A novel microstrip fed triple band patch antenna with TM_{10}, TM_{02} and TM_{12} induced modes

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ABSTRACT

In this study, a patch antenna with three different operating frequencies (2.94 GHz, 4.5 GHz, and 5.7 GHz) is proposed. The dimensions of the antenna are as follows: 23.4 mm by 30.4 mm by 1.6 mm. The triple band characteristic may be achieved by adjusting the width of the quarter wave transformer (QWT), which in turn modifies the impedance matching in such a manner as to excite the TM10, TM02, and TM12 modes. These modes are able to have additional verification provided by the current distribution on the patch. Altering the width of the QWT provides the proposed antenna with the ability to fine-tune its resonant frequencies. At the resonant frequencies, the impedance bandwidths of -10 dB are 69 MHz, 40 MHz, and 110 MHz, respectively. 5.7 GHz has a gain of 1.5 dB, while 4.5 GHz has a gain of 0.7 dB, and 2.94 GHz has a gain of 2 dB. Additionally, this antenna finds its applications in wireless systems in the S and C bands of the frequency spectrum. The antennas are validated using a vector network analyzer (VNA) after being simulated with mentor graphics software three-dimensional electromagnetic modeling (3DEM) and analyzed with it.

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1. INTRODUCTION

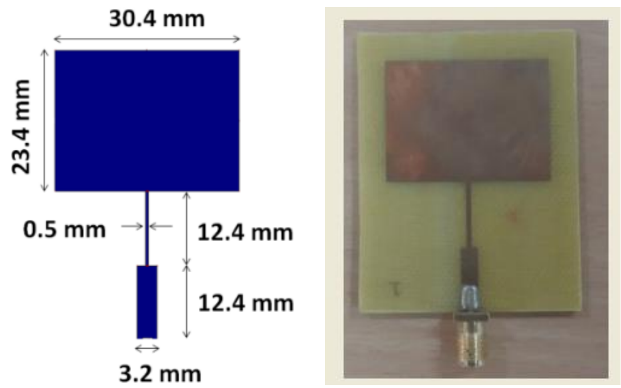
The meteoric evolution of modern wireless systems is placing greater demands on antenna designs. Many of the wireless systems now operate in dual or more than dual frequency bands. This has enhanced necessity of dual or triple band or multiband antennas. The multiband microstrip patch antennas have far-fetched applications in wireless communication systems. Different subscribers can use multibands simultaneously for variety of purposes.

Many researchers have investigated the design of a single patch antenna for multiple band applications using different techniques. Infact, slots/slits have been used in the radiating patch and ground plane, to obtain multiband operations [1]–[10]. Reconfigurable antenna is one of the technique used by many researchers to design multiband antennas [11]. Metamaterials are the promising new candidates for designing multiband antennas [12]–[19]. To realise multiband operations fractals have been used [20]–[23]. Higher order modes based multiband antennas [24], [25]. Pair of slots are etched at the opposite edges of rectangular microstrip patch to increase bandwidth and gain [26]. A triple band microstrip antenna for wireless communication [27]. According to Chen *et al.* [28] L-shaped slots are used on the radiating patch and ground plane of the antenna to obtain triple band antenna.

However, the techniques mentioned above results in perturbing the patch or ground, which leads to changes in radiation pattern. In the proposed work, a triple band patch antenna is designed without using any type of slits/slots. In the proposed work, three-dimensional electromagnetic modeling (3DEM) simulation software is used to obtain return loss, surface current distribution, radiation pattern, gain and directivity. Simulation results are validated using vector network analyzer (VNA).

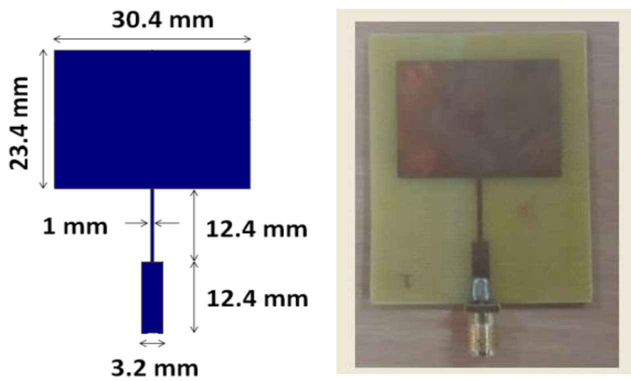
2. ANTENNA CONFIGURATION

A reference antenna (RA) is designed with dimensions of 23.4 mm×30.4 mm corresponding to an operating frequency of 3 GHz. The rectangular microstrip antenna uses low cost FR4 substrate with parameters such as relative permittivity of 4.4, thickness of the substrate 1.6 mm and tangent loss of 0.0245. A microstrip line feed excites RA through quarter wave transformer (QWT). The dimensions of QWT are length, Lt=12.4 mm and width, Wt=0.5 mm, whereas the microstrip line feed is having feed length, Ls of 12.4 mm and width, Ws of 3.2 mm. Figure 1(a) shows a RA schematic diagram and Figure 1(b) shows a RA with fabrication. The proposed antenna has been designed by varying and optimizing the width of QWT. Schematic diagram of the optimized patch antenna is shown in Figure 2(a) and fabricated antenna is shown in Figure 2(b) respectively. Table 1 provides the dimensions of optimized antenna.



(a) (b)

Figure 1. The RA for (a) schematic diagram and (b) fabricated antenna



(a) (b)

Figure 2. Proposed antenna for (a) schematic diagram and (b) fabricated antenna

Table 1. Dimensions of the proposed antenna

Dimensions	In mm
Patch length, L	30.4
Patch lidth, W	23.4
Feed line length, Ls	12.4
Feed line width, Ws	3.2
Length of QWT, Lt	12.4
Width of QWT, Wt	1

3. PARAMETRIC STUDY OF THE DESIGNED ANTENNA

Parametric study is carried out by varying the width of the QWT. The resonant frequency, return loss, bandwidth and impedance of the designed antenna are investigated. Table 2 shows a performance of the proposed antenna by carrying out the parametric study. Parametric study is carried out by varying Wt from 0.5 to 1.3 mm and keeping other parameters constant as shown in Table 2. For parameter Wt=1 mm, a triple band is obtained at a resonant frequencies of 2.94 GHz, 4.5 GHz and 5.7 GHz and the corresponding bandwidth obtained is 150, 180 and 330 MHz, respectively. Table 2 also shows a comparison of simulated results experimental/measured results and they found to be in good agreement. This can also be verified from the simulated and measured return loss characteristics of the proposed antenna as plotted in Figure 3.

Table 2. Performance of the proposed antenna

Width of the QWT in mm	Resonant frequency in GHz		Return loss in dB		Bandwidth in MHz		Impedance in ohms
	Simulated	Measured	Simulated	Measured	Simulated	Measured	Simulated
0.5	2.93	2.8	-10.87	-11.8	29	40	26.9+j0.1
	5.7	5.1	-10.02	-11	63	130	73.7+j30
0.6	2.93	2.8	-12.0	-16.7	40	90	30.4+j0.1
	5.7	4.4	-10.7	-14.4	81	100	70.8+j30
0.7	2.93	2.8	-15.0	-13.1	52	50	34.0+j0.2
	5.7	4.4	-11.0	-13.5	93	60	66+j29.5
0.8	2.94	2.8	-15	-16	58	60	36+j28
	5.6	5.0	-11	-11.2	86	98	69.9+j29
0.9	2.94	2.8	-17	-19	63	99	40.2+j0.2
	5.6	5.5	-11	-12	98	120	65.0+j 27
1	**2.94**	**3.1**	**-23.0**	**-16.2**	**69**	**150**	**45.5+j0.3**
	4.5	**4.8**	**-10.1**	**-13.2**	**40**	**180**	**63.7+j32**
	5.7	**5.6**	**-11.41**	**-19.9**	**110**	**330**	**58.5+j28**
1.1	2.94	2.9	-25	-18.1	65	120	48.5+j0.3
	4.5	4.4	-11	-12.0	40	130	62.7+j30
	5.7	5.6	-10.4	-11.2	101	100	57.5+j29
1.2	2.94	3.1	-24	-14.2	67	110	48.5+j0.1
	4.5	4.6	-10.5	-11.0	25	70	62.7+j30
	5.7	5.6	-11.4	-10.1	104	97	55.5+j21
1.3	2.94	2.9	-23	-18.2	61	70	46.5+j0.5
	4.5	4.4	-10	-10.5	30	45	66.7+j36
	5.7	5.5	-11	-13.5	98	80	59.5+j33

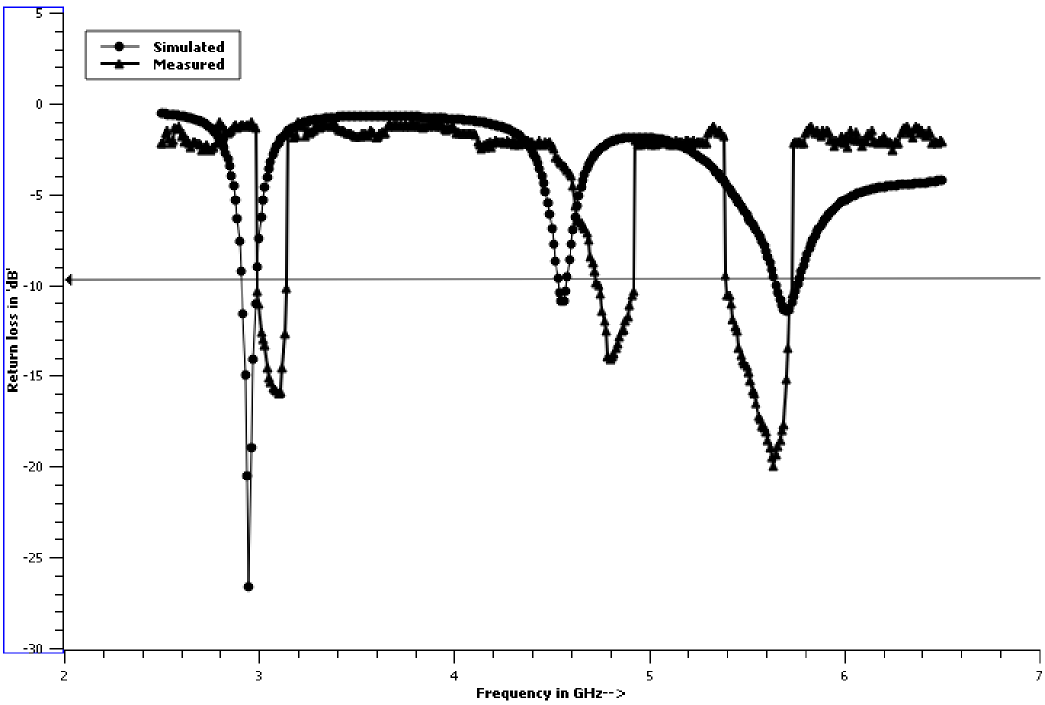
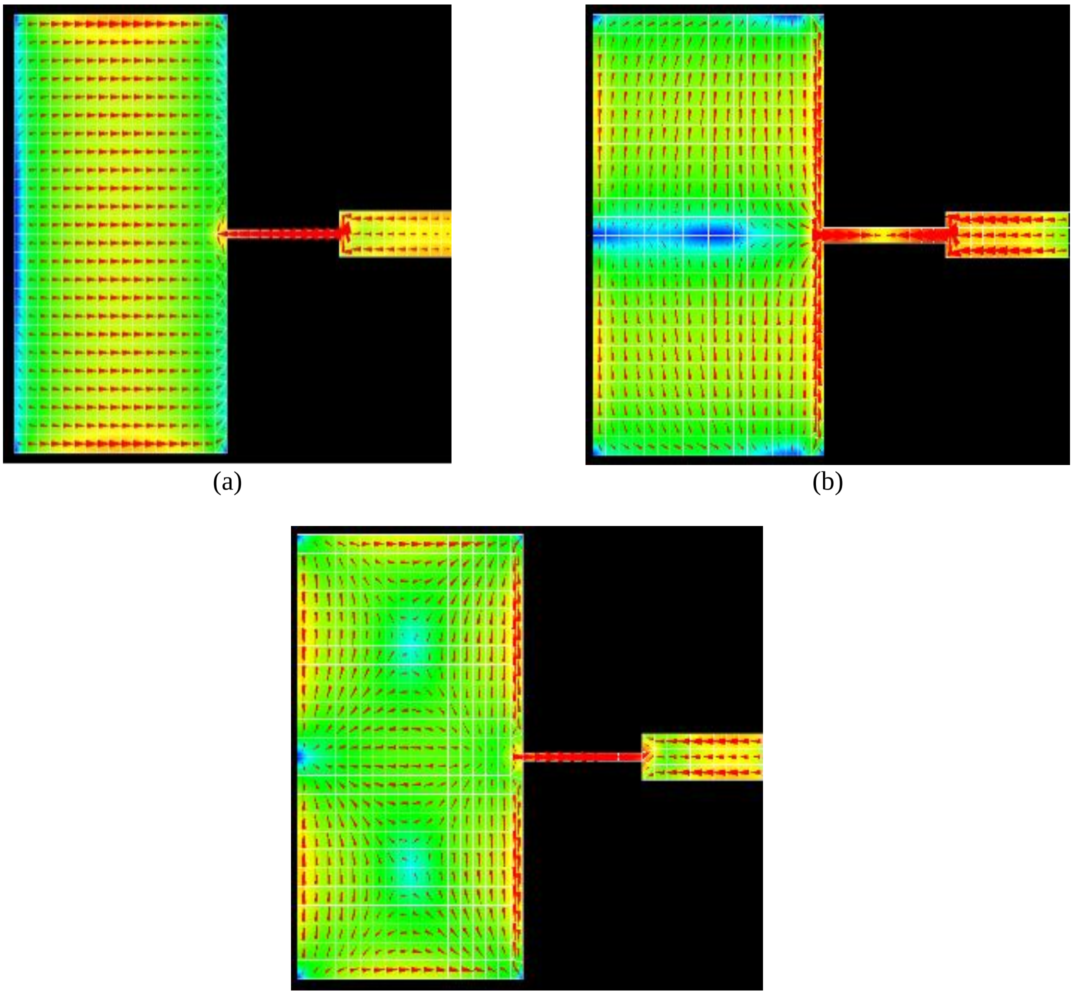


Figure 3. Simulated and measured return loss characteristics of proposed antenna with corresponding width of 1 mm

4. RESULTS AND DISCUSSIONS

The parametric study of the microstrip patch antenna has been done. The proposed antenna offers triple frequency bands. Figure 4(a) shows the current distribution and resonance at 2.93 GHz are due to the fundamental mode excitation of TM_{10}. Similarly, Figure 4(b) shows resonance at 4.5 GHz is due to the TM_{02} mode excitation. Further, Figure 4(c) shows resonance at 5.7 GHz is due to the TM_{12} mode excitation.



(a) (b) (c)

Figure 4. Current distribution in the proposed antenna; (a) current distribution for W=1 mm at 2.93 GHz, (b) current distribution for W=1 mm at 4.5 GHz, and (c) current distribution for W=1 mm at 5.7 GHz

The experimental results are obtained using VNA. Therefore, the measurement results in triple frequency bands starting from 3.0 GHz to 3.15 GHz, 4.75 GHz to 4.93 GHz and 5.48 GHz to 5.81 GHz. Also, measurements provide an antenna gain of 2 dBi corresponding to 2.9 GHz. Figure 5(a) shows E plane & H plane radiation patterns corresponding to frequency of 2.93 GHz, Similarly, Figure 5(b) shows E plane & H plane radiation patterns corresponding to frequency of 4.5 GHz. Further, Figure 5(c) shows E plane & H plane radiation patterns corresponding to frequency of 5.7 GHz. It is evident from the figures that the radiation pattern is stable and broadside in nature. Whenever the current is out of phase a null is created in the radiation pattern. This antenna is suitable for wireless communication applications.

Figure 6 show the variation of frequency with gain, efficiency, and directivity of proposed antenna for W=1 mm. Proposed antenna resonates at 2.94 GHz with a gain of 2 dB, an efficiency of 37%, and a directivity of 6.3 dBi. Also proposed antenna resonates at 4.5 GHz with a gain of 0.7 dB, an efficiency of 20%, and a directivity of 7.6 dBi. In addition proposed antenna resonates at 5.7 GHz with a gain of 1.5 dBi, an efficiency of 15.7%, and a directivity of 9.6 dBi.

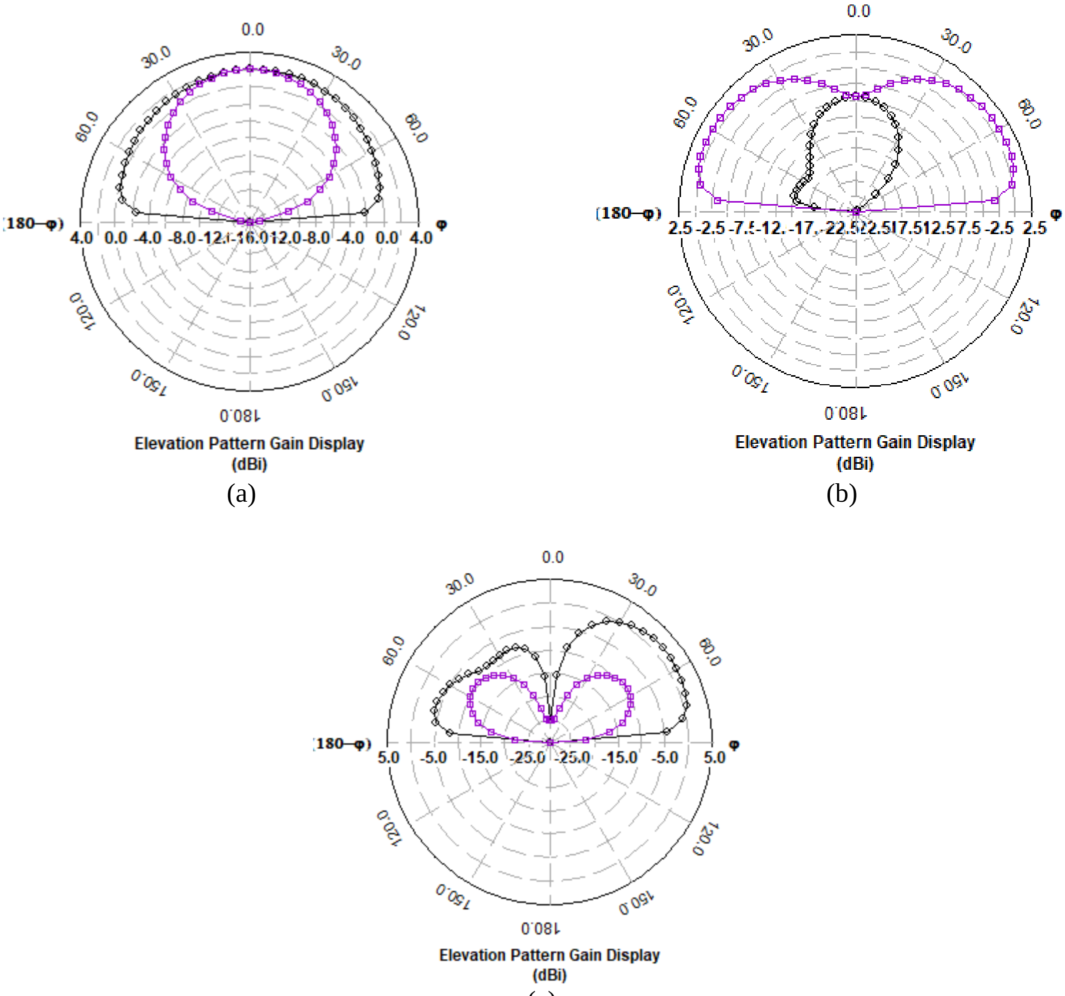


Figure 5. The radiation pattern of the proposed antenna; (a) 2.93 GHz, (b) 4.5 GHz, and (c) 5.7 GHz

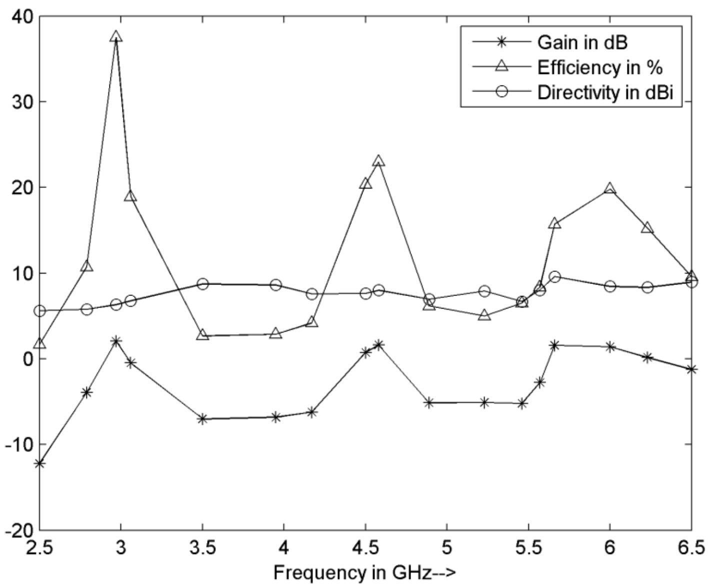


Figure 6. Frequency versus gain, efficiency, and directivity of proposed antenna

5. CONCLUSION

The techniques for realizing a multiband antenna often involve perturbation of radiating patch or ground plane and combination of both, leading to radiation pattern being distorted abruptly. A parametric study by adjusting the width of the QWT is studied in this paper to realize triband with good radiation pattern. It has been observed that the optimized width of quarterwave transformer of 1 mm dimension results in triple bands due to the excitation of TM_{10}, TM_{02}, and TM_{12} modes and radiation patterns are found to be stable. The change in width causes the proper impedance matching and results in a gain greater than 0 dB in all the bands of operation. Further this antenna finds application in S and C band wireless applications.

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