Progress In Electromagnetics Research C, Vol. 13, 159–170, 2010

A COMPACT CPW-FED UWB SLOT ANTENNA WITH CROSS TUNING STUB

J. William and R. Nakkeeran

Department of ECE
Pondicherry Engineering College
Puducherry-605 014, India

Abstract—Design and analysis of a compact coplanar waveguide (CPW) fed Ultra Wideband (UWB) slot antenna is presented in this paper. The antenna consists of a rectangular slot with cross like structure at the anterior portion of the feed which acts as tuning stub. The CPW feed is designed for 50 Ω impedance. The physical dimension of the proposed antenna is 19 mm (length) × 20 mm (width) × 1.6 mm (thickness), and the electrical size is $0.3\lambda_l$ (length) × $0.32\lambda_l$ (width) (f_l = 4.8 GHz). The characteristics of the designed structure are investigated by using MoM based electromagnetic solver, IE3D. An extensive analysis of the proposed antenna in the frequency and time domains is presented. The antenna was fabricated with FR4 substrate and characterized by measuring return loss, radiation pattern (5.5 GHz) and gain. The measured results are appreciably in good agreement with the simulated ones. A better impedance bandwidth is obtained from 4.8 GHz to 12.8 GHz that constitutes a fractional bandwidth of 90% with return loss less than or equal to −10 dB (VSWR ≤ 2). Time domain analysis of the antenna is also performed, which witnessed the linear phase and less distortion. The simple configuration and low profile nature of the proposed antenna leads to easy fabrication that may be built for any wireless UWB device applications.

1. INTRODUCTION

UWB is a short range unlicensed wireless communication system which has a potential to offer a high capacity with low power compared with the contemporary wireless systems for short range applications. After the release of UWB for unlicensed application by the Federal Communications Commission (FCC), it receives much

Corresponding author: J. William (wills.susan@gmail.com).

attention by researchers due to its inherent properties of low power consumption, high data rate and simple configuration [1]. With the rapid developments of UWB systems, a lot of attention is being given to designing the UWB antennas. The design of antennas for UWB applications must satisfy the following requirements. They are ultra wide impedance bandwidth, omni directional radiation pattern, constant gain high radiation efficiency, constant group delay, low profile and easy manufacturing [2]. Interestingly the planar slot antennas with CPW fed posses the features mentioned above with simple structure, less radiation loss, less dispersion and easy integration of monolithic microwave integrated circuits (MMIC) [3]. Hence, the CPW fed planar slot antennas [4–10] are identified as the most promising antenna design for wideband wireless applications.

In planar slot antennas, the slot width and feed structure affect the impedance bandwidth of the antenna. The wider slot gives more bandwidth, and the optimum feed structure gives good impedance matching [11]. The CPW feed line with various possible patch shapes available in the literature such as 'T', cross, forklike, volcano and square are used to give wide bandwidth [12–15]. The proposed antenna in this paper designed with a compact rectangular slot and a cross like structure at the anterior portion of the feed. While comparing the same type of antennas existing in the literature [16–20], the proposed antenna accounts 66% of size reduction. Though the fractional bandwidth of this antenna is reduced by 18% of the existing antennas, the observed 90% fractional bandwidth of the proposed structure is more than sufficient for any UWB applications. The pattern obtained from the simulation is almost stable across the matching band with an average gain of 3 dBi. The simulation software used for this analysis is IE3D [21]. The paper is organized as follows: Section 2 brings out the geometry of the antenna. In Section 3, simulation results and analysis are discussed. Obtained experimental results are given in Section 4. Section 5 concludes the paper.

2. ANTENNA STRUCTURE

The structure of the antenna is shown in Fig. 1. The parameters 'W_1' and 'L_1' are the width and length of the rectangular slot, 'W_2', 'W_3'. 'L_2' and 'L_3' are the widths and lengths of the cross stub. 'd' is the distance between the patch and feed line. 'W' and 'L' are the width and length of the whole antenna respectively. In this study, a dielectric substance (FR4) with thickness of 1.6 mm and a relative permittivity of 4.4 is chosen as substrate. The CPW feed is designed for a 50 Ω characteristic impedance with fixed 1.8 mm feed line width and

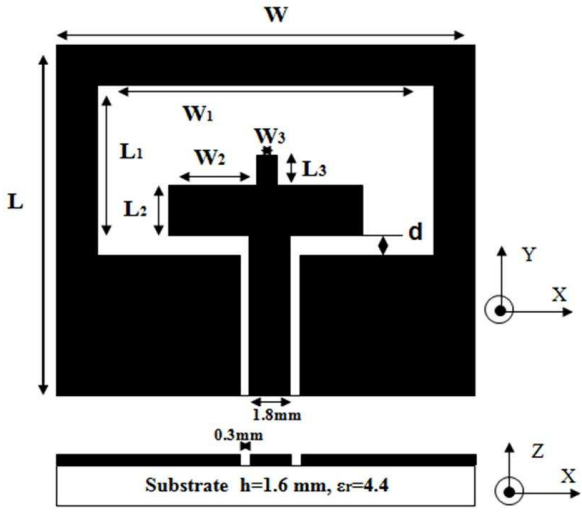


Figure 1. Geometry of the proposed CPW-fed rectangular slot antenna.

0.3 mm ground gap. The proposed antenna produces wide bandwidth with omni-directional radiation pattern. The wide bandwidth and impedance matching with reduced size of the antenna is achieved due to resultant of different surface magnetic currents.

3. SIMULATED RESULTS AND ANALYSIS

In this section, various parametric analyses of the antenna which are inevitable for any UWB antennas are carried out and presented. The analysis and optimization were performed for the best impedance bandwidth. The optimal parameter values of the antenna are listed in Table 1. The simulated return loss of the proposed antenna is shown in Fig. 2, which clearly indicates that the impedance bandwidth of the antenna is 8 GHz (4.8 GHz–12.8 GHz) for a return loss (S_{11}) less than -10 dB. The ultra wideband is due to the coupling between the rectangular slot and the tuning stub. The resonant frequency and bandwidth are controlled by the size of the rectangular slot, antenna and tuning stub. Proper geometrical selection of the antenna parameters results in the variation of field distribution, which in turn affects the characteristics of the proposed antenna.

Table 1. Optimal parameter values of the antenna.

Parameter	L	W	L_1	W_1	L_2	W_2	L_3	W_3	d
Values (mm)	19	20	10	15	3.5	4	1.8	1.9	1.4

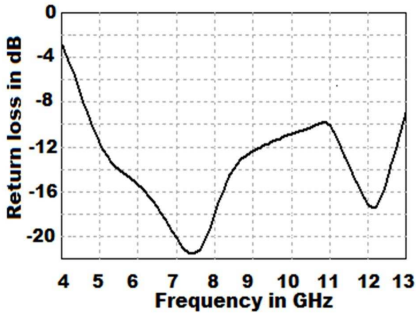


Figure 2. Simulated return loss of the proposed antenna.

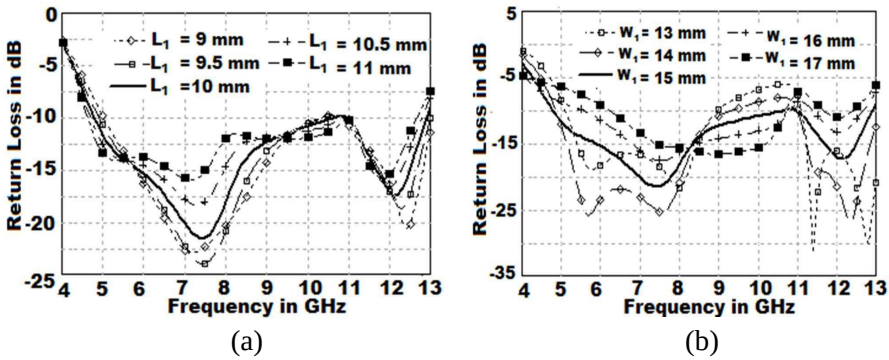
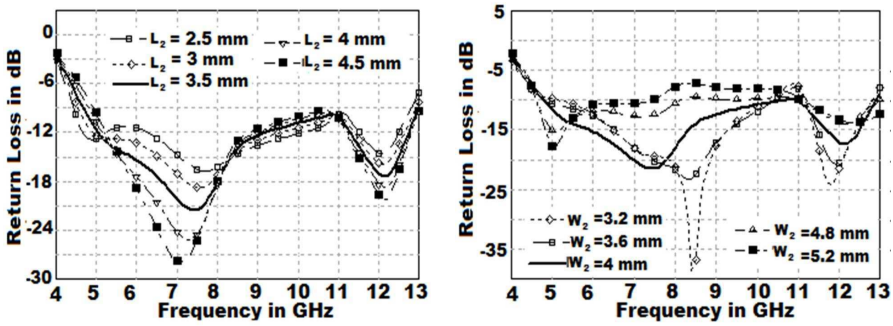


Figure 3. Simulated return loss for (a) different slot lengths L_1 and (b) different slot widths W_1.

3.1. Effect of Parameters W_1 and L_1

For the fixed values of L and W, the length and width of the rectangular slot 'L_1' and 'W_1' are varied, and the simulation results are displayed in Fig. 3. If the value of 'L_1' is increased, the impedance matching is reduced over the entire bandwidth. When it is decreased the impedance bandwidth of the antenna is reduced. Similarly, by varying the value of 'W_1' significant variations in the response are noticed, which clearly point out that these two parameters affect the



(a) (b)

Figure 4. Simulated return loss for (a) different slot lengths L_2 and (b) different slot widths W_2.

bandwidth and impedance matching of the antenna. It is also found that the optimal size of the slot is 10 mm × 15 mm.

3.2. Effect of Cross Tuning Stub

In this section, the effect of length and width of the cross patch tuning stub is presented. The length 'L_2' and width 'W_2' of the side arms of the cross patch are varied to study the effect of these parameters. The return loss curves for different lengths 'L_2' and widths 'W_2' are shown in Fig. 4. The effect of varying lengths' 'L_2' is illustrated in Fig. 4(a), which shows that increasing the length of the arm the return loss is slightly increased in the lower and upper resonance frequencies and vice versa for the decreasing the length, and the optimal length found for this case is 3.5 mm. The effect of width variation of the cross is shown in Fig. 4(b). It is observed that the return loss is reduced, and there is a slight shift in the resonance frequency when the width of the cross stub arm 'W_2' is increased. The decreasing in the width causes small reduction in the impedance bandwidth of the antenna. The best possible value for this case is 4 mm. Similarly, the stub length 'L_3' and width 'W_3' of the upper arm are varied, and the effect of the above parameters is displayed in Fig. 5. The optimal values of length 'L_3' is 1.8 mm, and width 'W_3' is 1.9 mm.

3.3. Effect of Feed Gap Distances

The simulated return loss for different feed gap distances (d = 0.6, 1, 1.4, 1.8 and 2.1 mm) is displayed in Fig. 6. The response clearly

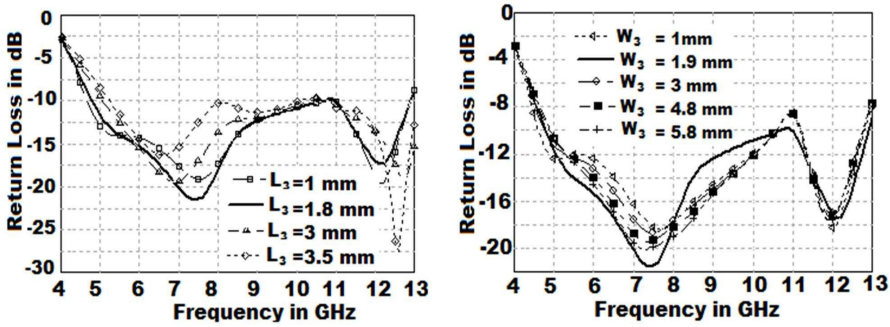


Figure 5. Simulated return loss for (a) different slot lengths L_3 and (b) different slot widths W_3.

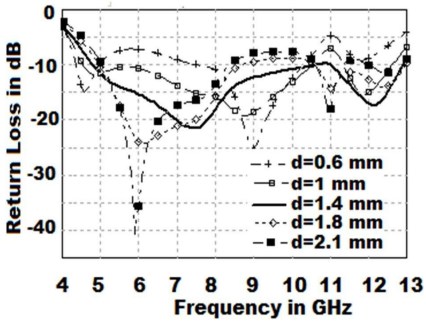


Figure 6. Simulated return loss for different feed gaps.

brings out that as the feed width increases, the impedance matching is improved in the lower frequency; however, the overall impedance bandwidth of the antenna is reduced. A significant variation in the impedance bandwidth is observed when the feed gap distance is increased. Hence, feed gap is one of the parameters which affects the impedance matching and impedance bandwidth. The optimal value found for this case is 1.4 mm.

4. EXPERIMENTAL RESULTS AND DISCUSSION

4.1. Frequency Domain Analysis

The prototype of the proposed antenna was fabricated for different parameters with their optimal values and tested, which is depicted in

Fig. 7. All the measurements are carried out using Vector Network Analyzer (VNA) Agilent HP 8250. The return loss is measured and plotted to indicate that it covers wide bandwidth of 7 GHz (4.2 GHz–11.2 GHz). The simulated and measured return losses of the proposed antenna are illustrated in Fig. 8. The discrepancy between the measured and simulated results is due to the effect of improper soldering of SMA connector or fabrication tolerance. The simulation results were obtained by assuming coplanar input port, whereas practically SMA connector was used. The imperfect transition between SMA feed to coplanar may introduce losses [22] and shift in the frequency. However, the measured bandwidth is relatively equal to the simulated impedance bandwidth, 8 GHz (4.8 GHz–12.8 GHz). Antenna radiation patterns at frequency 5.5 GHz for the E- and H-planes are measured and and its normalized values are plotted along with the simulated as shown in Fig. 9, which is omni-directional in H-plane and bidirectional in E-plane. The comparison of the measured antenna gain with the simulated one is shown in Fig. 10 which also shows reasonable agreement through the entire band.

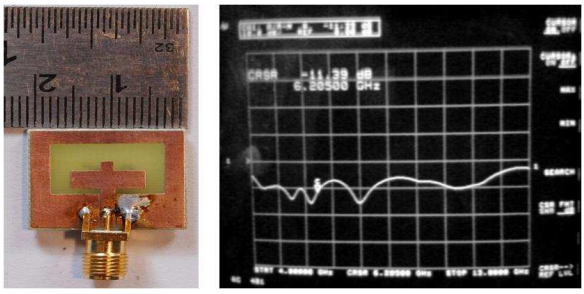


Figure 7. Fabricated antenna and its measured return loss.

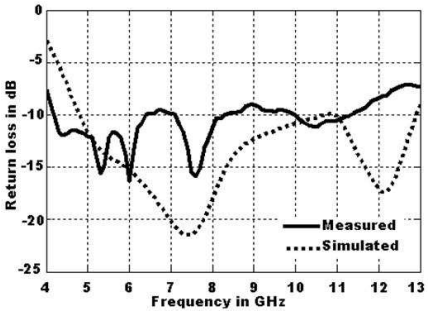


Figure 8. Comparison of return losses of the proposed antenna.

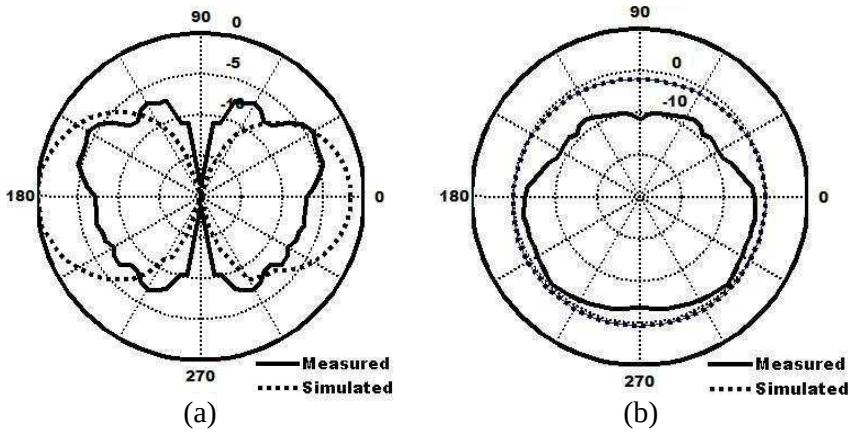


Figure 9. Measured radiation pattern at 5.5 GHz (a) E-plane, (b) H-plane.

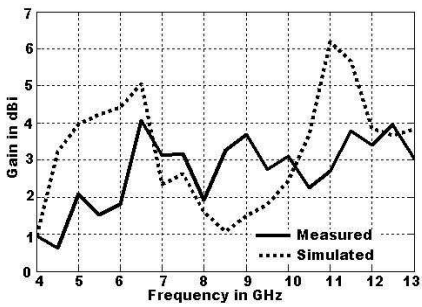


Figure 10. Gain comparison.

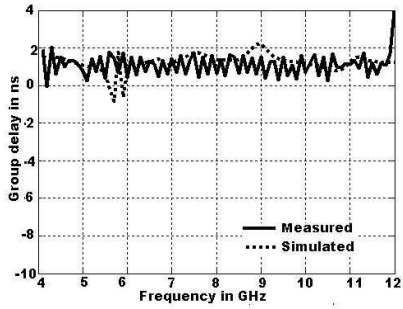


Figure 11. Group delay performance.

4.2. Time Domain Analysis

In ultra wideband systems, the information is transmitted using short pulses. Hence, it is important to study the temporal behavior of the transmitted pulse. The communication system for UWB pulse transmission must limit distortion, spreading and disturbance as much as possible. The channel is assumed to be linear time invariant (LTI) system to verify the capability of the proposed antenna for transmission and reception of these narrow pulses. The group delay is measured by placing two identical antennas at a distance of 75 mm which is greater than the far field distance of the antenna. The comparison of the measured and simulated group delays is shown in Fig. 11,

which illustrates that the group delay variation is within 2 ns which is acceptable. The transient response of the antenna performed from the transfer function of the system is computed using measured value of 'S_{21}' parameter [23]. The received output pulse is obtained by taking the Inverse Fourier Transform (IFT) of the product of transfer function and spectrum of the test input pulse. The cosine modulated Gaussian pulse is considered for this analysis with centre frequency of 6.85 GHz and pulse width of 220 picoseconds, whose spectrum is shown in Fig. 12. It satisfies the requirement of FCC mask for UWB indoor emission. The comparison of transmitted input pulse and received output pulse of the antenna is shown in Fig. 13, which ensures less distortion in pulse transmission and also guarantees that the designed antenna is capable of transmitting and receiving short pulses. The ringing effect in the waveform may be due to the transmission properties of the system.

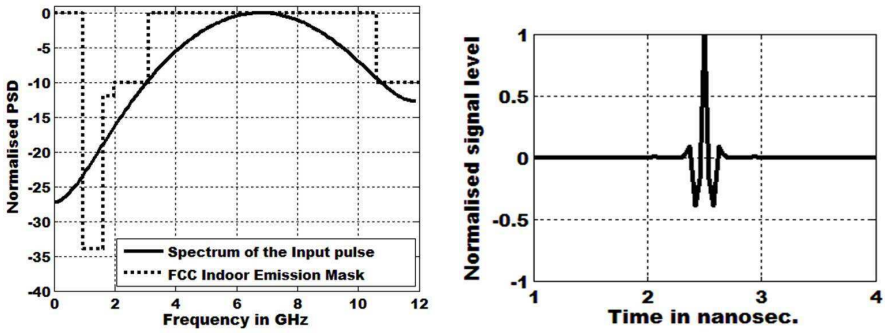


Figure 12. (a) Spectrum of the test input pulse with FCC mask and (b) input pulse in time domain.

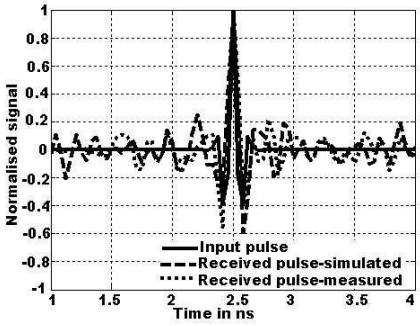


Figure 13. Comparison of input pulse with received output pulses.

5. CONCLUSION

This paper describes the detailed analysis and implementation of a CPW fed UWB slot antenna. The antenna has a unique cross like tuning stub at the anterior portion of the feed to enhance the coupling between the slot and feed. With the above structural features the overall dimension of the proposed antenna comes around 19 mm (length) × 20 mm (width) × 1.6 mm (thickness). A size reduction of 66% is obtained compared to the same type of antennas found in the literature by compromising 18% of fractional bandwidth. However, the observed 90% fractional bandwidth of the proposed structure is more than sufficient for any UWB applications. The time domain analysis of the antenna is also performed to ensure the suitability of the proposed antenna for the UWB environment. Thus, the proposed antenna is simple, easy to fabricate and can be integrated into any UWB systems.

ACKNOWLEDGMENT

The authors wish to express their sincere gratitude to Dr. A. Alphonse, Associate professor, Nanyang Technological University, Singapore for facilitating some of the measurements shown in the paper at Nanyang Technological University, Singapore.

REFERENCES

1. FCC NEWS (FCC 02-48), FCC News release, Feb. 14, 2002.
2. Ghavami, M., L. B. Michael, and R. Kohno, *Ultra Wideband Signals and Systems in Communication Engineering*, John-Wiley & Sons, New York, 2004.
3. Simons, R. N., *Coplanar Waveguide Circuits Components and Systems*, John-Wiley & Sons, New York, 2001.
4. Chiou, J. Y., J. Y. Sze, and K. L. Wong, "A broad-band CPW-fed strip-loaded square slot antenna," *IEEE Trans. Antennas and Propag.*, Vol. 51, No. 4, 719–721, 2003.
5. Chen, H. D., "Broadband CPW-fed square slot antenna with a widened tuning stub," *IEEE Trans. Antennas and Propag.*, Vol. 51, No. 8, 1982–1986, 2003.
6. Deng, S. M. and H. H. Kan, "Analysis of CPW-fed triangle patch antennas," *IEEE Trans. Antennas and Propag.*, Vol. 3, 398–401, 2001.
7. Alpesh, U. B., L. H. Christopher, et al., "Wide-band slot antennas

with CPW feed lines: Hybrid and log-periodic designs," *IEEE Trans. Antennas and Propag.*, Vol. 52, No. 10, 2545–2554, 2004.

8. Mahatthanajatuphat, C., P. Akkaraekthalin, S. Saleekaw, and M. Krairiksh, "A bidirectional multiband antenna with modified fractal slot FED by CPW," *Progress In Electromagnetics Research*, PIER 95, 59–72, 2009.
9. Jiao, J.-J., G. Zhao, F.-S. Zhang, H.-W. Yuan, and Y.-C Jiao, "A broadband CPW-FED T-shape slot antenna," *Progress In Electromagnetics Research*, PIER 76, 237–242, 2007.
10. Denidni, A. and M. A. Habib, "A broadband printed CPW-fed circular slot antenna," *Electronics Letters*, Vol. 42, No. 3, 135–136, 2006.
11. Lin, S.-Y., et al., "A novel compact slot antenna for ultra-wideband communications," *IEEE Antennas and Propagation International Symposium*, 5123–5126, 2007.
12. Ding, X. and A. F. Jacob, "CPW-fed slot antenna with wide radiatings apertures," *Proc. Inst. Elect. Eng./Microwave Antenna Propagation*, Vol. 145, 104–104, 1998.
13. Qu, S. W., C. Ruan, and B. Z. Wang, "Bandwidth enhancement of wide slot antenna fed by CPW and microstrip line," *IEEE Antennas and Wireless Propagation Letters*, Vol. 5, 15–17, 2006.
14. Yeo, J., Y. Lee, and R. Mittra, "Wideband slot antennas for wireless communications," *IEEE Proc. — Microwave Antennas and Propagation*, Vol. 151, 351–355, 2004.
15. Consoli, F., F. Maimone, and S. Barbarino, "Study of a CPW-fed circular Slot antenna for UWB communications," *Microwave and Optical Technology Letters*, Vol. 48, 2272–2277, 2006.
16. Chair, R., A. A. Kishk, and K. F. Lee, "Ultrawideband coplanar waveguide-fed rectangular slot antenna," *IEEE Antennas Wirel. Propag. Lett.*, Vol. 3, 227–229, 2004.
17. Eldek, A. A., A. Z. Elsherbeni, and C. E. Smith, "Rectangular slot antenna with patch stub for ultra wideband applications and phased array systems," *Progress In Electromagnetics Research*, PIER 53, 227–237, 2005.
18. Lin, Y.-C. and K.-J. Hung, "Compact ultrawideband rectangular aperture antenna and band-notched designs," *IEEE Trans. Antennas and Propag.*, Vol. 54, No. 11, 3075–3081, 2006.
19. Chen, X., W. Zhang, R. Ma, R. Zhang, and J. Gao, "Ultra-wideband CPW-fed antenna with round corner rectangular slot and partial circular patch," *IET Microwave Antennas and Propagation*, Vol. 1, No. 4, 847–851, 2007.

20. Li, Z., C. X. Zhang, G.-M. Wang, and W.-R. Su, "Designs on CPW-FED aperture antenna for ultra-wideband applications," *Progress In Electromagnetics Research C*, Vol. 2, 1–6, 2008.
21. FCC IE3D 14, Zeland Software, Ins., Fremont, USA.
22. Ma, K.-P., Y. X. Qian, and T. Itoh, "Analysis and applications of a new CPW-slot line transition," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 47, 426–432, 1999.
23. Licul, S. and W. A. Davis, "Ultra-wideband (UWB) antenna measurements using vector network analyzer," *Proc. of IEEE Antennas and Propagation International Symposium*, 1319–1322, 2004.