Design of Rectangular-Cut Circular Disc UWB Antenna with Band-Notched Characteristics

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Abstract:
This paper presents the design of CPW - feed rectangular-cut circular ultra wideband (UWB) antenna with notched-band characteristic. The antenna has been designed on a FR4 substrate with dielectric constant $\varepsilon r = 4.4$, loss tangent (tan δ) = 0.022 and substrate thickness h = 1.53 mm. The antenna has been optimized to exhibit UWB characteristics from frequency range 3.1GHz–12 GHz except the notched-band frequency 5.2 GHz to 5.8 GHz. The radiation pattern of this antenna is nearly omni-directional in H-plane and bidirectional in E-plane. The effect of various design parameters on notched characteristics have also been analyzed using 3D Electromagnetic simulator based on FEM method. The simulated results are in good agreement with FCC standards showing VSWR <2 throughout the band 3.1GHz to 12GHz, except the notched-band. This antenna can be easily integrated with microwave circuitry and useful for UWB applications.

Keywords: Microstrip antenna, Monopole antenna, Band-notched, CPW-feed and UWB system**.**

1. Introduction

In 2002, Federal Communication Commission (FCC) authorized unlicensed use of UWB band ranging from 3.1 GHz to 10.6 GHz. UWB system plays a dominant role in communication system as the antenna is one of the wireless communications components. The UWB antenna is a specific component whose transmitting and receiving properties differ from those for conventional narrowband operation. There lies different wireless communication systems which overlap the UWB band. To avoid interference due to these frequencies, UWB antenna must be able to reject such frequencies with very fine rejection characteristics. For this purpose, numerous notches are created at particular frequency band which have rejection characteristic over a limited bandwidth.

Lately, a number of antennas with band-notched property have been discussed and various methods have been used to achieve the function. UWB antenna can be achieved by use of simple microstrip line and proper designing of ground structure [1]. While widely used methods for notched-band are created slots on the patch or on the ground plane, i.e., straight, triangular, E-shaped, H-shaped, U-shaped, and folded strip-line slots [2-5]. The all these notches techniques are very expensive way to obtain notched characteristics in an expected band of frequency [6]. The notched bands can be generated by a band notched filter composed of double stepped impedance resonators (SIRs) [7-8]. Split ring resonator is one of the widely used and appreciated structure used for creating notches at particular frequencies [10-11]. Adding parasitic element is another advantageous method to generate notched band [9]. Square ring resonator and a square parasitic element can be used to have notched characteristics in UWB antenna [12-13]. The notched-band characteristic achieved by parasitic elements so far reported by having parasitic element on the back of substrate or adjacent to patch. This requires the double side printing or increase the overall size of antenna. In this paper, parasitic element to create notched-band is proposed, which does not require double side printing and also not increase the size.

This work is concentrated on achieving the UWB Monopole antenna with band-notched characteristics by the use of parasitic element. Antenna has a compact size of 38mm x 43mm x 1.53mm. Comparative study of simple circular disc as radiating element and modified circular disc with wide rectangular slit inserted is carried out in order to see its effect on operating frequency. Rectangular split ring is made as parasitic element inside the slot available which electromagnetically couple to the radiating patch giving notched-band at WLAN frequency.

2. Design of Antenna Geometry

The planar monopole antenna with CPW-feed is shown in Figure 1a. This monopole antenna is constructed from the circular disc of 18.4 mm diameter. A rectangular cut of size 14.6 mm x 8.0 mm is slotted from the circular disc of diameter 18.4 mm. This circular disc with rectangular cut is optimized for Ultra wide band (UWB) characteristics. To achieve the band notched characteristic, a rectangular split ring is inserted as parasitic element in rectangular cut space. The dimension of parasitic element is optimized using 3D electromagnetic simulator. The notation of optimized parameters of parasitic element is shown in Figure 1b. These optimized dimensions of parasitic element are tabulated in Table 1. This monopole antenna with parasitic element is designed using CPW fed patch antenna on generally available FR4 substrate of dielectric constant of 4.4, thickness 1.6 mm and loss tangent (tan δ) = 0.022.

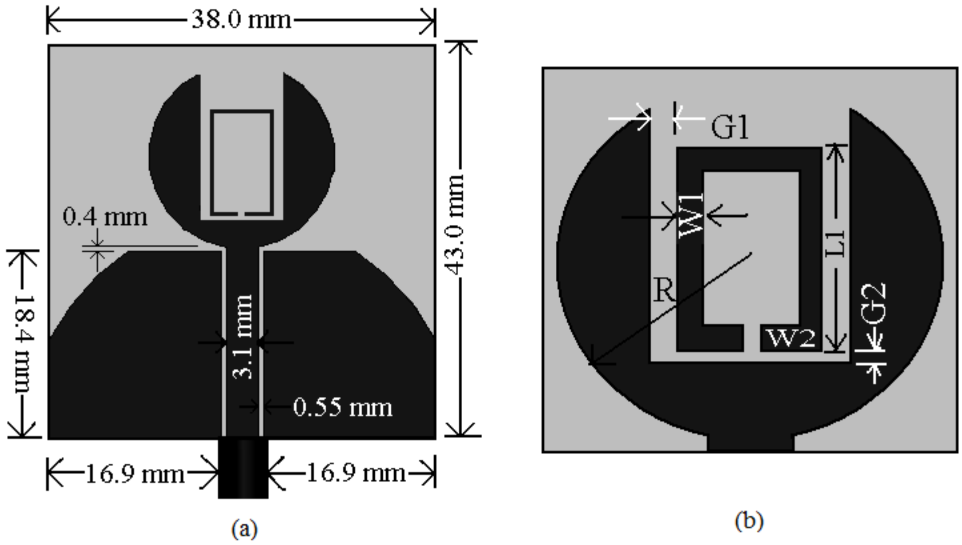


Fig. 1 (a) Proposed UWB antenna with parasitic element, (b) Parasitic element for band-notched characteristic

Traditional way of designing monopole yields length L of the radiating element as 25mm for lower end resonating frequency of 3 GHz

$$L = \frac{c}{4 \times F\_r\sqrt{\varepsilon eff}}$$

But choosing of circular disc as radiating element in place of straight line results in nearly 26% reduction in size as radiating element have length (diameter) of 18.4mm only. Radiating element and ground patch are of same dimension i.e. 18.4mm. The ground plane dimensions made of copper metal are optimized in width and length i.e. 16.9 mm x 18.4 mm. Feed width is optimized to 3.1mm with gap between ground and feed line as 0.55mm. Gap between radiating patch and Ground is optimized to 0.4mm as shown in Figure 1a.

To make use of available space created due to rectangular cut of dimension 14.6mm x 8mmmm in circular disc. A notched-band is created using rectangular split ring parasitic element positioned in the space obtained due to rectangular cut. Its length, width and slot width are optimized to get notched-band over WLAN frequencies i.e. 5.2 GHz to 5.8 GHz. The optimized parameters are listed in table 1.

Table 1 Optimized dimensions of parasitic element

Length		Width		Gap		Slit width
L1	L2	W1	W2	G1	G2	S
10.7	6.4	1.5	1.0	0.8	0.3	0.5

3. Current Distribution

The current distribution is calculated at various frequencies including notched-band frequency as shown in Figure 2. Current distribution of proposed antenna is obtained using HFSS clearly indicates that large amount of current is concentrated along vertical edges of the parasitic element and rectangular cut at notched frequency i.e. at 5.5 GHz. While there is very less or no current along parasitic element at other frequencies. Though parasitic element is not directly in contact with radiating patch, but at resonating frequency, it shows current due to electromagnetic coupling.

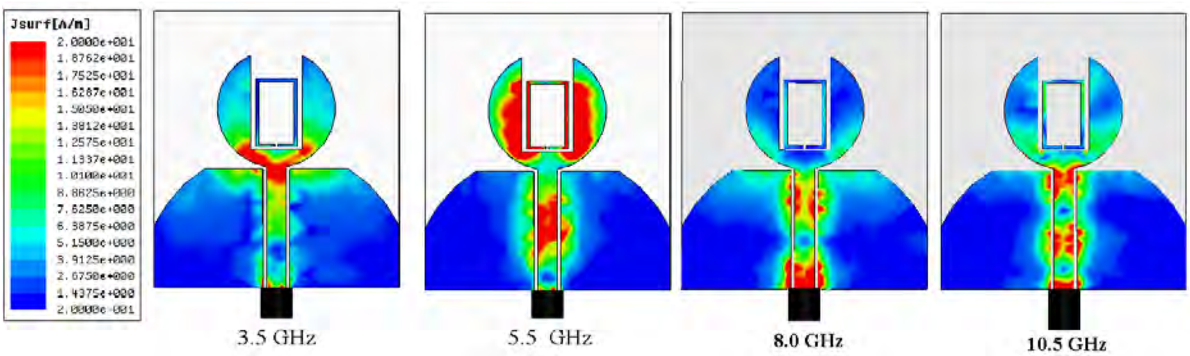


Fig. 2. Current Distribution of proposed antenna at different frequencies

4. Simulated Results and Discussion

The proposed antenna is optimized first, for each design parameters to achieve the required ultra wide bandwidth. In this, ground width, ground length, width and length of Rectangular cut in radiating patch, feed width, gap between feed and ground, and crucial gap between patch and ground are optimized rigorously. The optimized dimensions of this antenna are gap between patch and ground 0.4mm, gap between feed and ground 0.55mm, feed width 3.1mm, ground length 18.4 mm and ground width 16.9mm. The overall substrate size is taken 43mm x 38mm.

First, the circular disc of 18.4mm diameter was simulated. Then, a rectangular cut of dimension 14.6mm x 8mm was slotted. The rectangular cut dimension was optimized for ultra wide bandwidth. The simulated results of with and without cut of rectangular slot in patch are shown in Figure 3a. It is observed that the operating band shifts towards lower frequency side around 300 MHz. This is due to increase of electrical length of current path. Much effect on higher side operating frequency has not been observed. This indicates improvement in bandwidth and as well as some sized reduction due to rectangular cut in circular patch. The simulated VSWR is shown in Figure 3b with and without rectangular cut in circular disc.

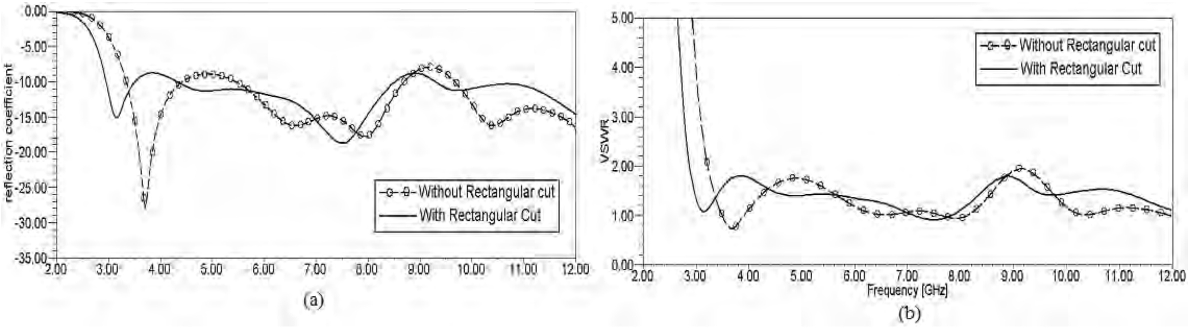


Fig. 3. Simulated (a) return loss and (b) VSWR with and without rectangular cut in circular disc

After this, parasitic element is inserted in rectangular cut space. The dimensions of parasitic element are optimized to have the correct notched center frequency and bandwidth. The optimized performance in term of the VSWR is shown in Figure 4 with and without notched-band. The VSWR is less than 2 over band starting from 3GHz to 12GHz except at notched band 5.2GHz to 5.8 GHz indicating strong rejection characteristics over this band.

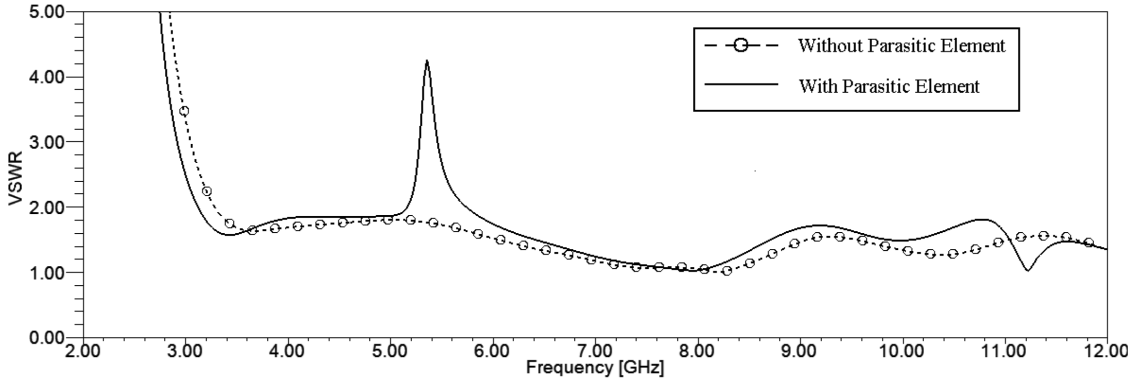


Fig. 4. Simulated VSWR with and without notched-band

5. Parametric Analysis

As can be seen from current distribution, length and width of parasitic element along with gap between patch and parasitic element play crucial role in defining notched-band center frequency and its bandwidth. These parameters are studied in detail in subsequent sections and best of them are selected to make final design.

5.1 Effect of Vertical Length L_1

The parasitic element with various design parameters is shown in Figure 1b. Vertical Length of parasitic rectangular split ring is varied from 12.7mm to 7.7mm in steps of 1.0 mm. The simulated VSWR is shown in Figure 5. It is observed as L_1 decreases the centre frequency of notched-band shifts towards higher frequency side with nearly constant bandwidth. This large variation is observed as changes in L_1 affects the current flowing in parasitic element. Interfering WLAN frequencies are in band 5.2GHz-5.8GHz, hence optimized L_1 is obtained as 10.7 mm for center frequency of WLAN band.

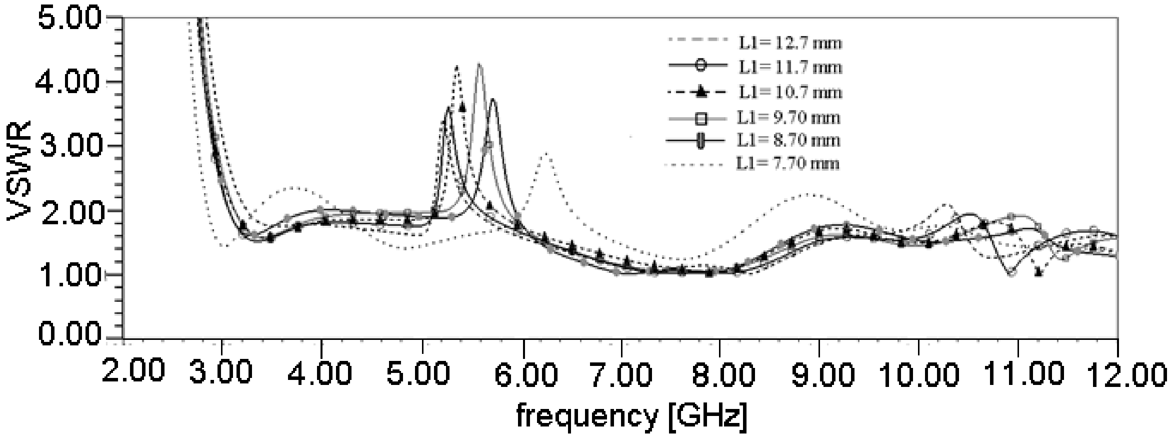


Fig. 5. Simulated VSWR for various value of vertical length L_1

5.2 Effect of Vertical Coupling Gap G_1

Coupling between rectangular split ring and patch also depends upon gap (G_1) between two elements. Thus, it plays crucial role in deciding rejection band. As the vertical coupling gap reduces from 0.8mm to 0.5mm, notched band shifts to higher end in frequency spectrum as shown in Figure 6. For our requirement of rejection in band 5.2GHz to 5.8 GHz, the optimized value is obtained to G_1=0.8mm.

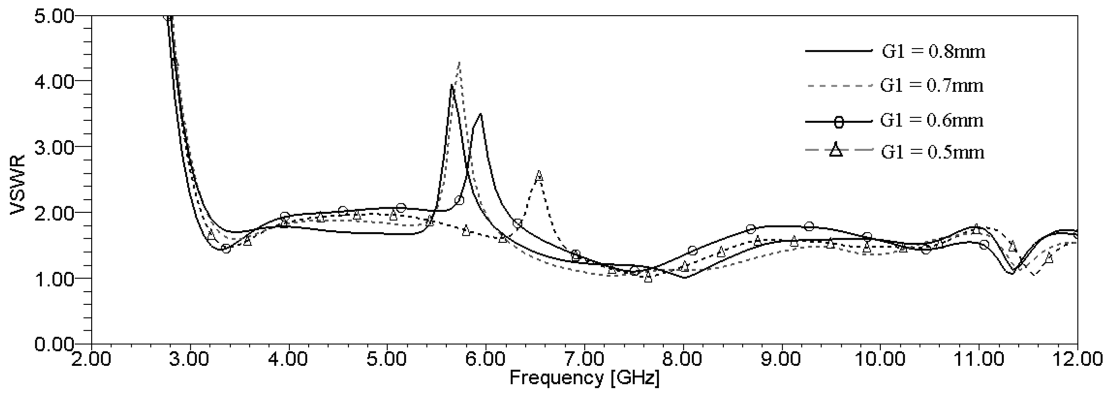


Fig. 6. Simulated VSWR for various value of vertical coupling gap G_1

5.3 Effect of Horizontal Coupling Gap G_2

Horizontal coupling gap also plays important role in deciding rejection notched-band. As the gap increases from 0.3 mm to 1.1 mm, quality of rejection (or VSWR) decreases due to less coupling and rejection band shifts to higher side as shown in Figure 7. Rejection bandwidth nearly remains constant. Thus, the optimized gap (G_2) for required notched band is obtained to G2=0.3mm .

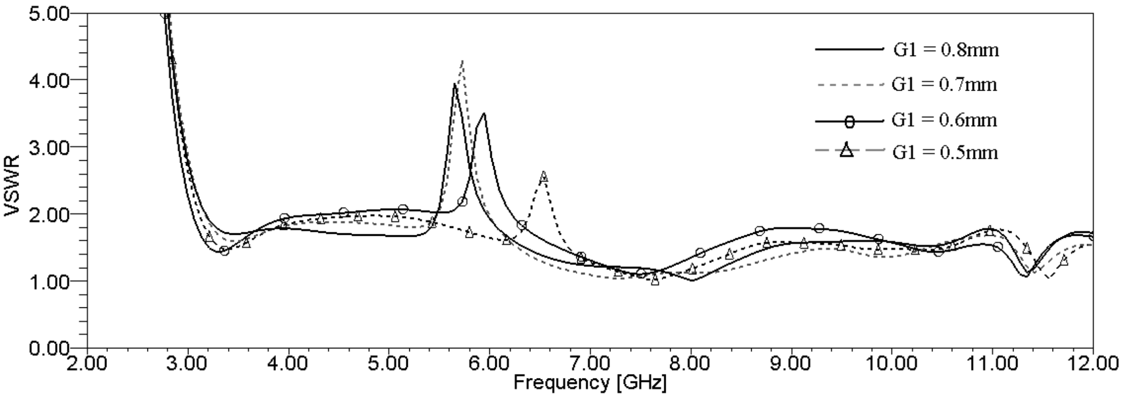


Fig. 7. Simulated VSWR for various value of horizontal coupling gap G_2

5.4 Effect of Width W_1 and W_2 of Parasitic Element

Width of parasitic element decides bandwidth of notched-band. The relationship between the width of element and rejection bandwidth is directly proportional i.e. as width of element increase bandwidth of rejection also increases. The simulated result shows the relation between width of vertical element W_1 and rejection band. As width W_1 increases from 0.5mm to 1.5mm rejection bandwidth increases by lowering the starting frequency of notched-band as shown in Figure 8a. Similar, effect of increasing bandwidth is observed when W_2 is varied from 0.5mm to 1.0mm as shown in Figure 8b. As there is no direct contact of parasitic element and radiating patch, variation of width does not have much effect on bandwidth. In other words, notch obtained is relatively stable.

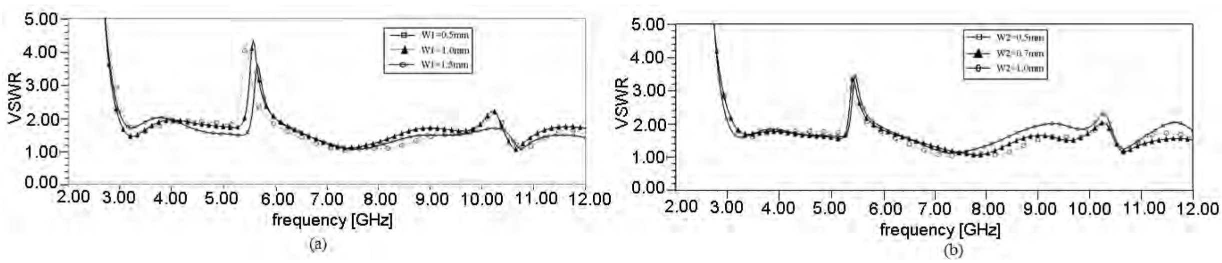
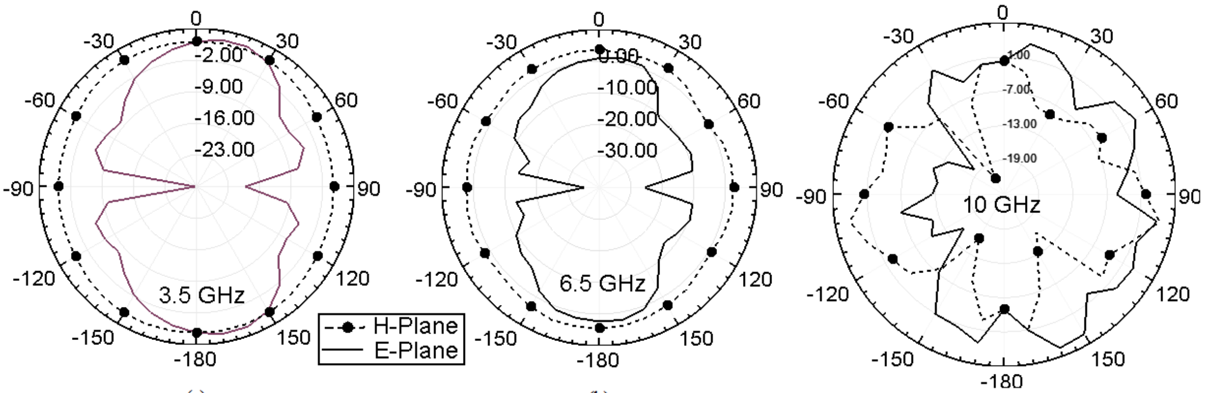


Fig. 8 (a) Simulated VSWR for various value of width of Parasitic Element W_1, (b) Simulated VSWR for various value of width of Parasitic Element W_2

6. Radiation Patterns

The simulated radiation patterns of the proposed antenna are shown in Figure 9. It is evident that the antenna exhibits omni -directional radiation pattern in H plane and bidirectional radiation pattern in E plane at lower edge of the spectrum. But it starts deteriorating at higher frequencies as shown in Figure 13. At these frequencies, the radiation patterns especially at the principle planes perpendicular to the antenna plane deteriorate because of the excitation of the higher-mode currents on the antenna structure as well as the enhanced edge currents on the ground plane.



(a) (b) (c)

Fig. 9. Simulated radiation pattern at selective frequencies (a) 3.5 GHz (b) 6.5 GHz and (c) 10 GHz

7. Peak Gain and Radiation Efficiency

Peak gain and radiation efficiency are most important characteristics to be studied while designing the antenna. The peak gain in dB, with and without parasitic element are calculated as shown in Figure 10a. Continuous increase in peak gain is observed as one traces from lower to higher frequency in frequency spectrum. Sharp dip in peak gain is observed at notched band due to parasitic element. This indicates the stopping of the external signal inference at notched-band. Radiation efficiency versus frequency is shown in Figure 10b for with and without notched-band. It is observed at notched frequency the radiation efficiency drop down drastically to less than 60% indicating that the antenna rejects WLAN application signal.

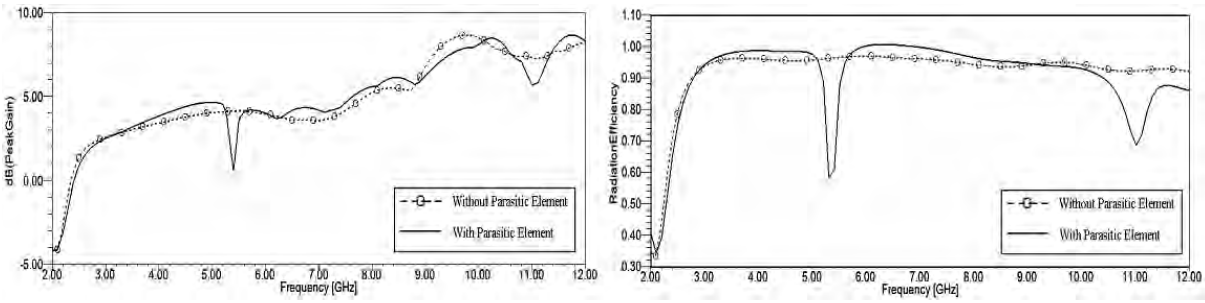


Fig. 10. Simulated (a) peak gain and (b) radiation efficiency with and without notched –band

8. Conclusions

Proposed antenna satisfies the UWB frequency requirements and shows operating band from 3.1GHz-12GHz with VSWR< 2 except the desired notched band of frequency 5.2GHz-5.8GHz . Furthermore, it can be stated from the simulation results that notched-band obtained using parasitic element can be tuned very finely to desired band by varying different parameters of parasitic element i.e. length, width, crucial gap between patch and element. It is observed notch-band obtained is stable in nature as compared to those technique like slot in patch or feed line. This antenna can be used for short range data transfer with very high data rate and other UWB applications for military like through Wall Radar Vision and as well as medical imaging etc.

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