

A COMPACT MONOPOLE ANTENNA FOR ULTRA-WIDEBAND (UWB) APPLICATIONS

Tonmoy K. Saha, Carlene Goodbody, Tutku Karacolak, Praveen K. Sekhar

School of Engineering and Computer Science, Washington State University Vancouver, Washington, USA

ABSTRACT: In this paper, a slotted circular ultra-wideband (UWB) microstrip patch antenna is reported. The antenna is designed, simulated, fabricated, and tested experimentally. The antenna operates over a 4.0-40 GHz (164% fractional bandwidth) range with a return loss of 10 dB and voltage standing wave ratio (VSWR) < 2. The designed monopole antenna is of dimensions 28.1 mm x 17.1 mm with an electrical size of $0.37 \lambda \times 0.23 \lambda$ at 4 GHz frequency. The antenna is fabricated on FR-4 substrate with a dielectric permittivity of 4.4, loss tangent of 0.02, and a thickness of 1.4 mm. The designed antenna exhibits nearly omnidirectional radiation patterns over the entire impedance bandwidth with more than 2.8 dB peak gain for the entire frequency range and 75% of average radiation efficiency. The presented antenna can be used in UWB communications along with C-band, X-band, K_u -band, K-band, K_a -band, WLAN and future wireless applications.

Key Words: Ultra-wideband (UWB) antenna, circular monopole antenna, finite ground, slotted patch, slotted ground, microstrip feedline.

1. INTRODUCTION

With an increase in the use of multipurpose wireless communication systems, ultra-wideband (UWB) antennas are becoming popular in future communication systems since its adaptation by Federal Communications Commission (FCC) in 2002 [1]. According to the FCC, UWB antenna exceeds the minimum bandwidth of 500 MHz or 20% of the center frequency. UWB systems offer other advantages such as high data rates with low manufacturing cost, simple design features, low power consumption, and operability in short and long-range frequency spectrum. Further, UWB antenna can be used to replace multiple narrowband single antennas [2]. At present, microstrip patch antenna design is popular in communication devices due to its easy integration with Monolithic Microwave Integrated Circuits [3].

In recent years, various UWB antennas have been investigated with microstrip patch antenna design [4-8]. But, few have accounted for the wide impedance bandwidth while maintaining higher radiation efficiency. In addition, the

electrical and physical dimensions of the investigated UWB antenna are large preventing its use in compact applications. An antenna with coplanar waveguide (CPW)-fed and a pair of symmetry curved radiating slot was analyzed for UWB applications to cover a bandwidth of 3-20 GHz with electrical dimensions of $0.64\lambda \times 0.4\lambda$ [9]. In another report [10], a CPW-fed UWB antenna was presented, which covers a bandwidth of 3-30 GHz and electrical dimension of $0.39\lambda \times 0.47\lambda$. Singhal et al. [11] investigated a hexagonal fractal antenna with 3.4-37.4 GHz bandwidth and electrical dimension of $0.32\lambda \times 0.34\lambda$. A fractal microstrip antenna was reported by Azari [12], which operates from 10 GHz to 50 GHz with electrical dimensions of $2\lambda \times 2\lambda$. An elliptical monopole antenna with trapezoid ground plane and bandwidth 1.02-24.1 GHz has been reported by Liu et.al [13]. It has large electrical dimensions and low gain at low frequencies. Further, a microstrip patch antenna has been studied and designed for multiple purposes in wireless communications [14]. This antenna operates in the bandwidth from 4.0 GHz to 19.8 GHz. The results of this study were based on just simulation. The investigated antennas though cover a relatively large frequency spectrum, however, occupy large electrical dimensions.

In this article, a compact UWB antenna is designed, simulated, fabricated, and tested. The antenna design was inspired from a previous study [14]. Significant improvements on this design are made by optimizing the antenna parameters, inserting slot in the feedline, and impedance matching. The designed antenna covers 4-40 GHz (164% fractional bandwidth), exhibits nearly omnidirectional radiation patterns over the entire impedance bandwidth with more than 2.8 dB peak gain and 75% of average radiation efficiency. The investigated antenna is electrically and physically compact, easy to design and fabricate in comparison to previously reported antennas. The investigated antenna design overcomes the limitations of UWB antennas such as narrow impedance bandwidth, large electrical dimension, and low gain reported earlier.

2. STRUCTURE OF THE ANTENNA DESIGN

The geometric structure of the proposed UWB monopole antenna is shown in Figure 1. The designed antenna is printed on a 1.4 mm thick FR-4 epoxy substrate with relative permittivity $\epsilon_r = 4.4$ and loss tangent $\tan\delta = 0.02$. The physical dimension of the antenna is 28.1 mm x 17.1 mm x 1.4 mm. The conductive radiating patch is printed on the top side of the FR-4 substrate, whereas the finite slotted ground plane is printed on the other side of the same substrate.

This is the author manuscript accepted for publication and has undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record. Please cite this article as doi: [10.1002/mop.31519](https://doi.org/10.1002/mop.31519)

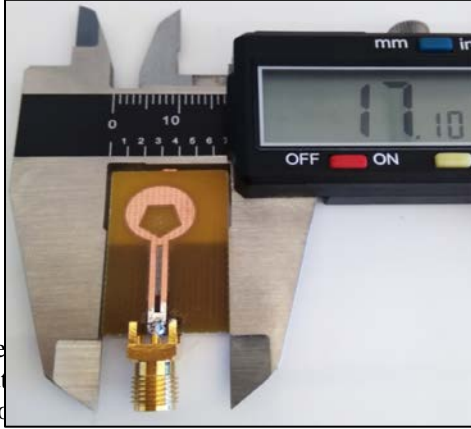


Figure 2. The fabricated UWB antenna

The antenna bandwidth is increased by the patch is related to the antenna. The radius of the patch was calculated using impedance matching [15] and then optimized using ANSYS HFSS (High Frequency Structure Simulator) software. To further improve the bandwidth (besides using the finite ground plane and circular radiator), a pentagon-shaped slot is embedded into the radiating patch without compromising the overall dimensions of the antenna. The dimensions of the rectangular microstrip feed line is calculated initially based on a previous design [16] and then optimized. The feed line is shifted right slightly from the center of the substrate, and a rectangular slot is cut into it to improve impedance matching.

Table 1 Optimized dimensions of the designed UWB antenna

Dimension	Value, mm	Dimension	Value, mm
L_{sub}	28.1	W_{sub}	17.1
L_g	15.04	W_{g1}	8
gap	0.2	W_{g2}	5.6
L_s	1.5	W_{sub}	3.5
L_f	15.26	W_f	2.62
L_{fs}	14.5	L_{fw}	0.7
R_C	5.04	R_P	3.2

To match the impedance and enhance the impedance bandwidth further, a notch is etched out from the ground

plane. Only one dimension of the antenna was adjusted at a time while keeping other parameters constant. The optimum design for a wideband antenna is obtained by the various dimensions of the antenna is given in Table 1.

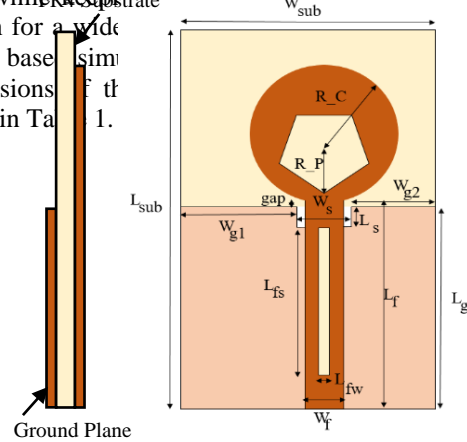


Figure 1. Geometry of the designed antenna

3. RESULTS AND DISCUSSION

The antenna is designed and simulated using finite element method (FEM) based ANSYS HFSS. The optimized antenna is fabricated with an LPKF S63 milling machine in the Radio Frequency (RF) Research Laboratory at Washington State University Vancouver to verify the simulated results. The antenna prototype, as seen in Figure 2, was tested with the Agilent PNA-L N5230C network analyzer. The simulated results (Figure 3) of the antenna indicates strong S Parameter (S_{11}) with return loss less than 10 dB (VSWR < 2) over a wide bandwidth 4 - 40 GHz. However, the antenna was tested experimentally from 4 - 20 GHz range due to the operational limitations of the network analyzer.

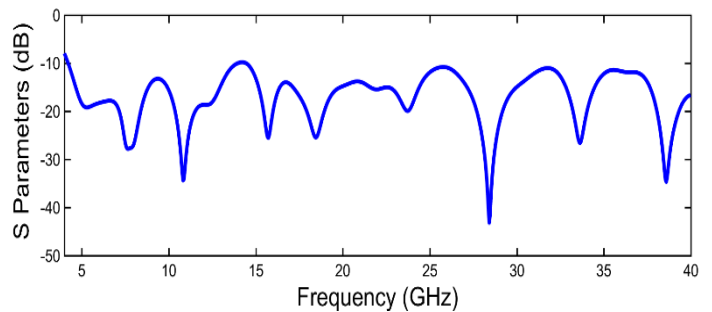


Figure 3 Simulated return loss of the designed antenna

As seen from Figure 4, the simulated and experimental results are in good agreement for the 10 dB return loss (up to 20 GHz). It can be inferred from the figure that most of the resonant frequencies of simulated and measured results matched. However, the return loss graph of experimental results shifted upward (as compared to simulation). Such discrepancy can be attributed to manufacturing tolerances SMA connector losses, measuring environment, and FR-4 substrate losses, particularly at the higher frequencies.

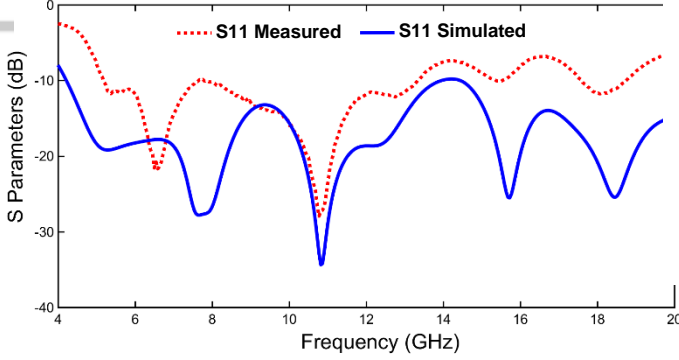


Figure 4 Simulated and measured return loss of the designed antenna

The simulated peak gain of the antenna as a function of frequency is shown in Figure 5. As observed, the antenna has a peak gain of 2.8 dB and above for the entire frequency band. With an increase in frequency, the peak gain seems to increase until 28.5 GHz. The maximum peak gain is observed to be 8 dB at 28.5 GHz.

From the frequency versus radiation efficiency plot (Figure 6), it appears that the radiation efficiency seems to decrease with an increase in frequency [17]. The average radiation efficiency was found to be of 75%. Observations from Figure 5 and 6 are consistent with an earlier finding that the geometry of the structure becomes larger than the corresponding wavelength [11].

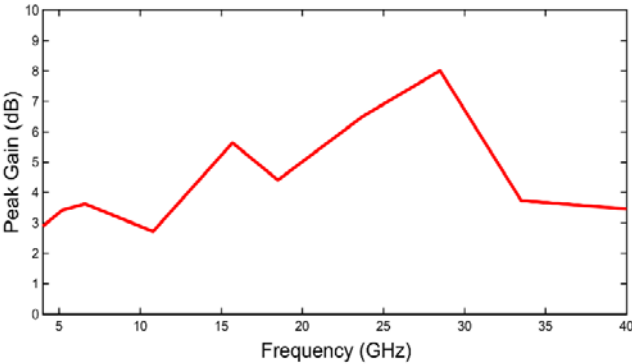


Figure 5 Simulated peak gain plot as a function of frequency

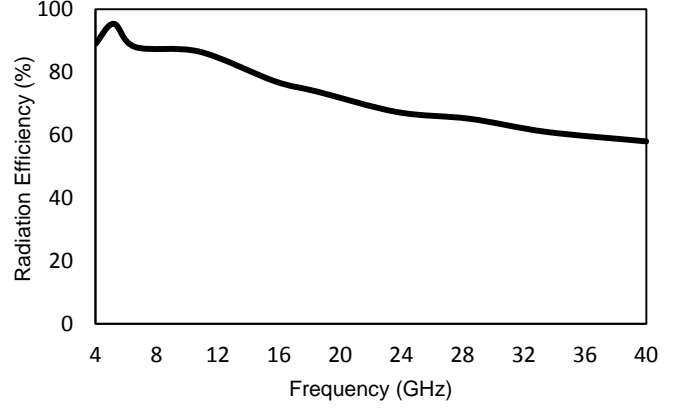


Figure 6 Simulated radiation efficiency plot as a function of frequency

The simulated 2D radiation patterns of the designed monopole antenna in co-polarized and cross-polarized radiated fields are shown in Figure 7 (a) and 7 (b) at 5.2 GHz frequency in the $\phi = 0^\circ$ and $\phi = 90^\circ$ planes. The cross-polarization values are 15 to 30 dB lower than the co-polarized values.

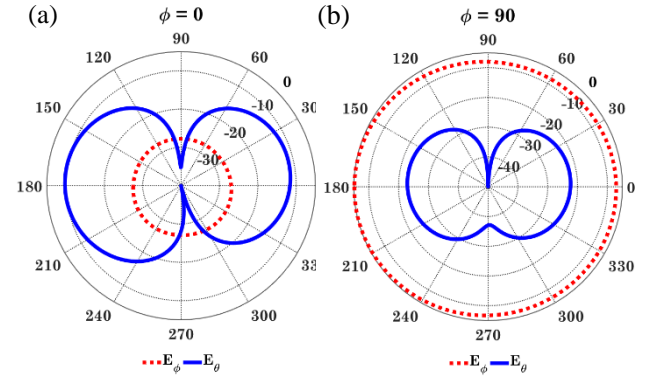


Figure 7 Radiation pattern of the antenna at 5.2 GHz for a) $\phi = 0^\circ$ and b) $\phi = 90^\circ$ planes

for the 10.8 GHz. For the 28.5 GHz frequency plot, the radiation patterns appear to be distorted and directional. Large physical size of the antenna at higher frequencies with reduced wavelength could explain such distortions [17,18].

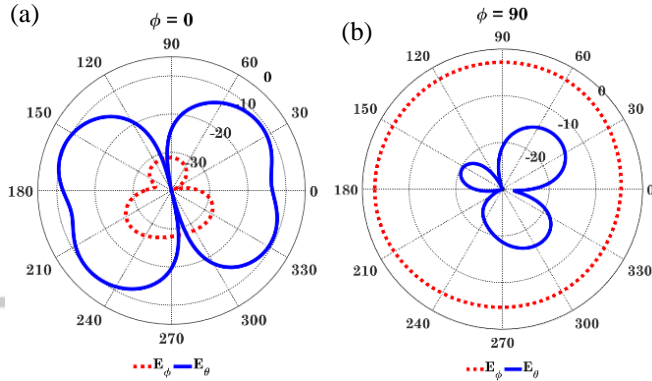


Figure 8 Radiation pattern of the antenna at 10.8 GHz for a) $\phi = 0^\circ$ and b) $\phi = 90^\circ$ planes

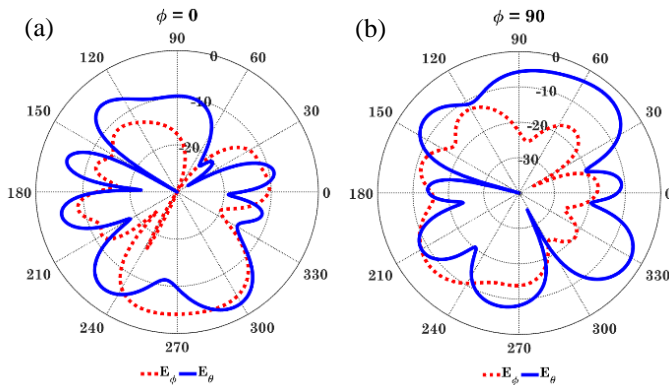


Figure 9 Radiation pattern of the antenna at 28.5 GHz for a) $\phi = 0^\circ$ and b) $\phi = 90^\circ$ planes

4. CONCLUSION

A printed planar circular monopole antenna is presented for UWB applications. The designed antenna is derived from a microstrip feedline by loading the slotted circular radiator and slotted finite ground plane to establish the wideband. Based on the optimized antenna geometry, the antenna was fabricated and tested. The resonant frequencies of the experimental and simulated results appear to match. The UWB antenna covers over 4-40 GHz (164% fractional bandwidth) range with a return loss of 10 dB or more (VSWR < 2). The antenna exhibits relative omnidirectional radiation pattern with more than 2.8 dB peak gain for the entire frequency spectrum, and an average radiation efficiency of 75%. The simulated antenna performance and experimental results indicate the suitability

of this antenna in UWB communications along with C, X, K_u , K_a band, WLAN and future wireless services.

5. ACKNOWLEDGEMENT

This material is based upon work by the National Science Foundation under grant No. 1503634.

REFERENCES:

- [1] F. FCC, and D. FCC, 1st report and order on ultrawideband technology, FCC, Washington, DC, (2002).
- [2] X. L. Liang, Ultra-wideband antenna and design. In: *Ultra Wideband-Current Status and Future Trends*. InTech; 2012.
- [3] J. R. James, P. S. Hall, and C. Wood. *Microstrip antenna: Theory and design*. Iet; 1981.
- [4] M. Peyrot
novel planar UWB monopole antenna formed on a printed circuit board, *Microwave and optical technology letters*, 48, (2006):933-935.
- [5] P. Ranjan, S. Raj, G. Upadhyay, S. Tripathi, and V. S. Tripathi, Circularly slotted flower shaped UWB filtering antenna with high peak gain performance, *AEU-International Journal of Electronics and Communications*, 81, (2017):209-217.
- [6] D. M. Elsheakh, and E. A. Abdallah, Ultra-wide-bandwidth (UWB) microstrip monopole antenna using split ring resonator (SRR) structure, *International Journal of Microwave and Wireless Technologies*, (2018):1-10.
- [7] K.-R. Chen, and J.-S. Row, A compact monopole antenna for super wideband applications, *IEEE Antennas and Wireless Propagation Letters*, 10, (2011):488-491.
- [8] M. Manohar, R. S. Kshetrimayum, and A. K. Gogoi, Printed monopole antenna with tapered feed line, feed region and patch for super wideband applications, *IET Microwaves, Antennas & Propagation*, 8, (2014):39-45.
- [9] J. S. Sun, Y. C. Lee, and S. C. Lin, New design of a CPW
ultrawideband slot antenna, *Microwave and Optical Technology Letters*, 49, (2007):561-564.
- [10] M. Mokhtaari, and J. Bornemann. Printed-circuit antennas for ultra-wideband monitoring applications. Paper presented at: *Electromagnetic Compatibility (APEC), 2012 Asia-Pacific Symposium on* 2012.
- [11] S. Singhal, and A. K. Singh, CPW-fed hexagonal Sierpinski super wideband fractal antenna, *IET Microwaves, Antennas & Propagation*, 10, (2016):1701-1707.
- [12] A. Azari, A new super wideband fractal microstrip antenna, *IEEE transactions on antennas and propagation*, 59, (2011):1724-1727.
- [13] J. Liu, S. Zhong, and K. P. Esselle, A printed elliptical monopole antenna with modified feeding structure for bandwidth enhancement, *IEEE Transactions on Antennas and Propagation*, 59, (2011):667-670.
- [14] M. N. Rahman, M. T. Islam, M. S. J. Singh, N. Misran, K. Mat, and M. Samsuzzaman. Compact microstrip patch antenna for multi-service wireless communications. Paper presented at: *Microwave Conference (APMC), 2017 IEEE Asia Pacific* 2017.
- [15] A. B. Constantine, *Antenna theory: analysis and design*, MICROSTRIP ANTENNAS, third edition, John Wiley & sons, (2005).

- [16] E. G. Lim, Z. Wang, G. Juans, et al. Design and optimization of a planar UWB antenna. Paper presented at: East-West Design & Test Symposium, 20132013.
- [17] R. Kumar, and S. Gaikwad, On the design of nano-arm fractal antenna for UWB wireless applications, *Journal of Microwaves, Optoelectronics and Electromagnetic Applications*, 12, (2013):158-171.
- [18] R. K. Singh, and D. Pujara, Design of an UWB (2.1–38.6 GHz) circular microstrip antenna, *Microwave and Optical Technology Letters*, 59, (2017):2762-2767.