Progress In Electromagnetics Research C, Vol. 46, 153–161, 2014

A Compact CPW-Fed Planar Pentagon Antenna for UWB Applications

Naima A. Touhami[1, *], Yahya Yahyaoui[1], Alia Zakriti[2], Khadija Bargach[1], Mohamed Boussouis[1], Mohammed Lamsalli[1], and Abdelwahid Tribak[3]

Abstract—In this paper, the design and analysis of a compact coplanar waveguide-fed ultra wideband pentagon antenna are presented. To achieve ultra wideband performance, two modifications are introduced. The first one is to remove a small fan angle on each side of the ground plan, and the second one is to modify the sharp of the patch in the width. The optimal dimensions can be achieved by a parametric analysis. The antenna design exhibits a very wide operating bandwidth of 16.7 GHz with a return loss better than 10 dB in the frequency range from 4.46 GHz to 21.14 GHz. The gain of the proposed antenna is 6.3 dBi. This antenna configuration will be useful for UWB indoor application as it is easy to fabricate and integrate with RF circuitry. All simulations in this work were carried out by using the electromagnetic software CST.

1. INTRODUCTION

With the explosive growth in the number of wireless communication users and applications, the number of wireless standards has been growing, and the demand for various types of wireless services has been increasing. Telecommunication industry is not the only market that benefits from the advances in wireless technology; healthcare, medical diagnosis, treatment and monitoring systems, automotive production and industrial remote monitoring systems have also considerably gained from improvement of the wireless systems. Consequently, the regulatory agencies, scientists, engineers and wireless product manufacturers are all facing some tough challenges in realizing efficient wireless communication systems.

Ultra-wideband (UWB) technology is one of the most promising solutions for future communication systems due to its high speed data rate and excellent immunity to multi-path interference. UWB antenna design has some challenges including the ultra wide band performance of impedance matching and radiation stability, compact antenna size, and low manufacturing cost for consumer electronics application.

To enhance the bandwidth of a patch antenna, several approaches have been proposed previously, such as using a thick substrate with low dielectric constant and multiple resonators [1], parasitic patches stacked on the top of the main patch or close to main patch in the same plane [2], U-shaped slot [3], L-probe feeding [4], lossy materials [5], a capacitively probe fed structure [6], a 3-D transition microstrip feed line [7] and a planar monopole antenna fed by a coplanar waveguide (CPW) [8–11]. Radiating elements patches of printed antennas have a variety of forms, triangular, rectangular, square, elliptical, circular, among others [1–13].

The design of relatively compact, planar monopole antennas based on the microstrip structures has been reported to meet the bandwidth requirement. Indeed, compared to the classical monopole antennas, the planar monopole antennas have a significantly wider bandwidth and similar radiation characteristics. A planar monopole antenna fed by a CPW is proposed to promise the aforementioned

Received 17 December 2013, Accepted 13 January 2014, Scheduled 20 January 2014
* Corresponding author: Naima Amar Touhami (nai_amar@yahoo.fr).
[1] Faculty of Sciences, University Abdelmalek Essaadi, Tetouan, Morocco. [2] National School of Applied Sciences, Abdelmalek Essaadi University, Tetuan, Morocco. [3] INPT: Institut National des Postes et Télécommunications, Rabat, Morocco.

impedance bandwidth together with satisfactory radiation characteristics. The CPW-fed planar monopole antenna exploits the CPW configuration to permit easy integration with the monolithic microwave integrated circuits.

In this paper, a CPW-fed pentagon planar ultra-wideband antenna is introduced. In order to obtain ultra wideband performance, some modifications are introduced. Details of the antenna design are discussed and simulation results of the proposed antenna are presented and analyzed. The simulated and measured results show that the proposed antenna presents a very wide impedance bandwidth.

2. CPW THEORY

A conventional CPW on a dielectric substrate consists of a center strip conductor with semi-infinite ground planes on either side separated by a small gap (Figure 1). CPW structures supporting quasi TEM mode have gained great attention in microwave and millimeter wave applications due to uniplanar structure. They are commonly used in Monolithic Microwave Integrated Circuits (MMIC). The CPW transmission lines have lower radiation loss and less dispersion than microstrip lines. Moreover, the characteristic impedance and phase velocity of CPW are less dependent on the substrate height and more dependent on the dimensions in the plane of the conducting surface. Due to this exceptional behavior, CPW structures have been explored a lot for compatible modern wireless communication gadgets.

The quasi-TEM approach and the analytic formulas are important steps in the initial design of a microwave circuit. The output of these formulas is the CPW characteristic impedance and the effective relative permittivity.

The characteristic impedance of a conventional coplanar waveguide structure can be computed using Equation (1) [14, 15].

$$Z_c = \frac{30\pi}{\sqrt{\varepsilon_{re}}} \cdot \frac{K'(k_1)}{K(k_1)} \tag{1}$$

where $k_1 = \frac{w}{w+2g}$ and $K(k_1)$ is the complete elliptic integral of the first kind and $K'(k_1)$ it's complement. The ratio $\frac{K'(k_1)}{K(k_1)}$ can be easily computed using (2).

$$\frac{K'(k)}{K(k)} = \begin{cases} \dfrac{\pi}{\ln\left(2\frac{1+\sqrt{k}}{1-\sqrt{k}}\right)} & \text{for} \quad 0 \le k \le \frac{1}{\sqrt{2}} \\ \dfrac{\ln\left(2\frac{1+\sqrt{k}}{1-\sqrt{k}}\right)}{\pi} & \text{for} \quad \frac{1}{\sqrt{2}} \le k \le 1 \end{cases} \tag{2}$$

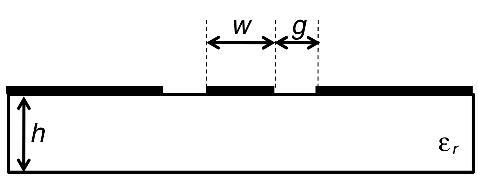


Figure 1. The definition of the main parameters for the analytic model.

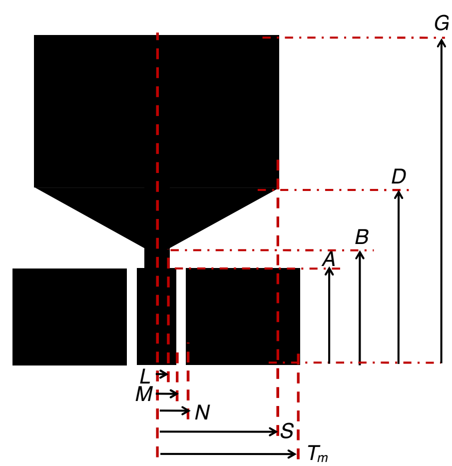


Figure 2. Geometry of CPW-fed antenna.

When taking into account the finite thickness of the substrate, the effective permittivity can be computed with Equation (3).

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} \cdot \frac{K(k_2)}{K'(k_2)} \cdot \frac{K'(k_1)}{K(k_1)} \tag{3}$$

where ε_r is the relative permittivity of the substrate and $k_2 = \frac{\sinh(\frac{\pi w}{4h})}{\sinh(\frac{\pi(w+2g)}{4h})}$.

3. ANTENNA GEOMETRY

In this paper, we have used coplanar waveguide (CPW) to feed the antenna. CPW transmission line is probably the most used for designing microwave circuits for mm-wave applications. It allows for easy fabrication and integration of active devices due to the presence of the center conductor in close proximity of the ground planes [16–19]. Unlike microstrip, CPW has substantially less losses at frequencies approximately above 20 GHz. This is due to a large proportion of the field existing outside the dielectric. As a result, the dielectric loss is lower and the dispersion of the signal is considerably less.

The first design of the proposed antenna is shown in Figure 2. In this design, the substrate FR4 is used as it is cheap and easy to fabricate. The substrate height is 1.6 mm, dielectric constant 4.3, and loss tangent 0.02. The antenna parameters are summarized in Table 1.

Table 1. Parameter's values of CPW-fed antenna.

Parameter	S	G	D	B	A	L	N	M	T_m
Dimension (mm)	8	19	9.5	5.5	5.2	1.1	2.5	2	11

4. SIMULATED RESULTS AND DISCUSSION

In order to evaluate the performance of the antenna shown in Figure 2, a simulation study is carried out using CST simulation tool. As shown in Figure 3, 10 dB return loss was achieved over the two expected wide frequency ranges from 4.48 GHz to 9.1 GHz and from 14 GHz to 16.1 GHz.

In order to enhance the performance of this antenna, a parametric study has been carried out and the critical antenna parameter has been obtained. Classifying the parameters does not imply that the

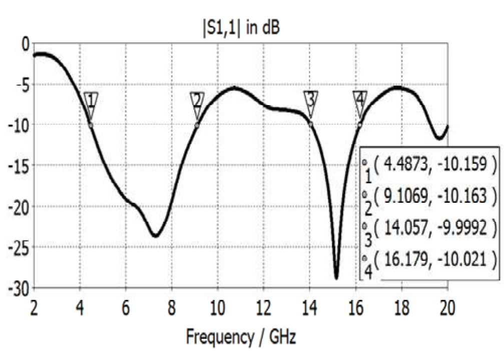


Figure 3. Simulated S_{11} reflection coefficient magnitude of the CPW antenna.

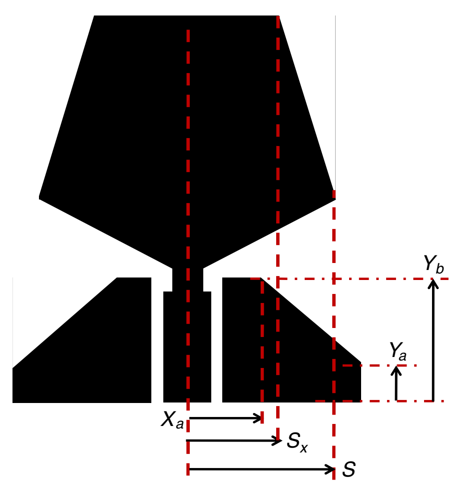


Figure 4. Geometry of the proposed CPW-fed pentagon antenna.

effect of each parameter is independent. Depending on the structure's shape and feeding mechanism, various parameters could be involved. However in general, dimensions of the radiator, the ground plane and the feed gap determine the impedance bandwidth.

In the following, we present a study which is performed to determine the effect of each of the bandwidth-enhancement design parameters. The ground plane is considered as part of the antenna and contributes to the radiation. Then, based on the idea to plate the disc one antenna, we examine the effect of a trapeze form ground plane in order to improve the impedance bandwidth ratio [20–22]. The effect of planar monopole antenna parameters is also studied to obtain a compact structure and to enhance the performance of the bandwidth. Figure 4 shows all studied parameters. The contribution of one parameter at a time is studied while the other parameters are set to their suboptimal values.

4.1. Effect of Y_a Parameter

First, we study the effect of varying the width of the rectangular ground plane (Y_b parameter) as illustrated in Figure 4. It is observed that increasing Y_b parameter from 5.2 mm (identical value of A parameter in Figure 2) to the optimal value of 6 mm, the impedance bandwidth can be wider (Figure 5).

4.2. Effect of S Parameter

In this paragraph, we study the effect of the S parameter which is related to the width of the planar monopole structure. It is observed in Figure 6 that decreasing this parameter from 8 mm down to 6.5 mm also improves the impedance bandwidth.

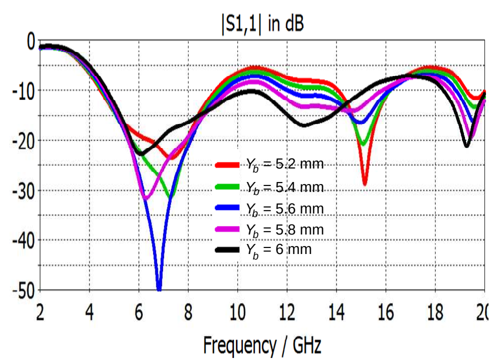


Figure 5. Simulated reflection coefficient curves for different Y_b values.

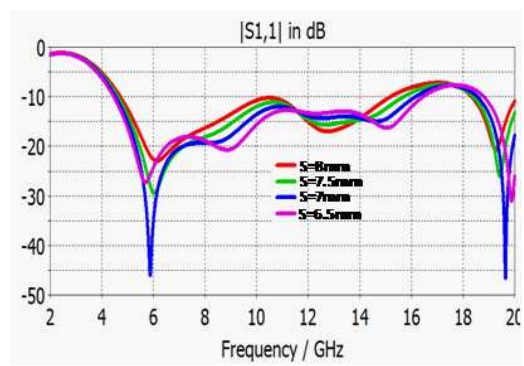
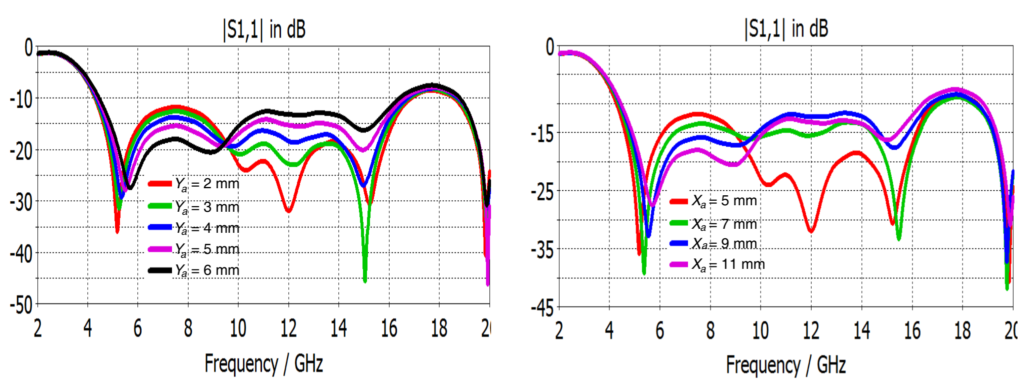


Figure 6. Simulated reflection coefficient curves for different S values.



(a) (b)

Figure 7. Simulated reflection coefficient curves for different (a) Y_a values and (b) X_a values.

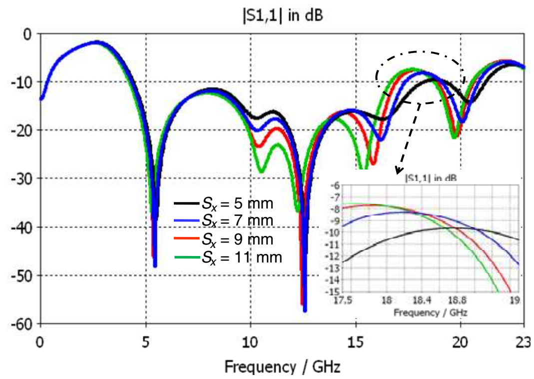


Figure 8. Simulated reflection coefficient curves for different S_x wideband antenna.

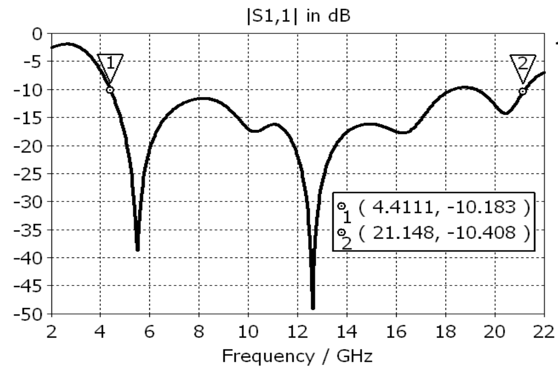


Figure 9. Simulated reflection coefficient of CPW antenna with optimal parameters.

Table 2. Optimal parameters values of the antenna.

Parameter	Y_b	S	Y_a	X_a	S_x
Dimension (mm)	6	6.5	2	5	5

Table 3. Comparison between recently proposed antennas and this antenna.

Antenna	Bandwidth (GHz)	Antenna size (mm^2)	Gain (dB)
This work	4.5–20	22×19	2.49–6.3
[23]	3–23	28×30	0.2–3.9
[24]	3–20	22.2×26.5	2.84–5.68
[25]	3.8–12	28×29	−4.5–3.5
[26]	3.1–11	26×30	1.5–4.6
[27]	3.1–10.6	35.2×28.18	0.42–4.2
[28]	3.1–12	24×35	< 4
[29]	2–12	35×30	Not defined
[30]	2–12	35×35	Not defined

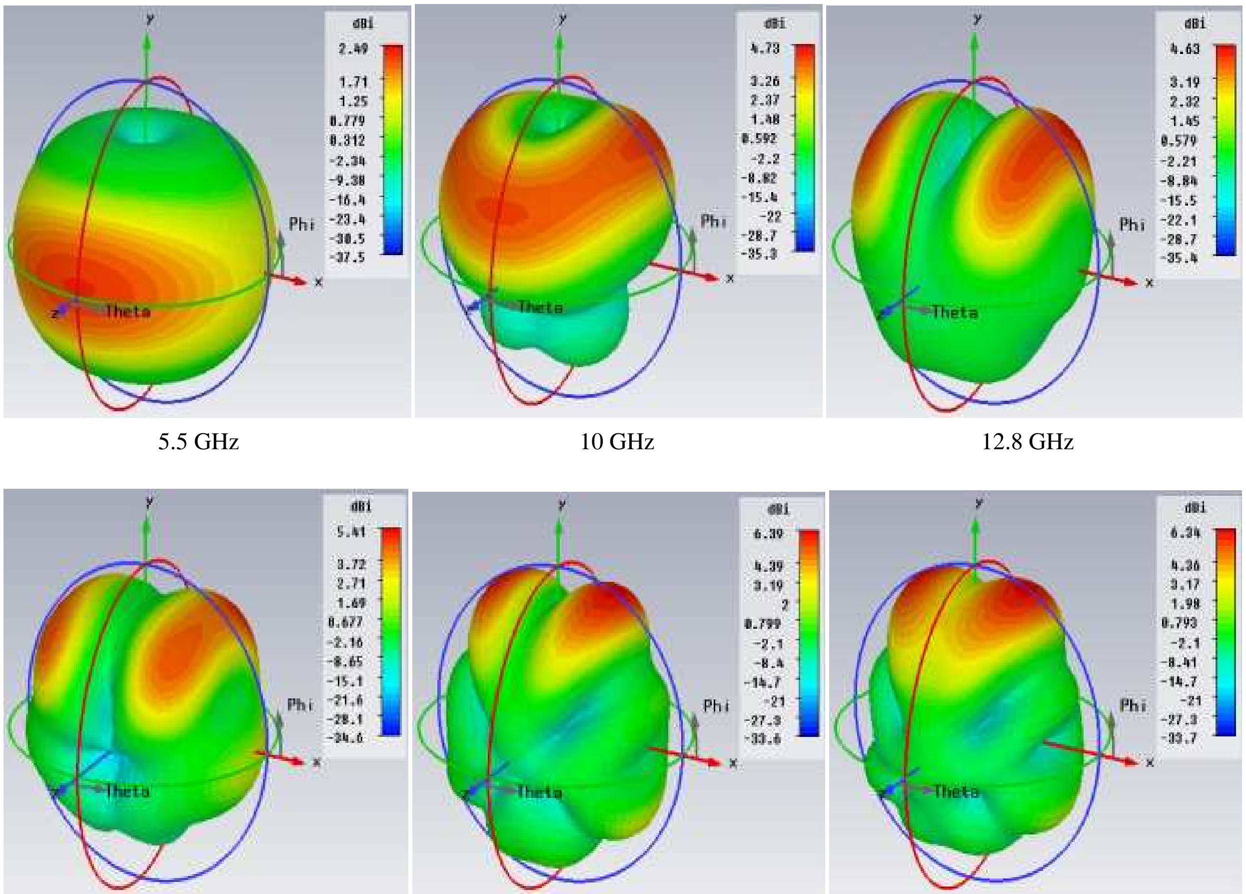
4.3. Effect of Y_a and X_a Parameters

Effect of trapeze form ground plane on the bandwidth performance is studied by varying Y_a and X_a parameters. As shown in Figure 7, it is observed that the optimal values are obtained for Y_a equal to 2 mm and X_a equal to 5 mm. Consequently, we conclude that the variation in the size of ground plane changes the antenna matching. This phenomenon confirms that the ground plane is part of the antenna.

4.4. Effect of S_x Parameter

In order to achieve a compact structure, we study, in this paragraph, the effect of the S_x parameter. S_x is varied from 5 mm to 8 mm while other parameters are fixed to their optimal values. The simulated reflection coefficients curves for different S_x parameters are presented in Figure 8. It is evident from this figure that the end of the band is considerably affected by changing the antenna width, and the first resonance is not significantly affected. The reflection coefficient magnitude is better than 10 dB over the frequency range 4.45 GHz to 21.14 GHz for an S_x value of 5 mm.

Finally, all optimal parameters of pentagon monopole antenna are summarized in Table 2.



5.5 GHz 10 GHz 12.8 GHz

16.3 GHz 20 GHz 21 GHz

Figure 10. 3D plot of field pattern shows the gain at each selected frequency.

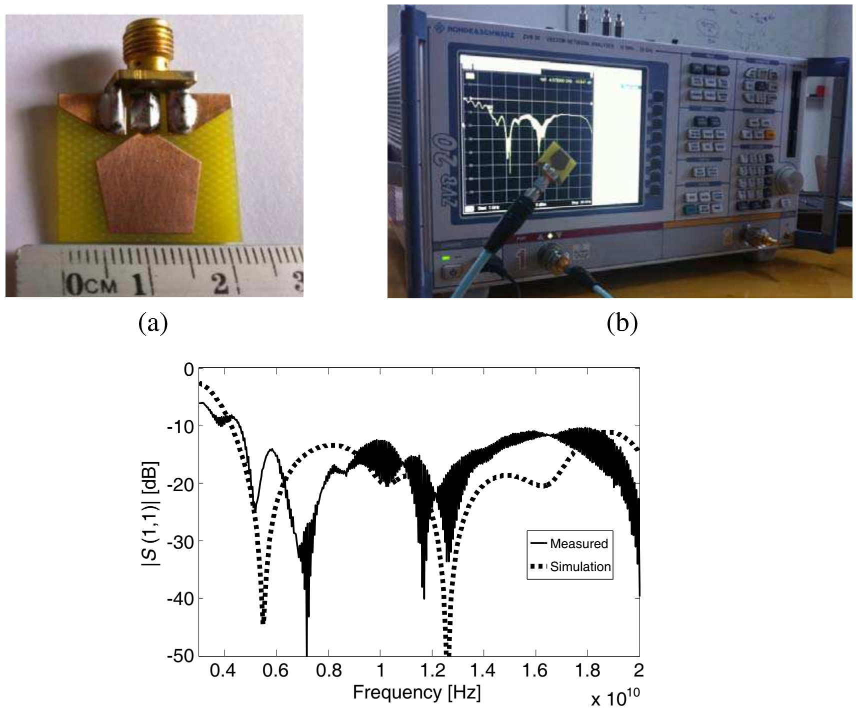
Figure 9 shows the simulated reflection coefficient of the pentagon antenna with optimal parameters. The bandwidth of this antenna increased drastically from 4.41 GHz to 21.14 GHz.

4.5. Gain and Radiation Pattern

The antenna gain is varying from 2.49 dBi to 6.39 dBi across the entire bandwidth. Figure 10 shows the 3D plot of the field pattern and the gain value of the proposed antenna at each selected frequency. The E (x-y plane) and H (y-z plane) fields in the figures reveal that at lower frequencies they have nearly perfect omnidirectional radiation patterns, but the radiation pattern degrades sharply at-higher frequencies. The proposed antenna has an acceptable quasi omnidirectional radiation pattern required to receive information signals from all directions.

4.6. Fabrication and Measurement

A prototype structure of pentagon antenna is fabricated on FR4 substrate with a relative dielectric constant of 4.3 and a thickness h of 1.58 mm (Figure 11(a)). In order to measure scattering parameters of the proposed antenna, we have been used a Rohde and Schwarz ZVB 20 vector network analyzer (Figure 11(b)), which its frequency range is limited to 20 GHz. The reflection coefficient was measured and compared to the simulated results. As can be seen in Figure 11(c), the measured resonances are very close to those obtained in the simulations. The -10 dB bandwidth spans the expected wide frequency range in both simulation and measurement. The results show that the antenna provides a very wide impedance bandwidth of 15.4 GHz from a frequency of 4.5 GHz to 20 GHz for which S_{11} is better than



(a) (b) (c)

Figure 11. (a) Photograph of the fabricated antenna. (b) Bank under test. (c) Simulated and measured S_{11} parameter.

10 dB. The measured results agree well with the simulated ones but some discrepancies have occurred, due to the fabrication inaccuracy and conditions of measurement.

4.7. Comparison between Recently Developed Antennas and the Proposed Antenna

Table 3 presents a comparison between the performance of some recently developed UWB antennas and the proposed antenna. The proposed antenna shows wide impedance bandwidth, compact size, and good gain features.

5. CONCLUSIONS

This paper presents the simulated and experimental results of a printed CPW-fed pentagon antenna. This configuration is shown to substantially enhance the antenna's bandwidth. The proposed antenna shows a very wide bandwidth of 16.7 GHz. In addition to being small in size, the antenna exhibits stable far-field radiation patterns over its operating range and a relatively high gain. Based on these characteristics, the proposed CPW-fed antenna can be used for wideband satellite and wireless communication applications.

REFERENCES

1. Yang, F., X. X. Zhang, X. Ye, and Y. Rahmat-Samii, "Wide-band E-shaped patch antenna for wireless communications," *IEEE Trans. Antennas Propag.*, Vol. 49, No. 7, 1094–1100, Jul. 2001.
2. Wu, C. K. and K. L. Wong, "Broadband microstrip antenna with directly coupled and gap-coupled parasitic patches," *Mirow. Opt. Technol. Lett.*, Vol. 22, No. 5, 348–349, Sep. 1999.
3. Huynh, T. and K. F. Lee, "Single-layer single-patch wideband microstrip antenna," *Electron. Lett.*, Vol. 31, No. 16, 1310–1312, Aug. 1995.

4. Guo, Y. X., C. L. Mark, K. M. Luk, and K. F. Lee, "Analysis and design of L-probe proximity fed patch antenna," *IEEE Trans. Antennas Propag.*, Vol. 49, No. 2, 145–149, Feb. 2001.
5. Wong, K. L. and Y. F. Lin, "Small broadband rectangular microstrip antenna with chip-resistor loading," *Electron. Lett.*, Vol. 33, No. 19, 1593–1594, Sep. 1997.
6. Gonzalez de Aza, M. A., J. Zapata, and J. A. Encinar, "Broadband cavity-backed and capacitively probe-fed microstrip patch arrays," *IEEE Trans. Antennas Propag.*, Vol. 48, No. 5, 784–789, May 2000.
7. Herscovici, N., "New considerations in the design of microstrip antennas," *IEEE Trans. Antennas Propag.*, Vol. 46, No. 6, 807–812, Jun. 1998.
8. Agrawall, N. P., G. Kumar, and K. P. Ray, "Wide-band planar monopole antennas," *IEEE Trans. Antennas Propag.*, Vol. 46, No. 2, 294–295, Feb. 1998.
9. Anob, P. V., K. P. Ray, and G. Kumar, "Wideband orthogonal square monopole antennas with semi-circular base," *IEEE Antennas Propagat. Soc. Int. Symp.*, Vol. 3, 294–297, Jul. 2001.
10. Ammanna, M. J., "The pentagonal planar monopole for digital mobile terminals; bandwidth considerations and modelling," *Int. Conf. Antennas Propagat.*, Vol. 1, 82–85, Apr. 2001.
11. Lee, E., P. S. Hall, and P. Gardner, "Compact wideband planar monopole antenna," *Electron. Lett.*, Vol. 35, No. 25, 2157–2158, Dec. 1999.
12. Wong, K. L., *Compact and Broadband Microstrip Antennas*, 1st edition, Chaps. 1, 2 and Chap. 4, 144–154, Wiley Ed., 2006.
13. Martinez-Vazquez, M., O. Litschke, M. Geissler, D. Heberling, M. Antonio, and D. Martinez-Gonzalez, "Integrated planar multiband antennas for personal communication handsets," *IEEE Trans. Antennas Propag.*, Vol. 54, No. 2, 384–391, Feb. 2006.
14. Varadan, V. K., K. Vinoy, and K. Jose, *RF MEMS and Their Applications*, John Wiley & Sons, Ltd, Chichester, UK, 2003.
15. Simons, R. N., *Coplanar Waveguide Circuits, Components and Systems*, Wiley-Interscience, 2001.
16. Azim, R., A. T. Mobashsher, M. T. Islam, and N. Misran, "Compact planar antenna for UWB applications," *IEEE ICMMT*, 1987–1990, 2010.
17. Cumhur Basaran, S., "Dual wideband CPW fed split ring monopole antenna for WLAN applications," *IEEE Trans. Antennas Propag.*, Vol. 978, No. 1, 174–177, 2010.
18. Yadav, R. K., J. Kishor, and R. L. Yadava, "Design of hexagonal patch antenna for mobile wireless system," *IEEE IJSTM*, Vol. 2, No. 4, 34–38, Dec. 2011.
19. Liang, X.-L., T. A. Denidni, L.-N. Zhang, R.-H. Jin, J.-P. Geng, and Q. Yu, "Printed binomial curved slot antennas for wideband applications," *IEEE Trans. Microwave Theory and Techniques*, Vol. 59, No. 4, 1058–1065, 2011.
20. Liang, X.-L., S.-S. Zhong, W. Wang, and F.-W. Yao, "Printed annular monopole antenna for ultra-wideband applications," *Electron. Lett.*, Vol. 42, No. 2, 71–72, 2006.
21. Zhong, S.-S., X.-L. Liang, F.-W. Yao, W. Wang, and X.-F. Bai, "Ultra-wideband printed antennas for communication applications," *Journal of Shanghai University*, Vol. 10, No. 1, 48–52, 2006.
22. Liang, X.-L., S.-S. Zhong, and W. Wang, "Tapered CPW-fed printed monopole antenna," *Mirow. Opt. Technol. Lett.*, Vol. 48, No. 7, 1242–1244, 2006.
23. Kim, S. J., J. W. Baik, and Y. S. Kim, "Design of a UWB slot antenna with frequency bandnotched characteristic," *Proc. of Inter. Symp. on Antennas and Propagation, ISAP 2006*, 2006.
24. Ahmed, E. S., "A CPW-fed printed monopole ultra-wideband antenna with E-shaped notched band slot," *Iraqi Society for Alternative and Renewable Energy Sources and Techniques*, 2010.
25. Zamel, H. M., A. M. Attiya, and E. A. Hashish, "Design of a compact UWB planar antenna with band-notch characterization," *Radio Science Conference*, 1–8, Cairo, Egypt, 2007.
26. Chu, Q.-X. and Y.-Y. Yang, "A compact CPW-fed planar ultra-wideband antenna with a frequency notch characteristic," *Proceedings of Asia-Pacific Microwave Conference*, Bangkok, Thailand, 2007.
27. Yoon, H., H. Kim, K. Chang, Y. J. Yoon, and Y.-H. Kim, "A study on the UWB antenna with band-rejection characteristic," *IEEE Antennas Propagat. Soc. Int. Symp.*, Vol. 2, 1784–1787, Monterey, USA, 2004.

28. Hong, C.-Y., C.-W. Ling, and S.-J. Chung, "Design of a planar ultra wideband antenna with a new band-notch structure," *IEEE Trans. Antennas Propag.*, Vol. 55, No. 12, 3391–3397, 2007.
29. Wu, S.-J., et al., "Study of an ultra-wideband monopole antenna with a band-notched open-looped resonator," *IEEE Trans. Antennas Propag.*, Vol. 58, No. 6, 1890–1897, 2010.
30. Qiu, C., et al., "Hybrid shaped band-notched ultra-wideband patch antenna," *Proc. of Inter. Symp. on Antennas and Propagation, ISAP 2007*, Niigata, Japan, 2007.