Design and Development of Multiband Antennas for Wireless Communication

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Abstract

Recent developments in the field of wireless communication industry continue to drive the requirements for small, compatible, and affordable multiband antennas. A new multiband antenna is proposed to face the challenges of multi-frequency operation. In this paper, a microstrip patch antenna with a T-slit or without T-slit is designed for multiband operations. This antenna shows the three distinct frequency bands, centered at 4.02 GHz, 6.18 GHz and 11.13 GHz. Furthermore, to increase the frequency bands the same antenna structure is modified by attaching a T-shaped slit on the radiating patch. This proposed modified antenna has four distinct operating frequency bands centered at 3.92 GHz, 5.82 GHz, 7.88 GHz and 11.35 GHz with improved return loss. The proposed antennas has compact size of 25 X 28 X 0.82 mm^3 including the ground plane and both antenna structures are designed on FR-4 substrate (Dielectric constant = 4.4) of thickness h = 0.8 mm. The proposed structures were simulated by using the electromagnetic (EM) simulation software. The simulated return losses are less than -10 dB at resonance frequencies. The presented antennas are suitable for multiband wireless communication systems. The Tetra-band antenna with compact size of 25 X 28 X 0.82 mm^3 including the ground plane is fabricated using FR-4 substrate (Dielectric constant = 4.4) of thickness h = 0.8 mm.

Keywords

Multiband, Microstrip Feed Line, Resonance Frequency, Rod-Shaped Parasitic Element, Slit, Slot

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Introduction

Now a day's wireless communication devices needed more and more frequency bands because of increasing wireless service requirements. As these devices also wants smaller dimensions for the real estate, antennas need to smaller their dimensions and more than one operating frequency bands while maintaining their performance. Due to this specification the demand for multiband antenna design is increasing continuously.

Multiband antennas have derived rapidly increasing attention in modern wireless communication systems in which the downward compatibility and the roaming capability among multi-standards are demanded. For example, (i) The global system for mobile communication (GSM), (ii) The general packet radio service (GPRS), (iii) The wireless local area networks (WLAN), (iv) The universal mobile telecommunications system (UMTS) are generally a dual band or multiband wireless standards communication devices.

Due to the gradually development of electronics and wireless communications, the requirement for mobile devices Operating at different standards or for different applications is extending. So, on the other hand, wireless communication systems are developing toward multi-functional devices. There are fixed and reconfigurable antennas are used for the multiband operation. A frequency reconfigurable antenna is more popular for multi-functionality operation due to their switching and tunable characteristics, impedance bandwidth, operating frequency, radiation pattern, and polarization, which is a well-suited for it[1].

A number of multiband antennas with notched band property have been proposed, and various techniques have been used to achieve the multiband operation. The mainly used methods are etching slots on the patch or on the ground plane, for examples H-shaped slot[2], U-shaped slot[3], C-shaped slot[4], etc. There are another technique is use of parasitic strips[5] near the radiation elements or the ground plane for achieving the notched band and multi-functionality. Most of the previous researches have been adapted the single-notched-band design; few researches have been focused on dual-notched-bands design. Dual-notched-bands antennas designs have been explained in the papers[6–8]. In these above papers the dual-band have been achieved by adding the proper slits in the near of radiating patch element and the ground plane, by the inserting of slit, the desired two rejected bands have been obtained. Mostly of them antennas have the lack of poor voltage standing wave ratio (VSWR) of the dual notched band antennas, this is the common factor all of these structures for dual band antennas. Due to lack of low VSWR, some UWB planar antenna structures with dual notched bands are reported in the literature. The UWB planar antenna is reported that have a T-slit on the top of radiating patch and U-stub besides the feeding line and the dual bands are achieved by using T and U-shaped. In[9] and[10], different shapes of the slots like square, ring and folded trapezoid are used to obtain the desired band notched characteristics of antenna. Single and multiple[11] half-wavelength U-shaped is used for the frequency band-notch function and the modified planar slits are inserted in the radiation patch to achieve the single and multiple band-notched functions, respectively. Band-notch function is also achieved by using a T-shaped coupled parasitic element in the ground plane in[12].

Recently, many techniques have been used to increasing the antenna bandwidth with the truncated ground plane with use of an L-shaped notch in the lower corner[13,14] and an inverted T-shaped notch in the middle[15]. For increasing the resonance frequency, two new slots are used in the ground plane and the bandwidth of antenna is increased by using these slots[16]. However, these antennas are not fulfilling the complete requirement of multiband operation for wireless technology.

In this paper, the multiband antennas are proposed for tri band and tetra band of operation for wireless communication systems. An octagonal-shaped rectangular patch antenna with L-slot in radiating element, U-slit near the feed line, and partial ground with rod shaped parasitic element is proposed for tri-band. The same structure is modified by attaching the T-slit on the top of radiating patch to achieve the tetra-band. These antennas are small in size and compact. These structures are designed with microstrip technology and suitable for multiband wireless communication.

The organization of this paper is as follows. In Section 2, basic design of proposed tri-band antenna is described. In Section 3, the modified structure is presented for tetra-band operation. In Section 4, the simulated results of proposed tri-band and tetra-band antenna design are presented and compared. Finally, the paper is concluded in Section 5.

Tri-band Antenna Design

An octagonal-shaped rectangular microstrip patch antenna is designed and their structure is shown in Fig. 1. In this structure, radiating patch has two L-slots and the feed line having two U-slit type structures. To achieve the broadband operation, partial ground with rod shaped parasitic structures are used.

This antenna is designed and simulated on FR-4 dielectric substrate that having dielectric constant (ε_r=4.4) and height of the substrate is 0.8 mm. The EM simulation software is used to design and optimize the antenna parameters to realize the proposed scheme for multiband operation.

The antenna has compact dimensions of 25 X 28 mm^2. In this antenna, for a better impendence matching over the full band, three steps with 0.8 mm length are designed in the upper part of the patch. The patch is fed through a 50 ohm microstrip transmission line.

As illustrated in Fig. 1, a pair of L-shaped slots in the corners of the radiating patch with vertical length L6, horizontal length L7 and thickness t2, are used to achieved the bands, these bands are covers all the 4.022 GHz and 6.183 GHz for C-band, 11.13 GHz band for Fixed satellite service. The U-slit are the dimension of horizontal length L2 and vertical length L4 are affects the second bands when all other parameter are fixed, the second band are move towards lower frequency when increasing L2, L4. The configuration is shown in Fig. 1(a).

A partial ground plane with dimensions of 5 X 28 mm^2 is used with a pair of rod-shaped parasitic element; these rod-shaped elements with vertical length L11, L12 and horizontal length L13 are placed on the back side of the dielectric substrate and are coupled with the octagonal-shaped radiating patch, shown in the Fig. 1(b). The matching impedance of antenna and bandwidth of the bands are controlled by varying the distance between these rod-shaped elements.

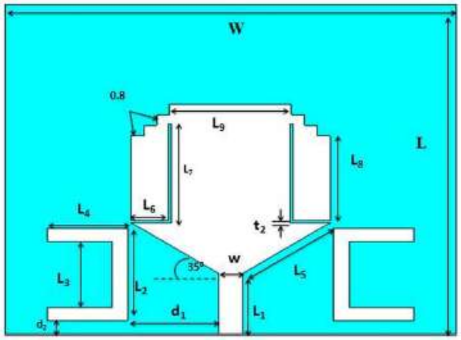
The width of the microstrip feed is fixed at w1=1.5 mm, and the length of that is L1=4.6 mm.

Modified Design for Tetra-band Antenna

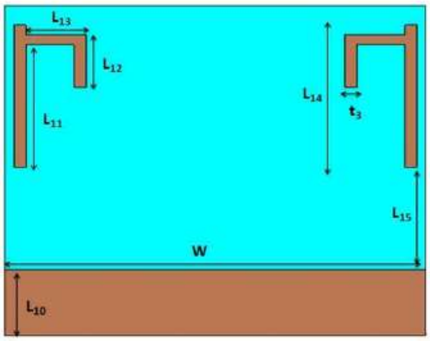
Case-I Antenna structure without T-shaped slit

Now a T-shaped slit in introduced in the structure and attached on the top of radiating patch. The T-shaped slit has vertical length L16, horizontal length L17 and thickness t4 as shown in Fig. 2.

By introducing the T-shaped slit in the antenna structure the number of frequency bands are increased and the frequency response of S11 parameter is improved which is described in the next section, by using the T-slit on the top of the radiating patch the center frequency of all the bands are shifted i.e. 4.0221 GHz



(a)



(b)

Figure 1. (a) Tri-band antenna design (top view), (b) Bottom view

Table 1. Key Dimansions of Tri-band Antenna Design

Antenna parameter	Value	Antenna parameter	Value
W	28mm	L11	9.26mm
L	25mm	L12	4mm
L1	4.6mm	L13	4mm
L2	7mm	L14	0.7mm
L3	5mm	L15	7.75mm
L4	5mm	t1	1mm
L5	6.7mm	t2	0.2mm
L6	2.3mm	t3	0.5mm
L7	7.5mm	d1	5.68mm
L8	6.6mm	d2	1mm
L9	7.56mm	w	1.5mm
L10	5mm		

is shifted to 3.927 GHz, 6.183 GHz is shifted towards 5.822 GHz and 11.13GHz is shifted towards 11.35 GHz and the new band which is introduced by the T-slit have the resonant frequency 7.88 GHz. This can be done by varying the T-slit structure accordingly the step size of the radiating patch. The ground plane is not changed and same as described in the previous section.

A T-shaped slit on the radiating patch is adopted to generate notched bands with central frequencies of 3.927 GHz WiMax, and 5.8 GHz WLAN, 7.88 GHz C- band and 11.35 GHz for Fixed satellite services.

The Tri-band antenna structure is designed without the T-shaped slit. This antenna structure is covering 4.02-11.13 GHz.

This antenna structure has three distinct frequency bands, centered at 4.02 GHz, 6.18 GHz and 11.13 GHz as shown in the Fig. 3. As shown in Fig. 3 the return loss is less than -10 dB which showing that this antenna is workable on these three frequency bands. The comparison of return loss and insertion loss is shown in Fig. 4.

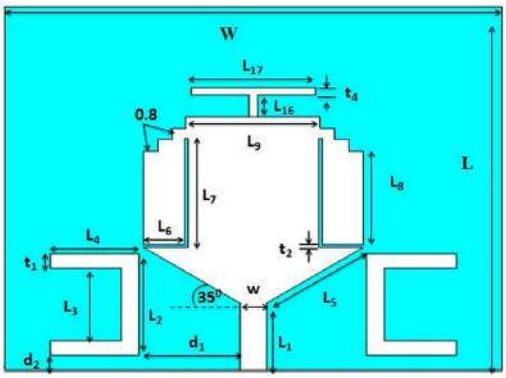


Figure 2. Proposed Tetra-band antenna design

Table 2. Key Dimansions of T-shaped Slit

Antenna parameter	Value
L16	1.5mm
L17	7mm
t4	0.5mm

Simulation and Results

The designed structures are simulated on the Electromagnetic (EM) simulation software. This software can be used to model and optimized the microstrip patch antenna structures. It can be used to calculate and plot the S11 parameters, monostatic RCS, insertation loss, current distributions as well as the radiation pattern.

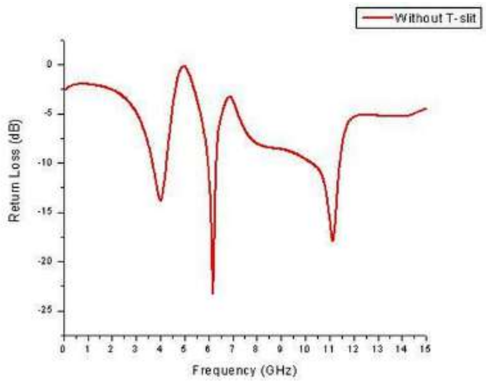


Figure 3. Return loss of Tri-band antenna structure

The computer simulation is done for two cases. The first one is for antenna structure without T-shaped slit as described in section II and second one is for antenna structure with T-shaped slit as described in section III.

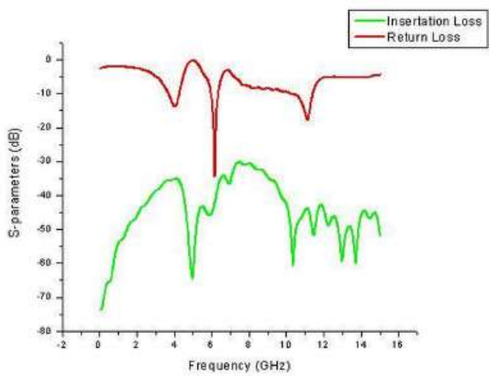


Figure 4. Comparison of Return and Insertion loss of Tri-band antenna structure

The radiation patterns of Tri-band antenna of directivity at theta is 90 degree for three resonance frequencies are shown in Fig. 5, 6, 7. The directivity of antenna is described by the shape of the radiation pattern, so from the Fig. 5, 6, and 7, it is clear that the radiation pattern is Omni-directional but it becomes directional when operating frequency band is increased.

The radiation pattern shown in Fig. 5, 6 and 7 are shows the frequency band of 4.022 GHz, 6.18 GHz and 11.13 GHz respectively.

The radiation pattern of the antenna can be change by the varying the gap between the ground and the radiating patch of antenna. It is also depended on the dielectric loss of the substrate material.

To understand the phenomenon behind this Tri-band performance, the simulated current distribution on the radiating patch for the proposed antenna at the band frequencies of 4.02, 6.18 and 11.13 GHz is

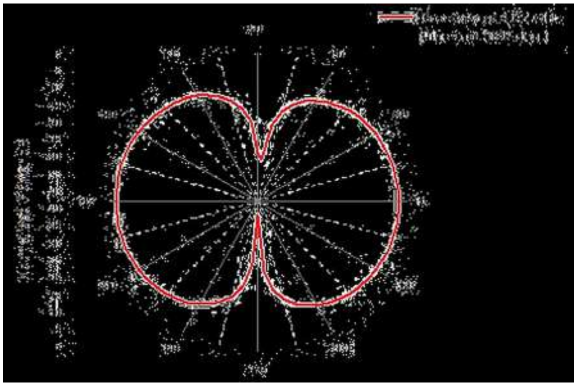


Figure 5. Radiation pattern of Tri-band antenna structure at 4.02 GHz

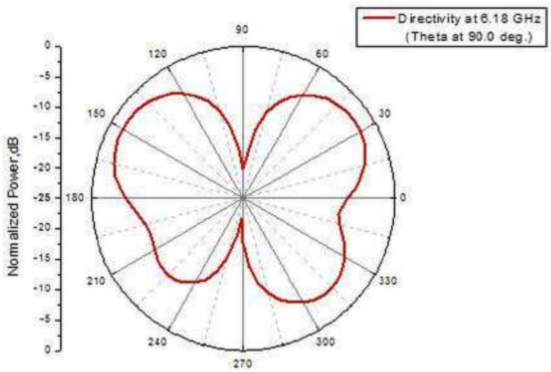


Figure 6. Radiation pattern of Tri-band antenna structure at 6.18 GHz

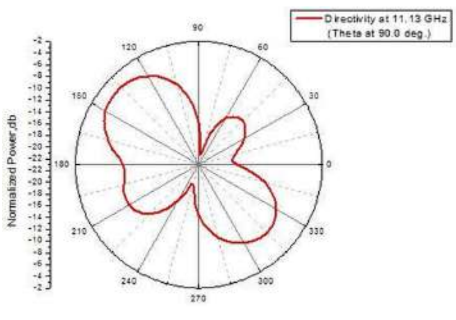


Figure 7. Radiation pattern of Tri-band antenna structure at 11.13 GHz

presented in Fig. 8, 9 and 10, respectively. It can be observed in Fig. 8, 9 and 10 that the maximum current on the edges of the L- slot at 4.02 GHz and 6.18 GHz and in 11.13 GHz at interior and exterior edges of the U-slit. By this we can see that the antenna impedance is changed by the use of these frequencies.

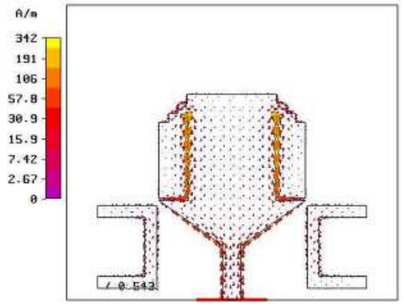


Figure 8. Current distribution of Tri-band antenna structure at 4.02 GHz

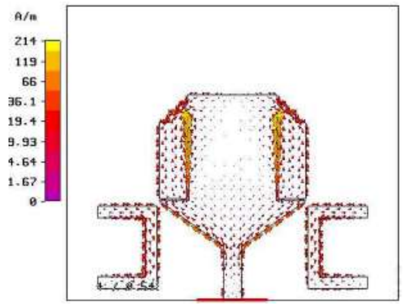


Figure 9. Current distribution of Tri-band antenna structure at 6.18 GHz

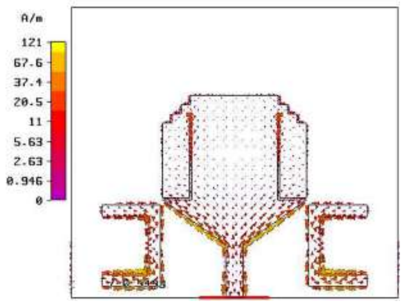


Figure 10. Current distribution of Tri-band antenna structure at 11.13 GHz

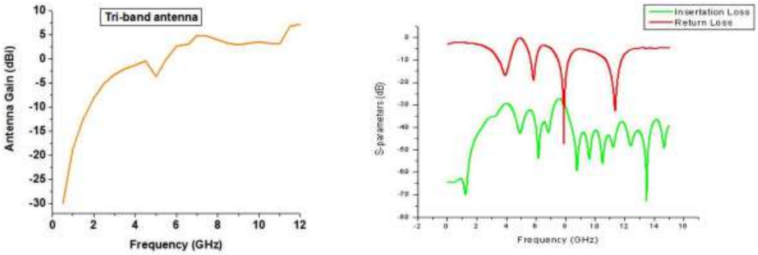


Figure 11. Gain of Tri-band antenna structure

As shown in Fig. 11, the simulated gain of Tri-band antenna from the 0 to 12 GHz is increases continuously but at the resonant frequency 4.02 GHz it started to decrease at the point of 4.6 GHz it gives notched value of the frequency, similarly at 6.18 GHz and 11.13 GHz gives the notched functionality.

The comparison of return loss and insertion loss for proposed antenna structure is shown in Fig. 12

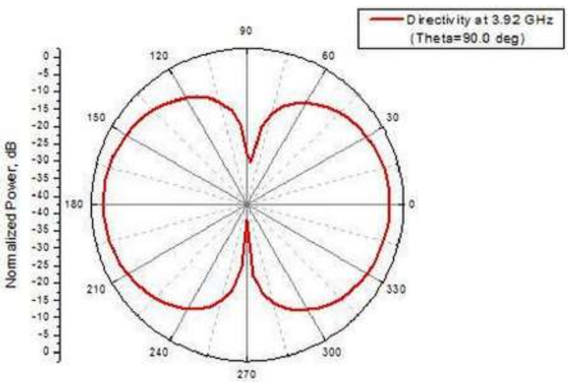


Figure 12. Comparison of Return and Insertion loss of proposed antenna structure

Case-II Proposed antenna structure with T-shaped slit

As shown in Fig. 3, the return loss of basic antenna structure is tuned for three frequency bands. The curve of return loss is not much appropriate between the 2nd and 3rd frequency bands. So for improvement of the return loss and increment by one more frequency band, a T-shaped slit is inserted in the proposed structure. Therefore, this structure works as a tetra-band microstrip antenna.

As shown in the Fig. 13, proposed structure has four distinct frequency bands centered at 3.92 GHz, 5.82 GHz, 7.88 GHz and 11.35GHz and operating range from 3.92-11.35 GHz. The bandwidth of resonance bands are also controlled by increasing the horizontal length of T-slit equal to each step of stairs in radiating patch. So the proposed structure has more smooth and extra operating frequency band than the basic antenna structure.

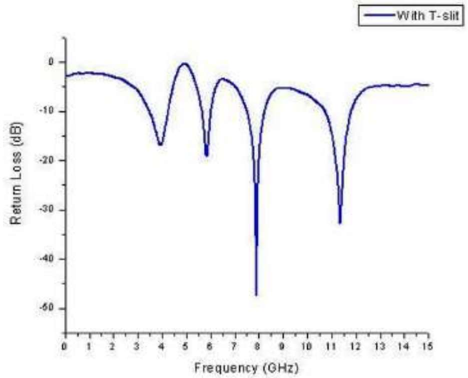


Figure 13. Return loss of Tetra-band antenna structure

The radiation patterns of Tetra-band antenna of directivity at theta is 90 degree for three resonance frequencies are shown in Fig. 14, 15, 16 and 17. The radiation pattern shown in Fig. 14, 15, 16 and 17 are shows the frequency band of 3.92 GHz, 5.82 GHz, 7.88 GHz and 11.35 GHz respectively. These patterns are Omni-directional but it becomes directional when operating frequencies are increased.

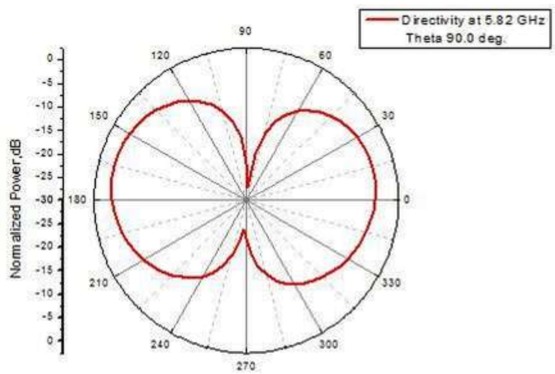


Figure 14. Radiation pattern of Tetra-band antenna structure at 3.92 GHz

To understand the phenomenon behind this Tetra-band performance, the simulated current distribution on the radiating patch for the proposed antenna at the band frequencies of 3.92, 5.82, 7.88 and 11.35 GHz is presented in Fig. 18, 19, 20 and 21, respectively. It can be observed in Fig. 18, 19, 20 and 21 that the maximum current on the edges of the L- slot at 4.02 GHz and 6.18 GHz and in 11.13 GHz at interior and exterior edges of the U-slit.

There are more current is also flow in the T-slit, due to this flow of current this structure is controlled by the changing in the dimensions of this slit and this structure also controlled by the small change in the L-slot and the U-slit also. By this we can see that the antenna impedance is changed by the use of these frequencies.

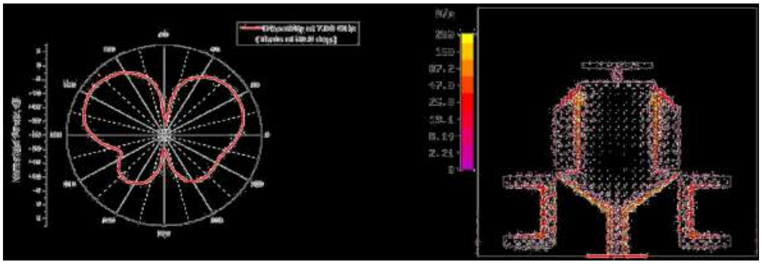


Figure 15. Radiation pattern of Tetra-band antenna structure at 5.82 GHz

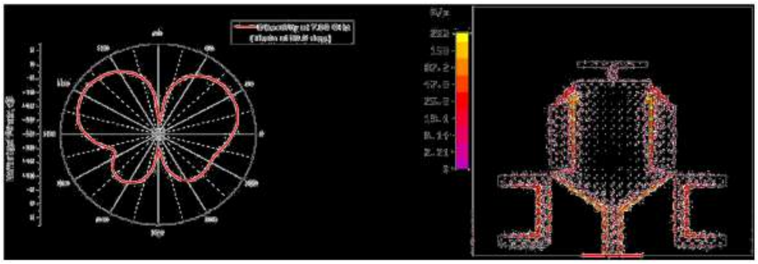


Figure 16. Radiation pattern of Tetra-band antenna structure at 7.88 GHz

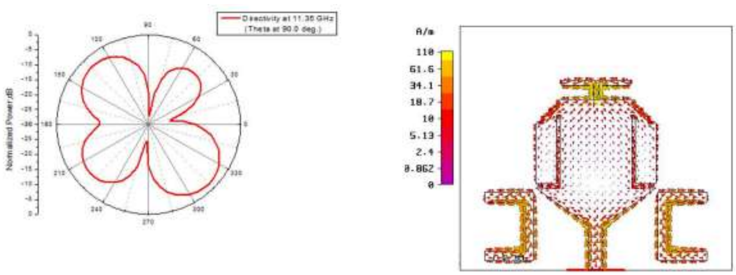


Figure 17. Radiation pattern of Tetra-band antenna structure at 11.35 GHz

As shown in Fig. 22, the simulated gain of Tetra-band antenna from the 0 to 12 GHz is increases continuously but at the resonant frequency 4.02 GHz it started to decrease at the point of 4.6 GHz it gives notched value of the frequency, similarly at 6.18 GHz and 11.13 GHz gives the notched functionality, so from the above Tri band antenna gain and Tetra-band gain are approximately similar to each other. So, it is clear from the above discussion that the gain performance parameter is not affected by the introducing a T-slit above on the radiating patch of the antenna.

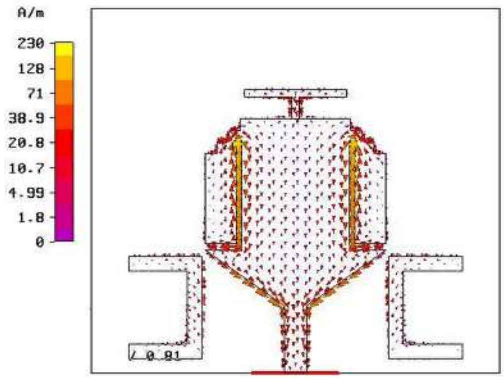


Figure 18. Current distribution of Tetra-band antenna structure at 3.92 GHz

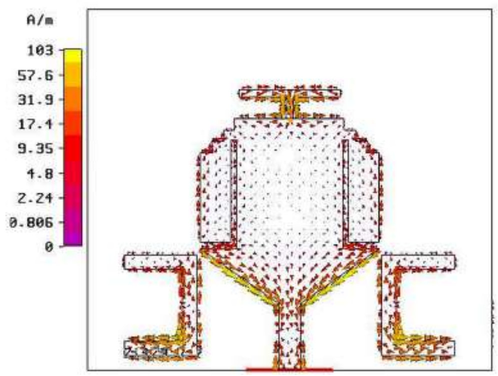


Figure 19. Current distribution of Tetra-band antenna structure at 5.82 GHz

Case-III Comparison of case-I & case-II

As shown in Fig. 23, the comparison of return losses of these two cases, it is clear that when a T-shaped slit is attached with the radiating patch the return loss of antenna is much improved, number of operating frequency bands and frequency range is also increased. The comparison of radiation patterns at central frequency 7.5 GHz is shown in Fig. 24.

Fabricated Structure and Results

Tetra-band antenna was fabricated using conventional microwave integrated circuit technology that is shown in Fig. **??**. This Tetra band antenna was fabricated on height of h= 0.8 mm. FR-4 substrate with the relative permittivity of 4.4 as discussed in above sections.

The fabricated antenna parameters are measured with vector network analyzer. The measured and simulated results of the antenna are compared and shown in the Fig. 25.

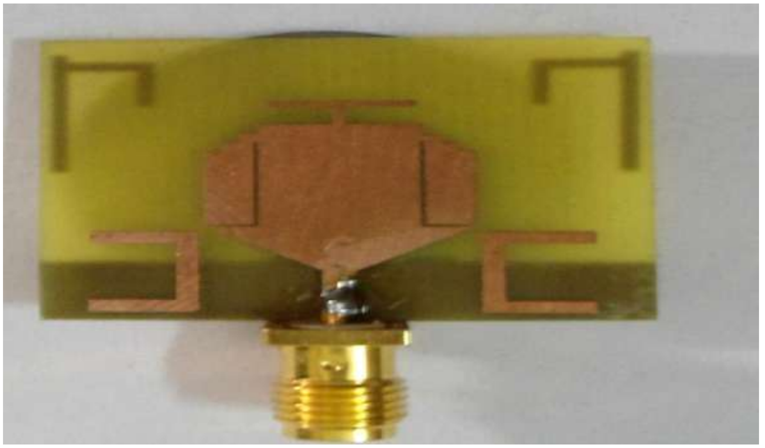


Figure 20. Current distribution of Tetra-band antenna structure at 7.88 GHz

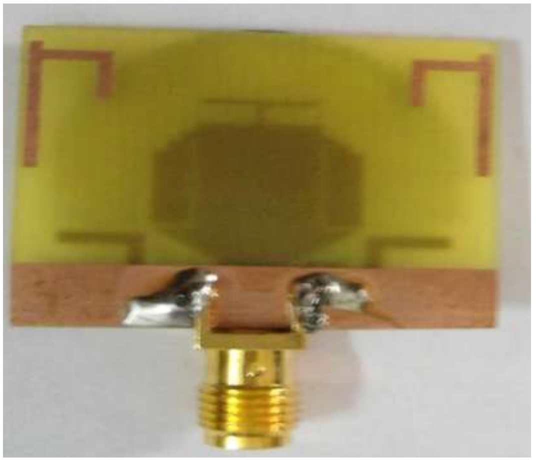


Figure 21. Current distribution of Tetra-band antenna structure at 11.35 GHz

The return loss of the tetra band antenna shown in Fig. 13 is compared with the measured results of the fabricated structure of the Tetra-band antenna with T-slit at above on the radiating patch. The Fig. 25 shows the comparison of the measured and the simulated results of the Tetra band antenna, from the Fig. 25, it is clear that the first band occurs at 5.9 GHz, Second band occurs at 6.8 GHz, third band occurs at 8.1 GHz and fourth band occurs at 11.35 GHz.

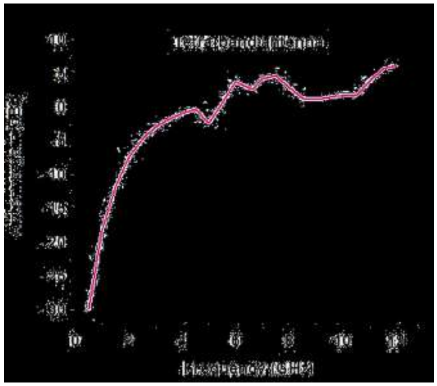


Figure 22. Gain of Tetra-band antenna structure

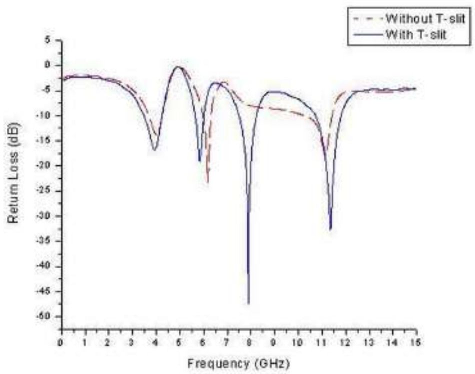


Figure 23. Comparison of return losses for case-I and case-II

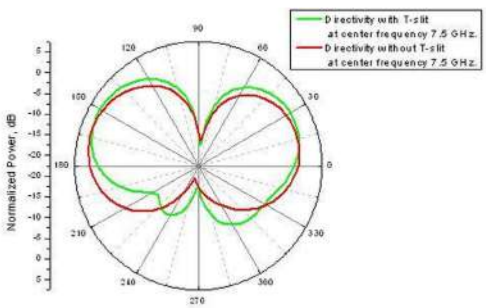


Figure 24. Comparison of radiation pattern for case-I and case-II at 7.5 GHz

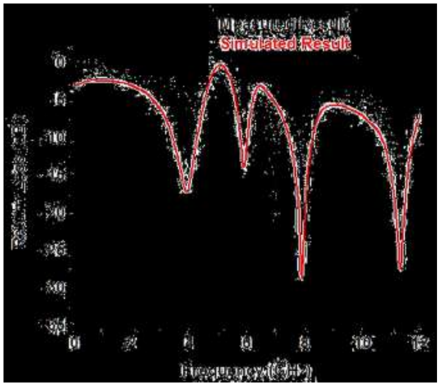


Figure 25. Comparison of Measured and simulated results of Tetra-band antenna

Conclusions

In this paper, a new approach to multiband antenna structure is shown for increasing the number of operating frequency bands and improvement in return loss. The comparison of these two cases is shown through return loss and insertion loss. The future aspect of this work is to increase the number of operating frequency bands by made change in the size of T-slit or using different shaped structures in place of U-slits and L-slots. This structure can be further modified by increasing the switch-ability of radiating patch by connecting PIN diode or RF-MEMS switch in switchable slot. These proposed antennas can be used for multiband wireless communication applications.

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