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Dual-Band Modified Circular Shaped Monopole Antenna for Wireless Applications

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Abstract:
This article describes a compact, low profile, modified circular-shaped Ultra Wide Band (UWB) antenna with dual-band operation for wireless communications. The antenna demonstrates the operation for dual-band and can be used to cover 2.4-2.48 GHz (Bluetooth) and 3.1-10.6 GHz (UWB) frequency bands. The antenna contains a modified monopole circular patch with a partial ground plane to cover the whole UWB band. The circular arc slot is embedded within the center portion of the modified circular radiating patch to resonate over the Bluetooth band. The antenna is created and modified on a low-cost FR-4 substrate with a dielectric constant of 4.4 and a loss tangent of 0.02. The antenna is feed by a 50 Ω microstrip line withthe overall surface area of 45×35 mm^2. The electromagnetic suite Ansoft's HFSS v.19.0 software is employed for the simulation of the antenna. The simulated VSWR is within the range of 2: 1 over 2.38-2.56 GHz and 2.86-11 GHz. The antenna exhibits all-around satisfying gain flatness having an omnidirectional radiation pattern over Bluetooth and UWB band.

Key Words: *UWB; Bluetooth band; dual-band; VSWR.*

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I. Introduction

In 2002, the Federal Communication Commission (FCC) declared an unlicensed 7.5 GHz (3.1 to 10.6 GHz) Bandwidth as Ultra-wideband (UWB) [1]. As per a released policy, UWB technology which relies on spreading very short pulses of a period of very few nanoseconds or smaller has now received tremendous focus in several fields for the small distance (< 10m) communications for wireless applications and bigger bandwidth. The UWB system has diverse benefits such as high data rate, covert transmission, more time resolution, low power consumption, low-cost implementation, resistance to interference, obstacle penetration, co-existence with narrow-band systems, and lots of more. Therefore, the UWB system is employed in radar, imaging, positioning, and communications. The planning principles and also the basic properties of the UWB antenna can be described in terms of both frequency and time domain representations [2]. Modern communication systems need only one antenna to have coverage over several types of frequency bands. As a result, the design of UWB antennas plays a very significant role in UWB systems. The ground plane effects reduce the current distribution of the monopole primary plane and these effects are suppressed by introducing a strip into the slot cut on the rectangle monopole antenna to extend UWB performance [3].

Bluetooth Wireless Technology aimed to unravel the requirement for wired connections between gadgets like laptops, mobile phones, and PDAs. In 1998, the Bluetooth Special Interest Group (SIG) was organized to promote the growth of the Bluetooth specification IEEE 802.15. The Bluetooth band ranges from 2.4 to 2.48 GHz. Later, MB OFDM UWB was selected to work with the Bluetooth Special Interest Group [4]. The designing of a planar dual-band monopole antenna includes two methods. The primary method is to integrate lower frequency bands (Bluetooth). For this purpose, an additional resonance strip of half-wavelength or quarter wavelength similar to their central band frequency is embedded in the geometry of the designed antenna [5-7].In [8], a planar monopole antenna for UWB application with supplementary three bands GPS/GSM/WLAN is presented. Antenna diversity technique is employed to extend the transmission quality of UWB systems and to stay away from multi-path fading [9]. In the second technique, to style an antenna to be engaging at 2-10.6 GHz, the 'notching' technique is employed to get rid of unwanted bands. Etching an appropriate structure on the patch or ground plane is the easiest method to get notch bands [10- 18]. In [19-20], slot loaded rectangular microstrip antenna reported for wireless communications Bluetooth/Wi-MAX.

In [21], a pentagonal-shaped patch antenna is meant and designed on an FR4 substrate to get UMTS and Bluetooth bands. The triple notch bands are achieved with the assistance of CPW feed UWB antenna with the addition of stub loader meander line resonator [22]. Three notch bands are acquired by adding a stub or slot in the radiating patch and parasitic stub within the ground plane [23]. The introduction of resonator structures (like split-ring resonators) is another approach to make notch bands [24-26]. Notch bands also can be designed and introduced by inserting stubs or embedding slots in the feed line [27].To meet the wants of easily portable wireless applications, wideband antenna accomplishment on a low cost and low size FR4 substrate material is required. Therefore, proposing an antenna with notch bands continues to be a remarkable interesting research topic due to difficult tasks involved in the addition of the bands without affecting another performance of the antenna. To beat this problem, we have suggested a UWB antenna with the assistance of a modified circular radiating patch. For the good impedance matching and to boost the bandwidth, the antenna's ground plane is modified. The whole dimensions of the antenna are 45×35×1.6 mm^3. A circular arc slot of half-wavelength is introduced into the modified circular radiating patch to integrate with a lower frequency Bluetooth band. The UWB execution of the antenna remains unchanged even after the addition of the circular arc slot. The simulation of the suggested antenna is carried out using simulation software Ansoft's HFSS v 19.0 [28].

II. Antenna Design and Geometry

The geometry of the desired antenna is depicted in Fig.1. The designed antenna is built on a 1.6 mm thick FR4 substrate with a dielectric constant of 4.4 and a loss tangent of 0.02. Substrate dimensions are 35×45 mm^2 and the substrate is feed by a 50 Ω microstrip feed line. A circular arc slot is introduced in the modified circular radiating patch. The ground plane has a rectangle shape with symmetrical proportionate slots at the corners and one slot in the middle. The electromagnetic suite Ansoft's HFSS v.19.0 software is used for the simulation of the proposed antenna [28]. Initially, the circular monopole antenna is designed by using semi-empirical equations [29].

The circular patch radius a is given by,

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

Where, $F = \frac{8.791\times10^9}{fr\,\sqrt{\epsilon r}}$

and always h should be in cm.

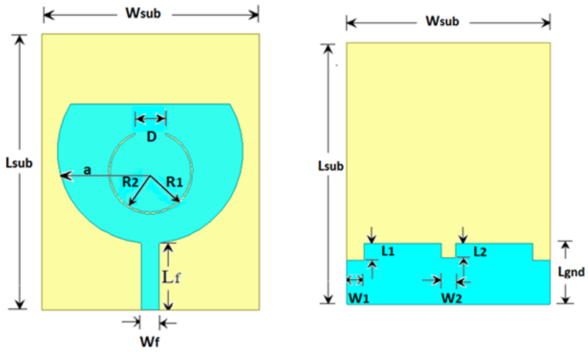
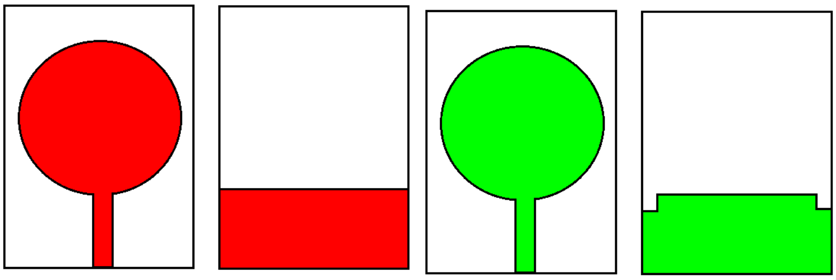


Fig.1. Design of the proposed modified circular-shaped printed monopole antenna with the circular arc slot.

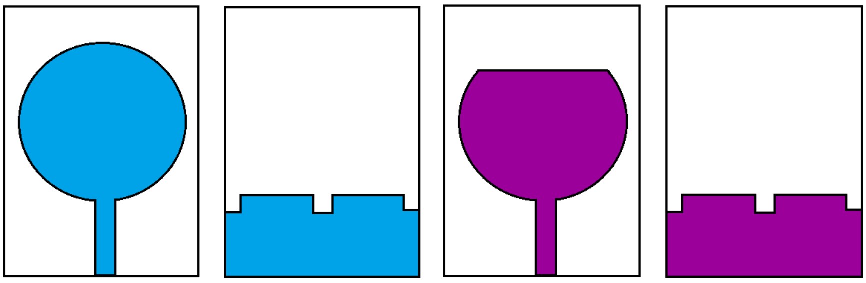
The dimensions of the designed antenna are optimized and given as: L_1 = 3mm, L_2 =2.5, W_1= 3, W_2=2.5, L_{gnd}=10.5, L_{sub}= 45 mm, W_{sub}= 35mm, H_{sub}=1.6 mm, L_f =11, W_f = 3, D=5, a = 15, R_1= 6.94, R_2 = 6.55.

A. Evolution of UWB

The evolution of the UWB antenna is presented in Fig.2. Firstly, a basic circular-shaped monopole antenna has been designed as shown in Fig.2 (a) Antenna 1. To increase the bandwidth, a beveling technique is used by inserting two symmetric slots at the two different ends in the ground plane as shown in Fig.2 (b) Antenna 2. As a result, frequency mismatched is observed. For the better enhancement of the bandwidth, the design is modified by inserting one more slot in the middle of the monopole ground plane as shown in Fig.2 (c) Antenna 3. Henceforth, an exact impedance bandwidth for voltage standing wave ratio (VSWR) 2:1 is achieved from 2.6-11 GHz. In the end, a required UWB range (2.6 to 11 GHz) is obtained by cutting a small semi-circular patch from the top of the circular radiating patch as shown in Fig.2 (d) Antenna 4.



(a) Antenna 1(b) Antenna 2



(c) Antenna 3(d) Antenna 4

Fig.2. Development of modified circular-shaped UWB monopole antenna.

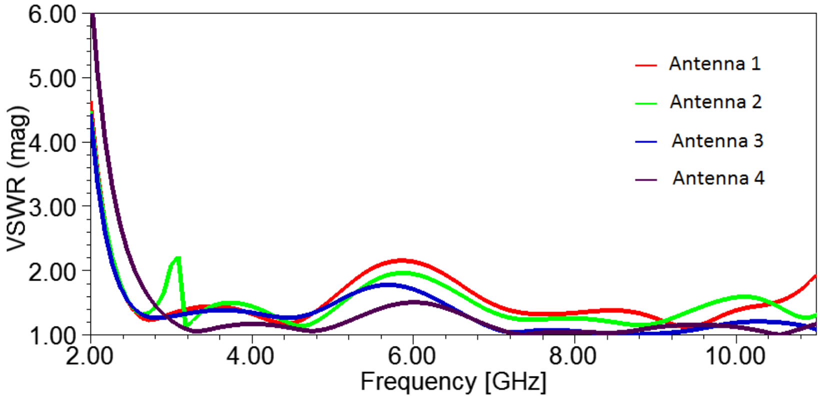
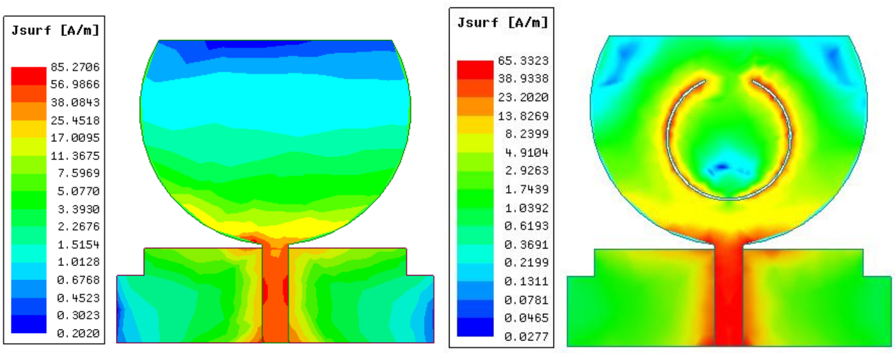


Fig.3 VSWR plots for UWB evolution antenna designs.



(a) (b)

Fig.4. Antenna Current Distribution at 2.44 GHz; (a) without slot, (b) with the slot.

B. Integration of the Bluetooth Band

The schematic diagram of the proposed dual-band antenna is shown in Fig. 1. For integrating the required Bluetooth band, first, it is essential to notice the current distribution of the modified circular radiating patch antenna at a center frequency. The current distribution is studied at a center frequency f_c = 2.44 GHz. It is noticed that there is a very little current flowing at the top of the radiating patch and a current goes on increasing as we move downwards towards the feed line. A circular arc slot of half the wavelength is inserted into the radiating patch.

$$\text{Where, } f_c = \frac{c}{2L_{slot}\sqrt{\epsilon_{eff}}}$$

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2}$$

f_c = centre frequency

$L_{slot} = \frac{\lambda}{2}$ the total length of the arcs

The length of the slot is converted into the circular arc. 2πr is given as the circumference of the circle, where r is the radius of the circle. For R1, 2πR1= 37.41 mm therefore R1= 5.95 mm. The dimensions of the proposed antenna are simulated using Ansoft's HFSS simulation software. After carrying out many optimizations, the radius of the greater circular arc (R_1) is taken as 6.8 mm and the radius of the smaller circular arc (R_2) is considered to be as 6.55 mm. The length of the circular arc is optimized and considered 0.2 mm greater than the actual length because dielectric losses occur in the substrate. The current distribution of the UWB antenna at 2.44 GHz with and without the circular arc slot is studied and shown in Fig. 4. It is noticed that there is a sudden and much change in the current path after the insertion of the circular arc slot. In Fig. 4(a) it is noticed that there is a very little current flowing at the center of the modified circular path at 2.44 GHz, while in Fig 4(b) it is observed that very large current is flowing along the sides of a circular arc.

III. Results and Discussions

A. Parametric Analysis To Obtain UWB Band

Antenna design is a modification of a circular monopole antenna. The execution of the antenna is conditioned on several factors such as the gap (g) between the radiating patch and the ground plane, and the length, width of the symmetrical or asymmetrical slots in the ground plane [6]. The radius of the circular arcs also plays a major role. The antenna performance is also conditioned on the formation of the ground plane and its dimension.

At first, the dimensions of the antenna are taken as the radius (a= 15) with $L_{sub} \times W_{sub}$ (45 mm× 35 mm) fed by a 50 Ω microstrip feed line. The gap between the ground plane and the radiating patch is 0.5. The gap (g) between the ground plane and the radiating patch plays a major role to advance the impedance bandwidth of the proposed antenna [5-6]. The change in 'g' can be achieved by changing the ground plane length (L_{gnd}). Initially, the length of the ground plane (L_{gnd}) is taken as 10.5 mm. The L_{gnd} is changed in pace from 10.5mm to 11mm. Fig. 5 shows the graph between VSWR and frequency of the changed ground planelength (L_{gnd}). It is observed that the antenna with L_{gnd} of 10.5 mm shows the bandwidth 12.96 GHz for the frequency range 2.86-15.82 GHz and 10.7mm shows the bandwidth 13.68 GHz for the frequency range 2.82 – 16.50 GHz. When L_{gnd} is taken as 11 mm, the bandwidthobserved is 13.96 for a range of 2.64-16.6 GHz. Thus, if L_{gnd} increases, the bandwidth also increases.

Later, the design is optimized by inserting a pair of symmetrical slots at the corners on the ground surface. To obtain the desired UWB band, variations in L_1 and W_1 are observed. Fig. 6 shows VSWR plots versus frequency for different $L_1 \times W_1$, it is observed that when$L_1 \times W_1$ increasesfrom 3×3 to 3.5×3.5 mm^2, then bandwidth increases from 12.96 to 13.67 GHz. Fig. 7 shows VSWR plots versus frequency for different $L_2 \times W_2$, it is observed that when$L_2 \times W_2$increasesfrom 2.5×2.5 to 3×3 mm^2, then bandwidthdecreases from 14.57 to 13.44 GHz.

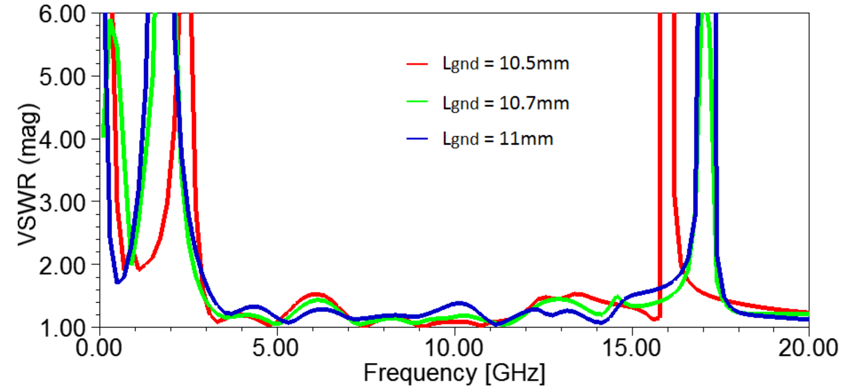


Fig.5 VSWR plots for the variation in length L_{gnd}.

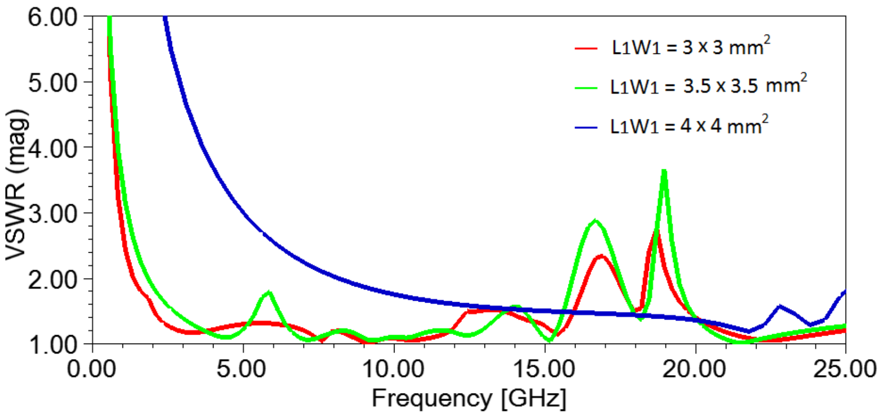


Fig.6 VSWR plots for the variation in the slot L_1W_1

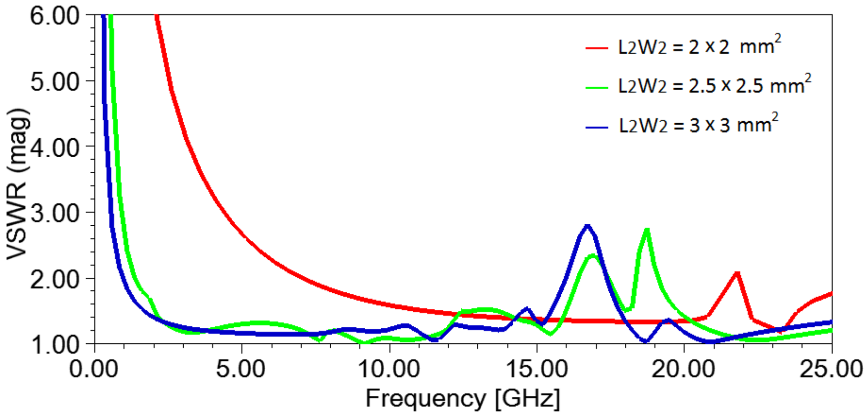


Fig.7. VSWR plots for the variation in the slot L_2W_2.

B. Parametric Analysis To obtain the Bluetooth Band

The initially designed antenna with a stepped ground plane is used to promote antenna performance. To attain the dual-band antenna, a half wavelength circular arc slot is etched at the center of the radiating patch to have an impact over the Bluetooth band. The antenna gains the dual-band operation because of the introduction to the circular arc slot. The length of the circular arc is taken identical to half of the wavelength of f_c that is 2.44 GHz. Several optimizations are done to encounter the precise location for the addition of the half-wavelength circular arc. A parametric study is done by varying the radius of the circular arc (R_1) and the distance (D). The impedance bandwidth of the Bluetooth band is studied by varying the circular arc within the geometry. The central resonating frequency is determined due to the variation in the length of a circular arc. The length of the circular arc is calculated theoretically, $\frac{\lambda}{2}$ = 37.41 mm. Fig. 8 shows the graph between VSWR and Frequency for the change in the value of D. The graph illustrates three values of D (4, 5, 6, 7). As D increases, the bandwidth also goes on increasing from 40, 100,120 and 290 MHz respectively. After so many variations, it was witnessed that for D= 5mm a proper Bluetooth band was achieved with a frequency range of 2.41 GHz to 2.5 GHz with VSWR in the range 2:1.

Fig.9. shows the parametric analysis for the various length of R_1 (radius of the bigger circular arc) in terms of VSWR. It illustrates four values of R_1 (6.8, 6.9, 6.92, and 6.94). As radius R_1 increases, impedance bandwidth of the Bluetooth band decreases from 180, 160, 140 and 120 MHz and corresponding VSWR decreases from 1.56, 1.54, 1.43 and1.24 respectively. Therefore, the optimized radius R_1 is taken as 6.94 mm. From Fig.10 it is seen that the VSWR of the proposed antenna is in the range 2:1.

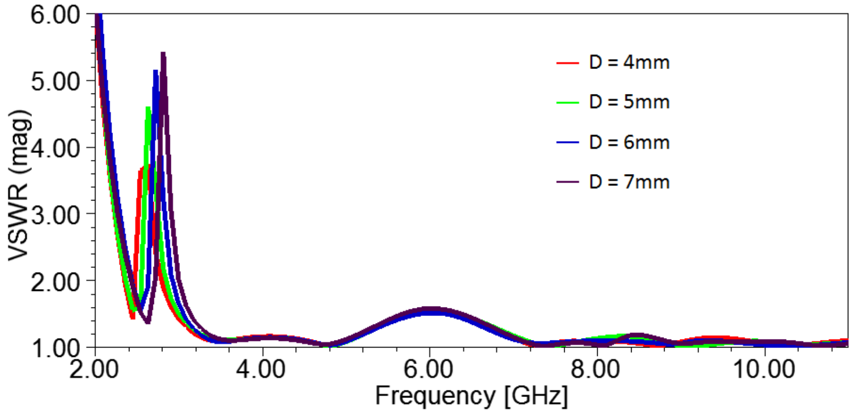


Fig.8 VSWR plots for the variation in the distance D.

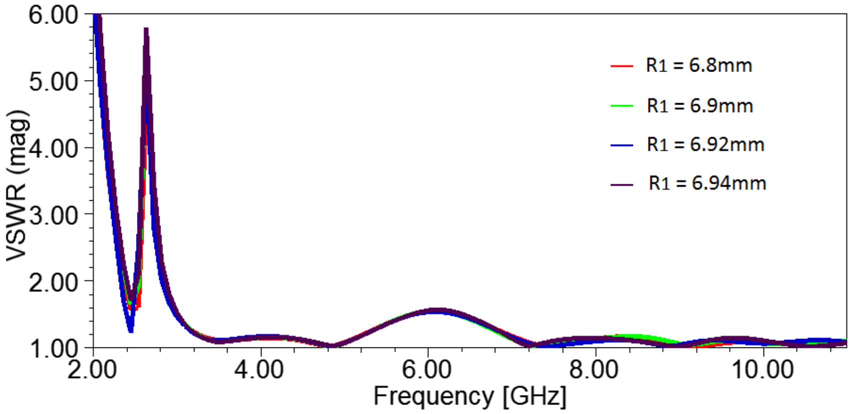


Fig. 9 VSWR plots for the variation in the radius R_1.

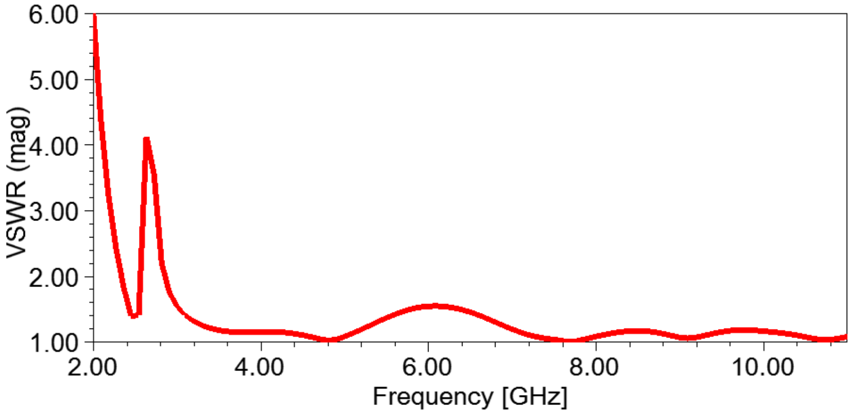


Fig.10 VSWR of the proposed antenna

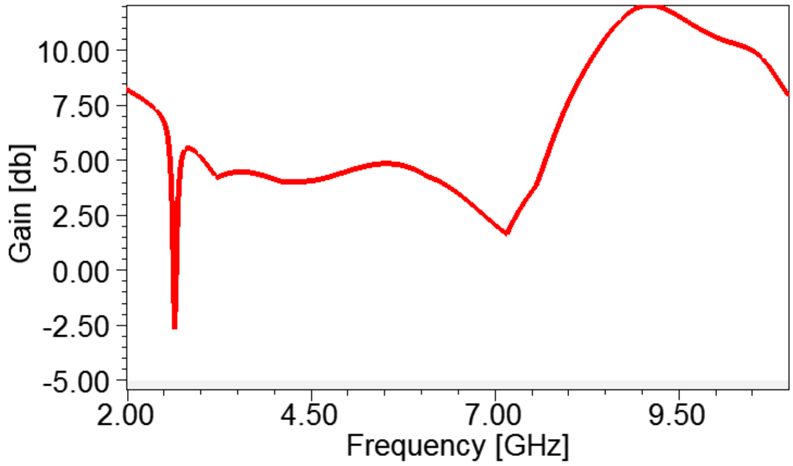
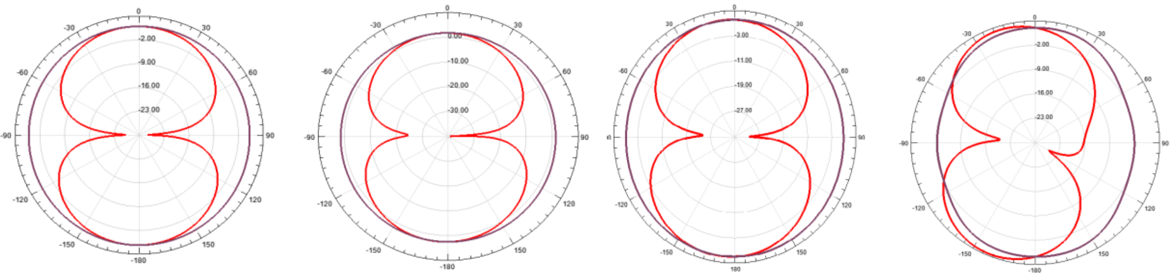


Fig.11 Gain versus frequency graph

Fig.11 shows the graph of Gain versus Frequency of the proposed dual-band antenna. Here, for the Bluetooth band and UWB, we observed a good gain. The Antenna's radiation pattern is represented in Fig. 12. It is noticed that at different frequencies like 3.1, 3.5, and 5.2 GHz, the radiation patterns of the antenna are alike. Thus, the entire UWB band shows a stable and omnidirectional radiation pattern. Fig.13 shows the simulated smith chart. All the frequencies 2.44, 3.1, and 10.6 GHz reside within the VSWR circle 2:1. Hence, good impedance matching is observed for both UWB and Bluetooth band.



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

Fig.12. Simulated Radiation Patterns at (a) 2.44 GHz, (b) 3.1 GHz, (c) 3.5 GHz, (d) 5.2 GHz

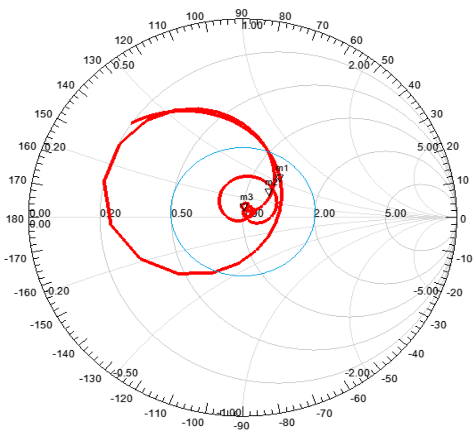


Fig.13. Simulated Smith chart of Dual-band Antenna

IV. Conclusion

A simple, compact, low cost and printed modified circular-shaped dual-band antenna is suggested in this article. The antenna is etched by a circular arc slot to path the current direction to resonate at the Bluetooth band. The Bluetooth band 2.38- 2.56 GHz is obtained by optimizing the dimensions of the circular arc slot. The Bluetooth band shows a slight movement to the lower frequency with a changing peak when the length of the circular arc is increased. The UWB response fully results in the 2.86-11 GHz band and does not have an effect of Bluetooth resonance. Hence, the designed antenna comes up with productive control over two operating bands. The antenna exhibits an almost same omnidirectional pattern, which recommends that the designed antenna is applicable and gives good results for UWB and Bluetooth applications.

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