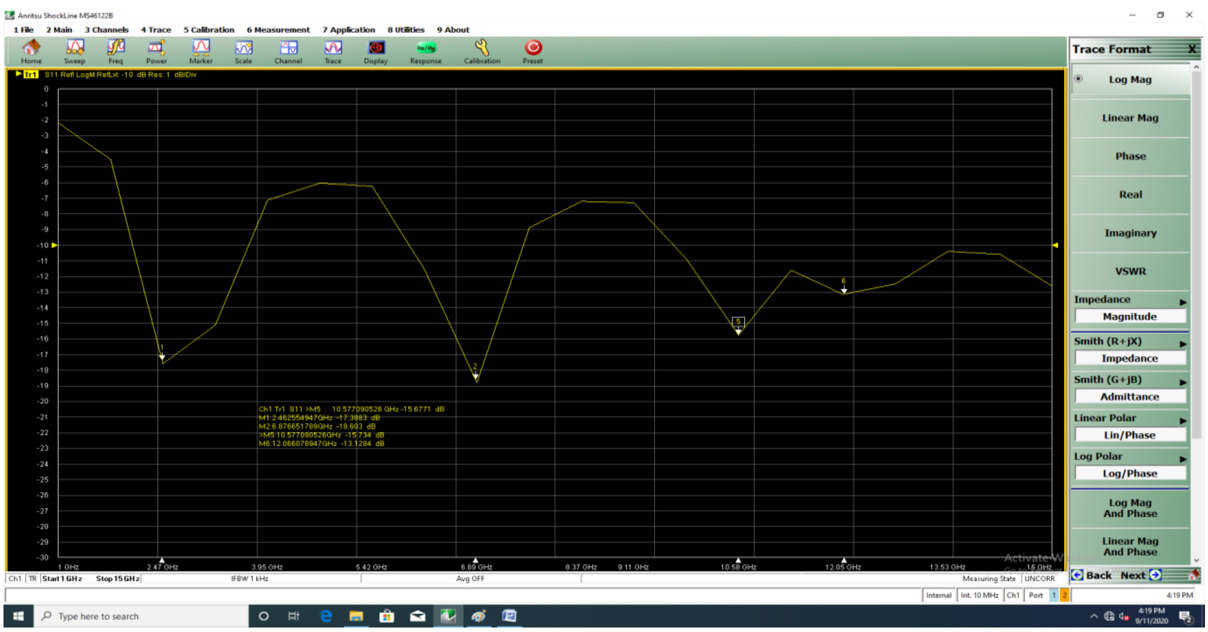
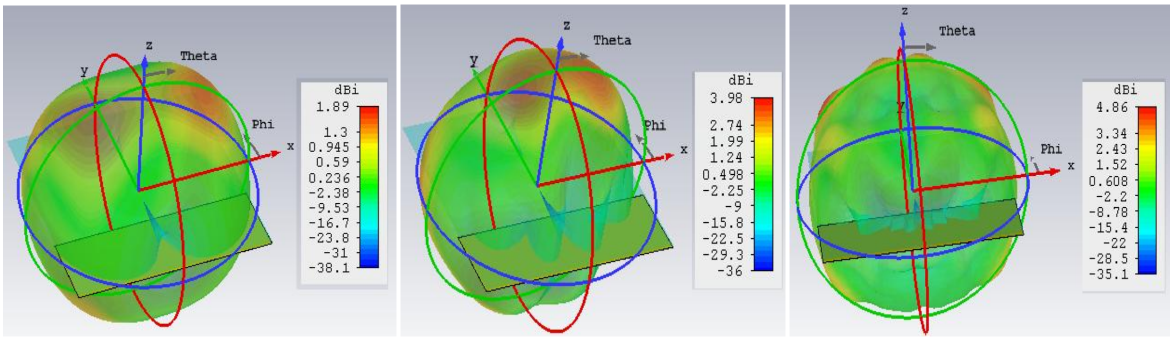


Figure 5: Return Loss of fabricated antenna tested on VNA

Table 2: comparison of simulated & fabricated results

Sr. No.	Parameter	Resonating Frequency (GHz)	S11 in dB	VSWR	Bandwidth in GHz	% Fractional BW
1	Simulated	2.32, 6.47 & 11.95	-31.8,-20.2 & -14.4	1.05, 1.21 & 1.46	0.7, 3.43 & 2.75	30.17, 53 & 23
2	Fabricated	2.46, 6.87 & 12	-15.1, -17.3 & -13.7	1.6, 1.2 & 1.5	1.66, 1.2 & 4.03	67.4, 17.4 & 33.5

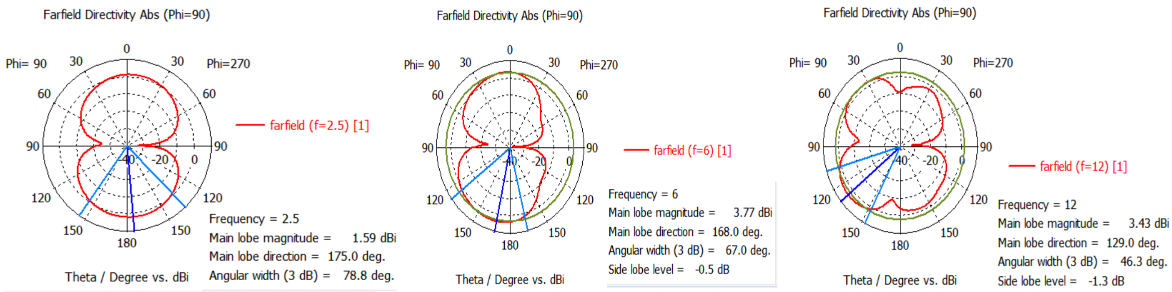
II) 3D radiation pattern antenna: It has been observed that, From the figure 6, 3D radiation pattern of the antenna have provided high directivities of 1.89 dBi, 3.98 dBi & 4.86 dBi at the frequencies of 2.4GHz, 6.47GHz & 12GHz.



6a 6b 6c

Figure 6: 3D Radiation pattern the antenna at three bands: 6a: 2.4GHz, 6b: 6.47GHz & 6c: 11.95GHz.

III) 2D radiation pattern of antenna: From the figure 7, it has been stated that the main lobe direction of 175˚& angular bandwidth of 78.8˚ with magnitude of 1.58dBi at frequency of 2.5GHz. Similar way the main lobe direction of 168˚and angular bandwidth of 67˚ with magnitude of 3.77dBi at frequency of 6GHz & side lobe level is of -0.5dB. And at 3rd band 12 GHz the main lobe direction of 129˚and angular bandwidth of 46.3˚ with magnitude of 3.43dBi at frequency of 6GHz & side lobe level is of -1.3dB. It has also observed from figure 7, that the back radiation is very small at these operating frequencies because of use of proper ground plane. The radiation pattern obtained is of end fire at 1st two bands and at 3rd band it is little bit Omni directional as shown figure 7a, 7b & 7c.

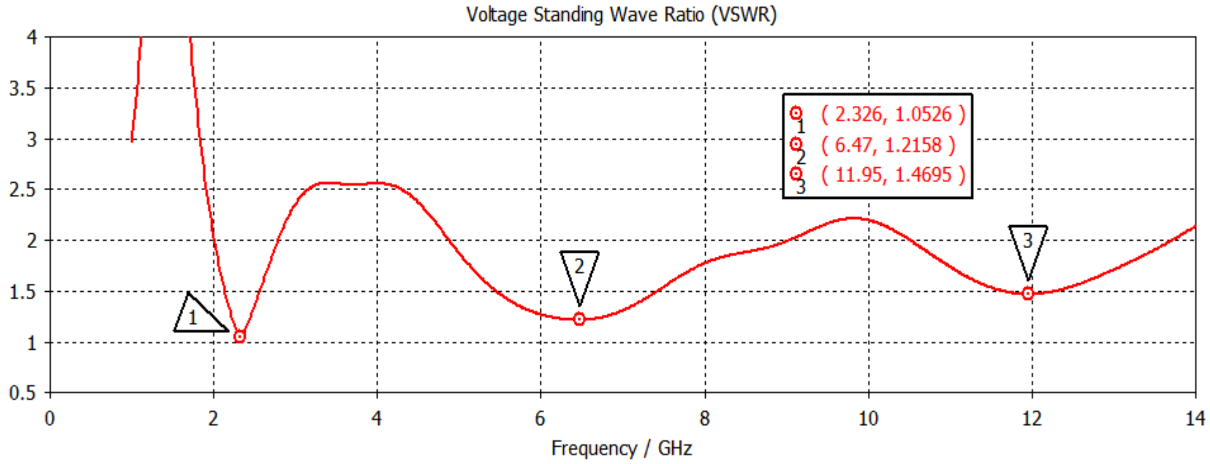


7a 7b 7c

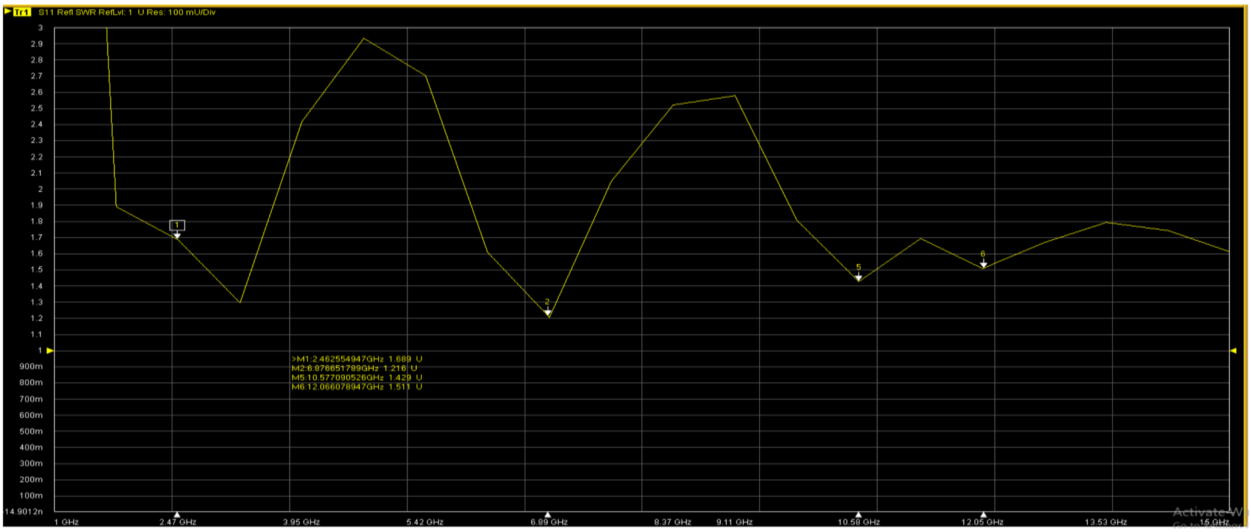
Figure 7: Polar plot of the proposed antenna at 7a: 2.5GHz, 7b: 6GHz & 7c: 12GHz

IV) VSWR of proposed antenna:

The figure 8 shows the VSWR plot & from this figure, it has been observed that the value of VSWR at three the frequencies 2.32GHz , 6.47GHz & 11.95GHz are 1.05, 1.21& 1.46 which are best for WiFi, WiMAX and 5G communication shown in figure 8a. The VSWR value describes the proper impedance matching between feed line & source applied so it must be used between 1 to 2 for proper radiation antenna. The VSWR vaules of fabricated antenna are 1.6, 1.2 and 1.5 at resonating frequancies of 2.46GHz, 6.87GHz and 12GHz, these values are perfeectly matched with simulated results shown in figure 8b.



8a



8b

Figure 8: VSWR of antenna, 8a: Simulated & 8b: Fabricated

V) Efficiency: The efficiency of antenna calculated by the ratio of power radiated by an antenna to the total input power fed to antenna.

The total efficiency differs from radiation efficiency due to losses takes place because of impedance mismatch.

$$\eta t = \eta r * ZI \qquad \text{eq (3)}$$

Where ηt = total effeciency, ηr = radiation effiecincy, ZI = Impendace mismatch loss.

From figure 9, it has been observed that the proposed antenna radiated at 3 frequancy bands. So the radiation and total efficiecy at three frequency bands are 78.83% & 76.61 at a frequency of 2.32GHz , 97. 98% & 95.63% at a frequency of 6.47GHz and 97.88% & 94.21% at 11.95GHz.

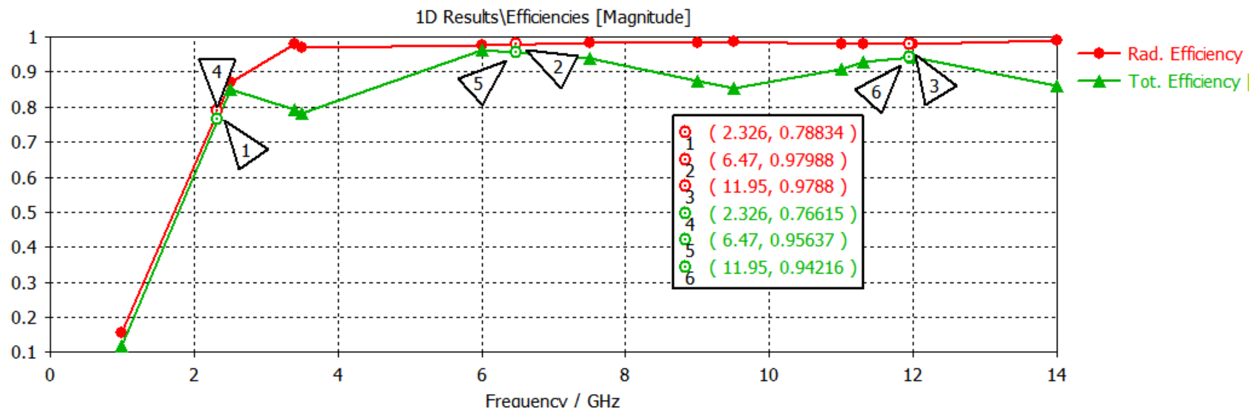


Figure 9: Radiation & total efficiency of the proposed antenna

4. **Fabricated Results:** The figure10 shows that return loss plot of fabricated antenna and from figure, it has been observed the fabricated antenna provides four frequency bands 1.75GHz, 3.95GHz, 7.6GHz and 12GHz. The proposed antenna provides simulated and tested results are nearly same. The fabricated antenna provides one extra band in comparison with simulated results. In fabricated results also the bandwidth is improved due to use of low dielectric constant, jeans as textile material and partial ground structure. The fabricated antenna is tested with Anthrusu VNA of 20GHz.

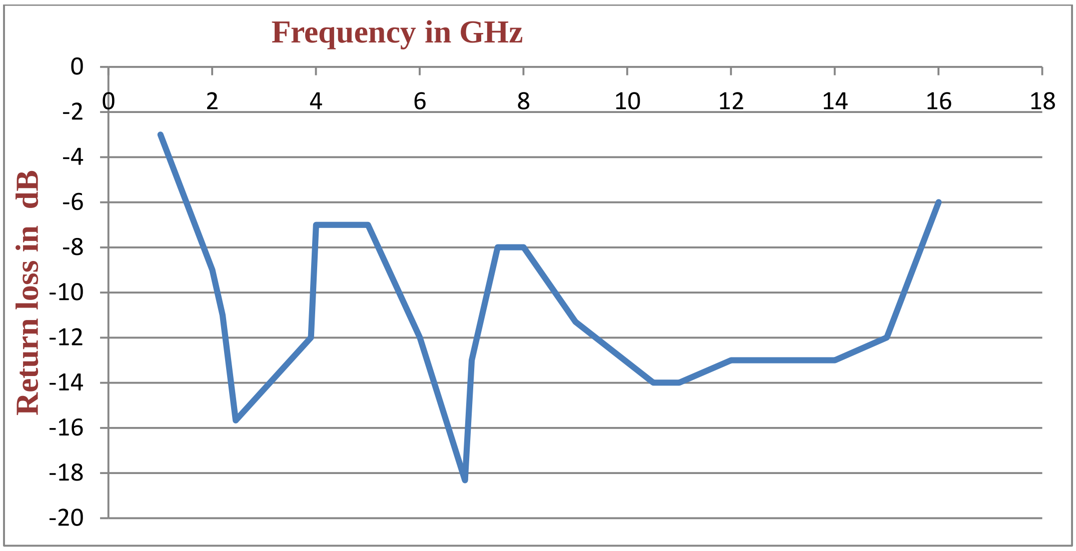


Figure 10: Return Loss of the fabricated antenna

The table 3 shows that the comparison of simulated results of designed antenna for three frequency bands and table 4 shows that the comparison of proposed work carried out & previous work done.

Table 3: Simulated Results

Sr No	Parameter	Proposed antenna			Textile antenna for microwave wireless power transmission
		Resonating Frequency (GHz)			Resonating Frequency (GHz)
		Fr1= 2.32	**Fr2=6.47**	**Fr3=11.95**	**3.42, 9.73 & 11.17**
1	Return loss S11 in dB	-31.827	-20.227	-14.420	-17, -18 & -26
2	VSWR	1.05	1.21	1.46	NA
3	Bandwidth	700MHz	3.43GHz	2.75GHz	50MHz, 200MHz & 700MHz
4	% Fractional Bandwidth	30.17	53.00	23.00	NA
5	Directivity in dBi	1.89	3.98	4.86	3.353, 4.2 & 5.1
6	Radiation Efficiency (%)	78.83	97.98	97.88	87.2
7	Total efficiency (%)	76.61	95.63	94.21	89.6

Table 4: Comparison between proposed antenna designs with other literature reported

Reference	Technique	Substrate and εr	Operating frequency GHz	Overall Dimensions mm	S11 Parameters dB	Bandwidth/ % Bandwidth	VSWR	Applications Mentioned
[1]	Circular shape & edge line feed	Jeans Er = 1.7	Triple bands 3.4, 9.7, 11.17	Radius 14 ground plane 86x30	-17, -18, -26	50MHz, 200MHz & 700MHz	NA	Wireless power transmission
[2]	Rectangular shape & Inset feed	Jeans εr = 1.67	Single band 2.45	W=45, L= 53, Hs=2.84 & full ground	-15.76	60MHz	1.38	Wi-Fi communication

[3]	Dual mode, Rectangular ring and inset feed	On body phantom	Single band 2.45	Patch 52.2 x 52.2 ground plane 80 x80	-31	NA	NA	On Body communication
[4]	Reconfigurable antenna, back to back snap on button	Foam with air	Dual band 2.45 & 5.8	L1= 60, W1= 55	-15 & -18	NA	Between 1 to 2	Wearable textile antenna
[5]	Rectangular patch for different substrate	Cotton 1.60, Polyester 1.90, Lycra 1.90 and Cordura 1.50	2.4	WxL= 46x53, 43x50, 43x50, 48x54	-32, -35, -29, -31	97, 40, 50, 48	2.4, 1.0879, 1.0944, 1.0917	NA
[6]	Moon strip shape for Multiband	Jeans εr = 1.7	5.44 & 10.15	Moon diameter 26 & substrate 50 x 50	-24 & -23	NA	NA	Satellite application
[7]	Circular – polarized textile antenna diamond shape	Thin textile spacer 1,65 to 1.75	ISM 2.4	Diamond s=23.3, ca=5.6,lg=17.28 line feed	-35	7.2% fractional	NA	Wearable garments
[8]	Dual band, rectangular dual L shape	Jeans cloth εr =1.7	Dual band 3.17 & 5.04	Wp =25, Lp= 40	-24, -18	100 & 30	1.86 & 1.79	Military
[9]	Wearable textile antenna	Jeans εr =1.6	2.45	Rectangular shape Wp=54, Lp=46.6	-32.57	NA	1 to 2	Wearable application
Proposed Work	**Circular shape with slits & partial ground**	**Jeans εr =1.7**	**Triple band 2.45, 6.47 & 11.95**	**Circular patch R=14, slits of 5x5 & 10x10, Ground plane 86 x 28**	**-31.8,-20.2 & -14.4**	**700, 3430 & 2750**	**1.05, 1.21 & 1.46**	**Wi-Fi, WiMAX & 5G communication**

5. CONCLUSION

In the proposed design, the circular microstrip textile antenna with edge feed has been designed at 2.4GHz frequency & provided return loss of -31.827dB. The designed antenna also provided the 2 additional bands of frequencies 6.47GHz & 11.95GHz due to use of 2 square slits and partial ground. The radiated efficiencies of antenna are 78.83%, 97.98% & 97.88 and total efficiencies are 76.61%, 95.63 & 94.21 at the frequency bands 2.32GHz, 6,47GHz & 11.95GHz. So it has been concluded that the proposed antenna is radiating with efficiency around 90% at multiple bands.

From the simulated and fabricated results, it is concluded the proposed antenna provided bandwidth improvement from 0.7GHz to 2.75GHz and both simulated & fabricated results are validated.

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