Rectangular Slot Super Wideband Antennas with Band Notch Characteristic Fed by CPW and Microstrip Line

Sachin Agrawal, Akshat Gururani

Abstract – **In this paper first, a coplanar waveguide (CPW) fed super wideband antenna (SWB) is proposed and investigated. It consists of a rectangular slot etched in a square-shaped patch which is blended on all its vertices for bandwidth enhancement. It achieved an impedance bandwidth of 165.4% from 2.84 GHz to 30 GHz or above with an almost stable pattern and peak gain of 7.8 dBi. Further, in order to achieve the band notch characteristic at WiMAX and C-band downlink, three vertical rectangular-shaped stubs are added inside the slot of the said antennas. It is found that due to the presence of the side arms, the proposed antenna attained a strong band rejection. Lastly, the proposed CPW-fed antenna is converted into a monopole antenna having the same material and physical dimension. It is investigated that both antennas tender approximately same impedance bandwidth and radiation pattern.**

Keywords – **Super wideband, Band notch, Impedance bandwidth, Gain.**

I. INTRODUCTION

With the progression in wireless technology, there is a rise in demand for high data rate in both short and long-range communication. In recent times, an abundance of data rates is created to satiate the resurgent demands of modern technology. As per Federal Communications Commission (FCC), the frequency range for Ultra-Wideband (UWB) technology is from 3.1-10.6 GHz (bandwidth ratio of 3.4:1) for applications in the field of radar imaging, remote sensing and wireless personal area network (PAN). The UWB technology can meet the demands for high data rate, but it can be further observed that this technology itself is not enough for longer range communication. To cover this range and even more, super wideband antenna (SWB) comes into the picture.

By definition, SWB is the type of antenna in which the bandwidth ratio of the upper and the lower cut-off frequencies is greater than or equal to 10:1. Unlike UWB, SWB antenna is not known to have a predetermined frequency range by any organizing body, as such. It can also be noted that there is no such limit for other existing wideband antennas.

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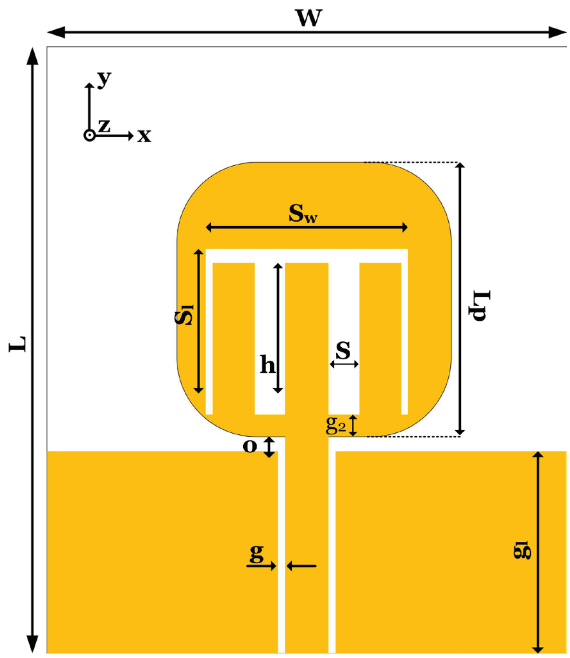

Fig. 1. Geometry of the proposed CPW-fed SWB antenna.

Previously, various planar antennas, have been proposed for SWB applications. Even though the reported SWB antennas in the literature have attained the frequency ratio of more than 10:1 in most of the cases, but with a lack of band-notch characteristics. For instant in [1], a microstrip fed modified rectangular shaped monopole antenna is proposed for SWB application. The reported design offered a high impedance bandwidth of 174% from 0.96-13.98 GHz with low-frequency coverage and compact size. In [2], a semicircular-shaped super wideband is presented. It exhibits an impedance bandwidth of 175.5% from 1.30-20 GHz with a peak gain of 5 dBi. In [3], a diamond shape slot with modified edges planar antenna is reported. It can operate from 3-20 GHz with 147% impedance bandwidth. The major problems associated with the above-discussed structures are that they did not support frequency spectrum above 20 GHz and band notch characteristics as well.

In contrast, a crescent-shaped monopole SWB antenna is proposed in [4]. The designed antenna operates in the range of 2.5-29 GHz and provides a bandwidth of 168.2%, but with the scarcity of band notch property. In parallel to this, various SWB antennas have been proposed that operate above 20 GHz [5]-[9], but none of the mentioned designs comprises band notch characteristics. On the contrary, a few SWB antennas attained 10:1 frequency ratio with band rejection property

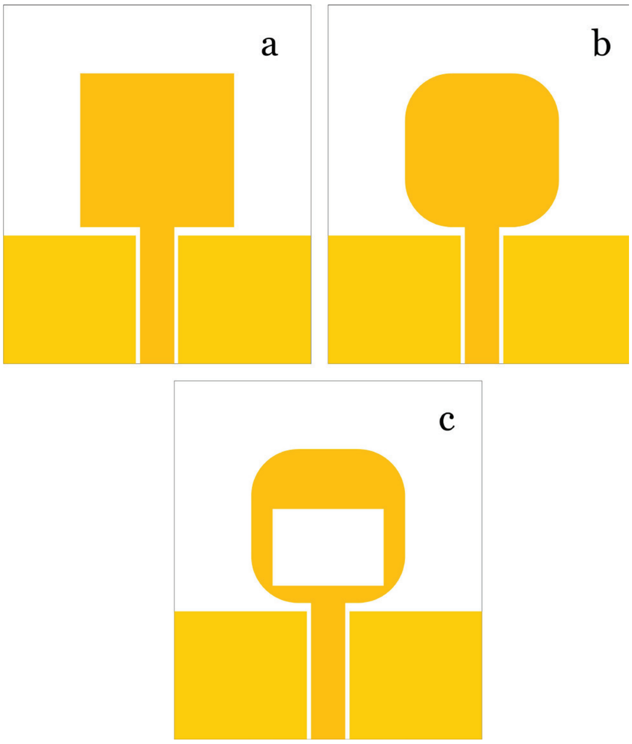

Fig. 2. Different design steps of the proposed CPW-fed SWB antenna.

[10]-[13], but in most of them, the notch rejection level is poor. In [11], the achieved bandwidth was appreciable but the rejection level was limited to -4 dB. In [12] and [13], both antennas cover frequency spectrum above 20 GHz and achieved an impedance bandwidth of 158% and 166.6%, respectively, but their rejection level was limited to -4.43 dB.

In this paper, a CPW-fed slot SWB antenna with a strong band rejection property is proposed and investigated. In order to achieve wider impedance bandwidth two important steps have been followed: (i) blending the corners of the square-shaped patch from the inside by 2 mm; (ii) etching a rectangular slot inside the patch of the given CPW-fed antenna. By doing so, a large impedance bandwidth of about 165.4% is achieved. It is investigated that after introducing the slot in the proposed design the peak gain is increased from 4.7 dBi to 7.8 dBi at 20.2 GHz. Furthermore, to overcome the problem of interference caused by the narrowband system such as WiMAX and C-band downlink, three vertical stubs (or a trident-shaped stub) are embedded in the rectangular slot. It is demonstrated that the presence of both side stubs improves the rejection level from 4.5 to 7.1 without affecting the lower and upper edge of frequency response. Afterward, the proposed CPW-fed antenna is converted into a monopole antenna to see the changes in the performance. It has been observed that the CPW-fed SWB antenna offers higher gain as compared to monopole. The CPW-fed SWB antenna yields a peak gain of 7.8 dBi, whereas the monopole 6 dBi. Finally, the proposed CPW-fed antenna is compared with the earlier reported works. It is found that the proposed antenna achieved an optimum impedance bandwidth with a strong band rejection.

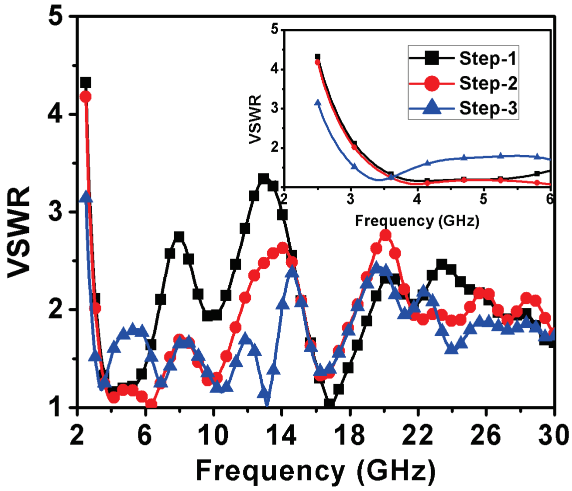

Fig. 3. Simulated VSWR of the different design steps.

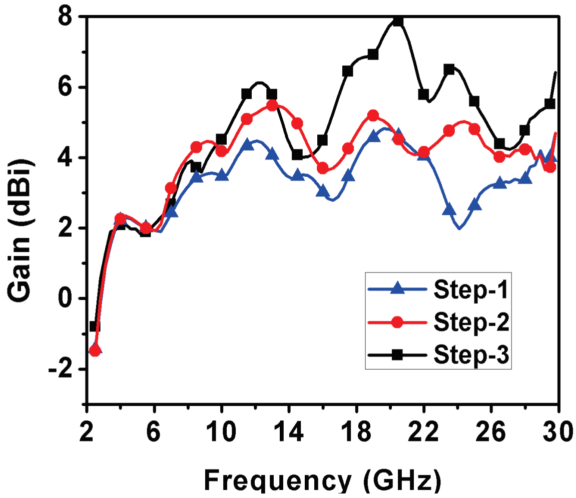

Fig. 4. Simulated gain of the different design steps.

II. Antenna Design and Discussion

Fig. 1 shows the cross-sectional views of the proposed SWB antennas. It is designed on an inexpensive FR-4 substrate of thickness 1.5 mm and a dielectric constant of 4.5. As seen, it consists of a square shape patch which is blended from its corners for bandwidth enhancement. In addition, three vertical stubs of same dimensions are introduced in the slot to achieve the band notch characteristic at WiMAX and C-band downlink. Fig. 2 depicts the different design steps of the proposed antenna. It can be seen that in the first step a square-shaped patch is used which is blended from all its vertices in the second step. Whereas, in the third step, a rectangular slot is etched in the square patch. In order to achieve higher impedance bandwidth the slot's size and position is optimized using CST Microwave studio. The optimized value of each design parameters are as follows: $L = 35$, $W = 30$, $S_l = 7.3$, $S_w = 10$, $L_p = 15$, $h = 6.8$, $S = 1.5$, $g = 0.25$, $g_1 = 13.5$, $g_2 = 1$ (all are in mm).

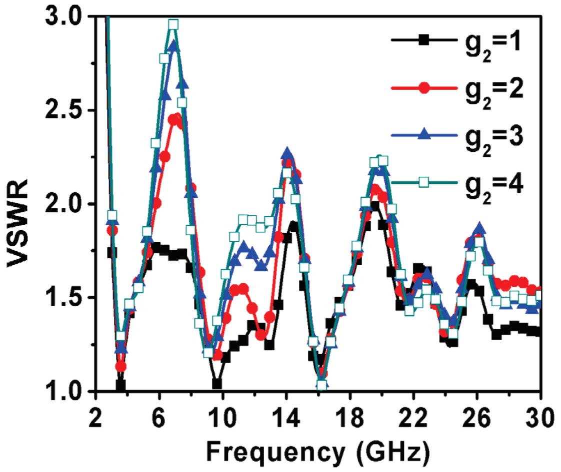

Fig. 5. Simulated VSWR for different offset values of g_2.

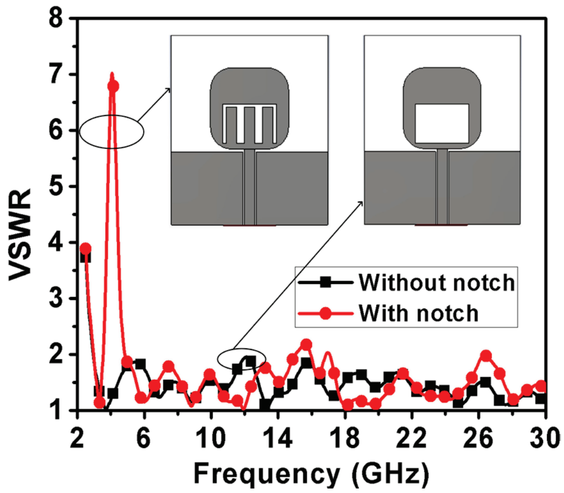

Fig. 7. Simulated VSWR with and without notch.

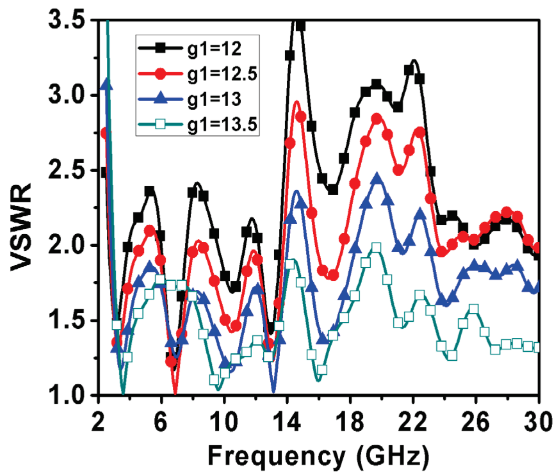

Fig. 6. Simulated VSWR for different values of ground plane height (g_1).

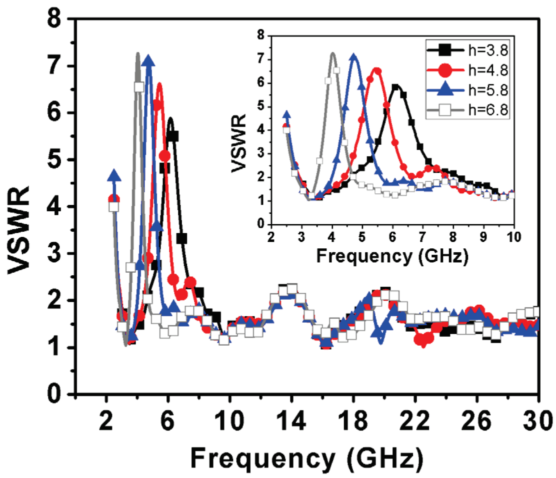

Fig. 8. Simulated VSWR for different value of stub height.

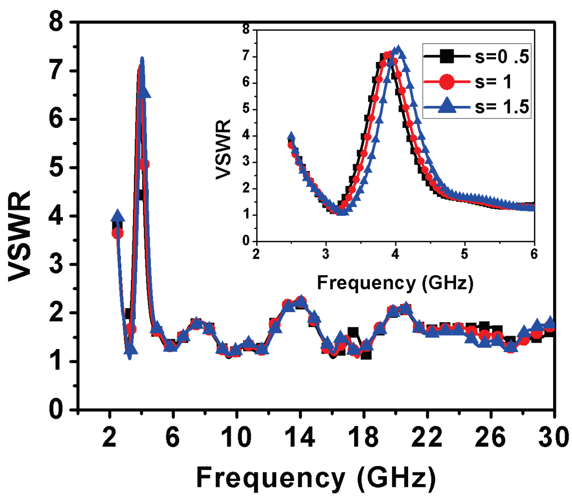

Fig. 9. Simulated VSWR for different value of gap (s) between stubs

Fig. 3 illustrates the simulated VSWR corresponds to different design steps shown in Fig. 2. As seen, blending of the patch vertices and the introduction of slot in the patch makes it easier to get a good impedance match in a large frequency range. Moreover, the lower cutoff frequency of the first step is shifted down from 3.34 GHz to 2.84 GHz in the third step and impedance bandwidth of around 165.4% between 2.84 GHz to 30 GHz is achieved. Fig. 4 shows the simulated gain of the different design steps. From step-1 to step-3, the antenna gain is continuously increasing in the entire frequency range. In step-1, the peak gain of the antenna is 4.7 dBi at 20.2 GHz, whereas in step-3 it is 7.86 dBi. These two results confirmed that the rectangular slot in the patch not only shifts the lower cutoff frequency down but also increases the antenna gain significantly.

Fig. 5 illustrates the simulated VSWR for different slot positions. As seen, slot movement in the upward direction degrades the antenna impedance matching, however the lower and upper cutoff frequencies remain unaffected. Fig. 6 depicts the simulated VSWR versus frequency for different ground plane height (g_1). It can be seen that decreasing the ground plane height (g_1) the impedance becomes worse and causes bandwidth reduction.

Since the aim of the proposed antenna is not only to achieve the wide impedance bandwidth but also to obtain the band notch characteristic at WiMAX and C-band downlink together. Therefore, three vertical stubs of the same dimension

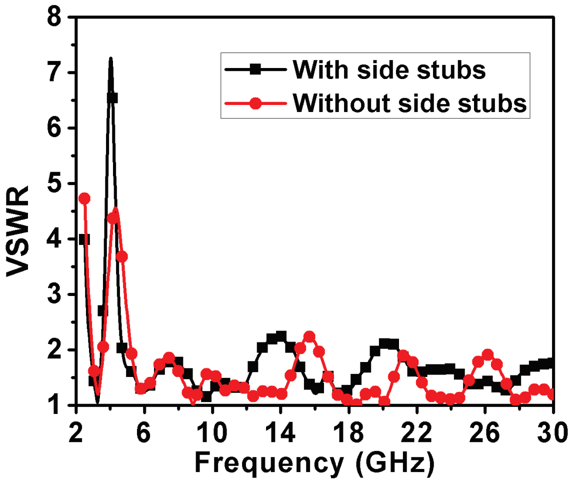

Fig. 10. Simulated VSWR with and without side stubs.

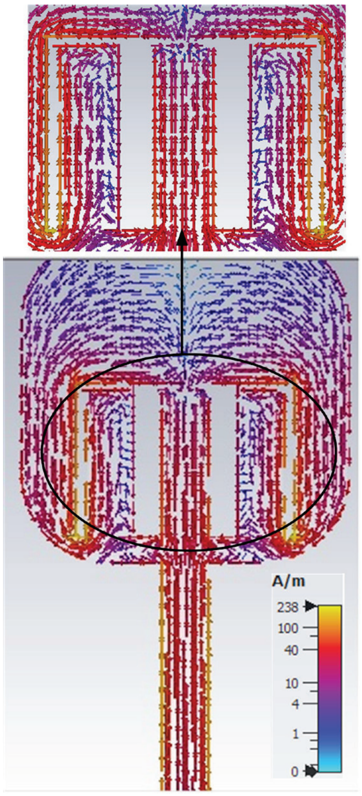

Fig. 11. Current distribution at 4.1 GHz.

called as trident shaped stub is introduced at the bottom side of the etched rectangular slot as shown in Fig. 1. The height and offset position of the vertical stubs are optimized to achieve a strong band rejection in the said frequency band. Fig. 7 demonstrates the simulated VSWR of the antenna with and without notch. As noticed, the proposed antenna strongly rejects the frequencies between 3.7 GHz to 4.75 GHz without affecting the upper and lower edges of the frequency response. Here, this trident-shaped stub acts as a λ/2 resonator at 4.3 GHz, therefore it creates an obstruction in the said rejection band. The resonant frequency of the trident- shaped stub can be calculated as: $f_{notch} = \frac{c}{2(3\times h)\sqrt{\varepsilon_{eff}}}$, where

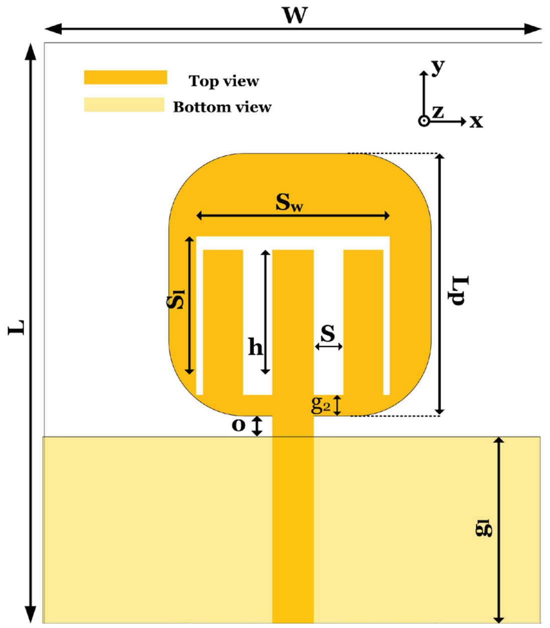

Fig. 12. Geometry of the proposed SWB monopole antenna.

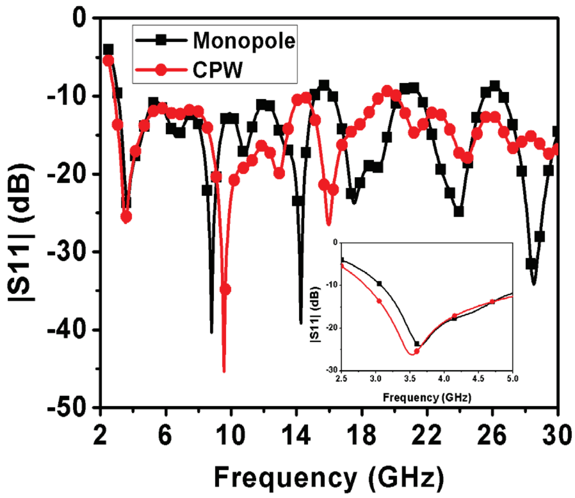

Fig. 13. Simulated $|S_{11}|$ of CPW-fed and monopole SWB antennas.

c is the speed of light, h is the height of stub and $\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2}$.

From this equation, one can see that increasing the stub height (h) reduces the resonant frequency of the notch band. It can also be verified from simulated VSWR for different stub heights (h) shown in Fig. 8. As seen, the rejection band is shifted downward by increasing the stub's height. Moreover, the rejection level becomes stronger by increasing the stub height. Here, it is worth mentioning that all the three stub's heights are varied together. The simulated VSWR corresponds to the relative position between the stubs are shown in Fig. 9. Here, the center stub is kept fixed and both the side stubs are shifted with respect to the center one. From result, it can be noticed that the stubs movement not much influencing the antenna performance. To show the importance of the side stubs in the band rejection, they are first removed from the design and then its performance is compared with the

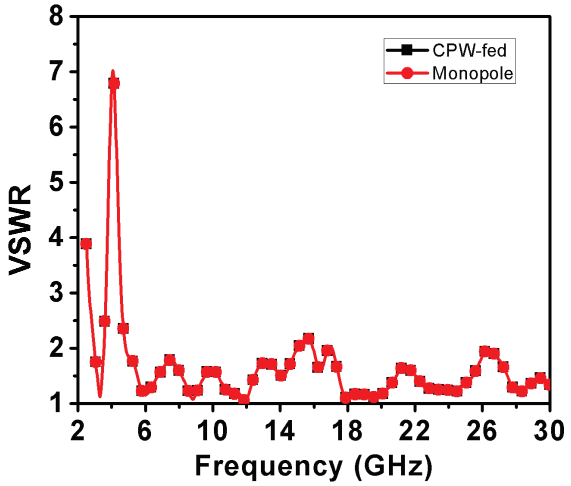

Fig. 14. Simulated VSWR of CPW-fed and monopole SWB antenna.

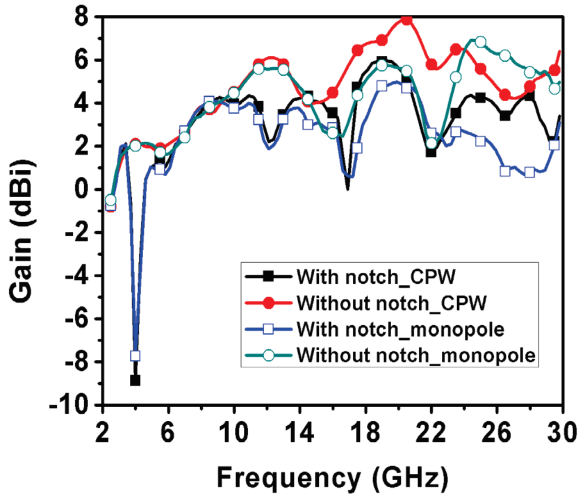

Fig. 15. Simulated gain with and without notch.

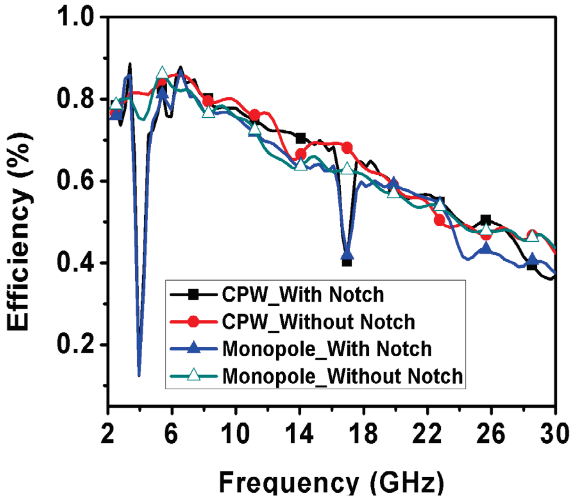

Fig. 16. Simulated radiation efficiency with and without notch.

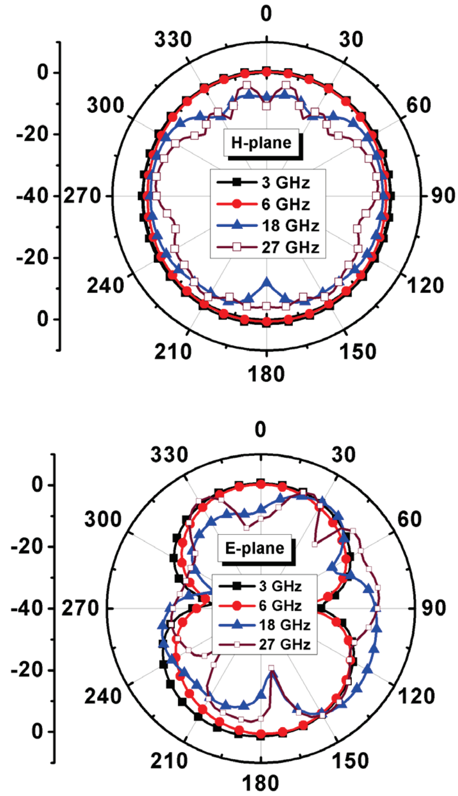

Fig. 17. Simulated radiation pattern of CPW-fed SWB antenna.

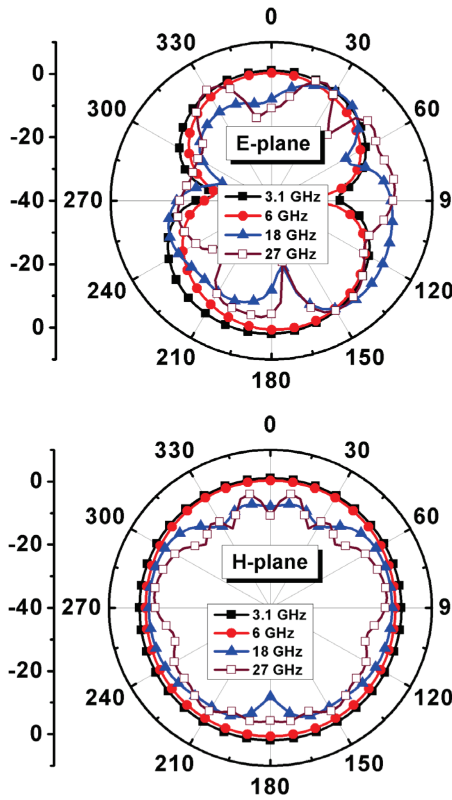

Fig. 18. Simulated radiation pattern of monopole SWB antenna.

TABLE 1
PERFORMANCE COMPARISON OF THE PROPOSED ANTENNA WITH THE EARLIER REPORTED WORKS

Ref.	Frequency response (GHz)	Impedance bandwidth (%)	Number of notches	|S11|/ Rejection level	Peak gain
1	0.96-13.98	174	None	-	approx 6
2	1.30-20	175.58	None	-	4.18
3	3-20	147	None	-	approx 10
4	2.5-29.0	168.25	None	-	6.1
5	3.5-37.2	164	None	-	3.5
6	3-35	168	None	-	11.2
10	3-50	177	Single 4.85-5.83	5	10
11	0.9-100	196	Single 4.7-6	4.41	approx 7
12	3.68-31.61	158	Single 7.86-11.0	approx 5	9.75
13	3.87-35	160.4	Single 7.24-11.1	approx 4	approx 10
Pro.	2.84-30	165.4	Single 3.7-4.75	7.1	approx 8

proposed design as shown in Fig. 10. It can be seen that the due to side stubs rejection level becomes stronger. Fig. 11 illustrates the current distribution at the notch center frequency (4.1 GHz) of the notch. As seen, the current at exterior edge of the slot is in the downward direction, whereas the current direction at the exterior edge of both side stubs is in the upward direction. Therefore, a destructive interferences will occur which causes no radiation in the rejection band.

Next, the proposed CPW-fed antenna is converted into a monopole antenna. Fig. 12 illustrates the geometry of the monopole SWB antenna. Here, it is worth noting that the physical dimension and the substrate of both antennas are exactly same. Fig. 13 depicts the simulated $|S_{11}|$ of both antennas. In both cases, the upper and lower cutoff frequency is identical. However, from the inset figure, it can be noticed that the CPW-fed antenna starts operating from 2.84 GHz, whereas the monopole from 3.07 GHz. Fig. 14 compares the band notch behavior of both antennas. It can be observed that the rejection band of both antennas occurs between identical frequency points. Further the simulated gain of both antennas with and without band notch characteristics is illustrated in Fig. 15. As seen, in the entire frequency range, the CPW-fed SWB antenna is providing a higher gain than the monopole. However, in the rejection band, the gain is symmetric, it reduces from 2 dBi to -8.6 dBi. Fig. 16 illustrates the simulated radiation efficiency of the proposed antenna. It can be observed that both monopole and CPW-fed structures show similar efficiency. Both antennas attained more than 60% efficiency from starting frequency point to 14 GHz, however above it starts reducing and reaches 40%.

Figs. 17 and 18 illustrate the radiation pattern of CPW-fed and monopole antennas at four frequencies, respectively. It can be noticed that in E-plane and H-plane, the radiation pattern of both antennas is identical. As seen, in H-plane the pattern is almost constant throughout the frequencies range. However, in E-plane the pattern is slightly distorted at higher frequencies range. This may be because of unequal phase distribution on the antenna aperture [14]. Table 1 compares the proposed work with the earlier reported works. It can be noticed that the proposed antenna tenders an optimum impedance bandwidth with a strong band rejection as compared to other works.

III. CONCLUSION

In this paper, two printed rectangular slot antennas fed by CPW and microstrip line with band notch characteristics are proposed for super wideband application. The proposed antennas tendered almost same impedance bandwidth (about 165.4%) and radiation pattern. Further, in order to enhance the rejection level, both of these antennas used two stubs at either side of the center stub. Through simulation, it is observed that due to these two stubs the rejection level is increased from -4.4 dB to -2.4 dB and the gain in the rejection band is reduced to -8.6 dBi.

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