Design of Integrated Triple Band-notched for Ultra-wideband Microstrip Antenna

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***Abstract*—Ultra-wideband (UWB) is one of the recent topics that received a great concern from academia and industry. However, UWB found many difficulties to be standardized due to the overlay working that made UWB an important potential interference source to many licensed and unlicensed spectrum throughout the band 3.1-to-10.6 GHz. This make many industries worried about deploying and standardizing this promising technology. Many techniques have been introduced by academia a friendly UWB design that can mitigate interference. One of these technologies recently proposed is band-notched technique. In this paper we propose a compact ultra-wideband microstrip antenna with triple band-notched 5.32 GHz, 8.45 GHz and 10.83 GHz. The proposed antenna consists of a rectangular patch with a partial ground plane that is fed by 50 Ω microstrip line. A band-stop function is created by inserting overlapped two u-shape slots on the radiator patch, added additional patch to ground plane side and slit in truncate ground plane. The proposed antenna is simulated in both the frequency domain and time domain. The achieved results show that the antenna performance has good impedance matching and stably performs omni-directional pattern in (*x, z*) plane over a bandwidth of 3.1 to 10.6 GHz. The proposed antenna could potentially minimize frequency interference from many underlying technologies i.e. WLAN, WiMAX and Aeronautical mobile bands.**

Keywords - Ultra-wideband antenna, Microstrip antenna, Partial ground plane, Band-notched

I. INTRODUCTION

In 2002, the Federal Communications Commission (FCC) allocated the ultra-wideband (UWB) frequency range from 3.1-10.6 GHz for unlicensed UWB applications. The limitation of equivalent isotropically radiated power (EIRP) in band emission does not exceed -41.3d Bm/MHz for extremely wide impedance bandwidth [1]. Printed planar monopole antennas have been designed to operate in UWB systems [2]. There are some wireless communication applications which have already occupied frequencies in the UWB band such as the wireless local area network (WLAN) a.k.a. IEEE802.11a/g and HIPERLAN/2 WLAN which operate at 5.15-5.35 GHz and 5.725-5.825 GHz, respectively and IEEE 802.16 (3.3~3.8GHz) [3]. In addition, the worldwide interoperability for microwave access (WiMAX) has also operated covering the frequency from 5.25-5.85 GHz in some countries [4]. One way to suppress these interfering signals is to use a spatial filter such as a frequency selective surface above the antenna. However, this approach requires too much space and expensive [5]. To disband this problem, the UWB antenna with build-in frequency notch structure is often chosen. A lot of functions have been used for frequency rejection in UWB antenna designs. The most popular technique to provide this character is embedded a slot on the patch or ground plane [6]. However, in order to achieve monopole antenna designing, a large ground plane is required, which could not be suitable for compact wireless devices. Some techniques are used to reject undesired frequencies, for examples, placing the parasitic strips on the opposite side of the radiating element [7], inserting two strips in the printed slot antenna to create two rejection bands [8], and embedding a C-shaped slit into the fed element with a parasitic strip in slot antenna [9].

However, the antennas have more complicated structures to implement than others. In [10], the band-notched slot antennas were studied, in which two types of narrow slits on the exciting stubs were used for two antennas, and two parasitic strips were placed in the rectangular slot for another one [11]. Although, the antenna design is capable of undesired frequency rejection, the parasitic strips lead to more complex structure.

In [12], the band-notched antennas were designed by using resonators with embedded narrow slits into the patches, in which the former used a small strip in the notched patch and the latter used a defected ground plane. However, most of these designs have single band-notched characteristics for the rejection of the WLAN band or WiMAX band, only a few articles addressed the dual or multi-band rejection designs.

The main problem of the frequency band rejection design is the difficulty of controlling the bandwidth of the notch band in a limited space. Furthermore, strong coupling between multi adjacent notch bands is obstacle to achieve efficient multi band-notched UWB antennas. Therefore, an efficient frequency bands rejection of the WLAN band, WiMAX band and other specific band is difficult to implement for UWB applications.

This paper introduce new UWB Microstrip antenna geometry for triple band rejection characteristics, by modifying rectangular patch with CPW-fed line and truncated ground plane, in this solution which modify the structure and incorporate of the antenna patch cross section techniques to achieve multi-band rejection designs, The proposed antenna consists of a microstrip patch with U-shape slots, offset feeding line, additional patch in bottom view and slit in truncated ground plane.

By achieve multi-band rejection increase number of band-notched which is necessary for UWB antenna to avoid interference from license technologies use same frequency (narrow band). The proposed antenna has compact size. Furthermore; the proposed antenna is cheap due to the use of low cost FR4 substrate with simple fabrication. The details of concept design, implementation, and simulation results are presented.

The reminder of this paper is organized as follows: Section 2 discusses the proposed UWB microstrip antenna. Section 3 presents the design procedure. In Section 4, results are evaluated and discussed. Finally, the paper concluded in Section 5.

II. The Proposed UWB Microstrip Antenna

This section presents the proposed UWB microstrip antenna design steps and calculations methodology. The geometry and configuration of the proposed ultra-wideband antenna is shown in Fig. 1. The proposed antenna is designed on FR4 substrate with a thickness of 1.6 mm, relative permittivity of 4.3, a rectangular patch is fed by a microstrip line printed on a partial grounded substrate. For this proposed model, the optimization was carried out to achieve the best impedance bandwidth. The microstrip line feed is designed to match 50 Ω characteristic impedance. The impedance matching of the proposed antenna is enhanced by correctly adjusting the dimension of the feeding structure and the patch size. Consequently, this antenna (will be referred to as antenna 1 in this paper) has a wideband impedance bandwidth with acceptable radiation pattern.

The geometry and dimensions of the wideband antenna with band-notched design (will be referred to as antenna 2) is depicted in Fig. 2 double U-shaped slot in patch, strip is added on the same side of truncate ground plane, offset strip line and slit in truncate ground plane. All these are employed to create a frequency band-notch and triple band antenna. Analysis of the notched design with different widths and lengths of the slots are performed to obtain the optimized dimensions.

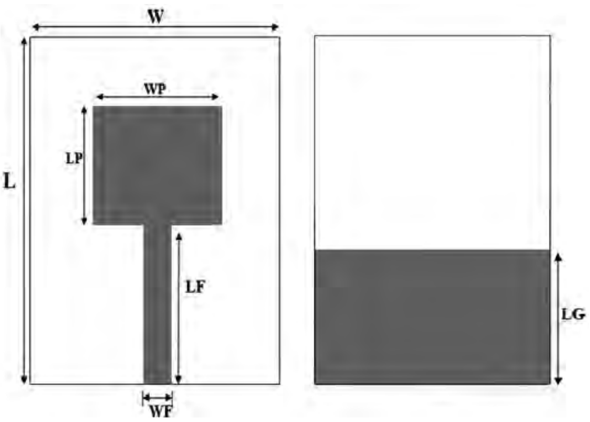


Fig. 1. Antenna without double U-slot, slit and additional strip in ground plane

III. Design Procedure

In this section, the procedure for designing conventional rectangular microstrip patch antenna is explained. Next, compact and triple notched-band rectangular microstrip patch antenna is designed for use in UWB frequency.

A. Antenna Configuration and Specifications

The three essential parameters for the design of a rectangular microstrip patch antenna are operation frequency ($\boldsymbol{f_0}$): The resonant frequency of the .Ultra-wideband (UWB) uses the frequency range from 3.1-10.6 GHz. Hence the antenna designed must be able to operate in this frequency range. The resonant frequency selected for antenna design is 6 GHz. The dielectric material selected for antenna design is silicon which has a dielectric constant of the substrate ($\boldsymbol{\varepsilon_r}$) of 4.3. A substrate with a high dielectric constant has been selected since it reduces the dimensions of the antenna, Height of dielectric (h). Hence, the essential parameters for the design are: $\boldsymbol{f_0}$= 7 GHz, $\boldsymbol{\varepsilon_r}$= 4.3 and h = 1.6 mm. The dimensions of the patch along its length have now been extended on each end by a distance ΔL, which is given empirically by Hammerstad in [13, 14] as:

$$\Delta L = 0.412h\frac{(\varepsilon_{reff}+0.3)(\frac{W}{h}+.264)}{(\varepsilon_{reff}-0.258)(\frac{W}{h}+0.8)} \qquad (1)$$

where h is the height of dielectric, W is the width of the microstrip patch antenna and ε_{reff} is the effective dielectric constant.
Then, the effective length (L_{eff}) of the patch can be calculated as follows:

$$\mathrm{L_{eff}} = \mathrm{L} + 2\Delta\mathrm{L} \quad (2)$$

For a given resonant frequency f_0, the effective length is given as:

$$\mathrm{L_{eff}} = \frac{\mathrm{C}}{2\mathrm{f_0}\sqrt{\epsilon_{\mathrm{reff}}}} \quad (3)$$

For a rectangular microstrip patch antenna, the resonance frequency for any TM_{mn} mode is given by as:

$$\epsilon_{\mathrm{reff}} = \frac{\epsilon_{\mathrm{r}}+1}{2} + \frac{\epsilon_{\mathrm{r}}-1}{2}\left[1 + 12\frac{\mathrm{h}}{\mathrm{W}}\right]^{-1/2} \quad (4)$$

The width W of microstrip patch antenna is given by [15] as:

$$\mathrm{W} = \frac{\mathrm{C}}{2\mathrm{f_0}\sqrt{\frac{(\epsilon_{\mathrm{r}}+1)}{2}}} \quad (5)$$

The design steps for the proposed UWB microstrip and calculations are given as follows:

Step 1: Calculation of the Width (W): The width of the microstrip patch antenna is given by Eq. 5 by substituting c = 3x10^8 m/s, ε_r = 4.3 and f_0 = 7 GHz, we get: W = 13.1635 mm.

Step 2: Calculation of effective dielectric constant (ε_{reff}): Eq. 4 gives the effective dielectric constant by substituting ε_r = 4.3, W = 13.1635 mm and h = 1.6 mm we get, $_{\mathrm{reff}}$ = 4.2703.

Step 3: Calculation of the effective length (L_{eff}): Eq. 3 gives the effective length by substituting ϵ_{reff} = 4.3, c = 3e8 m/s and f_0= 7 GHz we get L_{eff} =10.3696 mm

Step 4: Calculation of the length extension (ΔL): Eq. 1 gives the length extension by substituting ϵ_{reff} = 3.7499, W = 15.3574 mm and h = 1.6 mm we get: ΔL = 0.0190 mm.

Step 5: Calculation of actual length of patch (L): The actual length is obtained by Eq. 2 as, Substituting L_{eff} = 10.369mm and ΔL = 0.0190 we get: L = 10.3316 mm.

B. Design and Theoretical Consideration of Slot

This design procedure for overlapping U-shaped slot on patch antenna for antenna 2 is given in Fig. 2, by determining operation frequency (f_0) and the lower and upper frequency bounds of the bandwidth as f_{low} and f_{high}, respectively, as follows:

i. operation frequency, f_0 = 7 GHz
ii. Lower bound frequency, f_{low} = 3.1 GHz
iii. Upper bound frequency, f_{high} = 10.6 GHz

Slot thickness S defined as:

$$\mathrm{S} = \lambda_0/60 \quad (6)$$

In Eq. 6, we substitute λ_0 = c/f_0 = 42.8571 mm then we get S = 0.714285 optimized to 1 mm slot width W_1 and length L_1 are given empirically by:

$$(L_1 or\ W_1) = \frac{c}{2\mathrm{f_{low}}\sqrt{\epsilon_{\mathrm{reff}}}} - \frac{3}{2}(L + 2\Delta\mathrm{L} + S) \quad (7)$$

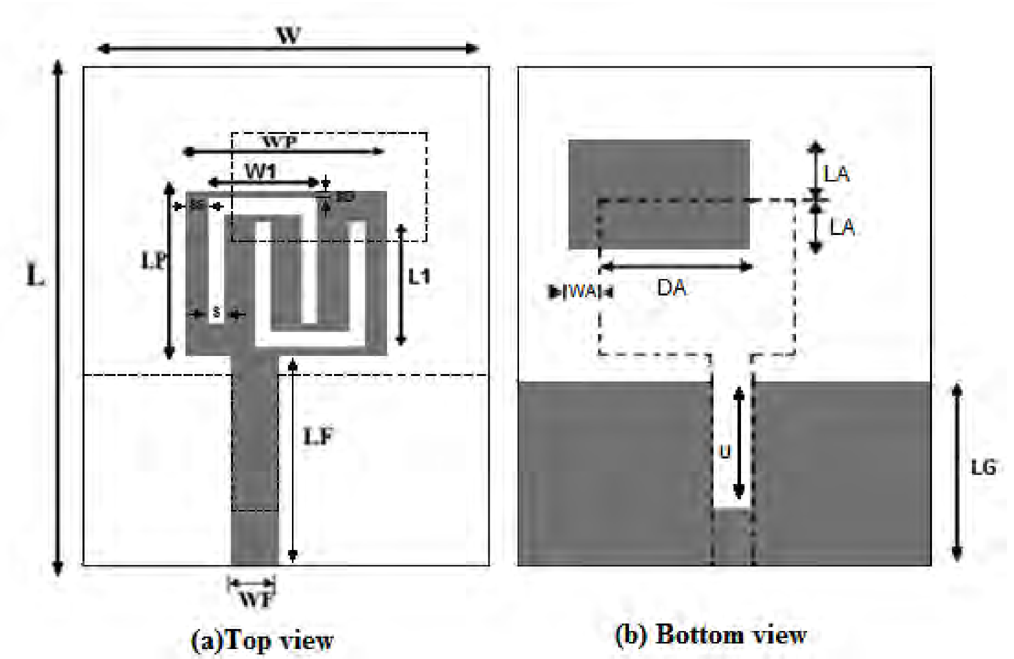


Fig. 2. Antenna with double U-slot, slit and additional strip in ground plane and offset strip line

In Eq. 7, if ΔL = 0.0190, L = 10.3316 mm, S = 1 mm, f_{low}= 3.1 GHz and ϵ_{reff} = 4.27, then we get: *L1* or *W1*) = 6.34 rounded to 7mm.

C. *Learning the Feeding Position*

The feeding position gives different return loss due to different feeding positions. It can be seen that from Fig. 3; the operating bandwidth is sensitive to the offset of the radiator and when the radiator shifts 2 mm away from the symmetrical position, the resulting bandwidth covering the entire UWB band.

It is worth noticing that the impedance matching is very sensitive to the dimensions of the antenna. For different stages, the antenna dimensions should be slightly re-optimized to achieve impedance matching purpose.

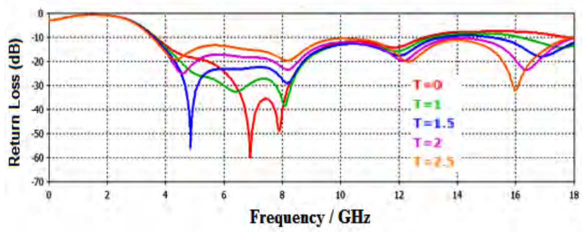


Fig. 3. Return loss due to different feeding positions

D. *Truncated Ground Plane*

Again, at this stage, to meet the impedance matching, the antenna dimension is slightly adjusted, it can be seen that the stable length of the ground plane for this design is 12.5 mm from Fig. 4; the impedance matching is significantly affected for this length. Return loss of the antenna change due to different lengths of the ground plane. This is due to the influence on current distribution in, since for a UWB planar antenna, the electric current is greatly affected by the shape and size of the system ground plane.

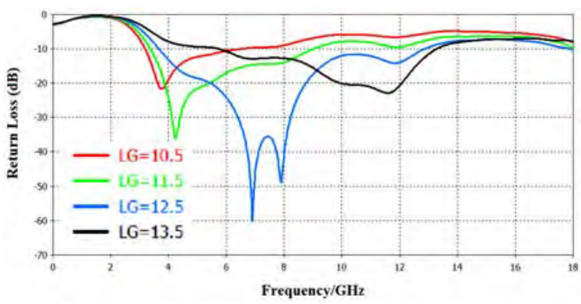


Fig. 4. Return loss due to varying ground plane length

E. Investigation of the Additional Patch

To cover more bands, a promising idea is to add an extra patch underneath the radiator, on the bottom side of the substrate in antenna 2 shown in Fig. 2. Intensive work has been done to investigate the antenna performance due to different dimensions of the additional patch [16].

TABLE I
ANTENNA PARAMETER

Parameter Used	**Value**
Length of the whole geometry, L	32 mm
Width of the whole geometry, W	26 mm
Length of the Ground, LG	12.5 mm
Width of Patch Antenna, WP	13 mm
Length of Patch Antenna, LP	10.5 mm
Width of the Feed, WF	3 mm
Length of the Feed, LF	13.5 mm
Patch & ground thickness Mt	0.1 mm
Strip length WS	10.5 mm
Strip width LS	18 mm
Distance from patch top to U-slot SD	0.5 mm
Distance from patch right bound to U-slot SS	1.5 mm
Slit depth U	8 mm

IV. RESULTS AND DISCUSSIONS

The Computer Simulation Technology (CST) microwave studio software is employed for antenna simulation and configuration, analysis and optimization [17]. The proposed antenna model is evaluated and the overall performance of the antenna. Parametric study for different parameters of the antenna is performed to find the most optimum dimension values. This analysis is done iteratively by varying one parameter while maintaining other parameters constant as shown in Table I. The antenna is built on a standard FR4 substrate, which its parameter values were optimally designed as been presented in Section 2 and substituted in the simulation processes.

The simulated return loss of the proposed antenna without double U-slot, slit and additional strip in ground plane is shown in Fig. 5. It is observed that, the calculated return loss curve for antenna 1 is less than –10 dB from 3.7 to 10.6 GHz. This is indicates that the impedance bandwidth of the antenna is 6.9 GHz.

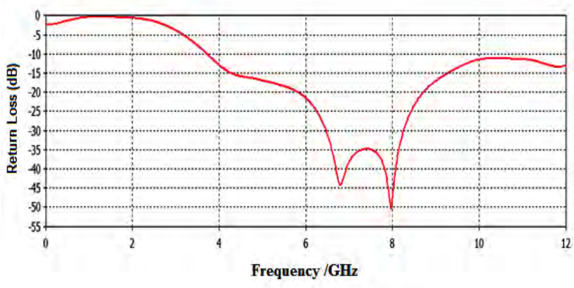


Fig. 5. Return loss without adjustment

As shown in Fig. 6, with the triple notched- band by etching double U-slot, additional patch in bottom side and slit in truncate ground plane as shown in antenna 2, a frequency multi notched- band from 4.65 to 6 GHz, from 8.12 to 8.96 GHz and 10.47 to 11.2 were achieved band rejection for WLAN, WiMAX and with triple band from 3.17 to 4.65GHz, from 6 to 8.12 GHz and from 8.96 to 10.47 GHz to achieved 1.48 GHz, 2.12 GHz and 1.51 GHz bandwidth alternatively.

Apart from that, the impedance bandwidth of the antenna 2 is divided to triple band with the calculation of return loss with less than –10 dB from 3.1 to 10.6 GHz.

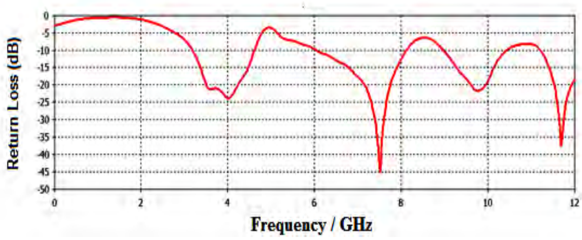


Fig. 6. Return loss with adjustment

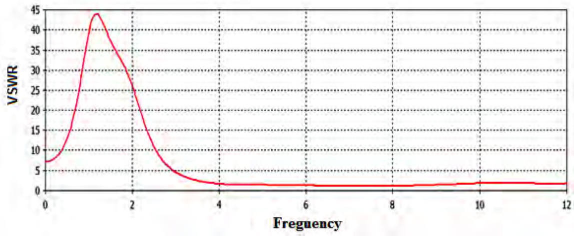


Fig. 7. VSWR without adjustment

Fig. 7 and 8 illustrate the comparison of simulated Voltage Standing Wave Ratio (VSWR) for the proposed antenna design without and with modification. It can be clearly seen that by modify antenna 1, the desired filtering property can be obtained. Compared to antenna 1 design, the triple band-notched can achieved by this adjustment, triple band has been successfully give VSWR > 2 and S11>-10 in all rejection bands, while it still maintains good impedance matching at other frequencies in the UWB band.

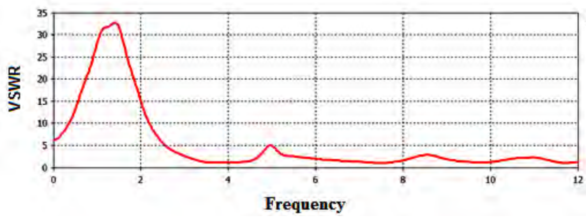
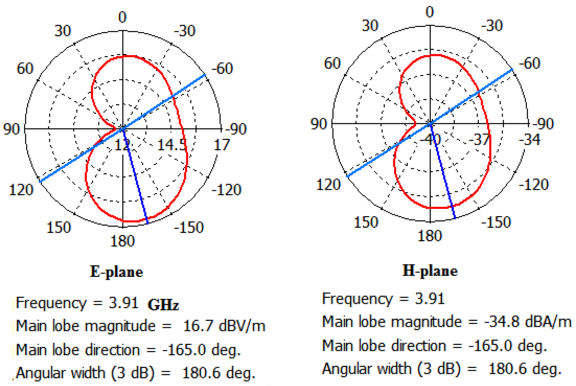


Fig. 8. VAWR with adjustment

The simulated radiation patterns of proposed antenna in the E-plane (xz-plane) and H-plane (yz-plane) for three different frequencies 3.91, 7 and 9.71 GHz are shown in Fig. 9. The patterns in the H-plane are quite omni-directional as expected. In the E-plane, the radiation patterns remain roughly a dumbbell shape like a small dipole leading to bidirectional patterns.



(a)

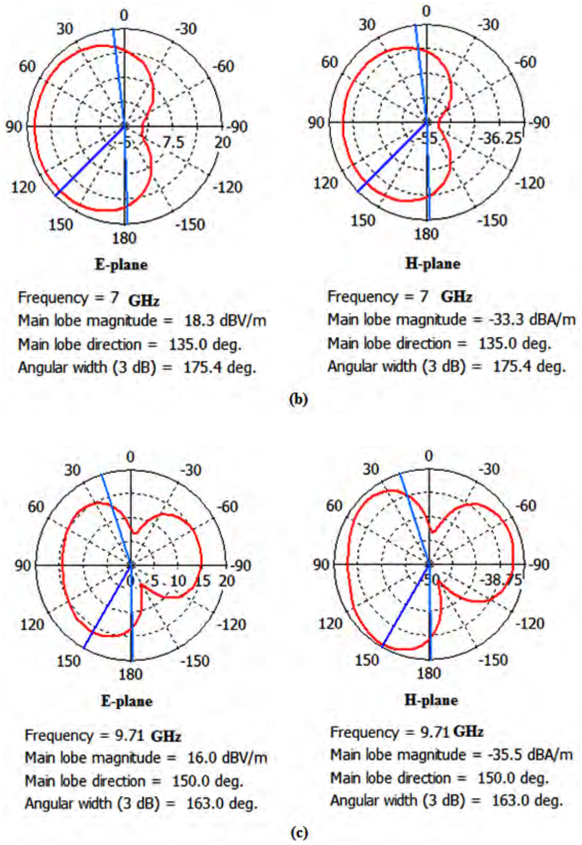


Fig. 9. Simulated E–plane and H–plane radiation patterns for the proposed antenna at (a) 3.9 GHz, (b) 7 GHz (c) 9.71 GHz

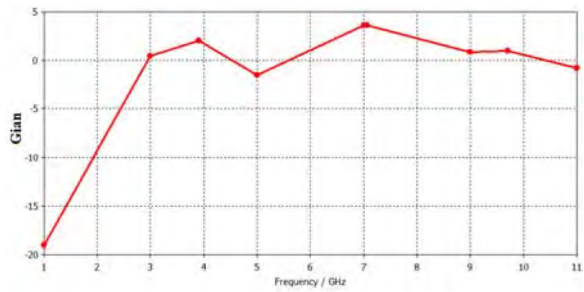


Fig. 10. Simulated gain of the proposed antenna 2

It has been seen that this proposed antenna has nearly omni-directional radiation pattern like normal monopole antennas. However, the omni-directional radiation properties have a little deterioration as frequency increases. Over the entire bandwidth, it is similar to a conventional wideband monopole antenna.

Fig. 10 presents the simulated gain for proposed antenna. The antenna gain in the UWB band is about 0.6 – 3.6 dBi. The variation in gain in overall bandwidth is 3 dBi but at 5 GHz the gain is –1.5 dBi and at 10.83 the gain is – 0.6 dBi so at these frequencies the loss will be occur.

V. Conclusions

This paper proposed design of simple rectangular microstrip antenna for UWB applications. The antenna is capable of achieving multi notched-band, is input impedance bandwidth must be from 3.1 to 10.6 GHz. Overlapping two U-shape slots in the radiating patch, additional patch in bottom side and slit in truncate ground plane are introduced to create a triple notched-band in order to minimize the potential interferences from other overlay systems when they coexist with UWB services and make more efficient multiband microstrip antenna. The proposed Microstrip antenna is easily integrated with RF/microwave circuits for low cost manufacturing and suitable for various UWB applications.

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