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Design and Characterization of an UWB Antenna with Multiple Band Notch using EMPro

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Abstract: In recent years, there has been an explosive growth in Ultra-wideband communication because of its characteristics like higher data rates, saturation of the frequency spectrum, low power consumption, etc. In this paper, an ultra-wide band (UWB) antenna which operates in the frequency band 3.1-10.6 GHz is designed. The designed antenna has an eye geometry patch and a ground layer. The antenna exhibits a 10 dB return loss bandwidth over the entire frequency band. By modifying the physical structure, the RCS (radar cross section) of the designed antenna is reduced. To avoid electromagnetic interference (EMI) with narrow band systems, the four pairs of meanders lines (MLs) are added to the antenna to generate multi band notch characteristic. These MLs act as resonators and main advantage of this technique is no extra space is required so that overall antenna is maintained. The EMPro simulation tool is used for antenna simulation.

Keywords: Ultra Wide Band (UWB), Antennas, Radar Cross Section (RCS), Electromagnetic Interference (EMI).

I. INTRODUCTION

The Ultra-wideband (UWB) technology is one of the most promising technologies for high data rate wireless communications, high-accuracy radars, and imaging systems since Federal Communication Commission (FCC) declared 3.1-10.6 GHz as ultra wide band frequency range. The UWB systems are differing from traditional narrow band systems. UWB systems transmit information in the form of very short pulses thus occupying very large bandwidth and enabling time modulation. There are many issues involved in designing of UWB systems among them one of the most important is designing an optimal antenna for UWB communication. It is preferred that UWB antennas have low profile, easy to fabrication and low production cost as like micro strip patch antennas.

Microstrip antennas became very popular since the 1970s owing to their ease of analysis and fabrication, lower complexity of shape and appealing radiation characteristics. On the other hand the major functioning disadvantages of microstrip antennas are narrow bandwidth, poor efficiency and low power. To enhance the impedance bandwidth, several bandwidth enhancement techniques have been proposed. These techniques include the use of an asymmetrical feed arrangement [5], a partial ground [6], adjusting the gap between radiating element and ground plane [2], beveling radiating element [3], beveling ground plane [4], cutting slot in the ground plane beneath the microstrip line [1] and cutting two notches in the radiating element.

However, the design of UWB communications systems is still facing many challenges. One of them is that UWB communication systems could easily be interfered by the nearby communication systems such as the wireless local area networks (WLANs) operating in the 2.45-GHz (2.4–2.484 GHz) and 5.05-GHz (4.9–5.3 GHz) bands and the worldwide interoperability for microwave access (WiMAX) system operating in the 3.35-GHz (3.3–3.4 GHz) and 3.5-GHz (3.4–3.6 GHz) bands. A simple solution to this problem is to design the UWB antennas with band-notched characteristics to suppress the interference signals. Different designs have been proposed to realize the band-notched characteristic for UWB antennas [7–12], for example using parasitic elements, folded strips [8], split-ring resonators (SRRs) [11], quarter-wavelength tuning stubs [8], meander-ground structures [10], resonated cells on the coplanar-waveguide (CPW), fractal tuning stub [12], slots on the radiator or ground [9] and slots or folded-striplines along the antenna feed line. However, most of these designs targeted at creating a single-notched band and only one achieved a triple-notched band using meander lines (MLs) [7].

In this study, an ultra-wide band antenna having an eye shaped patch and a ground layer is designed and simulated using EMPro simulation tool. The designed antenna radiates over the entire frequency band of ultra wide band communication (3.1 to 10.6 GHz). The radar cross section of the designed antenna is reduced by altering the physical size of the patch and the ground layer. Then, in order to avoid the electromagnetic interference, we created notches at frequency bands of narrow band systems by using meander lines. Again the antenna is simulated to observe the return loss at the notched frequencies.

II. ANTENNA STRUCTURE AND DESIGN

In this section the various simulated antenna models and their simulation results are shown. The simulated return losses of every designed model are shown with brief explanation.

A. *UWB Antenna*

The antenna is designed by using a dielectric material with the size of 60x65 mm and the thickness of t=0.508 mm.

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The dielectric constant of the material is ε=6.15. The patch of the antenna consists of intersection of two circular geometries which is like an eye as shown in Fig. 1. The centre of the upper circle with radius r_a=16 mm is located at x_a=30 mm and y_a=45 mm from the edges. The lower circle with the radius of r_b=17 mm is located at x_b=30 mm and y_b=30 mm from the edges of the antenna. The intersection of two circles is rotated counter clockwise by Θ=20 degrees. The eye shaped patch is connected to a strip line with the width of w_f=0.74 mm. The antenna is fed by a 50 ohm feed line. The ground layer of the antenna has a height of h_g=28.4 mm.

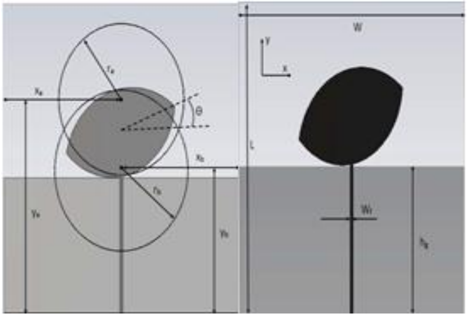

Fig. 1: Design of the front and the back side of the UWB antenna

The geometry of the designed antenna, having dielectric material Roger_RO3006 is drawn in the EMPro simulation tool and is shown Fig. 2. The Simulated result for return loss of the designed antenna is shown in Fig. 3. In this result we obtained below -10 dB return loss over the entire frequency except in the bands of 4.1 to 5.4 GHz and 6.3 to 6.8 GHz. Now by changing the dielectric material from Roger to FR4 which has dielectric constant is ε=4.5. Then the obtained simulation results of s11 return loss is shown in Fig. 4.

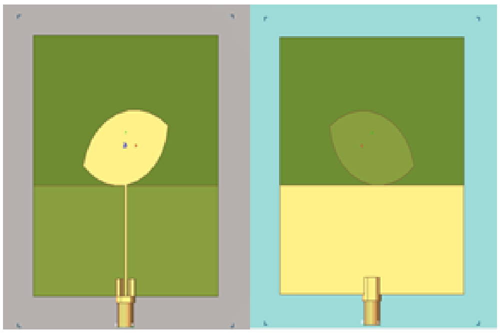

Fig. 2: Front and the back side of the simulated antenna

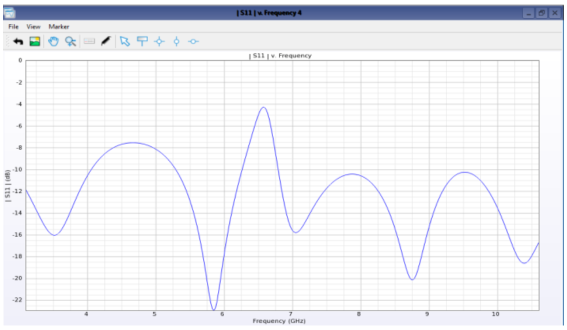

Fig. 3: Simulation results of return loss of the antenna (Roger dielectric material).

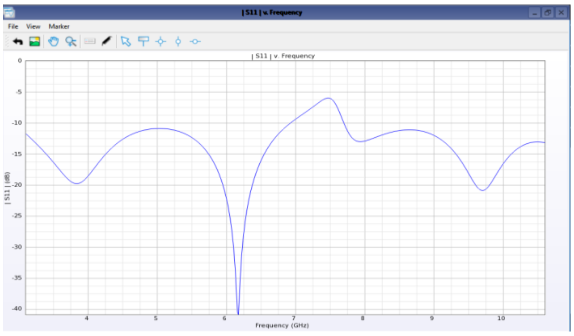

Fig. 4: simulation results of return loss of antenna (FR4 Dielectric material).

B. *UWB Antenna with reduced RCS*

The surface current distributions of the simulated antenna at 5 GHz and 10 GHz are obtained as shown in Fig. 5. The current distribution of the antenna is more intensive along the strip line. Additionally, current distribution at the patch is concentrated in the edge of the patch structure. At the ground layer the current distribution is concentrated in especially upper side of the layer. The current distribution is considered in order to reduce RCS of the antenna. First of all to reduce RCS, a circular structure with the radius of p_r=8 mm is extracted from the patch as illustrated in the Fig. 6.

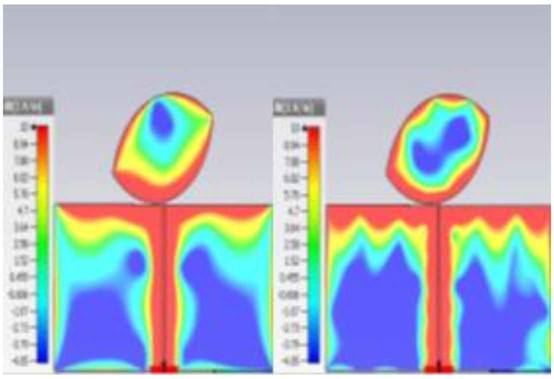

Fig. 5: Surface current distribution at (a) 5 GHz and (b) 10 GHz.

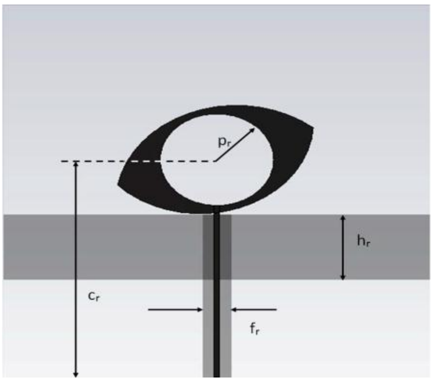

Fig. 6: Modified antenna with reduced RCS.

The origin of the circle is located c_r=37.5 mm from the edge of the antenna. Secondly, the height of the ground layer is shortened to h_r=11 mm. A line at the ground layer along the feed line with the width of f_r=4 mm is located to feed the patch. The geometry of modified antenna drawn in EMPRO is shown in Fig. 7.

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The simulated return loss of the modified antenna is shown in the Fig. 8.

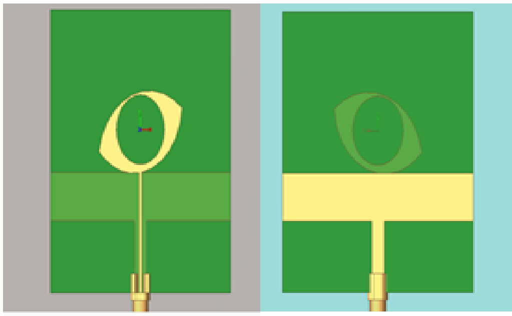

Fig. 7: Front and back side of modified antenna.

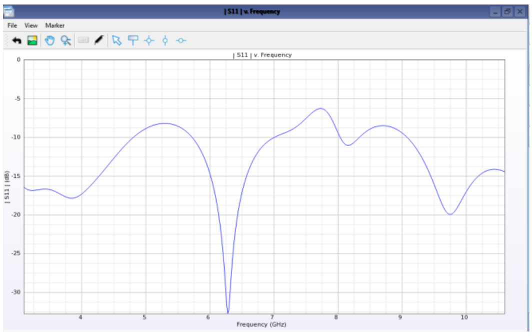

Fig. 8: simulation results of return loss of modified antenna

To optimize the return loss of the antenna, next the simulation is done by replacing the SMA connector by single feed line connector. SMA Johnson connector is a waveguide port of 50 ohms, which operates in the frequency range of 0 to 26.5 GHz, is replaced be a simple 50 ohms voltage or current source as shown in Fig. 9.

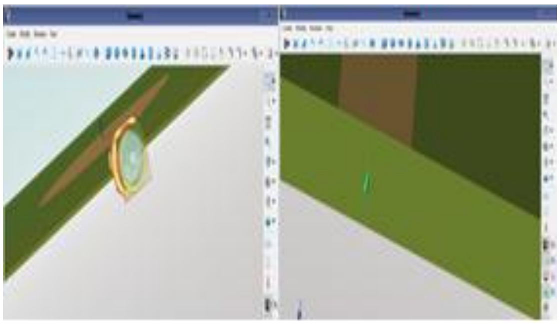

Fig. 9: SMA connector is replaced by single feed line

The simulated return loss of the modified antenna with single feed connector is shown in the Fig. 10. In these results we obtained return loss of -10 dB over the entire frequency range.

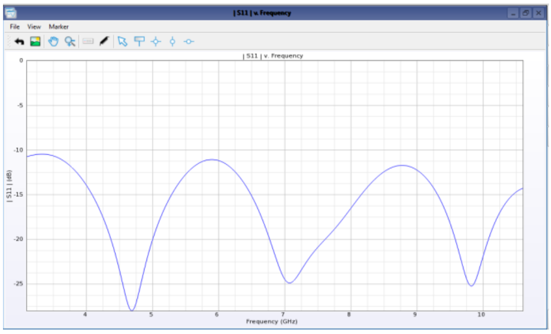

Fig. 10: Return loss of modified antenna with single feed line.

Then the effect of h_r on return loss of the antenna is analyzed by doing simulation for various hr heights. Here we have simulated the antenna with ground heights h_r=14, 11 and 9. The obtained return losses for these heights are shown in Figures. 11, 12, and 13 respectively. When the h_r height decreases S11 return loss decreases up to 10 dB at 4.8 GHz.

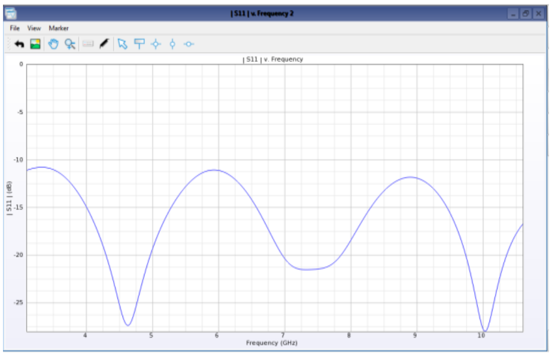

Fig. 11: Return loss of the antenna with h_r=14.

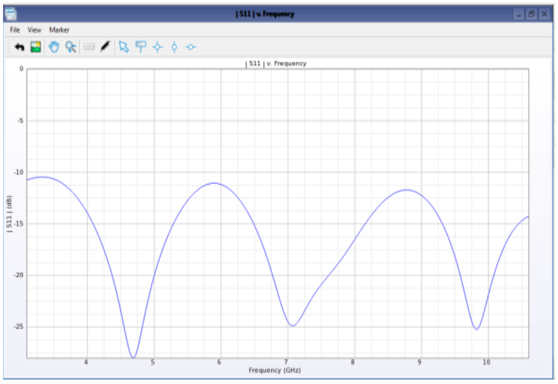

Fig. 12: Return loss of the antenna with h_r=11.

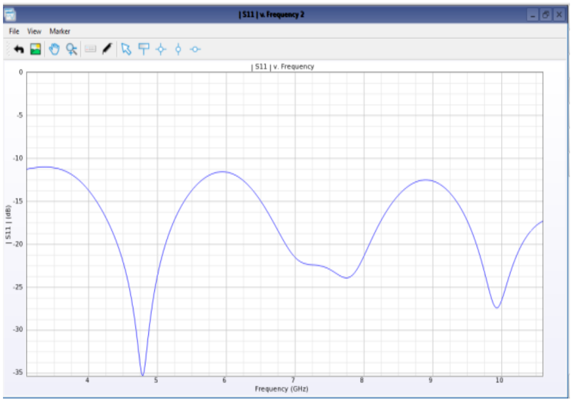

Fig. 13: Return loss of the antenna with h_r=9.

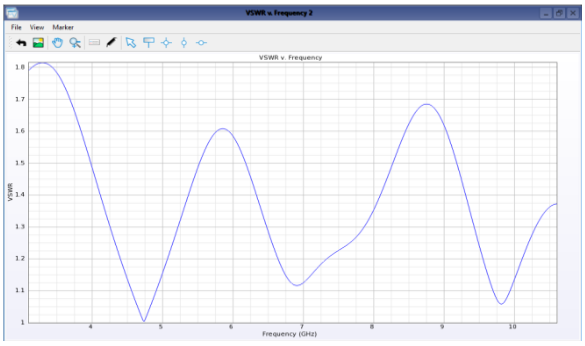

Fig. 14: VSWR vs. frequency plot

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In the Fig. 14, we can observe that VSWR of the simulated antenna over the entire frequency band. We obtained VSWR<1.82 entire operating frequency band.

As our requirement, an Omni-directional radiation pattern is desirable because of user mobility and freedom in the transmitter or receiver position. Omni-directional radiation pattern means that the signal waves passing through antenna shall be able to travel in all directions. The radiation pattern of the simulated antenna is shown in Figures. 15 and 16 below in both 2D and 3D view respectively. We obtained Omni directional radiation pattern in the range of 3.1 GHz to 10.6 GHz.

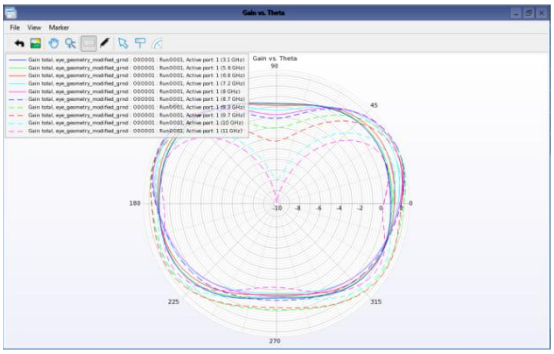

Fig. 15: 2D view of radiation pattern of the antenna (E-plane)

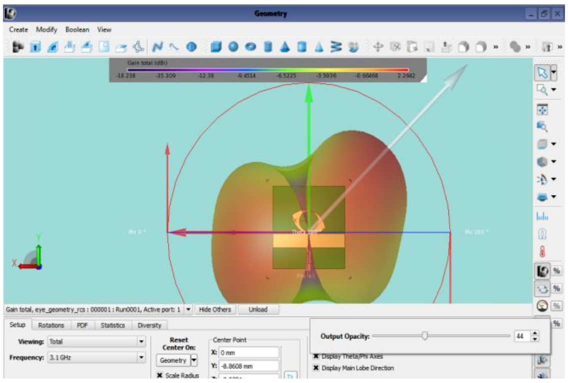

Fig. 16: 3D view of radiation pattern of the antenna at 3.1 GHz

C. *UWB Antenna with multi band notch characteristic*

The Four pairs of meander lines (MLs), working as resonators, are added to the antenna to produce a multiple band notch characteristic, yet without increasing the overall antenna size. Two types of feeding techniques, direct-connected feed and parallel-coupled feed, are used in the resonators. The Centre frequencies and bandwidths of the individual notches can be adjusted independently using the dimensions of the corresponding MLs. The basic concept is that when current is flowing on a microstrip line, it mainly concentrates at the edges, so we can place four pairs of MLs along the edges to create four notched bands.

To create band notches for the antenna at WLAN operating in the frequency bands 3.2 GHz (3.1 to 3.3 GHz), 5.05 GHz (4.9 to 5.20 GHz) and also at WIMAX frequency band 4 GHz (3.9 to 4.1 GHz), we place resonators implemented using MLs along the edges of the feed line and the ground plane.

The main advantage of this method is no extra space is required and so the overall compact size of the antenna is maintained. Two different types of feeding techniques, parallel-coupled feed (PCF) and direct-connected feed (DCF), as shown in Figs. 18 a and b, respectively.

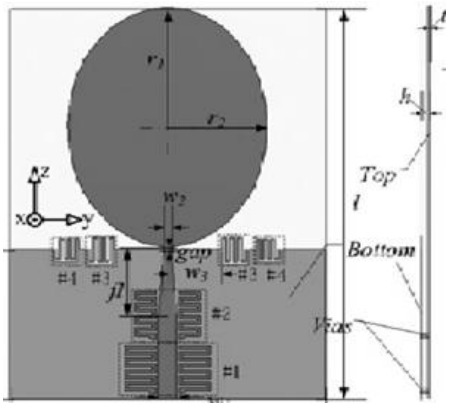

Fig. 17: Top view and side view of the proposed multi band-notched UWB antenna

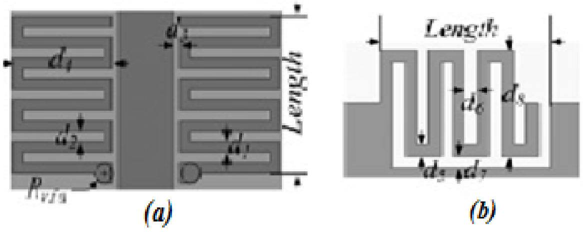

Fig. 18: a) PCF MLs placed along the feed line
b) DCF ML placed along upper edge of ground

The PCF MLs, that is, MLs #1 and #2 in Fig. 17, have an open circuit at one end and a short circuit to the ground through a vial at the other end. With an electrical length of $\lambda_g/4$ the MLs serve as electrically coupled $\lambda_g/4$ resonators, where λ_g is the guided wavelength approximately given by the below equation.

$$\lambda_g \cong \lambda_0/\sqrt{(\varepsilon_r+1)/2} \quad \ldots\ldots\ldots \quad \text{Equation. 1}$$

With λ_0 is the free space wavelength and ε_r being the relative permittivity of the substrate. At resonances, the signals on the feed line will be coupled to the MLs and then flowing through the vias to the ground plane and back to the source, creating high impedance for the signal and preventing the signal from flowing into the radiator.

The DCF MLs, that is, MLs #3 and #4 in fig 17, are just open-circuit stubs. With an electrical length of $\lambda_g/4$, the MLs are $\lambda_g/4$-resonators with direct-connected feed. At resonance, the MLs prevent the signal from passing through, again creating high input impedance. This causes severely mismatching to the antenna and reduces the return loss.

The Equation.1 is derived using the distributed-elements model and only applies to a straight microstrip line. For complicated structures with sizes much smaller than the operating wavelengths, the lumped-elements model should be used. In our design, the sizes of MLs #1, #2, #3 and #4 are 3 × 4.5 , 2.1 × 4.5 , 2.8 × 2.7 , 2.8 × 2.3 mm2, respectively.

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ML	d1	d2	d3	d4	Length	ML	d5	d6	d7	d8	Length
#1	0.3	0.3	0.25	3	4.5	#3	0.2	0.2	0.2	2.5	2.8
#2	0.3	0.3	0.25	2.1	4.5	#4	0.2	0.2	0.2	2.1	2.8

Table. 1: Dimensions of PCF MLs and DCF MLs (in mm)

It should be noted that the positions of these MLs need to be carefully selected in order to fit into the limited size of the antenna. Table1 shows that the sizes of the MLs are inversely proportional to the notch frequencies, so we place the two MLs with larger sizes along the feed line and then the other two MLs with smaller sizes at the upper edges of the ground plane. By doing this, we manage to place four pairs of MLs on the antenna.

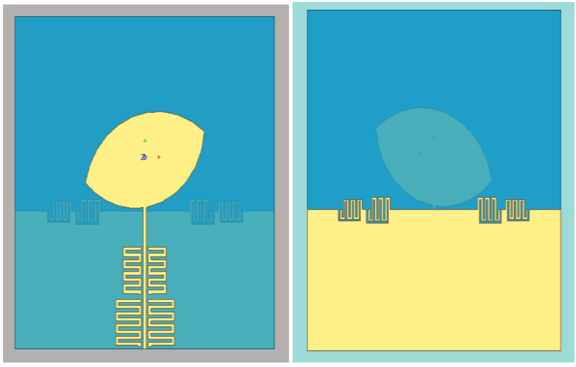

Fig 19: front and back side of the uwb antenna with multi band-notch characteristics.

The front and back side of antenna model with meander lines to produce notches at the frequency bands of narrow band systems, like WLAN and WIMAX is shown in the Fig. 19.

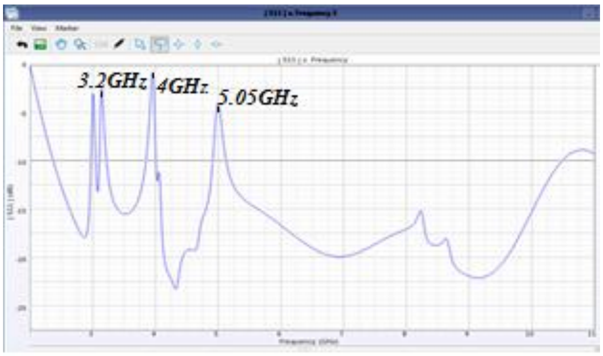

Fig. 20: Simulated return loss of the uwb antenna with multi band-notch characteristics.

We can observe in the Fig. 20, the return loss curve of the simulated antenna with multiple band notched characteristics. Here the return loss is maximum at WLAN operating in the frequency bands of 3.1 to 3.3 GHz and 4.9 to 5.20 GHz and also at WIMAX operating in the frequency band of 3.9 to 4.1 GHz.

Hence the antenna is not operating efficiently in these frequency bands of narrow band system thus produces notches and the antenna operates in the entire UWB frequency range without any interference.

III. CONCLUSION

An eye shaped ultra wide band antenna which radiates at 3.1–10.6 GHz is designed. The designed antenna is simulated using EMPro simulation tool. In the second stage, with help of surface current distribution some part of ground layer and patch are extracted to reduce the RCS of the designed antenna. The obtained return loss of the simulated antenna is less than -10 dB over the entire frequency range. The obtained VSWR is less than 1.82 and the radiation pattern of the antenna is Omni-directional. Then to avoid the interference, the design of a multiple band-notched characteristic for designed UWB antenna has been proposed. Without increasing the antenna size, four MLs are etched on the antenna to generate notches.

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