Frequency and Time Domain Investigation of Compact UWB Slot Antenna with Triple Band Notched Characteristics

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Abstract ─ In this paper, a simple compact ultrawideband (UWB) microstrip slot antenna with triple band notched characteristics is presented. In the proposed antenna, a good impedance matching over a very wide frequency range is achieved by adding two rectangular stubs to the bottom section of the simple rectangular patch. Moreover, by employing an inverted T-shaped stub connected to the ground plane and two U-shaped and Ω-shaped slots in the modified patch, triple band notched properties are obtained. This proposed triple band notched antenna with dimensions of 26×26 mm^2 has a very wide bandwidth from 2.5 GHz up to 19 GHz, which is about 150% fractional bandwidth of the center frequency. Unlike the most previous works reported in the literature, the triple band notched feature applied in the proposed antenna does not deteriorate the impedance bandwidth at higher frequencies. The radiation results such as gain, efficiency and radiation patterns as well as time domain properties of the proposed antenna show that it can be a good candidate for new super wideband applications.

Index Terms ─ Band notched characteristics, radiation patch, resonant slots, system fidelity factor.

I. INTRODUCTION

With advances in wireless communications and portable devices, designing of small planar UWB antennas has attracted more attentions. These planar antennas have many advantages such as simple structure, easy fabrication, and omnidirectional radiation pattern. More importantly, they have wide impedance bandwidth which comes up with an increased transmission data rate. Lately, many methods have been used to enhance the antenna impedance bandwidth, for instance, using L-shaped stubs on the back of the substrate [1], inverse T-shaped slots cut in the ground plane [2], employing truncated radiation patch [3], and a trident shaped feedline [4]. Due to the low power of UWB signals, low interferences with other narrowband signals can inherently occur. However, many techniques are presented to avoid interferences between UWB systems and other narrowband wireless systems such as WiMAX (3.3-3.6), WLAN (5.15-5.35 and 5.75-5.85), and X band with downlink frequency bandwidth 7.25-7.75 GHz. Hence, the structures with proper shape and size should be used to design band notched functions. They should reject only the undesired bands while their effects over the other pass band frequencies should be negligible. Some of these techniques include etching split ring resonators in the radiation patch [5] and embedding a pair of rotated V-shaped slots in the ground plane [6]. In this paper, a simple and compact UWB slot antenna with triple notched bands is presented. Two rectangular stubs with proper dimensions are added to the bottom of the rectangular radiation patch to enhance the impedance bandwidth to about 19 GHz. An inverted T-shaped stub connected to the ground plane and two resonant slots etched out from the radiation patch are employed to create triple band notched characteristics of the proposed antenna. In most antennas reported in the literature, band notched structures have limited upper edge of the frequency band. In fact, the higher-order harmonics of the band notched structures occur at the higher frequencies and deteriorate the impedance bandwidth. In [7], two methods have been presented to design a triple band notched antenna. One method uses multiple etched slots on the radiation patch, and the other one uses split ring resonators (SRRs) coupled to the feed line. In both of the above methods, a spurious stop-band emerged in vicinity of 10 GHz and accordingly, the bandwidth of the antenna is limited at higher frequencies. Moreover, the UWB antennas presented in [8-10] are the other examples that their band notched structures generate a spurious stop band at higher frequencies. The proposed triple band notched structure presented in this paper does not generate spurious stop bands at higher frequencies. Hence, the impedance bandwidth of the proposed antenna with and without band notched structure is almost the same at higher frequencies. The rest of the

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paper is organized as follows. In Section II, the antenna structure is described. The antenna design analogy is explained in Section III. In the next section, the radiation characteristics of the proposed antenna such as gain, radiation efficiency and patterns are discussed and explained. Moreover, time domain behaviors of the proposed antenna are studied at Section V. Finally, Section VI concludes the paper.

II. ANTENNA STRUCTURE

The proposed antenna contains a wide quasi-circle slot with radius of 12 mm in the ground plane and a simple rectangular radiation patch with size of 6.6×8 mm^2. Figure 1 shows the structure of the proposed triple band notched UWB slot antenna. A 50 Ω coplanar waveguide (CPW) feed line including a center strip of width 2.6 mm and two gaps of width 0.3 mm is used to excite the antenna. The antenna is fabricated on FR4 substrate with relative permittivity $\varepsilon_r = 4.4$, loss tangent of 0.018 and height of 1.6 mm. For good impedance matching over the operating bandwidth, two rectangular stubs are added to the bottom of the rectangular patch as shown in Fig. 1. An inverse T-shaped resonant stub inside the quasi-circle slot connected to the ground plane, and two Ω-shaped and U-shaped resonant slots cut from the radiation patch are employed to achieve notched bands. The proposed antenna has a simple structure and compact size of 26×26 mm^2.

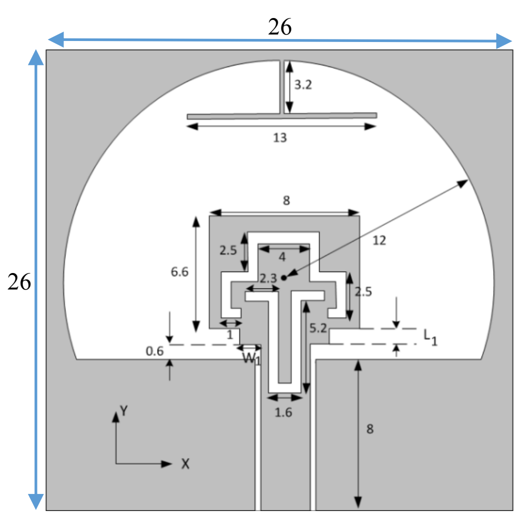


Fig. 1. Geometry of the proposed antenna (mm).

III. ANTENNA DESIGN AND DISCUSSIONS

A. Full-band UWB antenna design

High frequency structure simulator (HFSS) software, which works based on finite element method, is employed to obtain the simulation results. A quasi-circle slot and simple rectangular patch with proper dimensions are employed to satisfy UWB requirements. To further enhance the impedance bandwidth, two rectangular stubs with dimensions of $L_1 \times W_1$ are added to the lower section of the radiation patch as shown in Fig. 1. Figure 2 shows the VSWR diagrams of the antenna with and without these rectangular stubs. It can be seen from the figure that the lower cut off frequency is slightly decreased, and the VSWR at higher frequencies of the band is greatly improved. The middle band is slightly damaged but it is still acceptable (VSWR < 2).

Furthermore, to better clarify the role of these rectangular stubs, the VSWR diagrams of the modified antenna for different values of L_1 and W_1 are depicted in Fig. 3 and Fig. 4, respectively. In Fig. 3, L_1 varies from 0.5 mm to 1.5 mm, while W_1 is fixed at 0.8 mm. It can be seen that by increasing parameter L_1 to a specified value, the impedance bandwidth is improved at higher frequencies. However, further increasing the parameter L_1 causes the lower cutoff frequency to increase. The optimum value of L_1 is equal to 1 mm. Figure 4 shows the variations of W_1 when L_1 is fixed at 1 mm. Like the previous case, it is seen from the figure that by increasing W_1 to a specified value the impedance bandwidth can be improved, while further increasing W_1 deteriorates the bandwidth at lower frequencies. The optimum value of W_1 is obtained equal to 0.8 mm.

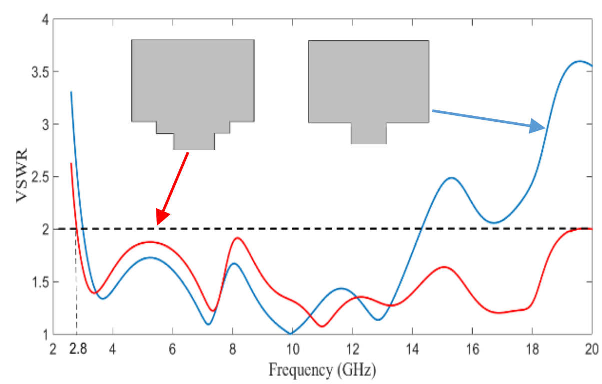


Fig. 2. VSWR of the antenna with and without rectangular stubs.

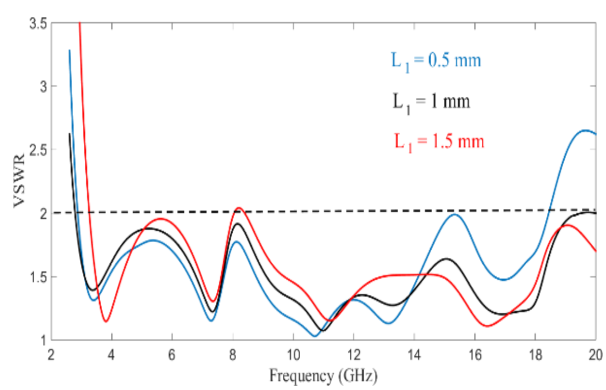


Fig. 3. VSWR of the antenna with different values of L_1 when W_1 is fixed at 0.8 mm.

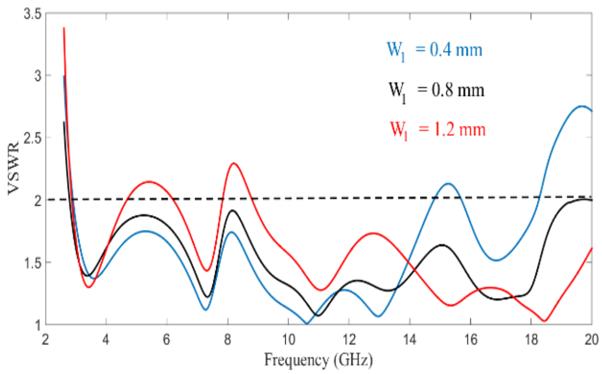


Fig. 4. VSWR of the antenna with different values of W_1 when L_1 is fixed at 1 mm.

B. Band notched structures design

To prevent the interferences between the UWB and WiMAX systems, an inverse T-shaped stub is connected to the ground plane of the proposed UWB antenna in order to provide a band notched property at WiMAX frequency band. The T-shaped stub, with a horizontal arm of 13 mm and a vertical arm of 3.2 mm, acts as a quarter wavelength resonator at 3.8 GHz (center frequency of the first notched band). At this frequency, the electrical current is mainly concentrated on the T-shaped stub and due to its resonance feature a band notched characteristic with center frequency of 3.8 GHz appears. To create band notched properties for WLAN band (5-6 GHz band), the Ω-shaped resonant slot with given values is etched out from the radiating patch. Finally, to reject the 7-8 GHz band, a U-shaped slot is cut from the radiating patch. The width of the T-shaped stub is fixed at 0.3 mm, while the width of the Ω-shaped and U-shaped slots are fixed at 0.5 mm. Figure 5 depicts the VSWR diagram of the three different single band notched antennas.

The proposed antenna, simultaneously applies these band notched structures in a single design and therefore an UWB antenna with triple band notched characteristics can be achieved.

Figure 6 shows the simulated and measured VSWR of the proposed antenna. The computer simulation technology (CST) software is also used to emphasize accuracy of the antenna design. As seen from the figure, by combining the band notched structures in the proposed antenna, the resonant frequencies are shifted to lower values. It is due to the mutual coupling of these filtering structures on each other. This phenomenon is more visible for WLAN and X band, because both the Ω-shaped and U-shaped slots are inserted in the radiation patch and placed near each other. Consequently, they have more effects on each other. Moreover, in the final design the size of these resonant stub and slots are slightly modified to have better impedance matching over the entire band.

It can be seen that the measured and simulated results are in good agreement. As mentioned earlier, unlike most antennas reported recently, the triple band notched structure introduced in this paper does not deteriorate the bandwidth of the proposed antenna, especially at higher frequencies. It is noted that by tuning the length of these filtering structures (inverse T-shaped stub, Ω-shaped and U-shaped slots), the center frequency of the notched bands can be controlled.

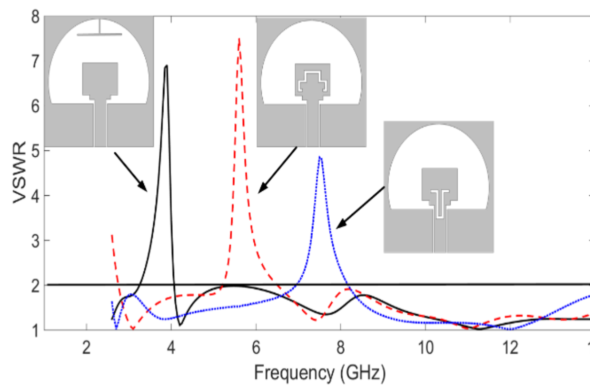


Fig. 5. VSWR of different single band notched antennas.

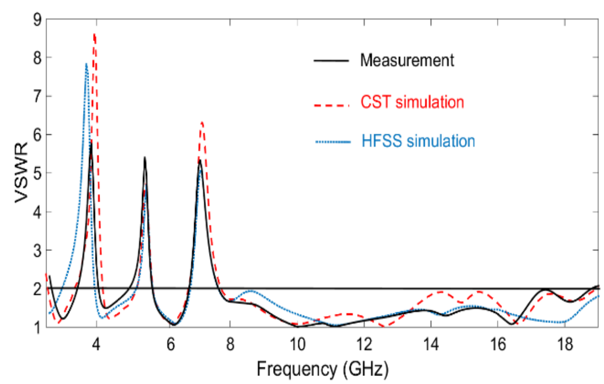


Fig. 6. Measured and simulated VSWR of proposed antenna.

IV. FAR FIELD RADIATION CHARACTERISTICS

Figure 7 shows the measured gain and simulated radiation efficiency of the proposed antenna. It is observed from the figure that the gain is almost constant with variations of less than 3.5 dB over the entire operating bandwidth, except at the notched bands. There are three high reductions in the gain and radiation efficiency diagrams due to the effect of the band notched structures. Figure 8 shows the radiation patterns of the proposed antenna in the two cut planes, E-plane (y-z plane) and H-plane (x-z plane) at three sample frequencies (2.8, 7.5 and 12 GHz). The radiation patterns are almost constant and omnidirectional in the H-plane and bi-directional in the E-plane.

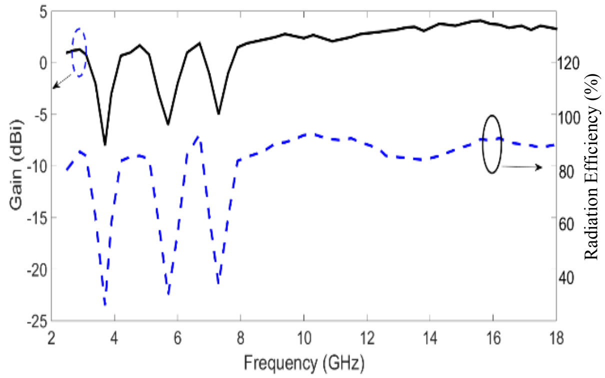


Fig. 7. Measured gain and simulated radiation efficiency of proposed antenna.

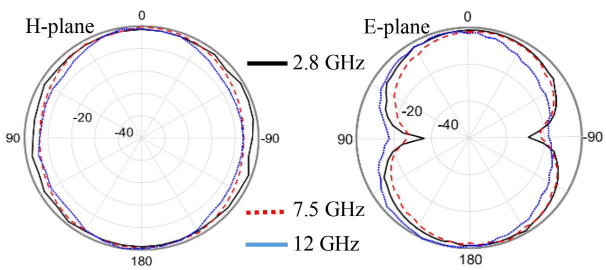
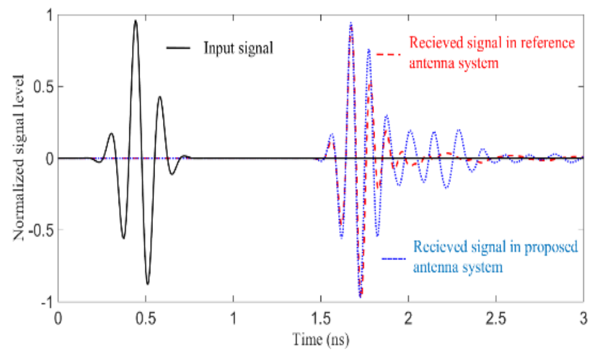


Fig. 8. Normalized far field radiation patterns of proposed antenna.

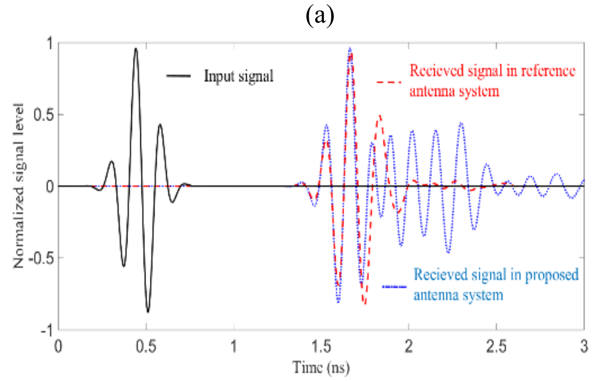
V. TIME DOMAIN CHARACTERISTICS

A significant property of UWB systems is the transmission of very narrow pulses in time. Antenna designing in the pulse-based UWB systems (impulse radio UWB communication systems), has a unique collection of design requirements. Therefore, further studies and investigations should be performed on time domain behavior of an UWB antenna.

In this section, two transmitting and receiving antenna systems including the reference antenna (antenna without band notched structures) system and proposed antenna (antenna with triple band notched structures) system in face to face and side by side scenarios are investigated. The CST software is employed to simulate time domain behaviors. In both scenarios, two identical antennas placed at a distance of 30 cm from each other, are employed for transmitting and receiving the UWB signal. A sixth derivative Gaussian pulse with a frequency spectrum corresponding to 3.1-10.6 GHz is used as the input signal. Figure 9 shows the input and received signals of the reference and proposed antenna systems in face to face and side by side scenarios, respectively. Figure 10 also demonstrates their power spectral density. FCC's outdoor and indoor mask are also shown for comparison. It can be seen that the proposed antenna system has a more distortion in the received pulse compared to the reference antenna system. It is due to the band notched properties of the proposed antenna. The power spectral density of the proposed antenna has three sharp nulls at the notched frequencies. It indicates that a portion of the input signal cannot be received effectively as shown in Fig. 10. Moreover, it can be seen that compared to the face-to-face scenario, both reference and proposed antenna system experience more distortion in received pulse for side-by-side scenario. This is due to the maximum radiation of the antenna in the Z-direction (see Fig. 1).

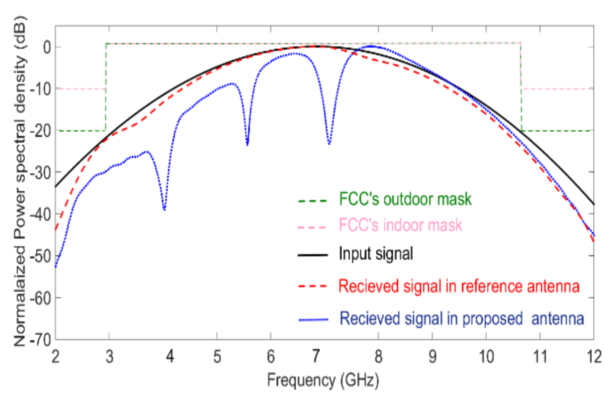


(a)

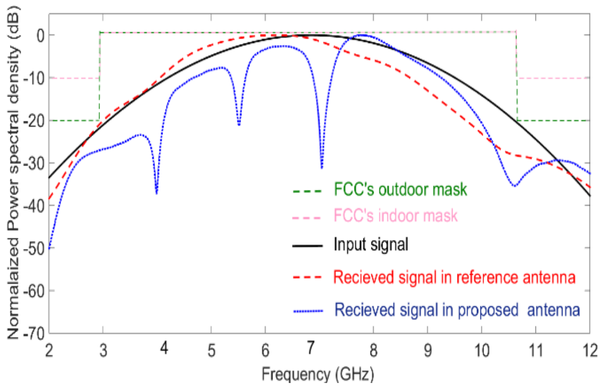


(b)

Fig. 9. Input signal and received signals for reference antenna system and proposed antenna system: (a) in face to face scenario, and (b) in side by side scenario.



(a)



(b)

Fig. 10. PSD of input signal and received signals for reference antenna system and proposed antenna system: (a) in face to face scenario, and (b) in side by side scenario.

In the time domain method, an important factor indicating the performance of the antenna is the fidelity factor. The fidelity is employed as a factor of similarity between the input and received signal and obtained as follows [11]:

$$F = \mathrm{Max}_\tau \left| \frac{\int_{-\infty}^{+\infty} S(t) r(t-\tau) dt}{\sqrt{\int_{-\infty}^{+\infty} S(t)^2 \int_{-\infty}^{+\infty} r(t)^2}} \right|, \quad (1)$$

where S(t) and r(t) are the input and received signals, respectively. The values of the system fidelity factor vary between 0 and 100%. A system fidelity factor value of 100% shows that the received signal perfectly fits the input signal, while a value of 0 indicates that the received signal is completely different than the input signal. A distortion higher than 50% can cause the pulse approximately unrecognizable [12]. The system fidelity factor of the reference antenna system and proposed antenna system in both face-to-face and side-by-side scenarios is calculated and reported in Table 1. It is observed that the system fidelity factor of the reference antenna pair is good (more than 90%). For the proposed antenna pair, the fidelity factor is slightly deteriorated because of the filtering structures of the proposed antenna.

Table 1: System fidelity factor for different scenarios

Different Scenarios	Fidelity Factor
Reference antenna system in face to face scenario	94%
Reference antenna system in side by side scenario	91%
Proposed antenna system in face to face scenario	84%
Proposed antenna system in side by side scenario	77%

VI. CONCLUSION

In this paper, a novel and simple triple band notched slot antenna is presented. In this antenna, the impedance bandwidth is highly improved by inserting two rectangular stubs between the rectangular patch and CPW feed line. Moreover, by using an inverse T-shaped stub connected to the ground plane, and two Ω-shaped and U-shaped slots in the radiation patch, triple band notched characteristics are achieved. The results reveal that the radiation properties as well as time domain behavior of the proposed antenna are satisfied. Due to these advantages, the proposed antenna can be a proper candidate for super wide band applications.

REFERENCES

[1] S. R. Emadian, M. Mirmozafari, C. Ghobadi, and J. Nourinia, “Bandwidth enhancement of dual band-notched circle-like slot antenna,” *Electronics Letters*, vol. 48, no. 7, pp. 356-357, Mar. 2012.

[2] S. R. Emadian and J. Ahmadi-shokouh, “Modified ground circle like-slot antenna with dual band-notched characteristics for super UWB applications,” *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 30, pp. 436-443, 2015.

[3] S. R. Emadian and J. Ahmadi-shokouh, “Very small dual band notched rectangular slot antenna with enhanced impedance bandwidth,” *IEEE Trans. Antennas Propag*., vol. 63, no. 10, pp. 4529-4534, 2015.

[4] S. R. Emadian, C. Ghobadi, J. Nourinia, M. Mirmozafari, and J. Pourahmadazar, “Bandwidth enhancement of CPW-fed circle-like slot antenna with dual band-notched characteristic,” *IEEE Antennas Wireless Propag. Lett*., vol. 11, pp. 543-546, 2012.

[5] D. Sarkar, K. Srivastava, and S. Saurav, “A compact microstrip-fed triple band-notched UWB monopole antenna,” *IEEE Antennas Wireless Propag. Lett*., vol. 13, pp. 396-399, 2014.

[6] S. Venkata, M. Rana, P. Bakariya, S. Dwari, and M. Sarkar, “Planar ultrawideband monopole antenna with tri-notch band characteristics,” *Progress In Electromagnetics Research C*, vol. 46, pp. 163-170, 2014.

[7] Y. Zhang, W. Hong, C. Yu, Z. Kuai, Y. Don, and J. Zhou, “Planar ultrawideband antennas with multiple notched bands based on etched slots on the patch and/or split ring resonators on the feed line,” *IEEE Trans. Antennas Propag*., vol. 56, no. 9, pp. 3063-3068, 2008.

[8] C. Zhang, J. Zhang, and L. Li, “Triple band-notched UWB antenna based on SIR-DGS and fork-shaped stubs,” *Electronics Letters*, vol. 50, no. 2, pp. 67-69, Jan. 2014.

[9] F. Zhu, S. Gao, A. Ho, A. Abd-Alhameed, C. See, T. Brown, J. Li, G. Wei, and J. Xu, "Multiple band-notched UWB antenna with band-rejected elements integrated in the feed line," *IEEE Trans. Antennas Propag*., vol. 56, no. 9, pp. 3063-3068, 2008.

[10] Y. Zhang, W. Hong, C. Yu, J. Zhou, and Z. Kuai, "Design and implementation of planar ultra-wideband antennas with multiple notched bands based on stepped impedance resonators," *IET Microw. Antennas Propag*., vol. 3, no. 12, pp. 1051-1059, 2008.

[11] A. Dastranj and H. Abiri, "Bandwidth enhancement of printed E-shaped slot antennas fed by CPW and microstrip line," *IEEE Trans. Antenna Propag*., vol. 58, pp. 1402-1407, 2010.

[12] G. Quintero, J.-F. Zürcher, and A. K. Skrivervik, "System fidelity factor: a new method for comparing UWB antennas," *IEEE Trans. Antennas Propag*., vol. 59, no. 7, pp. 2502-2512, July 2011.