Design, Analysis and Fabrication of Dual Frequency Distinct Bandwidth Slot Loaded Wash Cotton Flexible Textile Antenna for ISM Band Applications

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Abstract—Wearable textile antenna is most appropriate for Wireless Body Area Network (WBAN) applications due to its flexibility, compactness, and user compatibility. Dual band antenna has advantage in duplex communication, hence it is desirable. In this paper, a dualband microstrip antenna is designed using textile material as a substrate with a circular patch and a rectangular patch. Methods from literature and experimentation are compared based on performance parameters. Slots are loaded on the patch to achieve dual-band characteristics. HFSS software has been used to simulate the proposed antenna, and the results are compared with the fabricated antenna based on Voltage Standing Wave Ratio (VSWR), directivity, return loss, gain, impedance, and radiation pattern. Since the antenna operates with close proximity to the human body, the Specific Absorption Rate (SAR) is also calculated using the CST software and is found within the prescribed limits.

1. INTRODUCTION

In any communication system, antenna serves as an important element for transmission and reception of signals. For applications such as Satellite and Radar which require a low profile and light weight antenna, microstrip antenna comes as a viable candidate. Gaining its popularity in the 1970's, microstrip antenna consists of certain advantages such as unique radiation properties, low cross polarization, and capability to have a multi-frequency operation. The antenna is made up of the radiating patch for transmitting the signal perpendicular to the plane of body and ground patch used for shielding the human body.

In near future, human is expected to carry a variety of communication devices and medical sensors to communicate with the system continuously. This can be achieved by using a wearable textile antenna [1]. The main feature of this antenna is low profile and planar structure [2]. So, the antenna has to be installed on the day-to-day clothing. Microstrip patch serves as a valuable option for wearable application as it can be easily integrated on the garment.

A comparative study is conducted to find the difference between the textile antenna and standard Printed Circuit Board (PCB) antenna at different frequencies [3, 13]. The performance of the textile antenna is very similar to that of the conventional antenna. Thus, wearable antennas are found in a variety of networks like dual-band dual-polarization, medical and space applications [4, 5]. A novel triple polarization wearable antenna is proposed in [6], which imposes a limited frequency band of 2.4 GHz to 2.45 GHz, and it can be used for WBAN application. This method also provides minimum separation for isolation which does not cause any mismatch during polarization. A textile antenna can be fabricated using conducting fabric or conductive threads [7]. A phantom equivalent of the human body is used to analyze the effects on the performance. The performance of the antenna remains unaffected by the

human body [8]. The latest research in wireless technology has paved the way for body-worn antennas. The radiating element may be any good conductor while the substrate is made up of different cloth materials. Different patch antennas made of textile materials having different resonating frequencies were proposed. These antennas need a large ground patch to restrict the harmful radiation to the human body [9]. The Industrial Scientific and Medical (ISM) band is used for the development of body-worn antennas [10]. Designing different antennas for different frequencies becomes more time-consuming and complex while integrating with systems. To overcome these existing challenges a novel dual-band application-specific antenna is presented in [11, 12]. The rectangular and circular shapes of patches are the most commonly used in microstrip antenna. A comparative study shows that the use of a rectangular patch gives better return loss and VSWR, comparatively higher bandwidth, and reduced sidelobe level. A monopole flexi antenna is presented in [14] used for the ISM frequency band with reduced return loss at the same time, and it is only able to achieve moderate gain. Another distinct E-structure antenna is proposed and fabricated using denim as a substrate with Co-Planner Waveguide (CPW) structure to achieve a good amount of gain. The authors suggest to have the CPW with the full ground to avoid the backward wave towards the human body [15]. The bending effect of textile antenna, the variation in radiation pattern, SAR & resonance of antenna are reported [16]. The dielectric constant of different textile substrates is also reported and can be used while antennas are designed [18].

2. NUMERICAL STUDY

Different shapes and sizes of patches are usually used in the design of a textile antenna. The rectangle and circle are commonly used shapes because of less complicated analysis and ease in fabrication. For the first resonance frequency, the equations for the rectangular and circular patches are defined [19].

For the rectangular patch, the width (W) and length (L) of the patch are calculated using Equations (1), (2), & (3).

$$W = \frac{1}{2f_r\sqrt{\varepsilon_0\mu_0}}\sqrt{\frac{2}{1+\varepsilon_r}} \tag{1}$$

$$L = \frac{1}{2f_r\sqrt{\varepsilon_{eff}}\sqrt{\varepsilon_0\mu_0}} - 0.824\frac{\left(\frac{w}{h}+0.264\right)(\varepsilon_{eff}+0.3)}{\left(\frac{w}{h}+0.8\right)(\varepsilon_{eff}-0.258)}h \tag{2}$$

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{w}\right]^{-\frac{1}{2}} \tag{3}$$

For the circular patch, the radius 'a' is given by Equations (4) & (5).

$$a = \frac{F}{\left\{1+\frac{2h}{\pi\varepsilon_rF}\left[\ln\left(\frac{\pi F}{2h}\right)+1.7726\right]\right\}^{-\frac{1}{2}}} \tag{4}$$

$$F = \frac{8.791\times10^9}{f_r\sqrt{\varepsilon_r}} \tag{5}$$

To obtain the second resonance frequency & desired dual-band Characteristics, slots are inserted on the patch. The insertion of slots causes a change in the current density of the microstrip antenna.

3. ANTENNA DESIGN

The proposed antenna is analyzed and simulated using HFSS software. The textile antenna is designed using a substrate of wash cotton having dielectric constant 1.51 and thickness 2 mm. The dual-band resonance frequencies considered in the design of antennas are 2.4 GHz and 5.8 GHz. The co-axial feeding technique is used for the excitation of the antennas. Slots are inserted in the patch, and the dimensions are optimized to achieve the required results. The position of the coaxial feed is also optimized to
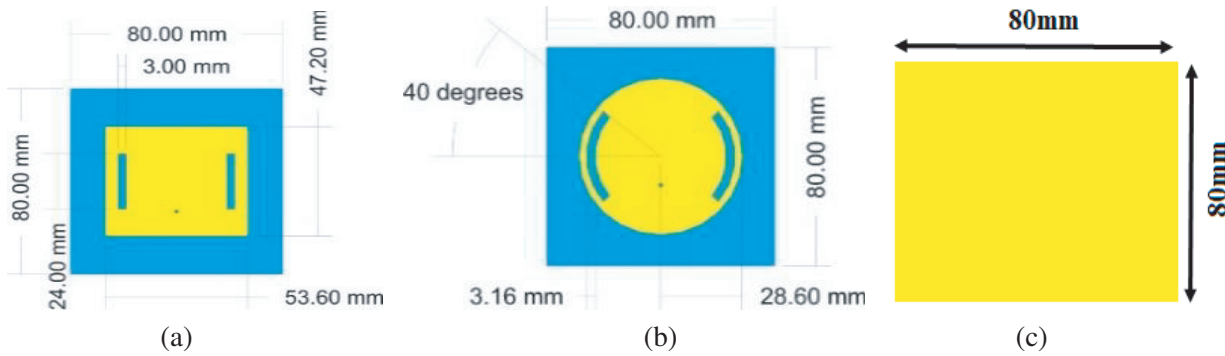
Figure 1. Slot loaded microstrip patch antenna. (a) Rectangular front view. (b) Circular front view. (c) Back view.

achieve the best result. The designed structure of the proposed antenna is shown in Figs. 1(a), (b) & (c).

The physical parameters of the antenna are summarized in Table 1.

Table 1. Physical parameters of antenna.

Parameters	Rectangular shape patch	Circular shape patch
Resonance frequency	Dual-band 2.4 GHz and 5.8 GHz	Dual-band 2.4 GHz and 5.8 GHz
Substrate material	Wash Cotton	Wash Cotton
Loss tangent	0.02	0.02
Size of substrate	$(80 \times 80 \times 2)\,\text{mm}^3$	$(80 \times 80 \times 2)\,\text{mm}^3$
Size of patch	$53.60\,\text{mm} \times 47.20\,\text{mm}$	$28.60\,\text{mm}$ (Radius)
Size of ground	$80\,\text{mm} \times 80\,\text{mm}$	$80\,\text{mm} \times 80\,\text{mm}$
Size of slots	$24\,\text{mm} \times 3\,\text{mm}$	Width $= 3.16\,\text{mm}$, inscribed Angle $= 80°$

The 3D structure of the designed rectangular and circular patch antenna is shown in Figs. 2(a) and (b). The performance of the antenna is evaluated using the parameters like return loss, VSWR, impedance, polarization, directivity, gain, and radiation pattern.
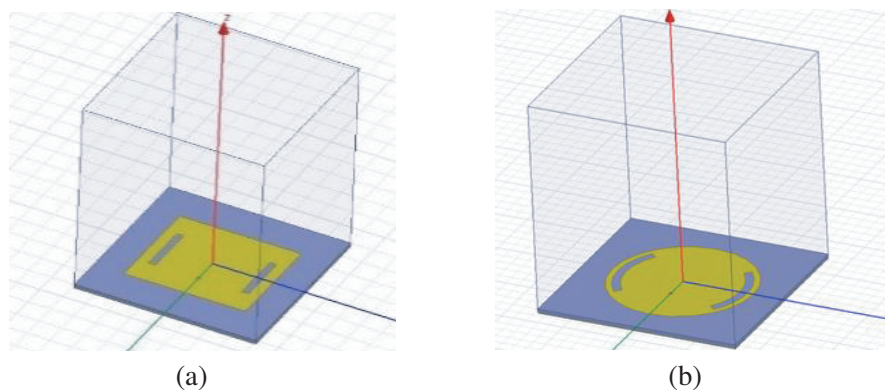

Figure 2. 3D view of slot loaded microstrip patch antenna. (a) Rectangular and (b) circular.

4. SIMULATION RESULTS

The frequency response of the antenna is observed in a frequency span from 1 GHz to 7 GHz. The return loss or S_{11} signifies the input reflection coefficient which specifies the part of the signal reflected at the port where the signal is applied. Ideally, return loss should be as low as possible for the resonance frequency of the antenna. As shown in Figs. 3(a) and (b), the return loss is at 2.4 GHz and 5.8 GHz–15 dB for the two antennas. Bandwidth measured is around 80 MHz and above 130 MHz for them.
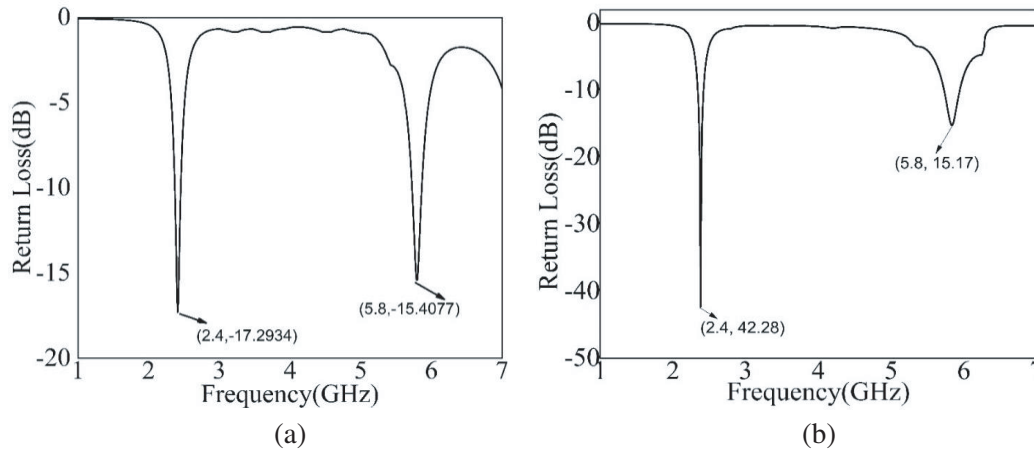

Figure 3. Return loss of slot loaded microstrip patch antenna. (a) Rectangular and (b) circular.

The VSWR is the ratio of the magnitude of signal maxima to the minima. Impedance mismatch causes the generation of standing waves in the transmission line affecting the efficiency of the antenna. The VSWR should be ideally 1 at the resonance frequency. The observed VSWR is 1.38 at 2.4 GHz and 1.48 at 5.8 GHz for rectangular slot loaded microstrip patch antenna as presented in Fig. 4(a). Also, the VSWR of circular slot loaded microstrip patch antenna is 1.17 at 2.4 GHz and 1.41 at 5.8 GHz, presented in Fig. 4(b).
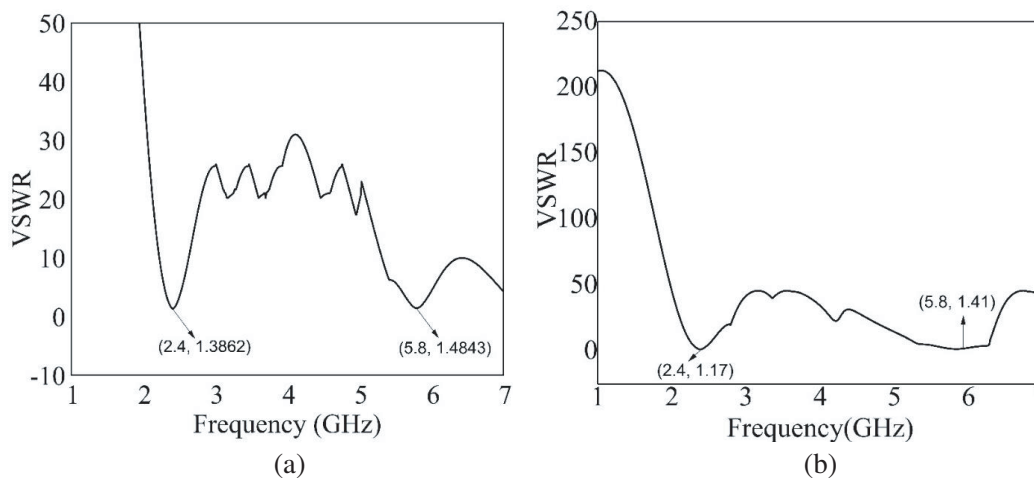

Figure 4. VSWR of slot loaded microstrip patch antenna. (a) Rectangular and (b) circular.

The polarization of the antenna is the relationship between components of the electric field vector and the direction of the incident signal. The obtained results of the axial ratio are above 3 dB, hence the polarization of the designed antenna is linear. For circular polarization, the axial ratio of antenna

should be below 3 dB, and if it is above 3 dB, the antenna becomes linearly polarized. The obtained results of axial ratio is above 3 dB, hence the polarizations of the designed antennas are linear, shown in Figs. 5(a) and (b).
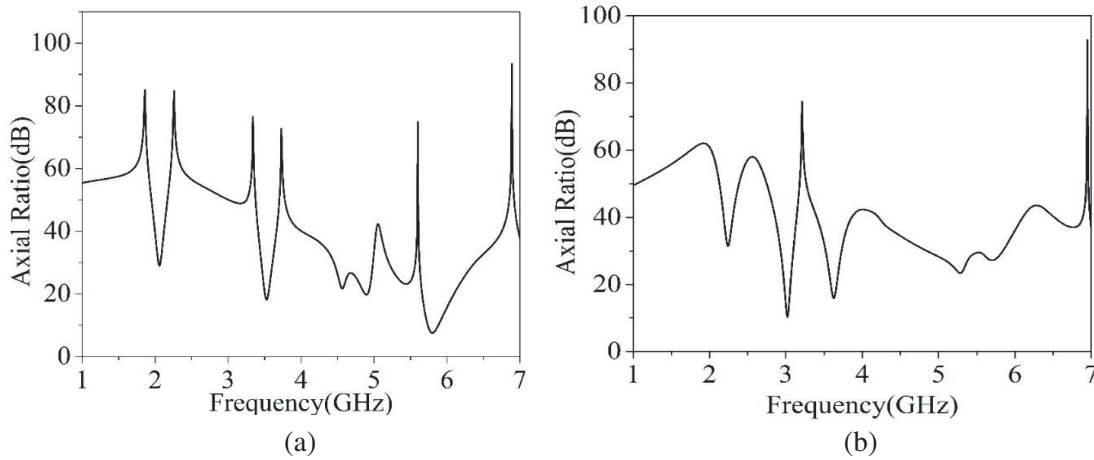

Figure 5. Axial Ratio of slot loaded microstrip patch antenna. (a) Rectangular and (b) circular.

Directivity of the antenna is the radiation of the signal in a particular direction as compared to other directions while the gain is closely related to directivity considering that the power required by the antenna is isotropic. The simulated directivity and gain of rectangular slot loaded microstrip patch antenna are 7.20 dB and 5.14 dB respectively at 2.4 GHz, and 9.03 dB and 7.14 dB respectively at 5.8 GHz which are shown in Figs. 6(a) and (b).
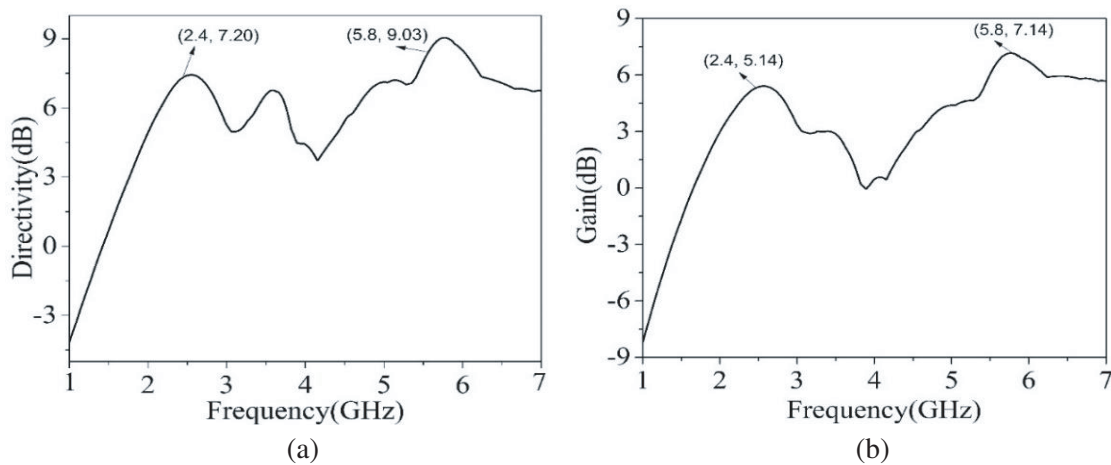

Figure 6. Rectangular slot loaded microstrip patch antenna. (a) Directivity and (b) gain.

Directivity of circular slot loaded microstrip patch antenna is 7.11 dB at 2.4 GHz and 7.48 dB at 5.8 GHz as shown in Fig. 7(a). The gain of circular slot loaded microstrip patch antenna is 5.03 dB at 2.4 GHz and 6.32 dB at 5.8 GHz as shown in Fig. 7(b).

Antenna impedance is closely associated with the efficiency. The impedance of the antenna should be equivalent to the characteristic impedance of the port for efficient transmission of the signal. As shown in Figs. 8(a) and (b), the impedance of the antennas at the resonating frequencies is found close to 50 Ω.

Figures 9(a) & 10(a) show omnidirectional radiation patterns with directivities of 7.20 dB and 7.11 dB for rectangular and circular slot loaded microstrip patch antennas at 2.4 GHz, respectively.
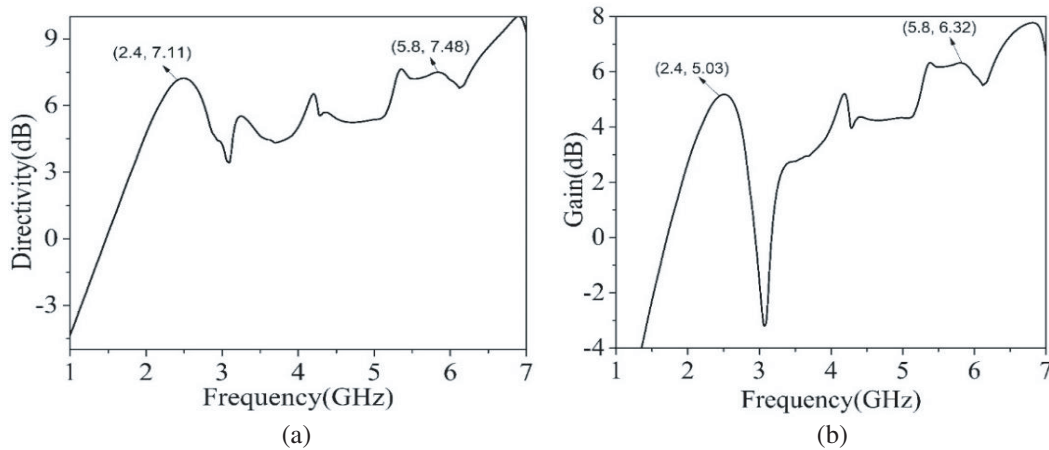
Figure 7. Circular slot loaded microstrip patch antenna. (a) Directivity and (b) gain.
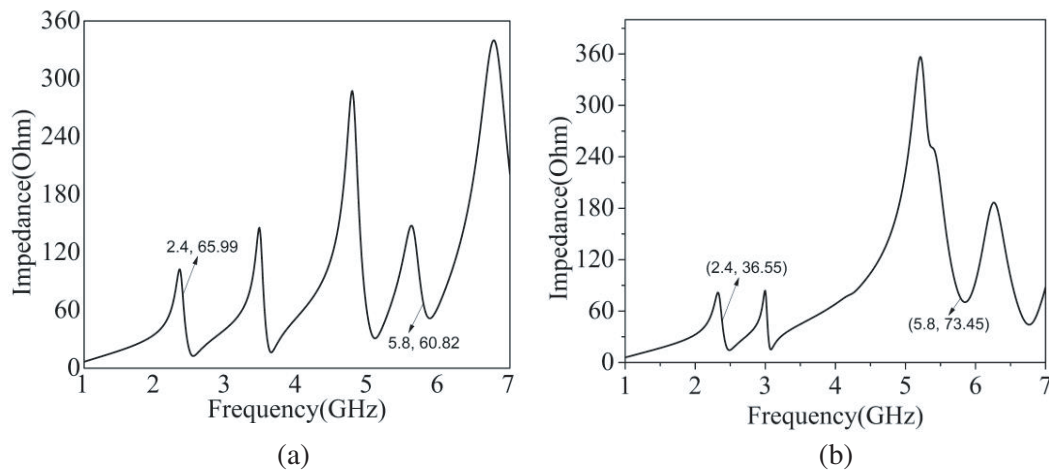

Figure 8. Impedance of slot loaded microstrip patch antenna. (a) Rectangular and (b) circular.

Fig. 9(b) and Fig. 10(b) show the radiation patterns with directivities of 9.02 dB and 7.48 dB for rectangular and circular slot loaded microstrip patch antennas at 5.8 GHz, respectively.

A phantom body is used to calculate the SAR in CST software. The antenna is placed on the chest of the phantom body with the ground patch facing towards the chest. The antenna is excited with 0.5 W power signal to observe the SAR. The SAR of both the simulated antennas are found well below the prescribed limit as seen in Fig. 11 and Fig. 12.

The simulated results of both antennas are summarized in Table 2.

5. RESULTS AND DISCUSSION

The fabrication of the antennas is done by using wash cotton as a substrate, and adhesive copper sheets are used as the patch. The copper sheet is cut precisely as per the dimensions and pasted to the substrate. SMA connector is used as a coaxial feed port. The fabricated antennas are shown in Figs. 13(a) and (b).

The testing of the antennas is conducted on R&S-ZVL Vector Network Analyzer (VNA), and the parameters like return loss, VSWR, and impedance are evaluated. The operating range of VNA is from 9 kHz to 13.6 GHz. The snapshots of the fabricated antenna with VNA while testing are shown in Figs. 14(a) and (b).
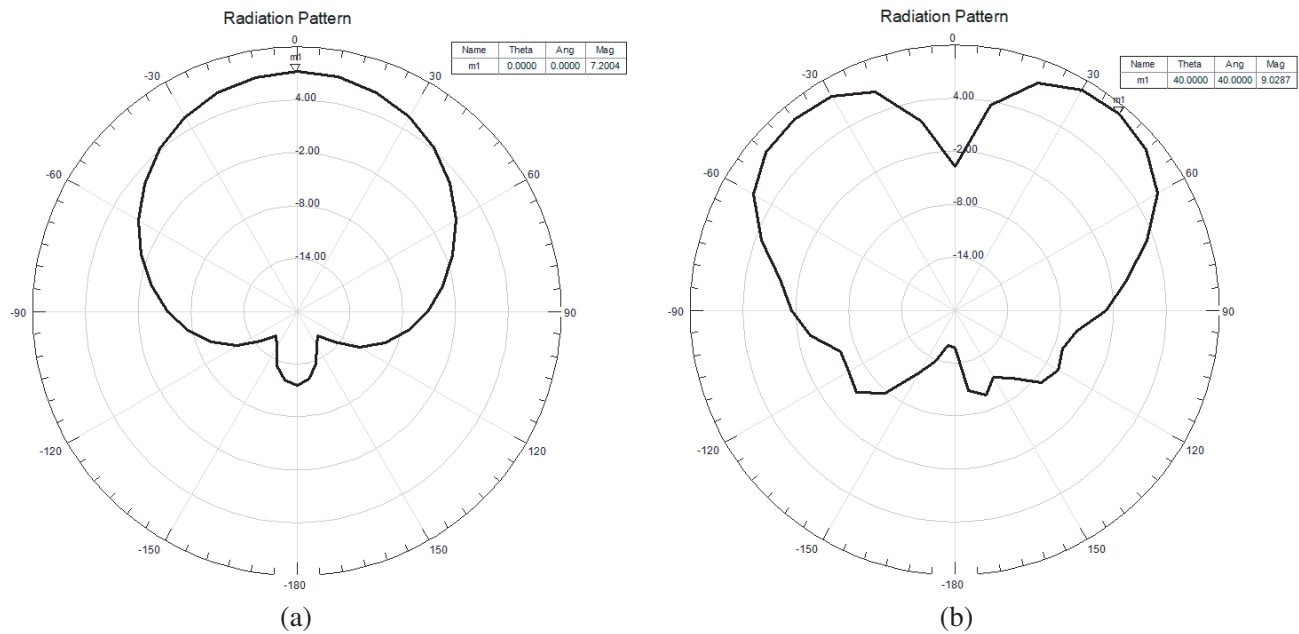
Figure 9. Radiation pattern of rectangular slot loaded microstrip patch antenna at (a) 2.4 GHz and (b) 5.8 GHz.
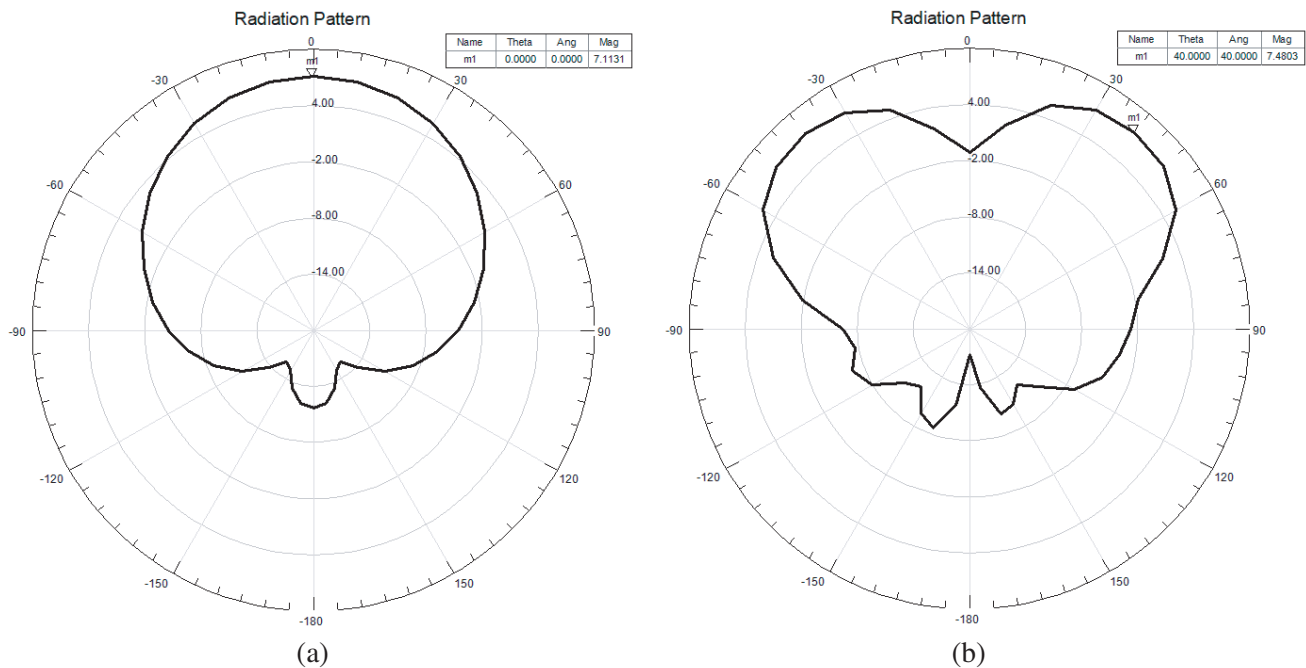

Figure 10. Radiation pattern of circular slot loaded microstrip patch antenna at (a) 2.4 GHz and (b) 5.8 GHz.

The obtained return loss of the rectangular slot loaded microstrip patch antenna is -16.272 dB and -13.771 dB at 2.4 GHz and 5.8 GHz, respectively. Similarly for circular slot loaded microstrip patch antenna, the return loss is -11.621 dB and -26.768 dB at 2.56 GHz and 6.02 GHz, respectively, which are in the desirable range and shown in Figs. 15(a) and (b).

The obtained VSWRs for rectangular slot loaded microstrip patch antenna are 1.374 and 1.457
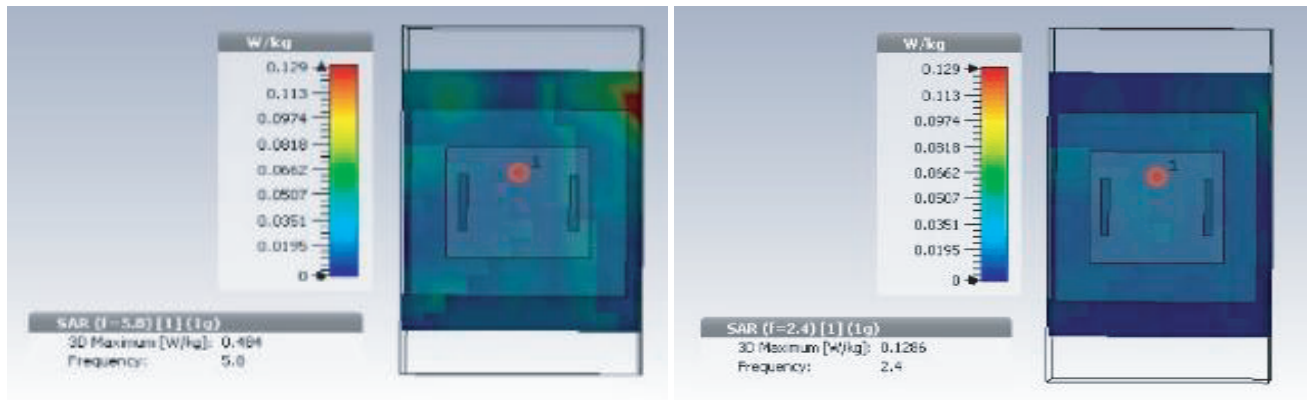
Figure 11. SAR of rectangular slot loaded microstrip patch antenna at 2.4 GHz and 5.8 GHz.
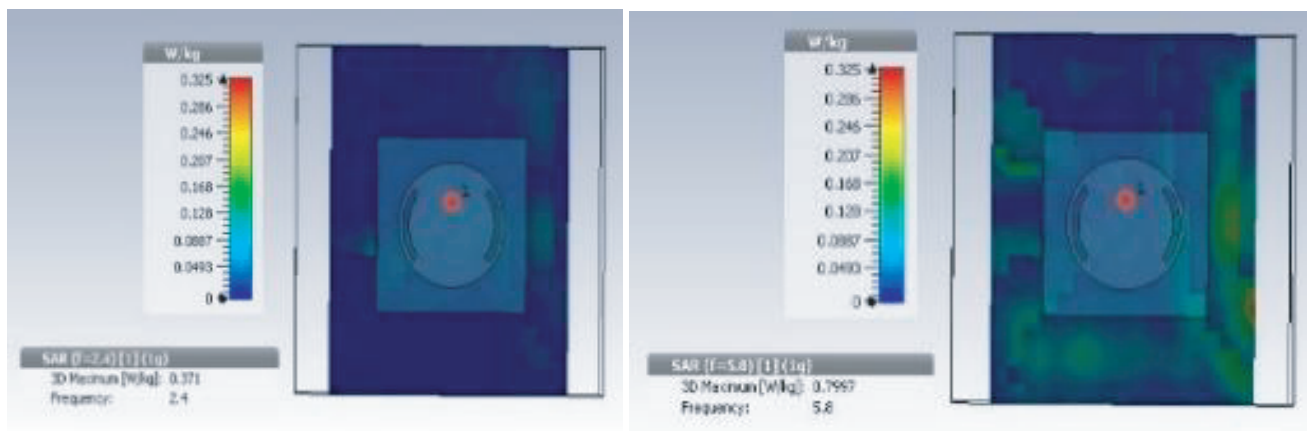

Figure 12. SAR of circular slot loaded microstrip patch antenna at 2.4 GHz and 5.8 GHz.

Table 2. Parameters of rectangular and circular slot loaded microstrip patch of antennas.

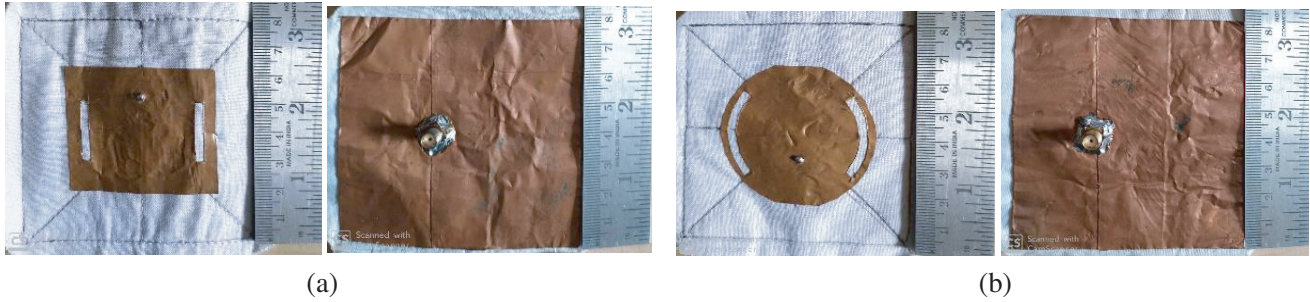| Parameters	Rectangular slot loaded microstrip patch antenna	Circular slot loaded microstrip patch antenna
Return Loss (dB)	−17.29 at 2.4 GHz	−42.28 at 2.4 GHz
	−15.40 at 5.8 GHz	−15.17 at 5.8 GHz
VSWR (dB)	1.38 at 2.4 GHz	1.17 at 2.4 GHz
	1.48 at 5.8 GHz	1.41 at 5.8 GHz
Gain (dB)	5.14 dB at 2.4 GHz	5.03 at 2.4 GHz
	7.14 dB at 5.8 GHz	6.32 at 5.8 GHz
Directivity (dB)	7.20 dB at 2.4 GHz	7.11 at 2.4 GHz
	9.02 dB at 5.8 GHz	7.48 at 5.8 GHz
Impedance	65.99 Ω at 2.4 GHz	36.55 Ω at 2.4 GHz
	60.82 Ω at 5.8 GHz	73.45 Ω at 5.8 GHz
SAR	0.128 W/kg @ 2.4 GHz	0.371 W/kg @ 2.4 GHz
	0.484 W/kg @ 5.8 GHz	0.799 W/kg @ 5.8 GHz

Figure 13. Front and back view of slot loaded fabricated microstrip patch antenna. (a) Rectangular and (b) circular.

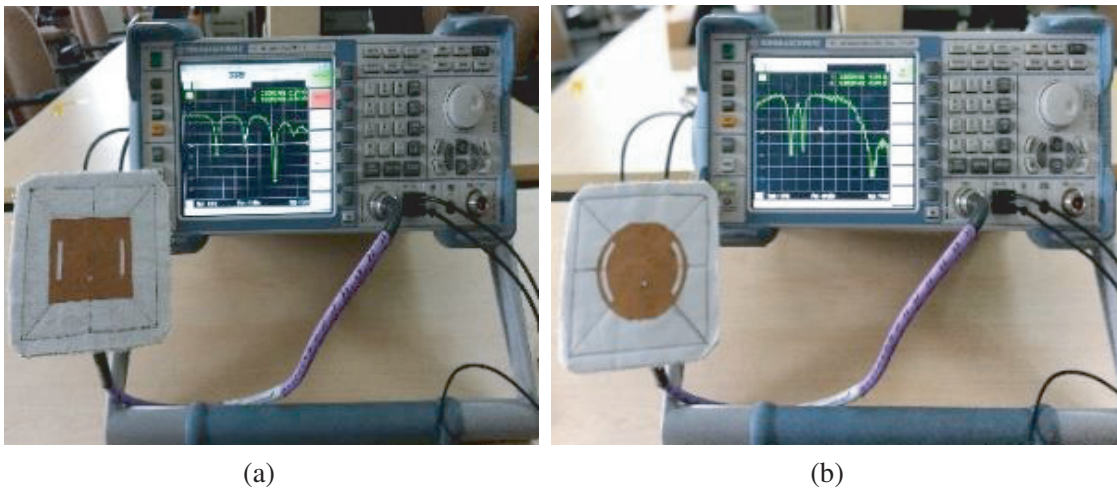**Figure 14.** Testing on Vector Network Analyzer of the fabricated antennas. (a) Rectangular and (b) circular.
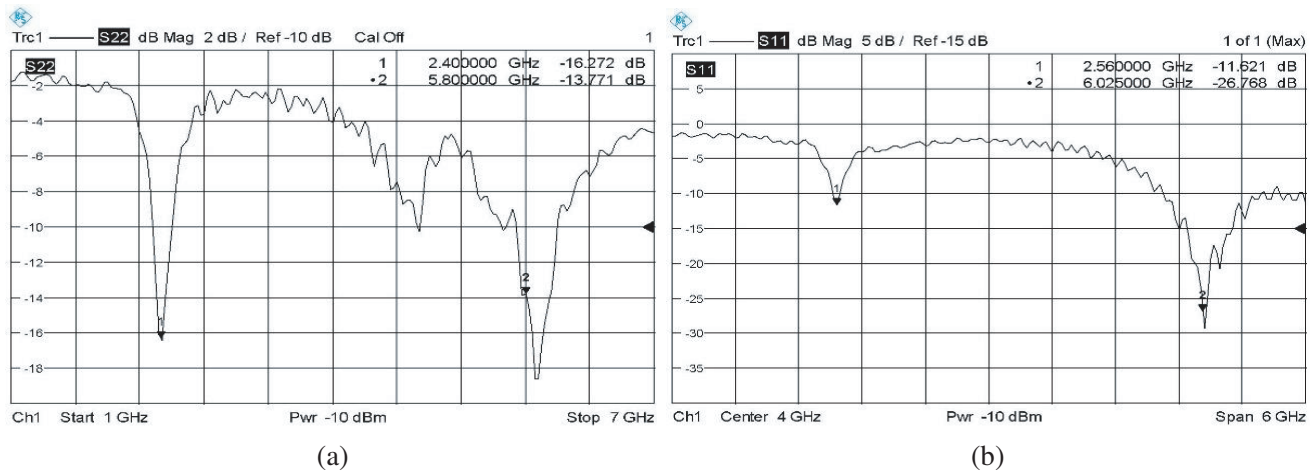

Figure 15. Return Loss of fabricated slot loaded microstrip patch antenna. (a) Rectangular. (b) Circular.

at 2.4 GHz and 5.8 GHz, respectively, as shown in Fig. 16(a). The obtained VSWRs are 1.736 and 1.153 for circular slot loaded microstrip patch antenna at 2.56 GHz and 6.02 GHz, respectively as shown Fig. 16(b).
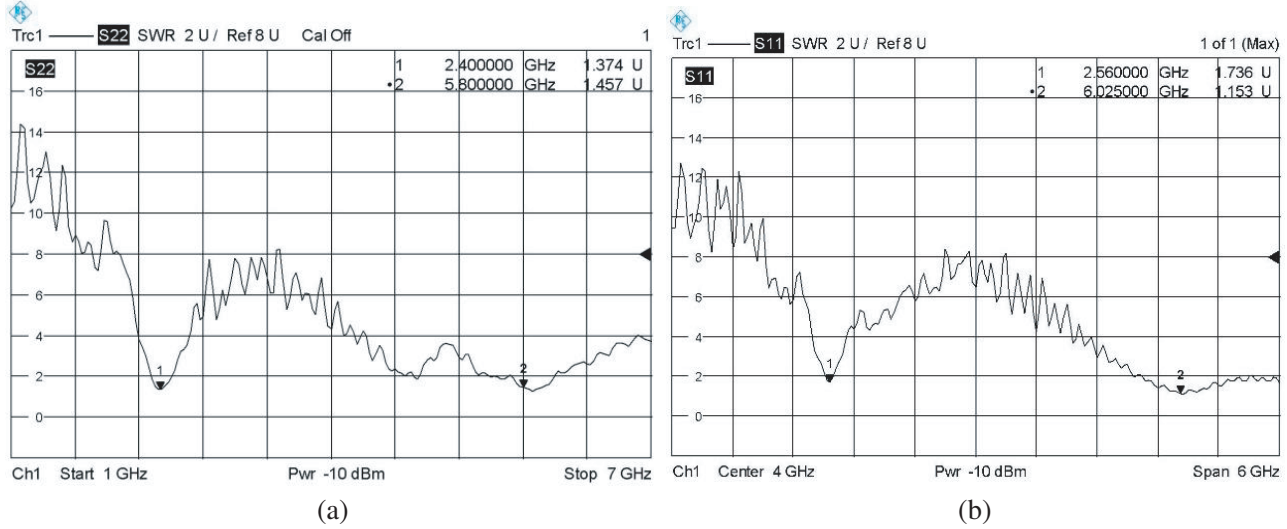
Figure 16. VSWR of fabricated slot loaded microstrip patch antenna. (a) Rectangular. (b) Circular.

With the help of Smith chart, the obtained impedance of rectangular slot loaded microstrip patch antenna is $54.076\,\Omega$, $42.473\,\Omega$ at $2.4\,\mathrm{GHz}$ and $5.8\,\mathrm{GHz}$, respectively as shown in Fig. 17(a). The obtained impedance is $32.147\,\Omega$ at $2.56\,\mathrm{GHz}$ and $36.122\,\Omega$ at $6.02\,\mathrm{GHz}$ for circular slot loaded microstrip patch antenna as shown in Fig. 17(b).
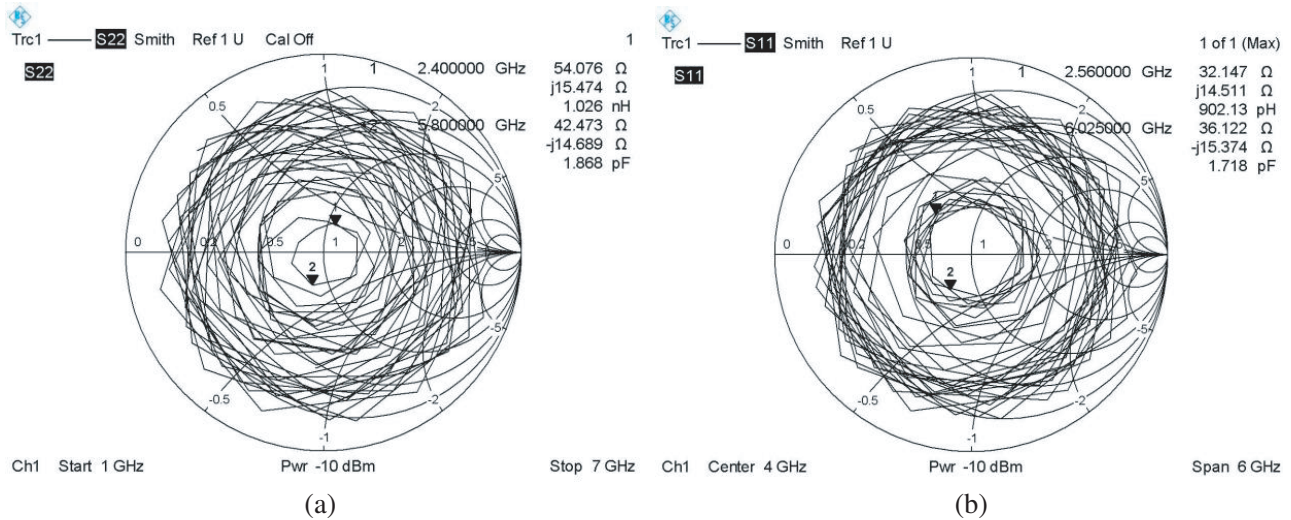
Figure 17. Impedance of fabricated slot loaded microstrip patch antenna. (a) Rectangular. (b) Circular.

The final results of both rectangular and circular slot fabricated antennas are summarized in Table 3. From the comparison, it is observed that the rectangular slot loaded microstrip patch antenna performs better than circular one. Also, the shift in resonance frequency of the fabricated circular slot microstrip patch antenna is observed due to rough curvature of circular copper patch and slots.

6. COMPARATIVE ANALYSIS

The contents of Table 4 represent comparative analysis with similar recent works. After comparison with the proposed antenna and reference papers [14–17], it is observed that gain is increased by 36.38%,

Table 3. Comparative analysis of simulated and fabricated results.

Antenna Parameters		Resonance Frequency (GHz)	VSWR	Return Loss (dB)	Impedance (Ω)
Rectangular Slot Loaded Microstrip Patch Antenna	Simulated	2.4	1.38	−17.29	65.99
		5.8	1.48	−15.40	60.82
	Fabricated	2.4	1.37	−16.27	54.07
		5.8	1.45	−13.77	42.47
Circular Slot loaded Microstrip Patch Antenna	Simulated	2.4	1.17	−42.28	36.55
		5.8	1.41	−15.17	73.45
	Fabricated	2.56	1.73	−11.62	32.14
		6.02	1.15	−26.76	36.12

Table 4. Comparison of proposed antenna recent textile antenna.

Different Antenna/ Antenna Parameters	Proposed Antenna Dual Slot Textile Antenna				2019, [14] Wideband monopole	2021, [15] E-shaped patch CPW feed structure:	2019, [16] E-shape triband dipole antenna:	2021, [17] Dipole antenna:
	Rectangular Patch		Circular Patch					
Size of antenna (mm²)	80 × 80		80 × 80		50 × 64.1	32 × 30	80 × 80	75 × 80
Substrate material	Wash Cotton		Wash Cotton		Jeans cloth	Denim cloth	Denim fabric	Jeans cloth
Thickness of Substrate (mm)	2		2		2	2	2	0.44
Operating Frequency (GHz)	2.4	5.8	2.4	5.8	2.45	2.45	2.45	2.43
S_{11} (dB)	17.29	15.40	42.28	15.17	17.2	34	18	21
Gain (dB)	5.14	7.14	5.03	6.32	3.27	1.83	1.26	2.3
BW (MHz)	84.4	137.5	79.8	216.1	667	153	100	130
Directivity (dB)	7.20	9.03	7.11	7.48	-	-	-	-

64.40%, 75.49%, and 55.25%, respectively, at 2.4 GHz for rectangular slot loaded microstrip patch antenna and 34.99%, 63.61%, 74.95%, and 54.27% for circular slot loaded microstrip patch antenna. This change is observed due to dielectric of wash cotton substrate.

7. CONCLUSIONS

The proposed antenna results presented in this paper shows that the return loss, VSWR, gain and directivity of rectangular patch are better than the circular patch. Also, the dual resonances of ISM band are achieved with the help of slots. Fabricated antenna results show a slight deviation from the simulated results as there are no standard fabrication methods existing. Textile microstrip patch antennas are suitable for military and biomedical applications due to its compact size, simple planar configuration, low weight, flexibility, low SAR, and ease at installation. In future it can also be used for higher bandwidth application such as WLAN, WiMAX, and ISM band.

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