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Semi-circular compact CPW-fed antenna for ultra-wideband applications

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ABSTRACT

This paper presents a simple structure and small size antenna design with dimensions of 43×47 mm^2 to perform an ultra-wideband (UWB) frequency range using a semicircular co-planar waveguide (CPW). This antenna has been designed and simulated by the computer simulation technology (CST) microwave studio suit. In this work, we design an ultra-wideband antenna (about 2 GHz to 10 GHz) by feeding a semi-circular compact antenna via a co-planar waveguide for input impedance of 50 Ω. The CST simulation results show that our designed antenna has a very good impedance and radiation characteristic within the intended ultra-wideband. Because of the small size and the suitable shape, this antenna can be used in many wireless communication applications, such as a radio frequency identifier (RFID), indoor wireless local area network or wireless fidelity (WiFi), internet of things (IoT), millimeter waves communications (mmWave), global positioning system (GPS), and many applications of 6G systems.

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1. INTRODUCTION

Mobile communication becomes part of our daily life, as more data can be reached via a hand-size device [1]–[25]. This motivates many research centers in the world to focus on this device to make it smaller and perform better. This includes the design of antennas.

Since it was adopted by the United States, the federal communications commission (FCC) in 2002, ultra wideband (UWB) communications, which allocated the 3.1 GHz to 10.6 GHz band, have attracted great interest lately. The corresponding standards of IEEE 802.15.3a, which stand for the short rang high data rate, and the IEEE 802.15.4a, the low power low data rate have been presented [3]. This help this technology is one of the most promising technologies for short-range wireless communication systems.

UWB technology has increased in both academic and industry research laboratories as it is used in high-speed communication data rate, wireless link connectivity, sufficient radiation pattern properties, and sufficient impedance adaptation properties [1]. The system of UWB uses short-duration pulses for some nanoseconds to send coded signals. Such short-duration spread the signal energy very widely on bandwidth as we know from fourier transform formula.

The feature of short-duration pulses along with the low energy transmitted can ensure as low interference as possible with current narrow-band systems. Range information can be extracted via either the frequency/phase of continuous wave signal is modulated or via the short duration pulses are transmitted. In practice, the frequency modulated continuous wave and phase modulated continuous wave radar are used [6].

The technology of UWB shows adequate performance for many wireless applications such as radars, mobile wireless communication systems, vehicle-to-vehicle communications systems, behind-the-wall signal penetration, medical image picturing radio, position location, and wideband game applications, navy and defense applications [2]-[12]. Many articles have provided a similar design [8]-[12]. However, the design in this paper provides a small antenna with high bandwidth that is allocated in the ultra-wideband.

In this paper, we study the property of the proposed design of a semi-circular configuration with a co-planar fading for ultra-wideband applications. The design, as shown in Figure 1, basically, consists of a half-circle shape with a radius of r that is fed by the co-planar way with a dimension of Lg by Wg. The space between the semi-circular shape and the co-planar is good enough to pass the ultra-wideband frequencies, refer to it as t. There is a tiny space separation in the co-planar feed between the feeder and the wings called g. We used the computer simulation technology (CST) Microwave Studio Suit TM 2018 to perform the simulation and to run the optimization to obtain the ultra-wideband frequency and reduce the input impedance. CST suit is based on the method of the three-dimensional finite time-domain integration (FTID). the displayed simulation results provide and express the radiation pattern, the input impedance, gain, and the electromagnetic characteristics of the surface current distribution.

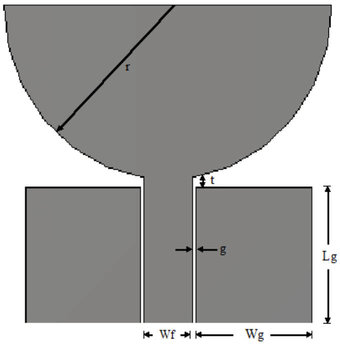


Figure 1. The geometric shape of the proposed CPW-fed coplanar slot antenna configuration

2. ANTENNA GEOMETRY

Using the CST suite software, we design the co-planar waveguide (CPW-Fed) co-planar semicircle antenna. The simulation results of CST for this design will show different parameters to show the characteristic of the design, such as the input impedance, S11, the return loss, radiation pattern, and the directivity and gain. The semicircle antenna is designed on a microstrip structure, where the wavelength λ_g that imports at the frequency designs can be calculated according to [5].

$$\lambda_g = \frac{\lambda_o}{\sqrt{\varepsilon_{eff}}} \tag{1}$$

Where ε_{eff} is an effective dielectric constant. λ_o is the wavelength in the air ε_{eff} is usually computed via the (2).

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} \tag{2}$$

Where ε_r is the circuit prints dielectric coefficients ε_{eff} is the effective parameter of dielectric coefficient. The design of antenna is implemented in this paper via considering the parameters in the following values: dielectric constant ε_r = 4.3, FR4 epoxy substrate thickness h = 1.54 mm, and loss tangent $tan\delta$ = 0.025. The values of the rest of the parameters of the design are stated in Table 1.

Table 1. The proposed antenna parameters

Parameters	value
g	0.5 mm
Wf	6.7 mm
Wg	20 mm
Lg	19 mm
t	1 mm
r	23 mm
h	1.54 mm

3. THE SIMULATION RESULTS

3.1. The implementation

In Figure 1, we see a rectangular shape of the radiator that has been fed by a 50 Ω co-planar waveguide transmission line CPW. Along with the antenna the feeding structure layouts on the same plane, leaving one substrate layer with a single sized metallization to be utilized. Such a structure yields a very easy manufacturing antenna with an extremely low cost. Most of the design implementation and optimization have been performed in the CST microwave studio, which is very well known in this field [3]. The design parameters can be found in Table 1, which shows the details of the configuration.

3.2. The results

The bandwidth of the can be found either by the corresponding return loss (S11) parameter or by voltage standing wave ratio (VSWR). Usually, the antenna bandwidth is determined as the return loss goes beneath 10 dB. The things that are presented in the results are the s-parameters, the VSWR, the radiation pattern of the proposed antenna, the gain and the bandwidth. All the results are presented in the associated figures. Figure 2, Figure 3, and Figure 4 show S11, VSWR, and the proposed antenna impedance, respectively. Figure 2 demonstrations that the bandwidth for the proposed antenna is taking place from 2.1 GHz to 9.8 GHz. It is clear in Figure 2 that the ultra-wideband properties of the design from looking at the S11 values, which the under -10 dB spans from 2 GHz until near the 10 GHz. We also study the case to change the parameter of the design to increase the band to reach 12 GHz, but that led to an increase in the value of S11 near the two values 3.5 GHz and 7 GHz. VSWR, which is shown in Figure 3, is calculated by:

$$VSWR = \frac{V_{MAX}}{V_{MIN}} = \frac{1+|\Gamma|}{1-|\Gamma|}, \quad (3)$$

Where the voltage reflection coefficient, Γ, is defined by:

$$\Gamma = \frac{V^-}{V^+} = \frac{Z_L - Z_O}{Z_L - Z_O}, \quad (4)$$

Where the value of Z_L represents the amount of load impedance and Z_0 represents the transmission line (which can be between the antenna and the feeding cable) characteristic impedance. The value of the reflection coefficient is also displayed by showing the equivalent plot of the scattering parameters S11.

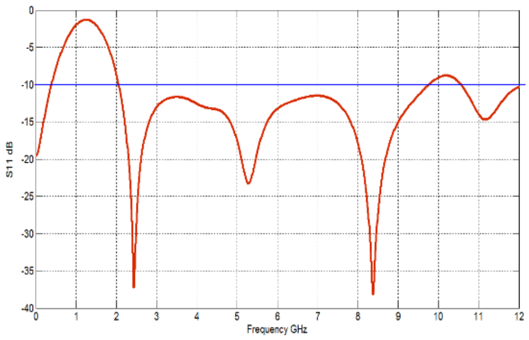


Figure 2. The simulated S_{11} for the antenna

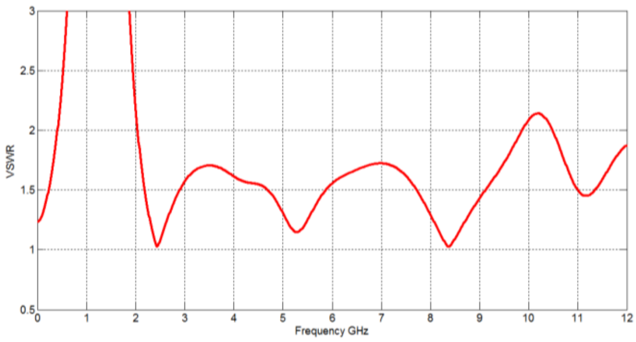


Figure 3. Simulated VSWR for the antenna proposed

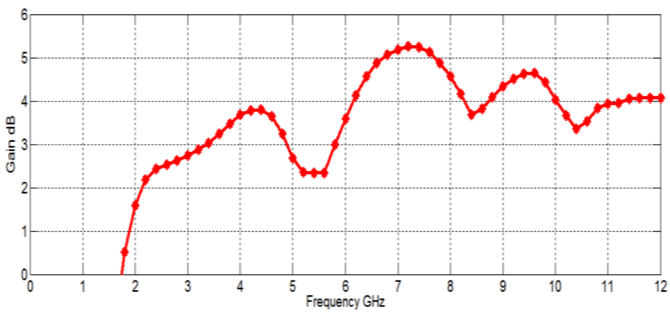


Figure 4. The simulation result of gain for the proposed antenna

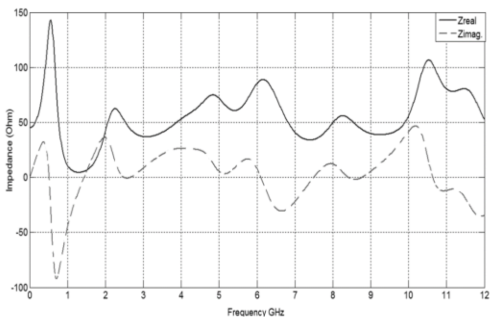
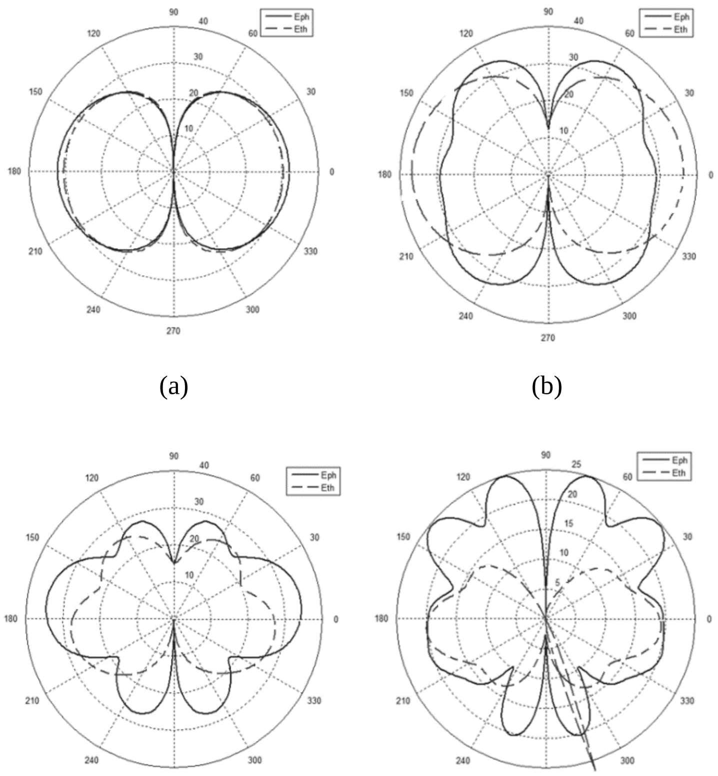


Figure 5. Simulated real and imaginary impedance

Figure 4 shows the relationship between antenna gain and the frequency in GHz. The proposed antenna for a wideband operating frequency is shown. From the figure, we can notice that the lowest gain is 2 dB at the frequency of 2.1 GHz and the maximum gain of 5.3 dB is achieved at 7.2 GHz. The average gain for the proposed antenna is around 4 dB.

The input impedance in the shape of the real and imaginary plot of the proposed antenna is displayed in Figure 5 over a range of frequencies that spans from 0.01 GHz to 12 GHz. Figure 5 shows the input impedance of the proposed antenna near and around to desired impedance (50 Ω). In Figure 6, the far-field radiated patterns in the frequencies of Figure 6(a) 2.5 GHz, Figure 6(b) 5 GHz, Figure 6(c) 7.5 GHz, and Figure 6(d) 10 GHz. The obtained results in these figures clearly display the high gain of the proposed antenna in the bandwidth within a range of 2.12 GHz to 9.8 GHz, at 55 Ω input impedance, which covers many applications such as wireless fidelity (WiFi), internet-of-things (IoT), and long term evolution (LTE).

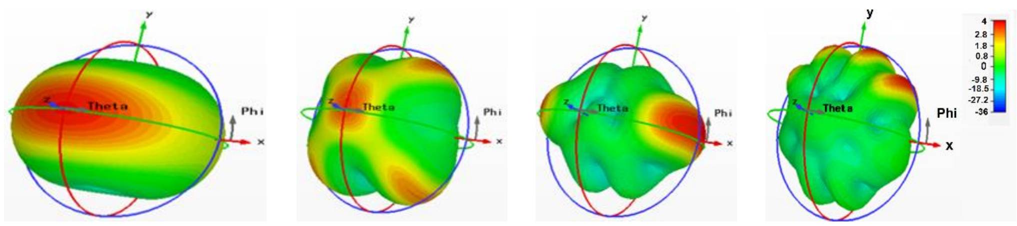
Figure 7 shows the 3D far-field radiation patterns for the four mentioned frequencies: Figure 7(a) 2.5 GHz, Figure 7(b) 5 GHz, Figure 7(c) 7.5 GHz, and Figure 7(d) 10 GHz. The color-coded power pattern shows the red to be higher power concentrated (focused). For 2.5 GHz, the power is focused in only two directions. After that, with increasing the frequency, the power start to distribute on multiple directions.



(a) (b)

(c) (d)

Figure 6. Far-field radiation pattern plot for (a) 2.5 GHz, (b) 5 GHz, (c) 7.5 GHz, and (d) 10 GHz



(a) (b) (c) (d)

Figure 7. 3D Far-field radiation pattern plot for (a) 2.5 GHz, (b) 5 GHz, (c) 7.5 GHz, and (d)10 GHz

4. CONCLUSION

The wideband aperture antenna has been designed and simulated to work with many ultra-wideband applications. The antenna is designed as a semi-circular compact fed by the CPW. The simulation is performed by CST microwave studio software. The antenna footprint dimension is 4.3 cm × 4.72 cm with a suitable impedance. The obtained results clearly show the high gain of the proposed antenna in the bandwidth within a range of 2.12 GHz to 9.8 GHz, at 55 Ω input impedance, which covers many applications such as WiFi, IoT, global positioning system (GPS), and LTE.

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REFERENCES

[1] A. Hosseinzadeh, M. Mirmozafari, M. V. Varnoosfaderani, C. Ghobadi, and J. Nourinia, "A U-shaped UWB antenna with band-notched performance," *Wireless Engineering and Technology*, vol. 4, pp. 177-180, 2013. [Online]. Available: https://www.researchgate.net/publication/276494174_A_U-Shaped_UWB_Antenna_with_Band-Notched_Performance

[2] S. S. Al-Bawri *et al.*, "Metamaterial cell-based superstrate towards bandwidth and gain enhancement of quad-band CPW-fed antenna for wireless applications," *Sensors*, vol. 20, no. 2, 2020, doi: 10.3390/s20020457.

[3] X. Qing and Z. N. Chen, "Compact coplanar waveguide-fed ultra-wideband monopole-like slot antenna," *IET Microwaves, Antennas & Propagation*, vol. 3, no. 5, pp. 889-898, 2009, doi: 10.1049/iet-map.2008.0075.

[4] M. Karthiyan, R. Sitharthan, T. Ali, and B. Roy, "Compact multiband CPW fed monopole antenna with square ring and T-shaped strips," *Microwave and Optical Technology Letters*, 2019, doi: 10.1002/mop.32106.

[5] H. -M. Chen, Y. -K. Wang, Y. -F Lin, C -Y. Lin, and S. -C. Pan, "Microstrip-Fed Circularly Polarized Square-Ring Patch Antenna for GPS Applications," *IEEE Transactions on Antennas and Propagation*, vol. 57, no. 4, pp. 1264-1267, 2009, doi: 10.1109/TAP.2009.2015855.

[6] K. V. Mishra, M. R. B. Shankar, V. Koivunen, B. Ottersten, and S. A. Vorobyov, "Toward Millimeter-Wave Joint Radar Communications: A Signal Processing Perspective, " *IEEE Signal Processing Magazine*, vol. 36, no. 5, pp. 100-114, 2019, doi: 10.1109/MSP.2019.2913173.

[7] H. M. AlSabbagh, F. E. Mahmood, R. M. Edwards, and J. A. Brister, "A UWB fractal antenna for body area network applications," *2012 Loughborough Antennas & Propagation Conference (LAPC)*, 2012, pp. 1-4, doi: 10.1109/LAPC.2012.6403090.

[8] H. M. AlSabbagh, F. E. Mahmood, S. Al-Rubaye, and R. M. Edwards, "The design of fractal antennas for UWB using MoM," *2011 Loughborough Antennas & Propagation Conference*, 2011, pp. 1-4, doi: 10.1109/LAPC.2011.6114094.

[9] M. Elhabchi, M. N. Srifi, and R. Touahni, "A Novel CPW-Fed Semi-Circular Triangular Antenna with Modified Ground Plane for Super Ultra Wide Band (UWB) Applications," *2018 International Symposium on Advanced Electrical and Communication Technologies (ISAECT)*, 2018, pp. 1-5, doi: 10.1109/ISAECT.2018.8618857.

[10] I. B. Vendik, A. Rusakov, K. Kanjanasit, J. Hong, and D. Filonov, "Ultrawideband (UWB) Planar Antenna with Single-, Dual-, and Triple-Band Notched Characteristic Based on Electric Ring Resonator," *IEEE Antennas and Wireless Propagation Letters*, vol. 16, pp. 1597-1600, 2017, doi: 10.1109/LAWP.2017.2652978.

[11] B. A. Asi, F. E. Mohmood, and M. A. Al-Ibadi, "Beam Tracking Using Least Mean Squares Algorithm for single-cell Massive MIMO Communication System," *IOP Conference Series: Materials Science and Engineering*, 2021, vol. 1152, doi: 10.1088/1757-899X/1152/1/012004.

[12] X. Wang, L. Wang, H. Zhou, and W. Lu, "A compact CPW-fed antenna with dual band-notched characteristics for UWB applications," *Microwave and Optical Technology Letters*, vol. 56, no. 5, 2014, doi: 10.1002/mop.28256.

[13] H. Zhang, H. Sun, T. Yang, Y. Mahe, and T. Razban, "Design of a Wideband and Dual-Polarized CPW-Fed Monopole Antenna for Future 5G Communications," *2016 IEEE 84th Vehicular Technology Conference (VTC-Fall)*, 2016, pp. 1-5, doi: 10.1109/VTCFall.2016.7880958.

[14] H. Nikookar and R. Prasad, "Introduction to Ultra Wideband for Wireless Communications," *Signals and Communication Technology (SCT)*, Springer Dordrecht, 2009. [Online]. Available: https://link.springer.com/book/10.1007/978-1-4020-6633-7

[15] J. Huang and X. Gong, "A Wide-Band Dual-Polarized Frequency-Reconfigurable Slot-Ring Antenna Element Using a Diagonal Feeding Method for Array Design," *2018 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting*, 2018, pp. 477-478, doi: 10.1109/APUSNCURSINRSM.2018.8608781.

[16] C. Lee and A. Fumagalli, "U Internet of Things Security - Multilayered Method For End to End Data Communications Over Cellular Networks," *2019 IEEE 5th World Forum on Internet of Things (WF-IoT)*, 2019, pp. 24-28, doi: 10.1109/WF-IoT.2019.8767227.

[17] V. Rajesh, R. P. S. Chaitanya, and K. K. Naik, "Analysis of semi-circular ring patch antenna with asymmetrical coplanar strip for satellite applications," *2018 Conference on Signal Processing And Communication Engineering Systems (SPACES)*, 2018, pp. 113-116, doi: 10.1109/SPACES.2018.8316328.

[18] F. Arena and G. Pau, "An overview of big data analysis," *Bulletin of Electrical Engineering, and Informatics*, vol. 9, no. 4, doi: 10.11591/eei.v9i4.2359.

[19] F. E. Mahmood, E. S. Perrins, and L. Liu, "Energy Consumption vs. Bit Rate Analysis Toward Massive MIMO Systems," *2018 IEEE International Smart Cities Conference (ISC2)*, 2018, pp. 1-7, doi: 10.1109/ISC2.2018.8656926.

[20] P. F. Freidl, I. Russo, E. Leitgeb, W. Bosch, T. Gigl, and G. Schultes, "Parametric and dispersion analysis of a dual-pol cavity-backed slot-fed UWB patch antenna," *2013 European Microwave Conference*, 2013, pp. 411-414. [Online]. Available: https://ieeexplore.ieee.org/document/6689201

[21] M. S. Bakr, S. W. O. Luhaib, I. C. Hunter, and W. Bosch, "Dual-mode dual-band conductor-loaded dielectric resonator filters," *2017 47th European Microwave Conference (EuMC)*, 2017, pp. 908-910, doi: 10.23919/EuMC.2017.8230992.

[22] M. Abbak, J. Janghi, and I. Akduman, "Compact slot type CPW-Fed ultra-wideband (UWB) antenna," *2012 15 International Symposium on Antenna Technology and Applied Electromagnetics*, 2012, pp. 1-4, doi: 10.1109/ANTEM.2012.6262410.

[23] R. Ullah *et al.*, "High-gain vivaldi antenna with wide bandwidth characteristics for 5G mobile and Ku-Band radar applications, " *Electronics*, vol. 10, no. 6, 2021, doi: 10.3390/electronics10060667.
[24] F. Mahmood, E. Perrins, and L. liu, "Energy-Efficient Wireless Communications: From Energy Modeling to Performance Evaluation," *IEEE Transactions on Vehicular Technology*, vol. 68, no. 8, pp. 7643-7654, 2019, doi: 10.1109/TVT.2019.2921304.
[25] V. Kaim, B. K. Kanaujia, S. Kumar, H. C. Choi, K. W. Kim, and K. Rambabu, "Ultra-Miniature Circularly Polarized CPW-Fed Implantable Antenna Design and its Validation for Biotelemetry Applications," *Scientific Reports*, vol. 10, no. 6975, 2020, doi: 10.1038/s41598-020-63780-4.

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