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Design and analysis of triple band-notched micro-strip UWB antenna

Heena Choudhary¹, Tejbir Singh²,³*, Kunver Arif Ali¹, Ashish Vats⁴, Pawan Kumar Singh¹, D.R. Phalswal⁵ and Vishant Gahlaut⁵

Abstract: In this paper, a compact ultra-wideband (UWB) antenna with triple notch bands is proposed. By etching out two ESRR of different dimensions in the radiating patch, two band-notched properties in the Wi-MAX (3–3.7 GHz), WLAN (5.125–5.825 GHz) are obtained. Furthermore, by placing SIR near the feed line–patch junction of the antenna, band notch property for the 7.9–8.4 GHz (X-band) frequencies is achieved. Design guidelines for implementing the notch-bands at the desired frequency regions are provided. The notched frequencies can be adjusted according to specification by altering the parameters of the ESRR and SIR. The effects of the key design parameters on band notch characteristics are also investigated. The realized antenna achieved an operating bandwidth (VSWR < 2) ranges from 2.94 to more than 11.3 GHz with triple notched bands of 3.0–3.7, 5.2–6.1, and 7.9–8.7 GHz. The proposed antenna is well designed and extensively investigated. The experimental results are given to verify that the proposed antenna with a wide bandwidth, three designated band-notched function which is suitable for modern high data rate UWB communication applications. The maximum simulated gain of

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PUBLIC INTEREST STATEMENT

Wireless connectivity has enabled a new mobile lifestyle filled with conveniences for mobile computing users. Consumers will soon demand the same conveniences throughout their digital home, connecting their PCs, personal digital recorders, digital cameras, high-definition TVs, personal digital assistants, and cell phones, to connect to each other in a wireless personal area network (WPAN) in the home. But today's wireless LAN and WPAN technologies cannot meet the needs of tomorrow's connectivity of such a host of emerging consumer electronic devices that require high bandwidth.

Ultra-wideband (UWB) technology offers a solution for the bandwidth, high data rates across multiple devices, cost, power consumption, and physical size requirements of next-generation consumer electronic devices for digital home and the office. In this context, the UWB antenna design plays a unique role because it behaves like a band pass filter and reshapes the spectra of the pulses and avoid undesired distortions.
the antenna is around 10.02 dBi with an average efficiency above 82.2% throughout the bandwidth.

Subjects: Electrical & Electronic Engineering; Electromagnetics & Communication; Electronic Devices & Materials

Keywords: ultra wide band (UWB); elliptical split ring resonator (ESRR); step impedance resonator (SIR); notch band; Wi-MAX; WLAN

1. Introduction

Ultra-wideband (UWB) technology has recently received much attention due to the characteristics such as low cost, low complexity, low spectral power density, high precision ranging and become the most potential candidate for short-range high speed wireless communication systems. Stemming from military radar applications, UWB communications are being researched intensively in both academic and industrial environments since the Federal Communications Commission (FCC) released 3.1–10.6 GHz unlicensed band for radio communication (Federal Communications Commission, 2002). Researchers have made many efforts to investigate different UWB antennas. Until now, various structures have been developed to achieve wideband antennas. However, in practical applications, antenna design for UWB systems is still facing many challenges. The designs of antenna for UWB applications face many challenges, including their impedance matching, radiation stability, compact size, low manufacturing cost, and EMI problems. The EMI problems are quite serious for UWB systems since there are several other existing narrowband services, which occupy frequency bands within the UWB bandwidth (Choi, Kim, Hwang, & Choi, 2014). A few examples of hostile systems are IEEE 802.16 Wi-MAX (3.3–3.7 GHz), IEEE 802.11a wireless-LAN (WLAN) 5 GHz (5.15–5.825), and ITU 8 GHz (8.025–8.4 GHz) band (Kim & Kim, 2010).

The system with the integration of external band reject filter having more complexity and size. Designers have re-sorted the approach of embedding parasitic elements or slots of different shapes in the radiating element or ground plane of the antenna systems in order to keep the antenna footprint unaltered.

Recently, a number of UWB antennas with band-notched properties were presented where various methods have been used to achieve the band notching.

(1) Cutting slots with different shape in the radiation patch (Jiang, Yan, & Zhang, 2010; Lee, Kim, Kim, & Yu, 2008; Li, Yang, Liu, & Jiang, 2010; Nguyen, Lee, & Park, 2012; Zhang, Zhou, Wu, Xin, & Ziolkowski, 2010).

(2) Inserting slits on the feed line (Chung, Park, & Choi, 2005; Ojaroudi, Ojaroudi, & Ghadimi, 2013).

(3) Adding parasitic strips or split rings near the feed line or around the ground plane (Islam, Azim, & Mobashsher, 2012; Kim, Jo, Jang, & Kim, 2011).

(4) Embedding resonator to filter to achieve the desired band rejection (Al-Husseini et al., 2012; Lin, Jin, & Ziolkowski, 2012; Sung, 2013; Wang, Yin, & Liu, 2013).

To reduce the complexity and size of the antenna system, the combination of the above mentioned techniques are used (Chu & Huang, 2011; Majeed et al., 2015; Sarkar, Srivastava, & Saurav, 2014; Wang, Pan, Xiao, & Sun, 2013; Zhang, Zhang, & Li, 2014). This paper presents a compact plane area $20 \times 24$ mm$^2$ with triple notch band characteristics by etching two ESRR and embedding a SIR. An ellipse having the same area as that of a circle would have a greater perimeter which implies that use of an elliptical SRR would provide lesser resonant frequency. This indicates miniaturization of the band-reject elements. Step impedance resonator is placed as a parasitic element near the junction of feed-line and radiating element to reject the ITU-specified X-band communication frequencies (7.9–8.4 GHz).
2. Antenna design and its geometry

This section describes the antenna geometry and the design process. A full wave analysis of the proposed structures is obtained by using the electromagnetic solver, HFSS™ v14.1 which is based on Finite element method (FEM) numerical technique. The objective of the design is to achieve the impedance bandwidth over the UWB frequency range with better gain, stable radiation patterns over the entire band excluding the rejected band (the notched band).

The proposed antenna is described in this section. The design starts with a micro-strip patch antenna where Figure 1(a) demonstrates the top view and Figure 1(b) depicts bottom view of the proposed triple band notched antenna structure with slots inserted at the partial ground plane.

The antenna is fabricated on $20 \times 24 \text{ mm}^2$ FR4 epoxy substrate with the relative permittivity $\varepsilon_r = 4.4$, a loss tangent $\tan \delta = 0.02$ and a thickness $h = 0.5 \text{ mm}$. It is composed of a 50Ω micro-strip feed line with the width of $W_f$ and length of $L_f$ to couple the input signal to the radiating patch, a planar radiating patch with two elliptical shape slots and partial rectangular ground plane with a rectangular and a pair of L shaped slots. Several aspects were considered to optimize the final design like the overall impedance bandwidth of the antenna, the bandwidth of the notched bands and the level of band rejection at notched frequency. The optimal antenna parameters are tabulated in Table 1. Proper impedance matching produces the very low return loss at the desired frequency. In the micro-strip feed line, the impedance of the micro-strip line is given by Zhang et al. (2014).
The analysis of the proposed antenna structure is based on transmission line modal analysis. Before proceeding to full-wave simulations, we need to make some initial guesses regarding the dimensions of the band-notch elements i.e. ESRRs and SIR.

(1) For an ESRR of major axis length $D_{ma}$, minor axis length $D_{mi}$, and width $W_{ESRR}$ (Figure 2(c)), the design equations for obtaining a band-notch at frequency $f_{notch}$ can be written as

$$Zc = \frac{120\pi}{\sqrt{\varepsilon_{eff}}} \left( \frac{1}{W_{f}} + 1.393 + 0.667 \ln \left( \frac{W_{f}}{h} + 1.444 \right) \right)$$  \hspace{1cm} (1)

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(1) For an ESRR of major axis length $D_{ma}$, minor axis length $D_{mi}$, and width $W_{ESRR}$ (Figure 2(c)), the design equations for obtaining a band-notch at frequency $f_{notch}$ can be written as

$$Se = K_e \pi (0.5 D_{mi} - W_{ESRR}) = \frac{\lambda_g}{2} = \frac{c}{2 \sqrt{\varepsilon_{eff, notch}}}$$  \hspace{1cm} (2)

$$K_e = 3(1 + k) - \sqrt{(3 + k)(1 + 3k)}$$  \hspace{1cm} (3)

where

$$\varepsilon_{eff} = \left( \frac{\varepsilon r + 1}{2} \right) - \left( \frac{\varepsilon r - 1}{2} \right) \left( \frac{1}{1 + 12 \frac{h}{W_{f}}} \right)^{\frac{1}{2}}$$  \hspace{1cm} (4)

Ellipticity $K = \frac{D_{ma}}{D_{mi}}$  \hspace{1cm} (5)

Table 1. Dimension of the proposed structure

| Parameter | Dimension (mm) |
|-----------|----------------|
| $W_g$     | 24             |
| $L_g$     | 8.1648         |
| $L_{g1}$  | 7              |
| $L_{g2}$  | 2.4778         |
| $W_s$     | 24             |
| $L_s$     | 20             |
| $h$       | 0.5            |
| $\theta$  | 6.4295         |
| $d1$      | 0.912          |
| $d2$      | 1.5788         |
| $W_{in}$  | 0.27           |
| $W_{out}$ | 0.3            |
| $W_f$     | 2.142          |
| $L_f$     | 8              |

Ellipticity $K = \frac{D_{ma}}{D_{mi}}$

For choosing the design parameters of the SIR for a desired notch frequency $f_o$, we have used the design guidelines from the following Equation (2):
Figure 2. Geometry of (a) ground and substrate, (b) radiating patch and (c) ESRR and SIR.
Figure 2 shows the geometry of the proposed antenna structure used for simulation in the next section. Larger ESRR is etched out to obtain a single band-notched antenna structure. To get this first band-notch at 3.4 GHz within the Wi-MAX band (3.3–3.7 GHz), the $D_m$ is fixed to 5.405 mm and analytical value of ellipticity $K$ has been obtained as 2.22. Another smaller ESRR with $D_m = 3.478$ mm and $K = 2.3$, is etched out to obtain second notch band at 5.7 GHz within the WLAN band (5.15–5.85 GHz).

In the final proposed design, a SIR element of suitable dimensions near the junction of the feed-line is placed and a radiating patch is also placed to obtain the notch band within the X band (7.9–8.4 GHz). The separation between the SIR and the micro-strip feed-line has to be kept small (0.3 mm) to ensure effective coupling keeping the available PCB fabrication limitations in mind.

3. Simulation results and discussion

The analysis of proposed antenna is done using the simulation performed on HFSS EM simulator for the frequency range of 1–12 GHz. Figure 3 shows the simulated VSWR of UWB antenna without slots in ground plane.

From the plot of simulated VSWR vs. frequency graph of the proposed antenna structure, it is seen that antenna covers 3–9.4 GHz for VSWR < 2 dB. It is clearly seen from the graph that the antenna without a slotted ground plane does not satisfy BW requirement of UWB technology. Hence BW enhancement technique i.e. slot loading is applied to avoid this.

Figure 4 shows the effect of the slot loading on bandwidth covered. From the plot of simulated VSWR vs. frequency graph of the proposed UWB antenna structure (With L shaped pair slot in addition with rectangular slot in ground plane), it is seen that the antenna has a bandwidth ranging from 2.94 to 11.3 GHz for VSWR < 2 dB, which covers a full UWB range. It is clearly seen from the graph and table 2 that the addition of slots in ground plane improves impedance matching and there is a considerable amount of enhancement in bandwidth.

\[
\frac{f_s}{f_o} = \frac{\Pi f}{2 \tan^{-1} \sqrt{K_i}}
\]  

(6)

\[
K_i = \frac{Z_2}{Z_1}
\]  

(7)

\[
\theta = \tan^{-1} \sqrt{K_i}
\]  

(8)

here $f_s = 2$nd harmonic frequency; $K_i = \text{ratio of different micro-paths}$. 

Figure 3. Graph of simulated VSWR characteristics of the UWB antenna structure without any slot in ground plane.
Band-notched characteristics of proposed antenna structure are investigated by taking the band-notch elements ESRR and SIR into consideration to discuss their effects on impedance bandwidth as shown in Figure 5.

**Figure 4.** Graph of simulated VSWR characteristics of the various structures.

| Antenna structure               | Bandwidth (MHz) |
|---------------------------------|-----------------|
| Structure 1                     | 3–9.4           |
| Structure 2                     | 3.2–11.1        |
| Structure 3                     | 3.2–11          |
| Structure 4                     | 2.94–11.3       |

**Table 2. Bandwidth covered for various antenna structures**

Band-notched characteristics of proposed antenna structure are investigated by taking the band-notch elements ESRR and SIR into consideration to discuss their effects on impedance bandwidth as shown in Figure 5.

**Figure 5.** Variation of the VSWR with frequency for the three different cases as mentioned.

- **Case-I:** one ESRR is etched out to obtain a single band-notched antenna structure.
- **Case-II:** additional ESRR is etched out to obtain double band-notched antenna structure.
- **Case-III:** SIR is placed near feed-line to obtain triple band-notched antenna structure.
It can be seen that the proposed antenna with an ESRR is a single band notched UWB antenna, which has a bandwidth ranging from 2.7 to 11.34 GHz with the VSWR less than 2 except a notch band 3–3.7 GHz. When the antenna has only two ESRR etched in the radiating patch, it can give two notch bands at 3.4 and 5.7 GHz to filter out the potential interferences from Wi-MAX and WLAN communication systems. When the proposed antenna integrates with two ESRR and SIR, it is a triple band notched UWB antenna to reject the undesired narrowband signals from Wi-MAX (3–3.7 GHz), WLAN (5.2–6.1 GHz) and ITU technology (7.98–8.7 GHz).

The simulated surface current distributions of the proposed resonator at three resonant frequencies are shown in Figure 6. As shown in Figure 6(a), the current at 3.4 GHz is mainly distributed around outer ESRR.

The current distribution at 5.5 GHz is mainly concentrated around the inner ESRR element as shown in Figure 6(b). Compared with other parts of the notch structure in Figure 6(c), a significant amount of current at 8.2 GHz is distributed on the SIR. Notch characteristic is found in this band, since the signal coupled from the main feed line to the resonator returns back to the feed line, and the two signals meet at a phase difference of 180°, cancels each other according to wave cancellation theory.
The measured peak gains of the designed antenna are depicted in Figure 7 which exhibits three sharp gain decreases at 3.4, 5.5 and 8.2 GHz as desired.

### 3.1. Effect of notched parameters on antenna performances

The key parameters are selected to discuss the effects on the band-notched characteristics.

1. The effect of the ESRR width $W_{ESRR}$ on the bandwidth of notch band is analysed by considering only one ESRR as shown in Figure 8.

   (2) It can be seen that the notch band shifts towards left side of graph as width of elliptical slot $W_{ESRR}$ reduced up to 0.2 mm from 0.5 mm. $W_{ESRR} = 0.3$ mm is optimized solution as it rejects whole interference band due to Wi-MAX technology.

2. The gap between the SIR and the micro-strip feed-line is also a considerable parameter as it has to be small to ensure effective coupling keeping the available PCB fabrication limitations in mind.

   Figure 9 exhibits the effects of gap between feed-line and SIR. As the gap goes narrow, the rejection band is widened and has high rejection characteristics. As the gap goes wide, the rejection band is narrow and has poor rejection characteristics.
(4) The initial length $\theta$ of the SIR is another parameter which has considerable effect on reject frequency (Figure 10).

As the initial length decreases, the notch frequency shifts right sides of the graph i.e. increase in notch frequency.

4. Conclusion
A compact triple band-notched UWB antenna has been presented and well designed by the use of the EM simulator HFSS™ v14. The notch bands are achieved by etching two ESRR in radiating patch and by embedding a SIR near feed line-patch junction. From the simulation, we found that the proposed antenna can prevent the potential interferences from Wi-MAX, WLAN and ITU systems. The results showed that the proposed antenna has a wide bandwidth ranging from 2.94 to 11.34 GHz.
rejecting the undesired narrowband signals from Wi-MAX (3–3.7 GHz), WLAN (5.2–6.1 GHz) and ITU technology (7.98–8.7 GHz). A prototype antenna is planned to be fabricated by the authors using low-cost FR4–Epoxy substrate as future work.

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References
Al-Husseini, M., Costantine, J., Christodoulou, C. G., Barbin, S. E., El-Hajj, A., & Kabalan, K. Y. (2012). A reconfigurable frequency-notched UWB antenna with split-ring resonators. In Proceedings of Asia-Pacific Microwave Conference (pp. 618–621).
Choi, H.-S., Kim, T.-W., Hwang, H.-Y., & Choi, K. (2014). An UWB antenna design with adjustable second rejection band using a SIR. IEEE Transactions on Magnetics, 50, 913–916.
Chu, Q. X., & Huang, T. G. (2011). Compact UWB antenna with sharp band-notched characteristics for lower WLAN band. Electronics Letters, 47, 838–839. http://dx.doi.org/10.1049/el.2011.1053
Chung, K., Park, H., & Choi, J. (2005). Wideband micro strip-fed monopole antenna with a narrow slit. Microwave and Optical Technology Letters, 47, 400–402.
Federal Communications Commission. (2002). Revision of Part 15 of the commission’s rules regarding ultra-wideband transmission systems, First note and order, ET-Docket 98–153. Washington DC: Author.
Islam, M. T., Azim, R., & Mobashsher, A. T. (2012). Triple band-notched planar UWB antenna using parasitic strips. Progress In Electromagnetics Research, 129, 161–179. http://dx.doi.org/10.2528/PIER12032604
Jiang, J. B., Yan, Z. H., & Zhang, J. Y. (2010). Dual band-notched ultra-wideband printed antenna with two different types of slots. Microwave and Optical Technology Letters, 52, 1930–1933. http://dx.doi.org/10.1002/mop.2029
Kim, D. O., & Kim, C. Y. (2010). CPW-fed ultra-wideband antenna with triple-band notch function. Electronics Letters, 46, 1246–1248. http://dx.doi.org/10.1049/el.2010.1415
Kim, D.-O., Jo, N. I., Jang, H. A., & Kim, C.-Y. (2011). Design of the ultra-wideband antenna with a quadruple-band rejection characteristics using a combination of the complementary split ring resonators. Progress In Electromagnetics Research, 112, 93–107. http://dx.doi.org/10.2528/PIER10111607
Lee, W. S., Kim, D. Z., Kim, K. J., & Yu, J. W. (2008). Wide-band planar monopole antennas with dual band-notched characteristics. IEEE Transactions on Microwave Theory & Techniques, 54, 2800–2806.
Li, Y. S., Yang, X. D., Liu, C. Y., & Jiang, T. (2013). Dual and tri-band notched ultra-wideband (UWB) antennas using capacitively loaded loop (CLL) resonators. IEEE Transactions on Antennas and Propagation, 61, 102–109. http://dx.doi.org/10.1109/TAP.2012.2223434
Lin, C. C., Jin, P., & Ziółkowski, R. W. (2012). Single, dual and tri-band notched ultra-wideband (UWB) antennas using capacitively loaded loop (CLL) resonators. IEEE Transactions on Antennas and Propagation, 60, 953–957. http://dx.doi.org/10.1109/TAP.2011.2167947
Majeed, A. H., Abdullah, A. S., Saydmarie, K. H., Abd-Alhameed, R. A., Elmegri, F., & James, M. N. (2015). Compact dielectric resonator antenna with band-notch characteristics for ultra-wideband applications. Progress In Electromagnetics Research C, 57, 137–148.
Nguyen, D. T., Lee, D. H., & Park, H. C. (2012). Very compact printed triple band-notch UWB antenna with quarter-wavelength slots. IEEE Antennas and Wireless Propagation Letters, 11, 411–414. http://dx.doi.org/10.1109/LAWP.2012.2192900
Ojaroudi, M., Ojaroudi, N., & Ghadimi, N. (2013). Dual band-notched small monopole antenna with novel coupled inverted U-Ring strip and novel fork-shaped slit for UWB applications. IEEE Antennas and Wireless Propagation Letters, 12, 182–185. http://dx.doi.org/10.1109/LAWP.2013.2245296
Serkan, D., Srivastava, K. V., & Saurav, K. (2014). A compact microstrip-fed triple band-notch UWB monopole antenna. IEEE Antennas and Wireless Propagation Letters, 13, 396–399.
Sung, Y. (2013). Triple band-notch UWB planar monopole antenna using a modified H-shaped resonator. IEEE Transactions on Antennas and Propagation, 61, 953–957. http://dx.doi.org/10.1109/TAP.2012.2223434
Wang, J., Yin, Y., & Liu, X. (2013). Triple band-notch ultrawideband (UWB) antenna using a novel modified capacitively loaded loop (CLL) resonator. Progress In Electromagnetics Research Letters, 42, 55–64. http://dx.doi.org/10.2528/PIERL13052810
Wang, J. W., Pan, J. Y., Xiao, K. N., & Sun, Y. Q. (2013). A band-notch UWB antenna with L-shaped slots and open-loop resonator. In The 2013 IEEE International Conference on Applied Superconductivity and Electromagnetic Devices (ASEMD), October 25–27 (pp. 312–315). Beijing: IEEE.
Zhang, H., Zhou, R., Wu, Z., Xin, H., & Ziółkowski, R. W. (2010). Designs of ultra wideband (UWB) printed elliptical monopole antennas with slots. Microwave and Optical Technology Letters, 52, 466–471. http://dx.doi.org/10.1002/mop.21098-2760
Zhang, C., Zhang, J., & Li, L. (2014). Tri-band-notch UWB antenna based on SIR-DGS and fork-shaped stubs. Electronics Letters, 50, 67–69. http://dx.doi.org/10.1049/el.2013.2513
