Muhammad USMAN[1], Haitham ALSAIF[1], Muhammad Tajammal CHUGHTAI[1], Sajid Mehmood ASIF[2]

Electrical Engineering Department, College of Engineering, University of Hail (1), Hail, Kingdom of Saudi Arabia
Electronic and Electrical Engineering, University of Sheffield (2), Sheffield, S1 4ET, United Kingdom

doi:10.15199/48.2019.04.42

Design of Compact Ultra-Wideband Monopole Semi-Circular Patch Antenna for 5G wireless communication networks

***Abstract**. This paper presents , a novel design of semi-circular patch antenna for Ultra-wideband (UWB) wireless communication systems. The monopole is compact with structure size of 25x25 mm^2 and thickness of 1.6 mm. It has been fabricated on a FR-4 substrate with relative permittivity of Ɛr=4.4. The designed antenna has an ultrawide bandwidth, from 3GHz to 11.5 GHz based on -10dB criteria, which covers the entire UWB allocated by FCC for such applications. Also, the design shows high performance in terms of impedance match between feeding line and radiator. Radiation pattern results have been studied at all resonant frequencies (3 GHz to 11.5 GHz) and they have almost omni directional pattern. The monopole has been fabricated and experimentally measured for verification and both simulation and experimental results show good agreement. The overall antenna gain is 1.8 dBi with bandwidth of 125% for UWB. Therefore, the simulated and measured results confirm that the antenna satisfies the requirements for ultra-wideband applications. Design, simulation, and optimization process have been completed using industrial simulation software called High Frequency Structural Simulator (HFSS).*

Streszczenie.** W artykule opisano projekt półokrągłej anteny szerokopasmowej do systemów WiFi. Antena ma powierzchnię 25x25 mm i grubość 1.6 mm. Psamo częstotliwościowe antent jest od 3 GHz do 11.5 GHz. Symulacje I pomiary potwierdziły przydatność tej antny do pasma UWB.* ***Projekt kompaktowej ultra-szerokopasmowej anteny do bezprzewodowej komunikacji 5G

Keywords: Ultra Wideband, Monopole Antenna, 5G Wireless Communication.
Słowa kluczowe:antena, pasmo UWB, telekomunikacja 5G.

Introduction

The massive mobile data requirement has increased, in last ten years, mainly due to the video content. This is due to the capability of mobile handsets supporting 4k resolution which requires the data rate of 15.4Mbps[1]. This increase is due to the increasing number of user and viewing time. This will result in an annual traffic of 296.8 excabytes(EB) by 2019[2]. Therefore, 5G communication network (IMT 2020) is the suggested solution to match this high data demand, with a capability of reaching up to data rate of 20Gbps. 5G is not only targeting enhanced mobile broadband (eMBB), but also it has diverse usage scenarios including, ultra reliable and low latency communication (URLLC) and massive machine type communication(mMTC). In order to meet with the design challenges of 5G , frontend antenna layout for base stations and mobile hand set is an intense area of research. Recently, technology of ultra-wideband has received high importance and growth in wireless communication systems due to its remarkable features. Federal Communication Commission (FCC) has allocated a frequency band ranging from 3.1 GHz to 10.6 GHz for such applications [3-8]. These systems are characterized by extreme high data rates over their wide bandwidth, low power consumptions [9-12]. Hence, designing a compact antenna with high performance in terms of operating frequency, radiation pattern, power gain, and fabrication cost remains a challenging task[13-17].

Micro strip patch antennas are widely used in ultra-wideband systems due to their advantages such as low cost, simplicity, light weight, and structure size. Thus, proposed antenna is a patch semi-circular antenna fed by a micro strip line as shown in figure 1(a). Next section will present details of the antenna structure and parameters.

Antenna Design

Fig.1 shows the geometry structure of the proposed semi-circular monopole antenna. The entire design and parametric optimization process have been carried out using industrial standard simulation software named as HFSS[15] . Table 1, shows detailed parameters dimensions in mm. The patch has been printed on a substrate material of FR-4 which had relative parameter value of Ɛr=4.4 and a tangent loss of tan δ= 0.02. All this was fed by a micro strip feeding line having an impedance of 50Ω.

The total structure size of the proposed antenna is 25 × 25 mm^2. The monopole has a partial ground plane on the backside as shown in fig.1(b) having a total length of 25 mm and a width of 7 mm.

Fig.1(c) represents the fabricated semicircular patch antenna according to the design parameters given in table 1. Next section presents monopole simulation results and experimental measurements with parametric investigations in terms of reflection coefficient, bandwidth, and radiation pattern at the two main planes (Elevation or E and Azimuth or H planes). Both simulation and experimental results show good agreement with minor difference due to fabrication and experimental equipment tolerance.

Table.1: Parameters of the Antenna

Parameter	Unit(mm)
Substrate Length (L)	25
Substrate Width (W)	25
Radius of Semicircular Patch (R)	12
Transmission line Width(T1)	3
Transmission Line Width(T2)	2.5
Transmission Line Length(TL)	5.5
Slot Width (SW)	1
Slot Length (SL)	6.5
Ground plane width (GW)	7
Ground plane length (GL)	25

Results and Discussion

Parametric studies have been carried out on crucial parameters that play main role in the impedance matching as part of performance optimization process. Fig.2(b) reveals the reflection coefficient in dB as a function of frequency in GHz for several lengths of ground plane. It can be observed that a width (GW) of 7 mm results in wide operating frequency (from 3 GHz to 11.5 GHz) that covers the entire UWB set by FCC, while other lengths causes to shortage in impedance match that lead to a drawback in the bandwidth. Also, the micro strip feeding lines has been optimized as shown in fig.2(a) for different widths. At TL1= 3 mm and TL2 = 2.5mm more power input has been accepted by the radiating structure and lower return loss occurred. In addition, the semi-circular patch has the main role in this designing process. Fig.2(c) presents the high effect of the semi-circular radiator size on the impedance match and bandwidth represent by the reflection coefficient (Γ). Fig.2(d) presents both simulated and experimentally measured S11 as a function of frequency in GHz after optimization process. Normalized radiation pattern to the maximum values for the monopole antenna have been simulated and measured experimentally and shown in polar form in the fig.3. It illustrates both planes elevation or E plane and azimuth or H plane at the two resonant frequencies (4.9GHz, and 7.5GHz). It can be noticed that the radiation has approximatelyomni directional pattern over all the operating frequency with minor distortions. Thus, the proposed monopole can be used at any placement direction within the wireless system. Both simulation and experimental results show good agreement with minor difference due to fabrication and experimental tools tolerance.

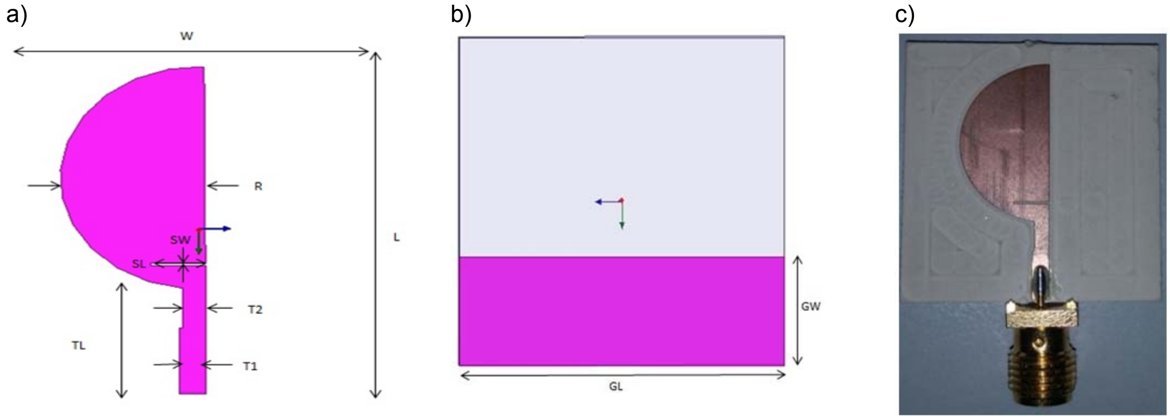


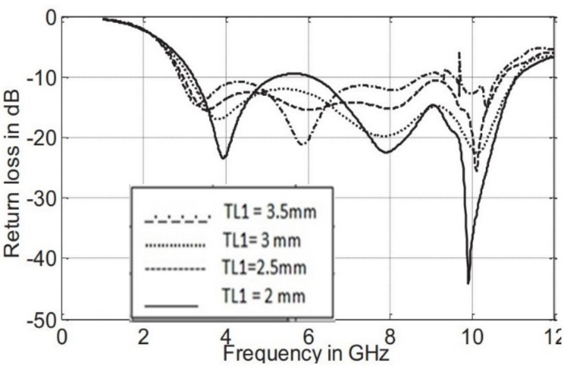
Fig.1: Proposed UWB antenna. (a) Front View (b) Ground Plane (c) Fabricated Antenna (Picture Not up to Scale)

Results and Discussion

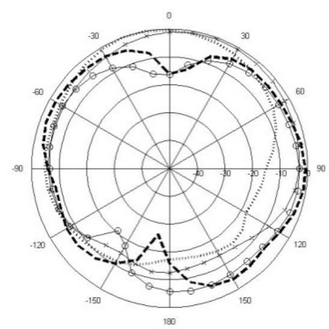
Parametric studies have been carried out on crucial parameters that play main role in the impedance matching as part of performance optimization process. Fig.2(b) reveals the reflection coefficient in dB as a function of frequency in GHz for several lengths of ground plane. It can be observed that a width (GW) of 7 mm results in wide operating frequency (from 3 GHz till 11.5 GHz) that covers the entire UWB set by FCC, while other lengths causes to shortage in impedance match that lead to a drawback in the bandwidth. Also, the micro strip feeding lines has been optimized as shown in fig.2(a) for different lengths (TL). At TL1= 3 mm and TL2 = 2.5mm more power input has been accepted by the radiating structure and lower return loss occurred. In addition, the semi-circular patch has the main role in this designing process. Fig.2(c) presents the high effect of the semi-circular radiator size on the impedance match and bandwidth represent by the reflection coefficient (Γ). Fig.2(d) presents both simulated and experimentally measured S11 as a function of frequency in GHz after optimization process.

Normalized radiation pattern to the maximum values for the monopole antenna have been simulated and measured experimentally and shown in polar form in the fig.3. It illustrates both planes elevation or E plane and azimuth or H plane at the two resonant frequencies (4.9GHz, and 7.5GHz). These two arbitary frequieny values have been chosen to represent the midband section of the addressed UWB. It can be noticed that the radiation has approximately omni directional pattern over all the operating frequency with minor distortions. Thus, the proposed monopole can be used at any placement direction within the wireless system. Both simulation and experimental results show good agreement with minor difference due to fabrication and experimental tools tolerance.

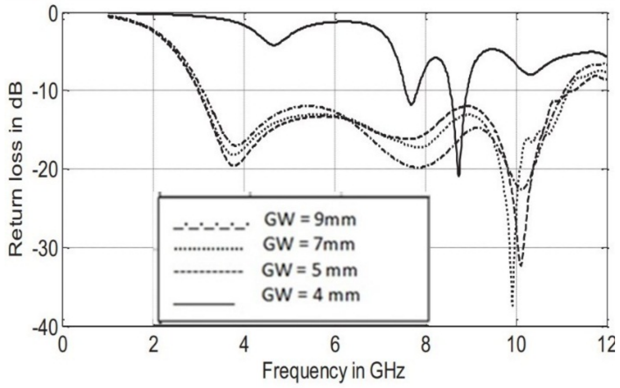
.



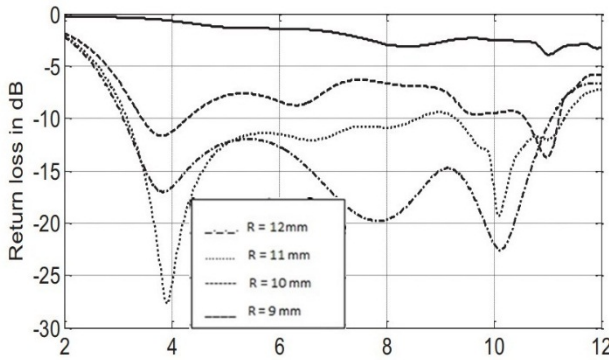
(a) S11 for Different values of TL



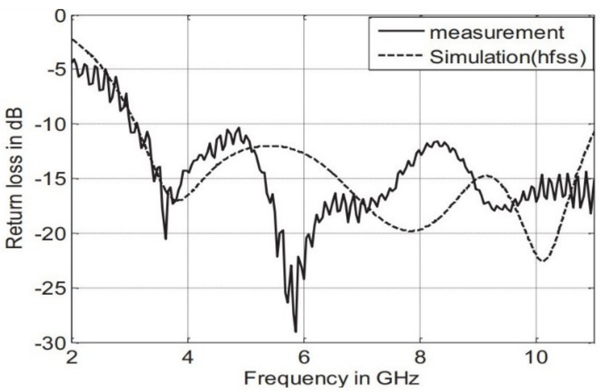
(a) X-Z plane 4.9 GHz



(b) S11 for Different values of GW

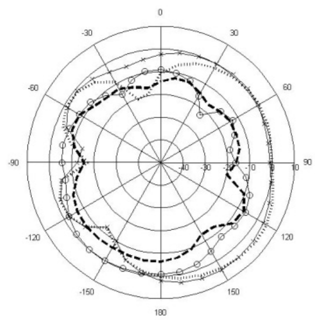


(c) S11 for Different values of R

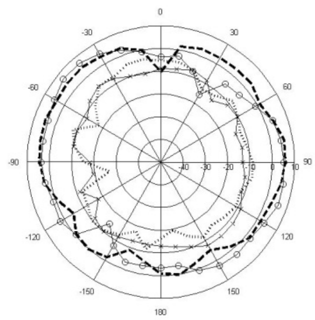


(d) Simulated and Measured values of S11

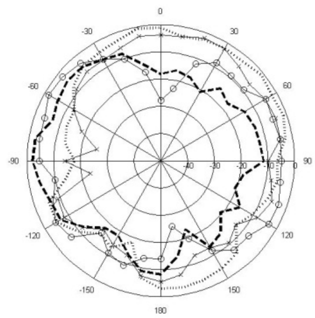
Fig.2: Simulated and Measured return loss. (a) S11 for different values of TL1. (b) S11 for different values of GW. (c) S11 for different values of R. (d) Measured and simulated return loss for fabricated antenna shown in figure 3 according to parameters of table 1.



(b) Y-Z plane 4.9 GHz



(c) X-Z plane 7.5GHz



(d) X-Z Plane 7.5GHz

Fig.3: Measured and simulated normalized far field radiation pattern of the proposed semicircular patch antenna at X_Z plane and Y-Z plane at 4.9 GHz and 7.5 GHz. ('ooo' simulated EΦ, 'xxx' measured Size Eθ, '-----' simulated EΦ, '…...'measured Size Eθ)

.

Conclusion

A novel , compact semi-circular patch antenna for Ultra-Wide Band wireless applications has been designed. The patch antenna is fabricated on a substrate material FR-4 with relative permittivity of Ɛr=4.4 and structure size of 25×25 mm^2 .As part of optimization and instigation process, parametric studies has been carried out on several parameters. The patch also has been fabricated and experimentally tested and achieved satisfactory measurements over UWB ranging from 3 GHz to 11.5 GHz which are in an excellent agreement with simulated and measured results, interms of returnloss, bandwidth and gain. In addition, the antenna shows omni directional radiation patterns in E and H plane.The maximum measured gain of the antenna ranges from 1.7 dBi to 4dBi over the entire band with band width up to 125%. Therefore, the results indicate that monopole is suitable for the UWB systems.

Acknowledgement

The authors would like to thank University of Hail, represented by the deanship of scientific research for funding this project under research grant number 160556.

***Authors**:*

Dr. Muhammad Usman, Associate Professor of Electrical Engineering, Electrical Engineering Department, University of Hail, , Kingdom of Saudi Arabia, Email: m.usman@uoh.edu.sa.

Dr. Haitham Alsaif, Assistant Professor of Electrical Engineering, Electrical Engineering Department, University of Hail, , Kingdom of Saudi Arabia, Email: h.alsaif@uoh.edu.sa.

Dr. Muhammad Tajammal Chughtai, Assistant Professor of Electrical Engineering, Electrical Engineering Department,

University of Hail, , Kingdom of Saudi Arabia, Email: mt.chughtai@uoh.edu.sa
Dr. Sajid Mehmood Asif, Electronic and Electrical Engineering, University of Sheffield, Sheffield, S1 4ET, United Kingdom. Email: *s.m.asif@ieee.org*

REFERENCES

[1] High Efficiency Video Coding, document Rec. H.265, ITU-T SG13,Apr. 2013.
[2] T. S. Rappaport, G. R. Maccartney, M. K. Samimi, and S. Sun,"Widebandmillimeter-wave propagation measuremen
[3] ts and channel models for future wireless communication system design*," IEEE Trans. Communications*., vol. 63, no. 9, pp. 3029–3056, Sep. 2015.
[4] New public safety applications and broadband internet access among uses envisioned by FCC authorization of ultra-wideband technology," First Report and Order (FCC 02-48), Action by the Commission February 14, 2002, February, 2002."
[5] H. Alsaif, M. Usman, M. T. Chughtai, and J. Nasir, "Cross Polarized 2×2 UWB-MIMO Antenna System for 5G Wireless Applications," *Progress In Electromagnetics Research M*, Vol. 76, 157-166, 2018. doi:10.2528/PIERM18101103.
[6] Haitham AL-Saif, Muhammad Usman, Muhammad Tajammal Chughtai, and Jamal Nasir, "Compact Ultra-Wide Band MIMO Antenna System for Lower 5G Bands," *Wireless Communications and Mobile Computing*, vol. 2018, Article ID 2396873,6pages,2018. ttps://doi.org/10.1155/2018/2396873.
[7] Usman, M., "Design Estimations and Channel Capacity Calculations for Spatial, Polarized MIMO Antenna System for Mobile Applications". *Przegląd Elektrotechniczny,* ISSN 0033-2097,R.92NR 6/2016, 154-159. doi:10.15199/48.2016.06.31.
[8] M. N. K. -S. Lim, and C.-P. Tan, "Design and construction of microstrip UWB antenna with time domain*," Progress In Electromagnetics Research*, vol. 3, 2008, pp. 153–164.
[9] K. Xu, Z. Zhu, H. Li, J. Huangfu, C. Li, L. Ran, "A Printed Single-Layer UWB Monopole Antenna With Extended Ground Plane Stubs", *IEEE Antennas and Wireless Propagation Letters*, Vol. 12, pp. 237-240, 2013.
[10] C.-L. R. X.-C. Yin, C.-Y. Ding, and J.-H. Chu, " A Planar U type monople antenna for UWB," *Progress In Electromagnetics Research Letters*, vol. 2, 2008, pp. 1– 10.
[11] N. Hossain, S. Pistorius, S. , "A diamond shaped small planar ultrawide band (UWB) antenna for microwave Imaging Purpose " *Antennas and Propagation Society International Symposium*, 2007 IEEE, 2007, pp. 5713-5716.
[12] Ericsson Mobility Report 2016, November 2016: available at: https://www.ericsson.com/assets/local/mobility-report/documents/2016/ericsson-mobility-report-november-2016.pdf
[13] GSMA Spectrum, 5G Spectrum, Public PolicyPosition, November 2016: available at: https://www.gsma.com/spectrum/wp-content/uploads/2016/06/GSMA-5G-Spectrum-PPP.pdf
[14] Federal Communications Commission, "Federal communications commission revision of Part 15 of the commission's rules regarding ultra-wide band transmission system from 3.1 to 10.6 GHz," FCC, Washington, DC, ET-Docket, 98-153, 2002.
[15] F. E. Tubbal, R. Raad and K. W. Chin, "A wideband F-shaped patch antenna for S-band CubeSats communications," 2016 10th International Conference on SignalProcessing and Communication Systems (ICSPCS), GoldCoast,QLD,2016,pp.1-4.
doi: 10.1109/ICSPCS.2016.7843349
[16] Jianchun, Xu & Zhao, Mingyang& Zhang, Ru & Lei, Ming & Gao, Xinlu& Huang, Shanguo& Bi, Ke. (2016). A Wideband F-ShapedMicrostripAntenna. *IEEE Antennas and Wireless Propagation Letters*. PP. 1-1. 10.1109/LAWP.2016.2606118.
[17] Usman, M., R. A. Abd-Alhameed, and P. S. Excell, "Design considerations of MIMO antennas for mobile phones," *PIERS Online*, Vol. 4, No. 1, 121-125, 2008.
[18] Ansoft High Frequency Structure Simulator corporation,2015.