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Miniaturized Dual-Band Antenna For Bluetooth And Ultra-Wideband Applications

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Abstract:
This paper presents a compact, low-profile, and planar integrated antenna for Bluetooth and Ultra-Wideband (UWB) applications. The proposed antenna operates in dual bands, covering the Bluetooth frequency range of 2.40 to 2.48 GHz and the UWB frequency range of 3.1 to 10.6 GHz. The antenna utilizes a circular-shaped patch fed by a microstrip line and is designed on an FR-4 substrate with dimensions of 35×45 mm2. To achieve resonance over the Bluetooth band, an arc shaped slot with a half-wavelength is etched into the radiating patch. The antenna is designed using the Finite Element Method (FEM) based ANSYS Electronics Desktop 2018.2.0 tool. The antenna exhibits satisfactory gain flatness and stable omnidirectional radiation patterns across the integrated Bluetooth and UWB bands. The proposed antenna demonstrates satisfactory performance, with results falling within the UWB frequency range and encompassing one Bluetooth band.
Key Word*: Ultra-Wideband, Bluetooth, GSM*

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I. Introduction

UWB antennas are a new and promising technology for short-range communication that can transmit data at very high speeds. In the US, the FCC has allowed unlicensed use of the 3.1-10.6 GHz band for UWB applications, with power limits to prevent interference with other narrowband applications [1]. However, UWB systems may still need to include band-rejection filters to avoid possible interference from existing WLANs, which operate in the 5.15-5.825 GHz band.

In [2], a new compact UWB antenna with reconfigurable notch bands for WLAN interference elimination is proposed. The antenna has a circular radiating patch, two pairs of L-shaped resonators, and a small T-shaped notch in the partial ground plane. Slot antenna with modified hexagonal shape offers 11.98GHz UWB bandwidth, excluding WLAN and WiMAX bands, achieved using L-shape and C-shape parasitic stubs [3]. In [4], A. H. Majeed et al. proposed UWB antenna with C- and U-shaped slots, covering 3.2-14 GHz and rejecting interfering signals at two designated bands by controlling notch frequency and slot dimensions. A new half-ellipse antenna (HEA) design is proposed and experimentally investigated [5]. The antenna's performance is affected by the height of the backed cavity and elevation from the ground. The HEA with a backed cavity can operate normally even when not attached to the ground surface, but with lower gain. In recent years, there has been a growing interest in developing simple and compact ultra-wideband (UWB) antennas. Monopole antennas of various shapes, such as planar inverted-F [6], spade-shaped [7], E-shaped patch [8], Biconical Antenna [9], compact UWB antennas has been designed and reported. Few studies have been conducted on integrating the UWB band with other narrow wireless bands. In [10], Ali Foudazi et al. investigated a small, multi-band planar monopole antenna that uses a diamond-shaped patch to cover the GPS, GSM, WLAN, and Ultra- wideband frequency bands. A new, compact UWB antenna with Bluetooth, GSM, and GPS bands is presented. The antenna has a low profile and consists of an octagonal slot fed by a rectangular patch [11]. In [12], authors designed a PIFA antenna that resonates at multiple frequencies, including GSM 900, GSM 1800, WLAN 2400MHz, Bluetooth, WiMAX, 3G, 4G, and UWB frequencies from 3.1 to 10.6 GHz for applications.

In [13], Anil Kamma et Al. proposed a monopole antenna with a band-notched frequency range of 5.1 to 5.8 GHz. This was achieved by adding two reverse split ring slots to the radiating patch of the antenna. A new UWB MIMO antenna is presented. It uses offset microstrip-line-fed lines to achieve wideband impedance matching and has band-notched characteristics [14]. In [15], a novel microstrip-line-fed patch antenna with four band notches in the Ultra- wideband (UWB) spectrum, fabricated on Rogers RT 5880 substrate, is proposed. Researchers have proposed high isolation band-notched MIMO antennas for UWB systems. These MIMO antennas consist of two monopole UWB antennas that are fed by vias and share a common area [16]. The authors have proposed a 35 mm diameter UWB antenna that is based on a balanced uniplanar crossed-slot configuration. This antenna can effectively reject the full 675 MHz WLAN band centered at 5.5 GHz, while still maintaining the best features of the original XETS design [17]. In [18], a small antenna with ultra-wideband (UWB) capabilities and two frequency bands that are suppressed is introduced. This paper presents the microstrip line fed printed antenna for Bluetooth and Ultra-Wide-Band applications. The circular shaped radiating element is fed by a microstrip line for wideband performance. The arc shaped slot is introduced to achieve extra Bluetooth band. The antenna can achieve a wide impedance bandwidth for Bluetooth and UWB applications, respectively. The effectiveness of the proposed design is verified through numerical simulations, which assess its return loss, gain, and radiation characteristics.

II. Antenna Design

a) Evolution of UWB Antenna

The development of the UWB antenna is shown in Figure 1. Initially, a basic circular disc monopole antenna was designed, as shown in Figure 1(a) as Antenna 1. A beveled technique was used to increase the bandwidth by inserting asymmetric slots at the corners of the ground plane, as shown in Figure 1(b) as Antenna 2 and resulting in the final UWB antenna design, as shown in Figure 1(c) as Antenna 3. It was observed that the corner slots enhanced the vertical current flow, resulting in a good impedance match. This had no significant effect on performance characteristics such as impedance bandwidth or radiation pattern. The optimized values that gave desirable outcomes were fixed and carried over to the next stage.

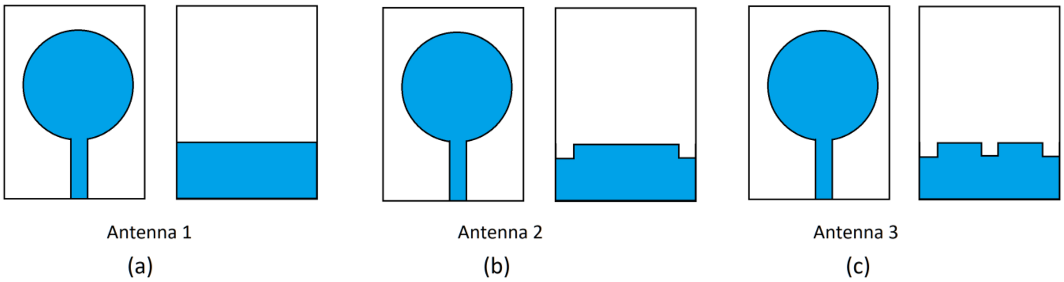


Fig. 1: The Evolution of printed circular shaped UWB monopole antenna.

The impedance bandwidth of the antenna is influenced by the current distribution on the radiating patch. Additionally, the gap between the radiation patch and the ground plane is a crucial factor in controlling the impedance bandwidth. The beveled ground plane ensures a seamless transition from one resonant mode to another, resulting in a good impedance match and stable gain over a broad frequency range. The antenna's ability to achieve high gain at low and high frequencies is attributed to the bevel on the ground plane. Figure 2 shows the Return loss plot for various antenna designs.

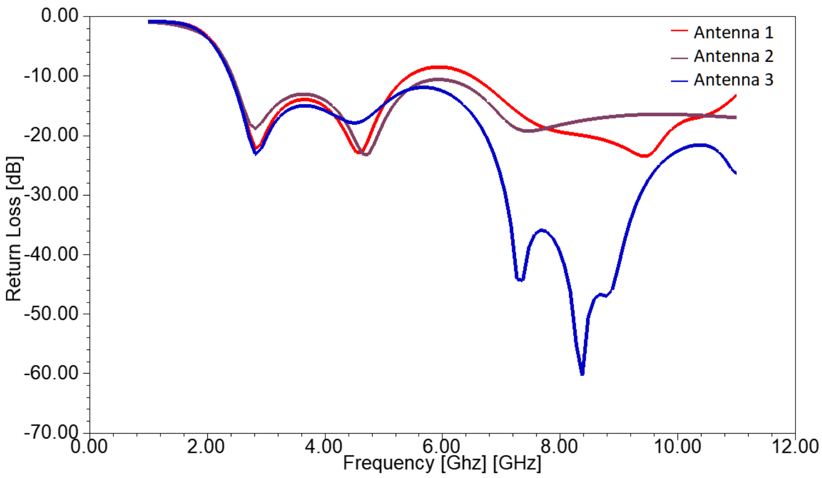


Fig. 2: Return loss plot for various antenna designs

b) **Antenna Geometry**

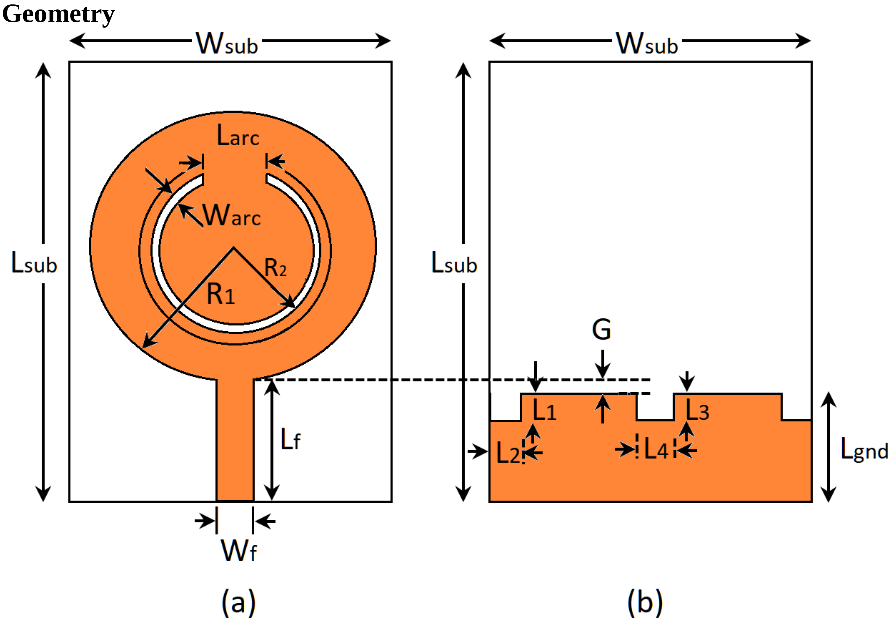


Fig. 3: Schematic of the proposed printed monopole Antenna with arc shaped slot.

The design of the printed circular monopole antenna, shown in Figure 1, is composed of a circular-shaped patch printed on a 35×45 mm^2 FR-4 substrate. One arc-shaped slot is incorporated into the circular patch. The ground plane is rectangular and features asymmetrical slots at the corners and one slot in the middle. The antenna's simulation has been conducted using Ansys Electromagnetics Suite [19]. The antenna's design utilizes low-cost FR-4 material with a thickness of 1.6 mm and a dielectric constant of 4.4. The circular monopole printed antenna, with radius R_1, is fed by a 50 Ω microstrip line feed. The equations for the circular patch antenna with radius R_1 are provided in [20],

$$a = \frac{F}{\left\{1 + \frac{2h}{\pi \epsilon_r F}\left[ln\left(\frac{\pi F}{2h}\right) + 1.7726\right]\right\}^{1/2}} \qquad (1)$$

$$where\ F = \frac{8.791 \times 10^9}{f_r\sqrt{\epsilon_r}} \qquad (2)$$

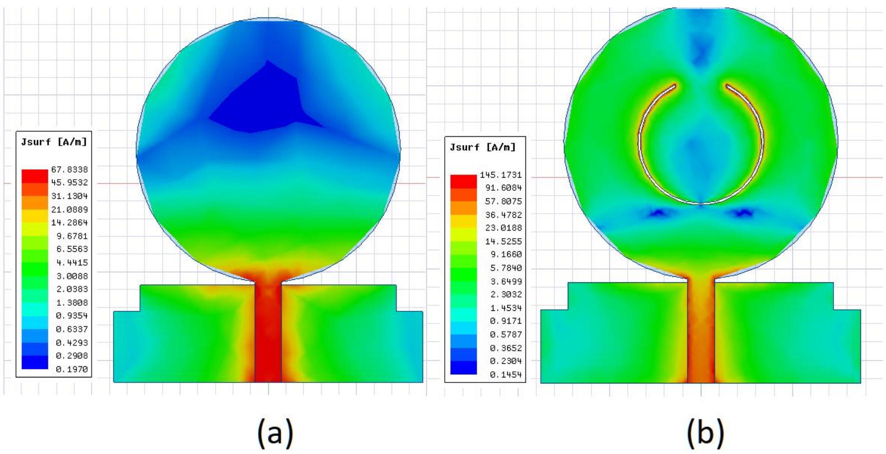


Fig. 4: Current distribution of the UWB antenna at 2.44 GHz; (a) without arc slots, (b) with slots.

c) Design of Bluetooth integrated UWB Antenna

The design of the antenna is primarily based on the distribution of current on its surface. When the UWB antenna is activated, the distribution of current on its surface can be seen at 2.44 GHz. It has been observed that there is very little current in the centre of the radiating patch as shown in the Figure 4. To achieve resonance over the Bluetooth band (2.40-2.48 GHz), a circular arc with a half-wavelength is etched into the radiating patch as shown in Figure 1. For Bluetooth band (2.4 to 2.48 GHz): centre frequency (f_c) = 2.44 GHz and λ/2 = 37.41 mm.

Where

$$\lambda = \frac{c}{f_c\sqrt{\frac{\epsilon_r + 1}{2}}}$$

The length of the circular arc is calculated from the circumference of the circular arc. Circumference of the circle = $2\pi\times R_2$. So for finding R_2, $2\pi\times R_2$=37.41mm and R_2=5.95 mm.
The proposed antenna is simulated using ANSYS Electronics Desktop 2018.2.0 [19]. Following table gives the design parameters of the proposed antenna.

Table no 1: Design parameters of the proposed antenna

Parameters	Dimensions (mm)
$W_{sub}\times L_{sub}$	**35×45**
L_f	11.37
W_f	3
R_1	15
R_2	5.95
W_{arc}	0.25
L_{arc}	37.54
Lgnd	11
G	0.37
L_1	3
L_2	3
L_3	2.5
L_4	2.5

The gap between the radiating patch and ground plane is G =0.37 mm. Antenna structure is a variation of circular monopole antenna. The performance of the Quad band antenna depends on the number of parameters such as the gap (G) between the radiating patch and the ground plane, width and length of the symmetrical and asymmetrical step slots in the ground plane, radius of the circular arc of the circular monopole antenna.

III. Results and Discussion

The design of the antenna is based on the fact that the distribution of the current is strongest along the edge of the circular patch of the antenna. Figure 4 shows the surface current distribution of the Circular UWB monopole antenna at 2.44 GHz. It can be seen that there is very little current in the middle portion of the radiating patch as shown in the Figure 4.

A half-wavelength circular arc is added to the center of the radiating patch to enable resonance within the Bluetooth band as shown in Figure 1. This addition enables dual-band operation for the antenna. The length of the circular arc is approximately half the wavelength of the central Bluetooth band frequency, which is 2.44 GHz. To determine the ideal location for this half-wavelength circular arc, an optimization process is carried out. This optimization involves a parametric study that varies the length and width of the circular arc, where width represents the difference between the radii of the circular arc.

Arc shaped slot has length L_{arc} and by adjusting this length, desired band has been integrated. A parametric analysis is performed on each parameter in order to attain the intended outcomes. The central Bluetooth resonating frequency is determined by the length of the circular arc. This arc length is calculated from the circle's circumference and is approximately half the wavelength. Figure 5 shows Return loss plots for various arc lengths.

By changing the width of the circular arc within the geometry, the simulated antenna achieves maximum magnitude of return loss. Also it controls the impedance bandwidth of the Bluetooth band. Figure 6 shows Return loss plots for various arc widths.

The gap between the radiating element and the ground plane significantly impacts the antenna's impedance bandwidth. By employing a beveled ground plane, a seamless transition between resonant modes is achieved, ensuring consistent impedance matching and stable gain across a wide frequency range. This design enables the antenna to deliver high gain at both low and high frequencies. Figure 7 shows parametric analysis for Return loss plots versus various gaps (G).

The VSWR plot of the proposed UWB antenna shows that the VSWR is below 2.0 over the entire UWB frequency range of 3.1 to 10.6 GHz. This indicates that the antenna is well-matched to its feed line and will radiate efficiently over the entire UWB band. Figure 8 Shows VSWR plot of the proposed Antenna. Figure 9 depicts the radiation patterns of the antenna in the E-plane and H-plane at frequencies of 2.4 GHz and 3.5

GHz, respectively. Additionally, it is observed that the radiation characteristics are nearly omnidirectional in the H-plane, indicating that the signal is transmitted equally in all directions.

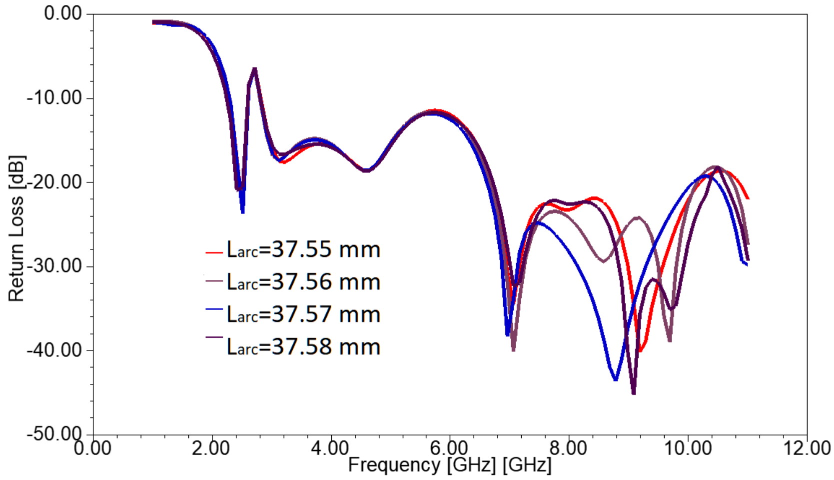


Fig. 5: Return loss plots for various arc lengths

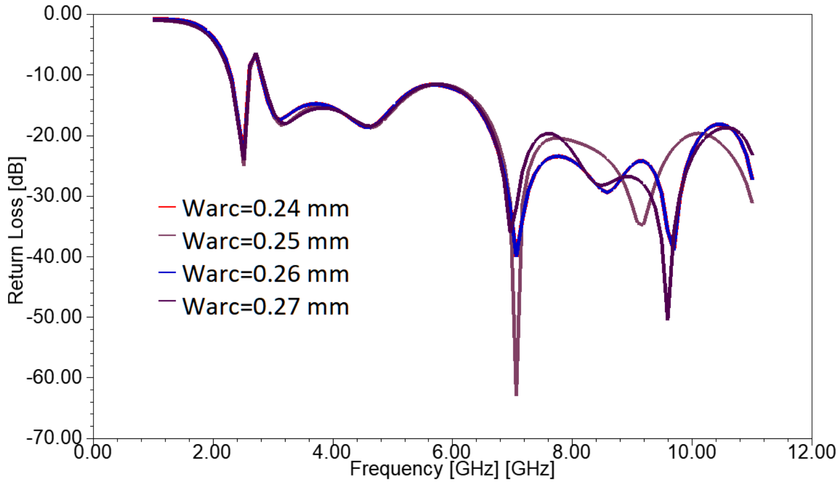


Fig. 6: Return loss plots for various arc widths

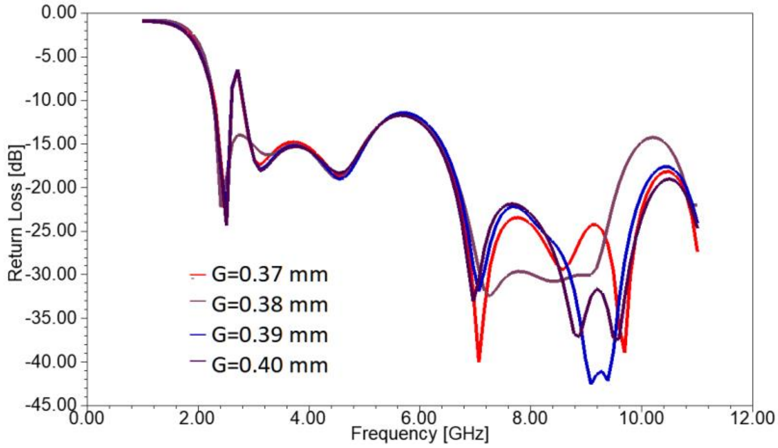


Fig. 7: Return loss plots for various gaps (G)

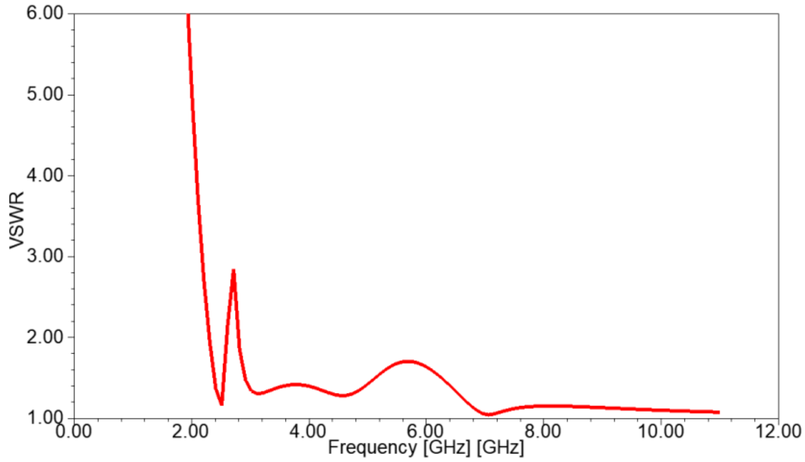
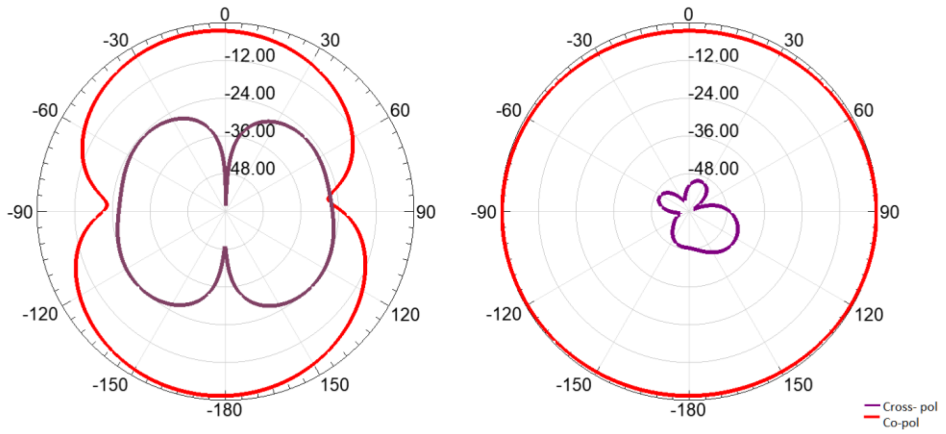
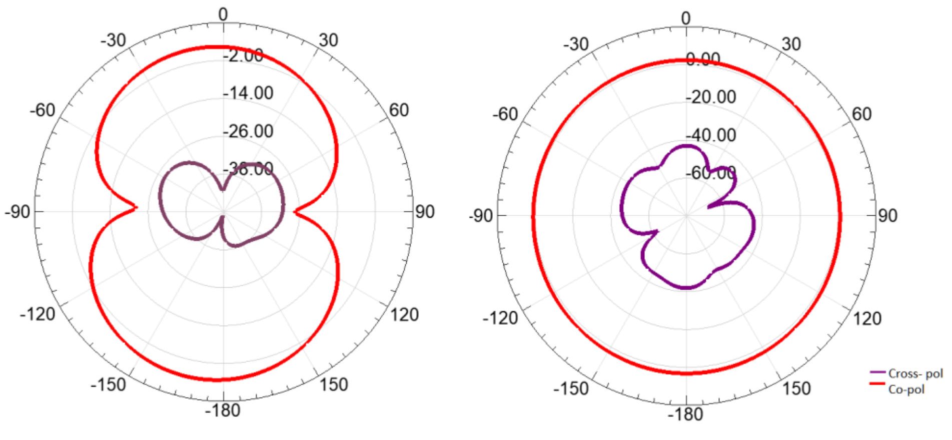


Fig. 8: VSWR plot of the proposed Antenna



(a)



(b)

Fig. 9: E – Plane and H – Plane Radiation patterns at (a) 2.4 GHz, (b) 3.5 GHz.

IV. Conclusion

The development of a UWB slot antenna with one additional usable frequency band, encompassing the complete Bluetooth band is described in this article. The proposed UWB antenna features a circular shape with a compact design. The half-wavelength arc shaped slot inserted on to the circular shaped patch to introduce one additional Bluetooth frequency band. The results of the proposed antenna demonstrate consistent radiation patterns throughout the entire UWB band, including the extra Bluetooth band. Fine-tuning of the Bluetooth band can be achieved by varying the length and width of the arc-shaped slot.

References

[1] Federal Communications Commission. Revision Of Part 15 Of The Commission's Rules Regarding Ultra-Wideband Transmission Systems. Tech. Rep. ET-Docket 98–153. Washington, DC, USA: Federal Communications Commission (FCC); 2002:FCC02-FCC48.

[2] S. W. Yik, Z. Zakaria And N. A. Shairi, "A Compact Design Of Reconfigurable Dual Band-Notched UWB Antenna," 2018 IEEE International Workshop On Electromagnetics:Applications And Student Innovation Competition (Iwem), Nagoya, Japan, 2018, Pp. 1-2, Doi: 10.1109/Iwem.2018.8536707.

[3] S. C. Deshmukh, R. P. Labade And S. Sureshkumar, "Design Of Modified Hexagonal UWB Slot Antenna With Dual Band Notched Characteristics," 2018 International Conference On Advances In Communication And Computing Technology (ICACCT), Sangamner, India, 2018, Pp. 420-425, Doi: 10.1109/ICACCT.2018.8529440.

[4] A. H. Majeed, K. H. Sayidmarie, "UWB Elliptical Patch Monopole Antenna With Dual-Band Notched Characteristics", International Journal Of Electrical And Computer Engineering (IJECE), Vol. 9, No. 5, October 2019, Pp. 3591~3598.

[5] B. Wu, Y. Ji And G. Fang, "Analysis Of GPR UWB Half-Ellipse Antennas With Different Heights Of Backed Cavity Above Ground," In IEEE Antennas And Wireless Propagation Letters, Vol. 9, Pp. 130-133, 2010, Doi: 10.1109/LAWP.2010.2044475.

[6] H. I. Hraga, C. H. See, R. A. Abd-Alhameed And N. J. Mcewan, "Miniaturised UWB Antenna For A Wireless Body Area Network," 2012 Loughborough Antennas & Propagation Conference (LAPC), Loughborough, UK, 2012, Pp. 1-4, Doi: 10.1109/LAPC.2012.6402977.

[7] W. T. Li, X. W. Shi And Y. Q. Hei, "Novel Planar UWB Monopole Antenna With Triple Band-Notched Characteristics," In IEEE Antennas And Wireless Propagation Letters, Vol. 8, Pp. 1094-1098, 2009, Doi: 10.1109/LAWP.2009.2033449.

[8] A. A. Deshmukh, A. A. Desai, P. Kadam And K. P. Ray, "Ultra-Wide Band E-Shaped Patch Antenna," 2016 IEEE Annual India Conference (INDICON), Bangalore, India, 2016, Pp. 1-5, Doi: 10.1109/INDICON.2016.7839154.

[9] Ding Yu, Weigang Zhai, Guitao Xie And Longjun Zhang, "A Novel Omni-Directional UWB Biconical Antenna With Band-Notched," Proceedings Of 2011 IEEE CIE International Conference On Radar, Chengdu, 2011, Pp. 1172-1175, Doi: 10.1109/CIE-Radar.2011.6159762.

[10] A. Foudazi, H. R. Hassani And S. Mohammad Ali Nezhad, "Small UWB Planar Monopole Antenna With Added GPS/GSM/WLAN Bands," In IEEE Transactions On Antennas And Propagation, Vol. 60, No. 6, Pp. 2987-2992, June 2012, Doi: 10.1109/TAP.2012.2194632.

[11] M. Bod, H. R. Hassani And M. M. Samadi Taheri, "Compact UWB Printed Slot Antenna With Extra Bluetooth, GSM, And GPS Bands," In IEEE Antennas And Wireless Propagation Letters, Vol. 11, Pp. 531-534, 2012, Doi: 10.1109/LAWP.2012.2197849.

[12] A. Kamma, G. S. Reddy, S. K. Mishra And J. Mukherjee, "Printed Band - Notched U Shaped Ultra Wide Band Antenna With Modified Split Ring Resonator," 2012 IEEE Asia-Pacific Conference On Antennas And Propagation, Singapore, 2012, Pp. 251-252, Doi: 10.1109/APCAP.2012.6333232.

[13] L. Kang, H. Li, X. Wang And X. Shi, "Compact Offset Microstrip-Fed MIMO Antenna For Band-Notched UWB Applications," In IEEE Antennas And Wireless Propagation Letters, Vol. 14, Pp. 1754-1757, 2015, Doi: 10.1109/LAWP.2015.2422571.

[14] L. Ge, H. Liu, L. Tian And Z. Li, "Design Of Novel Patch Quadruple Band-Notched UWB Antenna," 2022 IEEE 5th International Conference On Electronics Technology (ICET), Chengdu, China, 2022, Pp. 823-829, Doi: 10.1109/ICET55676.2022.9824512.

[15] D. Lu, J. Zhao And S. Bi, "Design Of High-Isolation Band-Notched Via-Fed UWB MIMO Antennas With Multi-Objective Optimization," 2020 IEEE MTT-S International Microwave Workshop Series On Advanced Materials And Processes For RF And Thz Applications (IMWS-AMP), Suzhou, China, 2020, Pp. 1-3, Doi: 10.1109/IMWS-AMP49156.2020.9199743.

[16] C. R. Medeiros, J. R. Costa And C. A. Fernandes, "Compact Tapered Slot UWB Antenna With WLAN Band Rejection," In IEEE Antennas And Wireless Propagation Letters, Vol. 8, Pp. 661-664, 2009, Doi: 10.1109/LAWP.2009.2022063.

[17] P. Meena And A. Garg, "A Design Of Compact Ultra-Wide Band Antenna With Dual Band Notched Characteristics," 2017 International Conference On Information, Communication, Instrumentation And Control (ICICIC), Indore, India, 2017, Pp. 1-5, Doi: 10.1109/ICOMICON.2017.8279091.

[18] R. K. Raj, R. Sharma, P. K. Dhakar, D. K. Pareek And S. Singh, "Dual Band Notched Antenna With S-Slot For Ultra Wide Band Applications," 2015 International Conference On Computer, Communication And Control (IC4), Indore, India, 2015, Pp. 1-4, Doi: 10.1109/IC4.2015.7375564.

[19] ANSYS Electronics Desktop 2018.2.0

[20] Constantine A. Balanis, "Antenna Theory: Analysis And Design", John Wiley & Sons, 3rd Edition, 2005.