Compact Single Wide Band-Notched Slot antenna using T-Stub with Large Bandwidth

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Abstract. A compact rectangular slot antenna with single wide band-notched characteristics is proposed. This co-planar waveguide (CPW) fed antenna is suitable for ultra wide band (UWB), X-, Ku- and K-band applications. The patch of the antenna is a modified rectangular slot with T-stub structure in an elliptical slot etched in the radiating patch. This T-stub structure creates wide band notched at WLAN and ITU communication channels to avoid interference problem. A pair of a semi-circular structure is created in the ground for improvement in impedance matching at higher frequencies. The simulation is carried out using high frequency structure simulator (HFSS) which is finite element method (FEM) based tool. The proposed antenna has a broad bandwidth of 161% and a compact size of 14 x 14 mm^2. The size and bandwidth for the proposed antenna have been compared to that of earlier work and it is found that the performance of the proposed antenna is far better. This antenna operates over a wide band in the frequency range from 3 to 28 GHz with VSWR < 2 except frequency range from 4.5 to 8 GHz. The frequency range from 4.5 to 8 GHz filters-out entire WLAN and lower ITU communication channels to avoid the interference problem with UWB. The omnidirectional radiation patterns of fabricated antenna are presented. A negative measured peak gain is seen in the notched band. The measured results of the fabricated proposed antenna have been compared with the simulated results for the return loss and a close agreement between both the results is observed.

Index Terms ï Elliptical slot, wide band-notched, semi-circle, T-stub, CPW.

1. Introduction

The federal communications commission (FCC) has removed the restriction on frequency band from 3.1 to 10.6 GHz and opened the door for commercial applications in 2002. Besides many advantages like requirement of low power and high data rate for short distances, a UWB antenna exhibits stable radiation pattern and gain across the wide frequency bandwidth. The ease in fabrication and compatibility with other RF components makes it even more attractive. A wider bandwidth is achieved for slot antennas. The radiation and dispersion loss are small for CPW-fed slot antenna in comparison to microstrip feed. A possibility of misalignment exists in microstrip feed designs since the radiator and microstrip feed is on one side while ground is on the other side of the substrate. This alignment problem is ruled out for CPW-fed designs. A slot antenna finds applications in wireless communication system and being also explored in medical equipment used microwave imaging.

Recently, a very small sized rectangular slot antenna [1] has been designed. Several antennas with varying geometry like rectangular slot [2]-[3], semi-circle slot [4]-[5], circular slot [6] and polygon-shaped [7] have been reported. Different techniques have been implemented to enhance bandwidth. A pair of parasitic patches [8]-[9], rotated slot [10], fork-like tuning stub [11] and fractal-shaped slot [12] have been used to increase bandwidth. Other narrow band communication channels like WiMAX, WLAN, and ITU co-exist with UWB spectrum [13]. Various band notch techniques have been applied to avoid the interference problem. It includes etching of different shapes of slots in the conducting patch and ground structure [14]-[18]. A good insight to concepts related to defections in ground plane defining the performance of antenna has been introduced in [19]. Other techniques include spiral loop resonator [20], resonant strip, square ring resonator (SRR) and complimentary square ring resonator (CSRR) [21]-[23] and T-stub [24]. A composite right and left hand (CRLH) UWB filter at WLAN band of less than ə/9 length is created [25]. A comparison between microstrip line feed and CPW feed for broadband operation of slot antenna has been demonstrated [26].

In this paper, it is proposed to design, simulate, fabricate and measure the parameters of the compact rectangular slot antenna with a single band-notched property in terms of return loss, gain and radiation pattern for UWB, X-, Ku and K-bands. The proposed antenna is prototype using FR-4 substrate. The FR-4 substrate has low cost and readily available. The design is proposed since it has a compact size and the geometry is oriented to provide significant bandwidth. The slot antenna is CPW-fed which eliminates the alignment error. The design of the proposed antenna is carried out using HFSS software [27]. The proposed antenna is fabricated and comparison is made between the simulated and measured results in terms return loss, gain and radiation pattern. Also, the size and bandwidth of the proposed antenna are compared to that of earlier quoted references and it is seen that the performance of the fabricated proposed antenna is far better. The design of the proposed antenna along with parametric study using HFSS is discussed in the following section.

2. Proposed antenna design and parametric study

A slot antenna with rectangular patch is developed. The antenna has a compact size with overall dimensions of 14x14mm^2 with FR4 substrate whose relative dielectric constant, Ů = 4.4, loss tangent, tan ŭ = 0.02. The substrate has a thickness of 1.6mm.

In this design, the co-planar waveguide fed design has rectangular slot in the ground structure. The shape of the slot is kept similar to that of the radiating patch shape to achieve wider bandwidth. The broad bandwidth of the antenna is achieved by proper dimensions of the patch and ground plane. The slot design with T-stub is shown in Figure 1. It can be observed that the ground slot and patch having similar shape provide improved impedance matching.

2.1. Full band slot antenna

Figure 2 presents the return loss versus frequency for slot antenna and the steps are incorporated for antenna patch modification along with additional semi-circular slots. It is evident from the Fig.2 that in the first step, the simple rectangular patch antenna provides operating frequency range from 2.9 to 15 GHz. In the second step, the rectangular patch is modified and provided rounded shape at the bottom side. It enhances the operating bandwidth up to 16 GHz. In the third step, two semi-circular slots of radius of 1 mm have been etched symmetrically to the feed line in the ground plane. It can be observed from the simulation results that the semi-circles near the feed are implemented to enhance the bandwidth having more than 28 GHz with return loss > 10 dB.

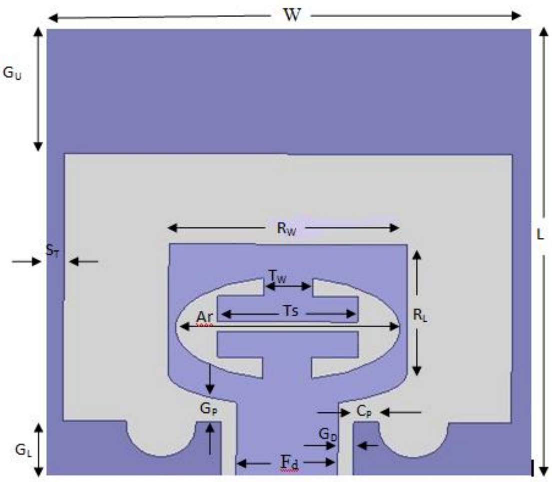

Fig. 1. Geometry of the proposed slot antenna with single wide band-notched

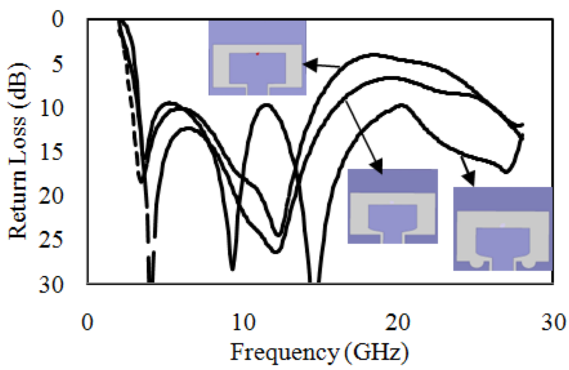

Fig. 2. Simulated return loss for the development stages of the proposed antenna

2.1.1. Parametric analysis

In this section, the effect due to variation in different design parameters has been discussed. The purpose of this study is to optimize the proposed slot antenna through parametric analysis. The results for parameters, namely, feed-width, the gap between feed and ground, the gap between ground and patch and position of semi-circular slots have been observed.

2.1.1.1. Variation in feed line width

The width of the feed line is varied and the results are observed. The parameter, F_d denoting the width of feed line is varied from 2.7 to 3.0 mm. Figure 3 shows the comparison of return loss versus frequency for all the four cases. With an increase in feed thickness from 2.7 to 2.9 mm, the impedance matching is improved. At F_d = 3.0 mm, a mismatch in impedance matching is observed at lower frequencies. The feed thickness, F_d = 2.9 mm is selected since it provides impedance matching with return loss > 10 dB up to 28 GHz.

2.1.1.2. Variation in gap between the feed and the ground

The gap, G_d between the feed and the ground has been varied and the results are observed. The parameter, G_d is varied from 0.4 to 0.5 mm in the step size of 0.05 mm. The effect on return loss versus frequency for these three values of G_d is represented in Figure 4. The gap, G_d = 0.45 mm is taken since it provides smooth coupling of resonant frequencies.

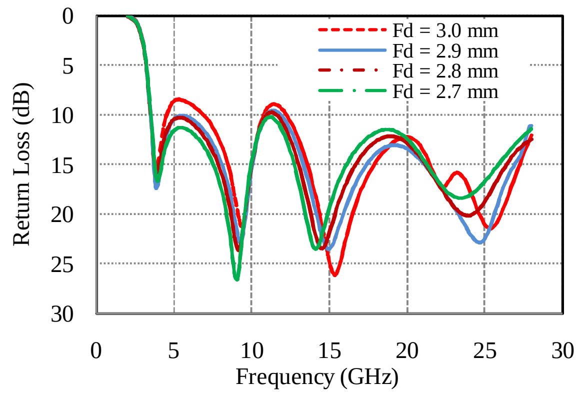

Fig.3. Effect on return loss versus frequency for variation in the feed thickness

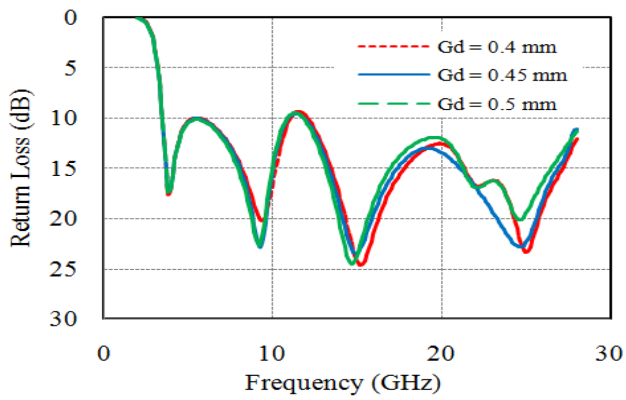

Fig. 4. Comparison of return loss versus frequency for gap between the feed and the ground

2.1.1.3. Variation in gap between the patch and the ground

The gap, G_p between the lower surface of the patch and the ground has been varied and the results are seen. The parameter, G_p is varied from 0.5 to 0.7 mm in the step size of 0.1 mm. The comparison of return loss for the three values of Gp is indicated in Figure 5. At G_p = 0.6 mm, the impedance matching across the desired bandwidth with return loss > 10 dB is well achieved.

2.1.1.4. Position of semi-circle

The etching of semi-circle in the ground plane improves impedance matching at higher frequencies. The effect of varying the position of semi-circular slot denoted by C_p about feed line is observed. The impedance matching is improved as the position of the semi-circular slot is moved towards the feed-line. Figure 6 shows the comparison of return loss versus frequency characteristics for four values of C_p from 0.4 to 0.7 mm with step size of 0.1 mm in the ground plane. A large antenna bandwidth is obtained at C_p = 0.5 mm.

2.2. Band-notched slot antenna with T-stub

A band-notch characteristic has been introduced in the slot antenna by the implementation of T-stub inside an elliptical slot within the radiating patch. This elliptical slot with T-stub acts like a parallel LC circuit [24]. This LC circuit produces high impedance at the notch frequency. The ellipse is comparable to inductor and T-stub corresponds to the capacitor.

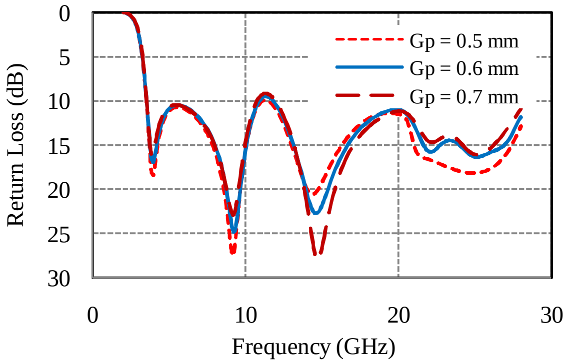

Fig.5. Comparison of return loss versus frequency characteristics for the gap between patch and ground

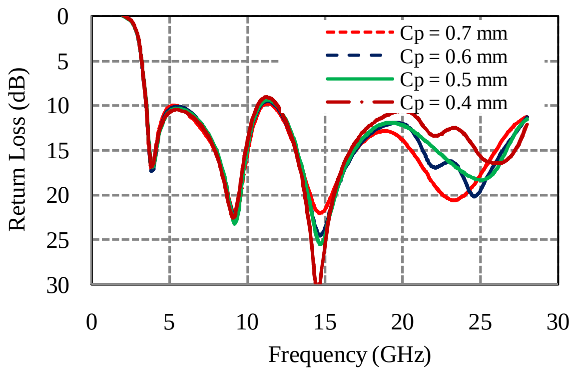

Fig. 6. Comparison of return loss versus frequency characteristics for semi-circle position

The notch frequency can be controlled by proper tuning of axial ratio (Ar) of elliptical slot and length of T-stub (Ts). An analysis of notch structure that behaves like LC circuit is discussed in the following section.

2.2.1. Notch analysis

The notch band characteristic produced by T-stub inside the elliptical slot on the radiating patch is analyzed. By varying the parameters corresponding to the axial ratio (Ar) of an ellipse and the length of T-stub, (Ts), the notch position and notch bandwidth may be tuned to get the desired antenna bandwidth.

2.2.1.1. Variation in axial ratio

The axial ratio (Ar) of the elliptical slot is varied and it is observed that with the increase in the ratio from 1.9 to 2.1, the band notch is shifted towards the lower frequency range. Figure 7 represents the comparison of return loss versus frequency characteristics for the three axial ratio values. At Ar = 2, the notched band is achieved at the desired position along with required bandwidth.

2.2.1.2. Variation in length of T-stub

By the change in the length of T-stub parameter, Ts from 3.6 to 4.2 mm with a step size of 0.2 mm, the notched band is moved to lower frequency range but, the overall antenna bandwidth is reduced. Figure 8 gives the comparison of return loss versus frequency for parameter Ts. The Ts = 4 mm is selected since it provides large antenna bandwidth.

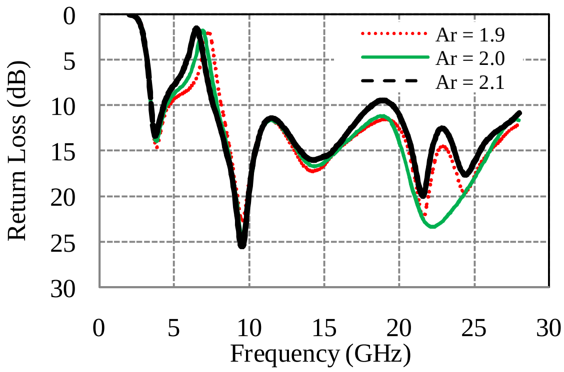

Fig.7. Comparison of return loss versus frequency characteristics for variation axial ratio (Ar) of elliptical slot

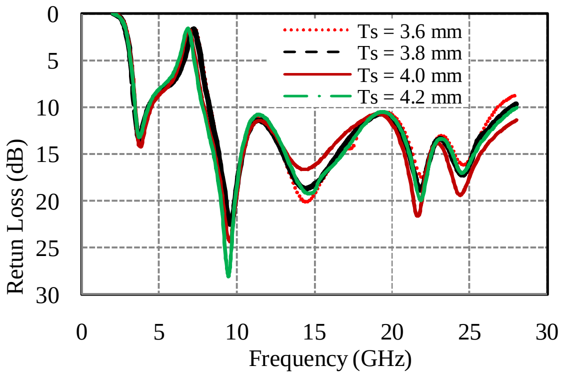

Fig. 8. Comparison of return loss versus frequency characteristics for variation in length of T-stub of Ts

Figure 9 demonstrates that the notch band may be tuned to cover the entire WLAN and ITU band if Ar = 2.15 and Ts = 2.6 mm are selected. With these values the operating bandwidth is achieved up to 26 GHz.

The optimized values of the design parameters of the proposed antenna are shown in Table 1. Table 2 represents that the proposed antenna has a compact size and large bandwidth compared to other previously designed antennas.

The simulated group delay versus frequency characteristics is shown in Figure 10. The variation in group delay is stable and within the range of 2 ns for the full antenna bandwidth.

Finally, the proposed compact single wideband notched slot antenna using T-stub with broad bandwidth has been simulated through HFSS tool and the fabrication has been done through the photolithography process. Image of the fabricated proposed antenna is shown in Figure 11. Return loss measurement is carried out through VNA. The anechoic chamber is used to measure the radiation pattern and peak gain of the fabricated proposed antenna.

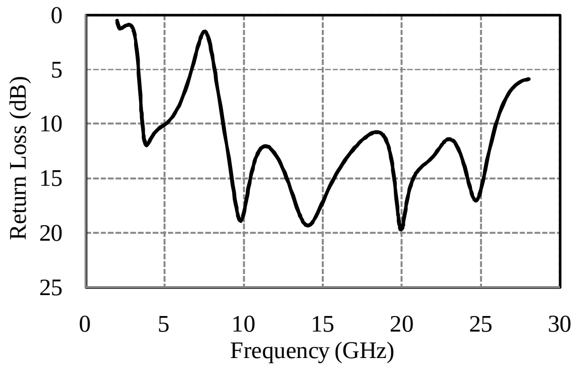

Fig. 9. Return loss versus frequency curve showing notch bandwidth from 5 to 8.7 GHz

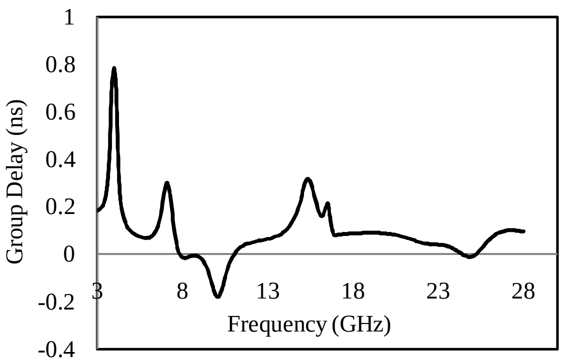

Fig.10. Group delay versus frequency

Table 1. Design values for the proposed slot design

Parameter	**Dimension (mm)**	**Parameter**	**Dimension (mm)**
W	14	R_L	4.0
L	14	G_P	0.6
S_T	0.6	G_D	0.45
G_U	4.0	C_P	0.5
G_L	1.7	Ar	2.0
F_d	2.9	Ts	4.0
R_W	6.8	T_W	1.4

Table 2. Comparison of previously designed slot antennas with the proposed antenna

Previously Designed Antennas	**Size (mm^2)**	**Bandwidth (%)**
[1]	15x15	>160
[2]	42x35	136
[3]	40x22	143
[4]	26x26	135
[5]	40x40	156
[6]	16x25	115
[12]	20x20	120
[13]	27x30.5	114
[14]	28x32	129
[15]	30x35.5	110
[16]	25x27	116
Proposed Antenna	**14x14**	**161**

Fig. 11. The fabricated proposed antenna

3. Results and discussion

The comparison of the simulated and measured return loss of the proposed slot antenna with T-stub is shown in Figure 12. A good agreement can be observed. Due to limitation at measurement facility, the proposed antenna characterization for return loss, radiation pattern and gain is performed up to 20 GHz. It can be concluded from the simulation result that the antenna provides operating bandwidth from 3 to 28 GHz.

The comparison of the simulated and measured 2-D radiation patterns in **E**-plane (xz-plane) and **H**-plane (yz-plane) for three different frequencies, namely at 3.7, 9.5 and 15 GHz is represented in Figure 13. It can be observed that the radiation patterns have been consistent across the UWB band.

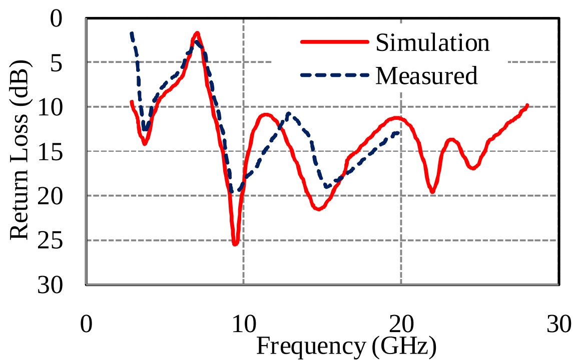

Fig.12. Simulated and measured return loss versus frequency for the proposed antenna

The simulated and measured peak gains of the proposed antenna in the frequency range from 3 to 20 GHz are compared in Figure 14. It is evident from the figure that the peak gain is negative just below 10 GHz since it corresponds to a notched band from 4.5 to 8 GHz. The gain curve represents stability within UWB operating band.

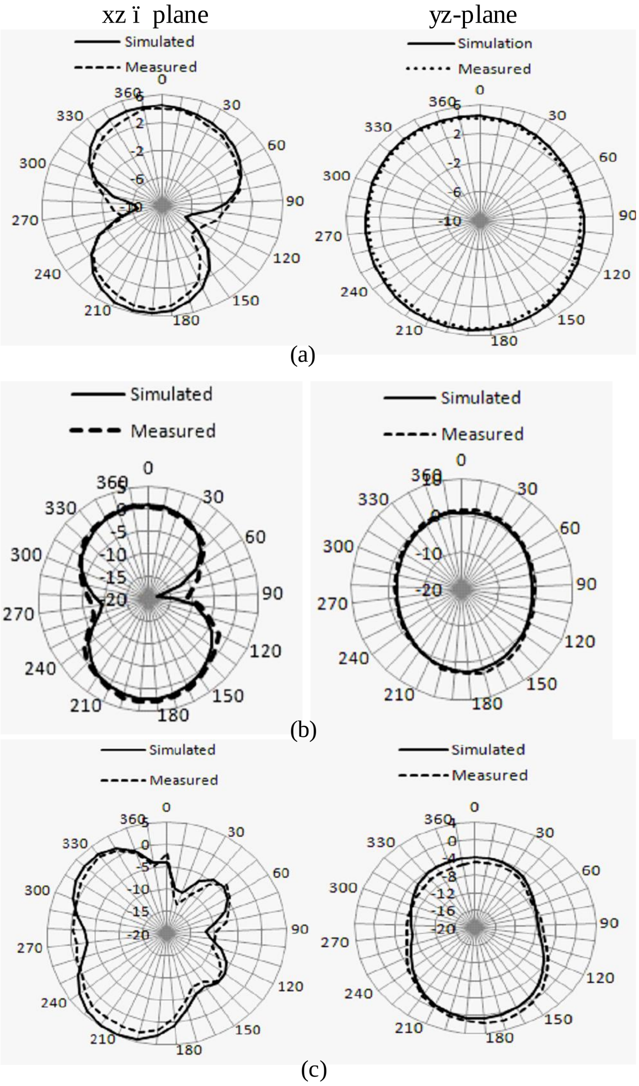

Fig.13. Comparison of Radiation Pattern of E-(xz) plane and H-(yz) plane (a) 3.7 GHz, (b) 9.5 GHz, and (c) 15 GHz

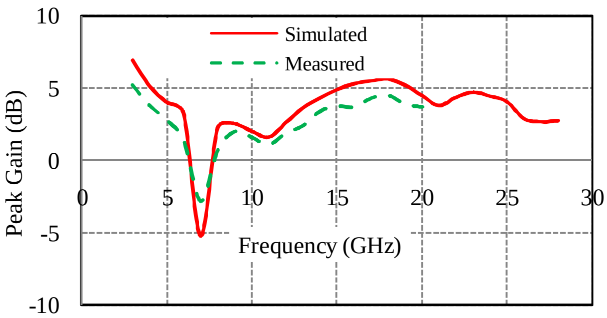

Fig.14. Comparison of simulated versus measured peak gain of the proposed antenna.

4. Conclusion

In this paper, a single wide band-notched compact slot antenna with improved bandwidth has been proposed for wireless applications. The proposed antenna can operate from 3 to 28 GHz frequency range except for the notch band (4.5 to 8 GHz). The wide notch band minimizes the interference with WLAN and lower ITU communication links. The defective ground structure is implemented for improving antenna bandwidth. The measured results show a good omnidirectional radiation pattern of the proposed antenna. The size of the proposed antenna is very small with large bandwidth as compared to earlier quoted references.

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