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# Metamaterial inspired circular antenna for Bluetooth band integration

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**ABSTRACT**

Within the rapidly evolving landscape of wireless communication technologies, this scientific paper delves into an innovative approach by exploring the integration of the Bluetooth frequency band into a circular antenna design. Leveraging the capabilities of metamaterials. The Bluetooth frequency band a cornerstone for short-range communications, takes center stage in our study. Traditionally associated with wireless connectivity in diverse applications, its integration into a circular antenna structure opens up new avenues for optimizing performance and functionality. Our research aims to not only enhance the efficiency of short-range communication systems but also contribute to the broader discourse on antenna design evolution. The computer simulation technology (CST) studio suite is utilized to show the recommended antenna design. By scrutinizing the symbiotic relationship between the Bluetooth frequency band and the circular antenna augmented with metamaterial, our study endeavors to push the boundaries of current design paradigms. We believe that this exploration will not only address the contemporary challenges associated with wireless communication but also pave the way for the development of more sophisticated, adaptable, and compact devices in the ever-expanding realm of telecommunications.



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## 1. INTRODUCTION

Due to their advantageous characteristics, including compact size, lightweight construction, and cost-effectiveness, microstrip patch antennas have garnered significant attention from numerous researchers and designers. These antennas find applications in diverse fields such as GPS, WLAN/WIMAX, ultra-wideband (UWB), and more. A basic microstrip patch antenna comprises a radiating patch with various geometrical shapes; such as rectangular, triangular, and circular or square. UWB technology has found extensive utilization in communication systems owing to the demand for high data rates, minimal power consumption, and reduced multipath interferences. The Federal Communications Commission's (FCC) endorsement of unlicensed UWB utilization within the 3.1 GHz to 10.6 GHz frequency range has prompted antenna engineers to design compact and efficient antennas tailored for this spectrum [1]. UWB antennas utilized in such communication scenarios must adhere to stringent electromagnetic requisites, including broad impedance bandwidth exceptional fidelity efficient performance, moderate gain, and omnidirectional radiation patterns. Furthermore, these antennas must also comply with equivalent isotopically radiated power (EIRP) restrictions to preserve the integrity of transmitted and received signals across time and frequency domains. Various monopole patch antenna configurations have been proposed to fulfill the UWB requirements effectively [2]–[5]. This scientific article introduces an innovative paradigm for the seamless integration of the Bluetooth frequency band into circular antenna architectures through the incorporation of metamaterials [6]–[10]. The focal point of this study is the proposal of an antenna characterized by its inherent simplicity, diminutive form factor, and exceptional capacity to manifest the complete gamut of radiation characteristics mandated by the FCC to meet the requisites of UWB communication systems [11]–[16]. The antenna's characteristics have been calculated using computer simulation technology (CST) studio suite.

## 2. LITERATURE REVIEW

Numerous investigations have been conducted over the years focusing on microstrip patch antennas. Among the challenges addressed is the issue of transmitting increased power to the receiver, a concern often encountered in high-gain antennas. The primary objective is to bolster the received signal strength. Leveraging reciprocity, high-gain antennas have the capacity to amplify received signals by a factor of 100 during transmission. The inherent directivity of directional antennas contributes to their effectiveness as they selectively concentrate signals within the main beam diminishing interference from other directions. This attribute not only enhances the robustness of the received signal but also minimizes potential disruptions. Employing this approach in wireless communication yields a notable increase in gain enabling the transmission of data at substantially higher power levels compared to earlier research endeavors.

In the work presented by Sharmin and Rahaman [17] they propose a microstrip patch antenna tailored for 5G technology. Featuring an innovative "slotted octagonal" shape patch. Envisioned for integration into future electronic devices this antenna operates at a frequency of 4.43 GHz positioning it within the C-band of the 5G communication spectrum. The design is particularly noteworthy due to its commendable gain of 3.05 dBi and an aesthetically pleasing radiation pattern, the study comprehensively examines various aspects of the antenna, focusing on its geometry and key metrics, including the reflection coefficient, gain, radiation characteristics, and input impedance plot. The results suggest that this designed antenna holds promise as a viable option for achieving 5G connectivity. Its unique shape and performance metrics make it a compelling candidate for contributing to the evolving landscape of 5G communication systems especially in the context of emerging electronic devices.

In the work presented by Rana and Rahman [18] proposed, devised, and documented the construction of a microstrip patch antenna intended for application in the rapidly evolving landscape of forthcoming wireless communication technologies. The primary objective of this study was to discover methods to reduce overall return loss. concurrently enhancing gain. and lowering the voltage standing wave ratio (VSWR). Building upon this premise a related study [19] explored a 5G high-band slotted microstrip antenna the utilization of such antennas holds the potential for achieving high bit rates, mitigating traffic congestion, and accommodating an increased number of users. Notably the integration of a square slot atop a circular slot in a rectangular microstrip antenna was investigated demonstrating improvements in return loss, gain, and bandwidth. The findings indicate that the introduced antenna configurations have a positive impact on these crucial performance metrics, paving the way for enhanced efficiency, and capabilities in wireless communication systems.

In the work presented by Abdulbari *et al*. [20] presented a novel microstrip patch antenna characterized by a T-shaped rectangular design. Operating within the frequency range of 3.6 GHz. This configuration aligns seamlessly with the demands of 5G applications. With dimensions measuring $22 \times 24 \times 0.25$ mm$^3$ the antenna employs a 50 $\Omega$ feed line for signal transmission. Contributing to its advantageous attributes including a compact size, low profile, and simplified structure the research paper thoroughly explores the antenna's characteristics encompassing key parameters such as radiation pattern, reflection coefficient, gain, current distribution, and efficiency. Notably the inclusion of a slot in the rectangular T-shaped patch antenna design led to remarkable achievements. This modification resulted in a lower operating frequency with an exceptional radiation efficiency of 98.474% and a peak gain of 2.52 dBi. Additional notable performance metrics include a fractional bandwidth of 42.81%, spanning from 2.90 GHz to 4.48 GHz, a resonant frequency of 3.6 GHz, and a return loss of 28.76 dB. These features collectively establish the antenna's suitability for 5G mobile applications. Positioning it as a promising contribution to the evolving landscape of wireless communication technologies.

In the work presented by Ezzulddin *et al*. [21] introduced a set of antennas designed to exhibit superior gain, directivity, and bandwidth compared to their predecessors. Leveraging advanced simulation tools such as CST and the high-frequency structure simulator (HFSS) the research experimentally measured key properties of the antennas including return loss (S11). VSWR, gain, directivity, bandwidth, and radiation pattern. These assessments were conducted for each of the microstrip patch shapes previously discussed. The results indicated that the proposed antenna configurations yielded performance metrics closely aligned with those of earlier studies conducted at the same frequency. This substantiates the efficacy of the proposed antenna design. Positioning it as an ideal candidate for deployment in 5G wireless communication systems. The enhanced gain, directivity, and bandwidth characteristics contribute to the antenna's potential to meet the evolving demands of advanced and efficient wireless communication technologies.

## 3. ANTENNA DESIGN

The schematic representation of the antenna's structure is presented in Figure 1. The antenna under consideration is manufactured on a 1.6 mm thick dielectric substrate composed of FR-4 material. It covers a spatial extent of 24×34 mm² and is connected through a 50 Ω impedance strip line. The substrate is characterized by a relative permittivity (εr) of 4.4 and a loss tangent of 0.02. The circular monopole antenna is designed using the (1)-(2) outlined in the methodology. In these equations the radius of the circular patch is denoted as 'a', the dielectric constant of the substrate is represented by 'εr', and the substrate thickness measured in millimeters is indicated by 'h' [22], [23]. Table 1 presents the dimensions of the proposed antenna design, outlining various parameters essential for its construction and performance.

$$a = \frac{F\,1}{\sqrt{1+\frac{2h}{\pi F \epsilon r}\left(ln\left(\frac{\pi F}{2h}\right)+1.7726\right)}} \quad (1)$$

where:

$$F = \frac{8.791\times 10^{9}}{fr\sqrt{\epsilon r}} \quad (2)$$

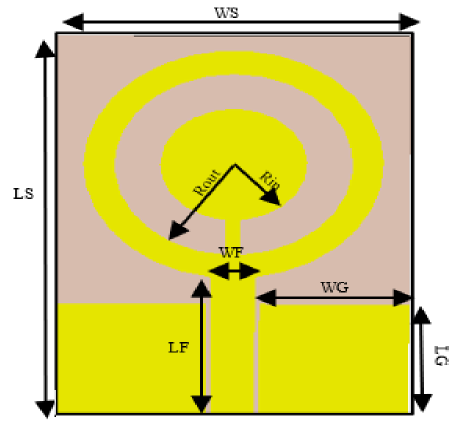


Figure 1. Geometry of the design antenna

Table 1. Dimension of the proposed antenna

| Parameter | Value (mm) |
|---|---|
| LS | 34 |
| WS | 24 |
| LF | 12.5 |
| WF | 3 |
| LG | 10 |
| WG | 10.2 |
| Rin | 5 |
| Rout | 7.5 |

## 4. RESULTS AND DISCUSSION

The antenna originally designed with a stepped ground plane has been employed to enhance antenna performance. In the case of the dual-band antenna a circular metamaterial is etched into the center of the radiating patch to affect the Bluetooth band. Figures 2 and 3 illustrates the relationship between VSWR and frequency as the value of Rin/Rout varies. The graph displays four different values of Rin (5, 5.3, 5.5, and 5.7) and Rout (7.5, 7.7, 7.9, and 8.1). It can be observed that as either Rin or Rout increases the impedance bandwidth of the Bluetooth band diminishes leading to a corresponding decrease in VSWR. Figure 4 provides a representation of the VSWR characteristics of the proposed antenna.

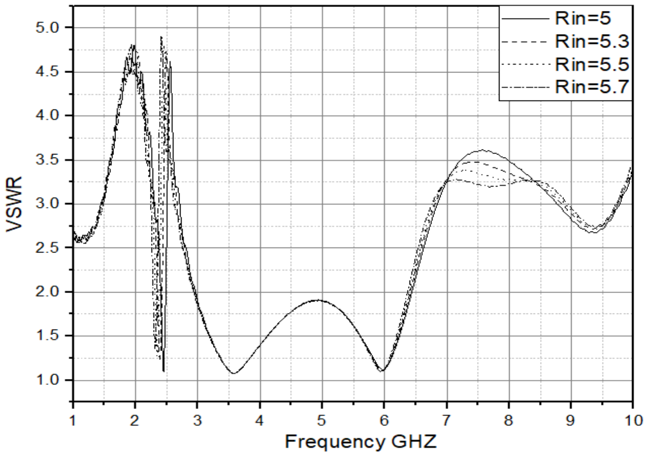


Figure 2. VSWR charts depicting the change in radius Rin

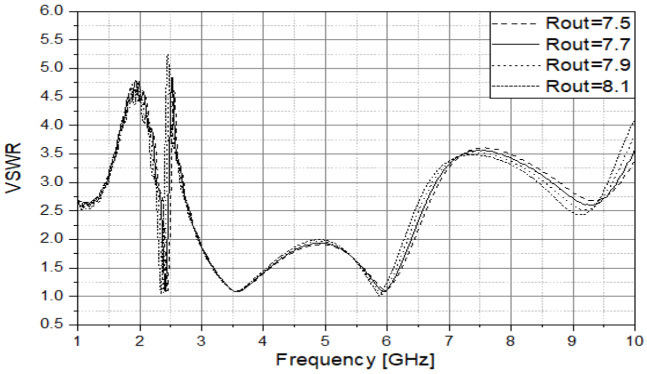


Figure 3. VSWR charts depicting the change in radius Rout

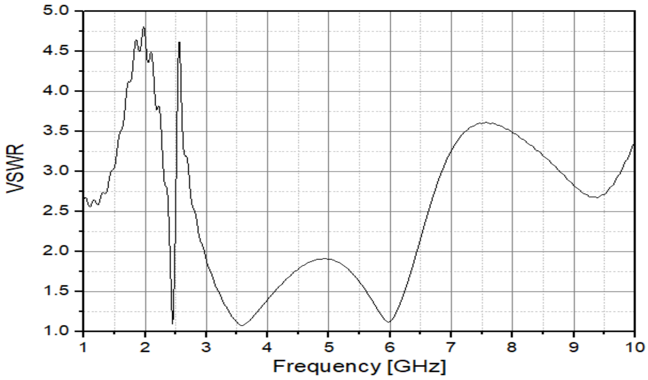


Figure 4. VSWR charts of the proposed antenna

The graph shown in Figure 5 depicts the relationship between gain and frequency for the proposed dual-band antenna. Importantly, our observations indicate that the antenna exhibits favourable gain levels both in the Bluetooth band and in the frequency ranges specified by the FCC. This suggests that the antenna design is well suited to performance in these frequency bands.

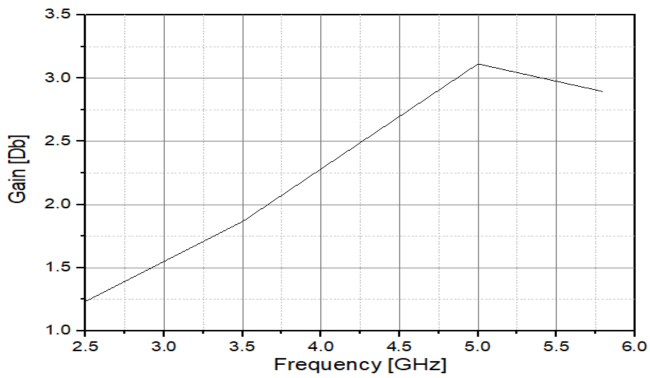


Figure 5. Gain versus frequency graph

### 4.1. Current distribution

The Figures 6 and 7 depict current distributions at different frequencies. Specifically at 2.4 GHz, 3.5 GHz, 5.2 GHz, and 5.8 GHz. Observing these current distributions reveals that when a vertical band is incorporated into the circular ring, it leads to an even split of the current into two bands at the junction. Subsequently there is a merging at the opposite end followed by a downward flow through the vertical band. Consequently the electrical length of the antenna increases. Allowing it to effectively accommodate longer wavelengths than before. The ring structure contributes to radiation across the entire frequency range, but at higher frequencies the central band exhibits the highest current indicating that it primarily contributes to higher resonances [24], [25].

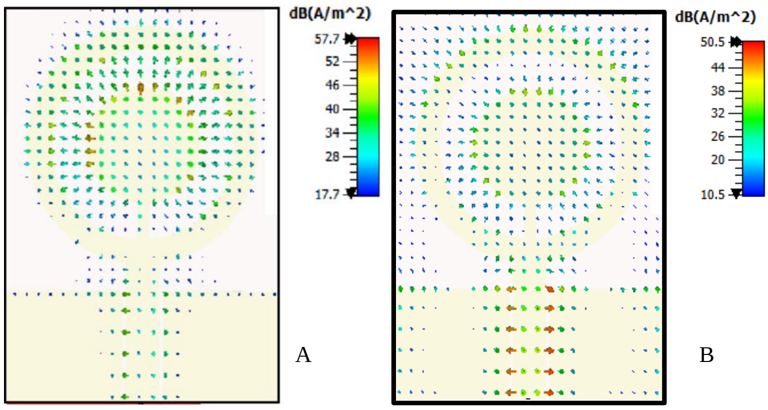


Figure 6. Current distribution of the proposed antenna at (A: 2.4 GHz and B: 3.5 GHz)

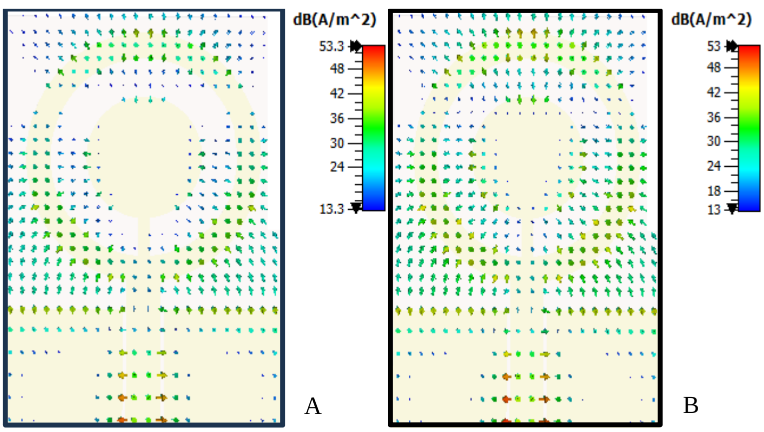


Figure 7. Current distribution of the proposed antenna at (A:5.2 GHZ and B:5.8 GHZ)

In Figures 8–11 the radiation pattern resulting from the simulation of an antenna spanning operational frequencies of 2.4 GHz, 3 GHz, 5.2 GHz, and 5.5 GHz is depicted. A reference is utilized to assess the radiation characteristics pertinent to Bluetooth and UWB applications. The observed radiation pattern in the E-ylane exhibits a configuration resembling that of a "dumbbell 8". This particular arrangement emerges as a consequence of the current's flow which moves towards the antenna and is subsequently emitted by it. These current traverses a slot positioned on the antenna's patch leading to the generation of an electric field pattern. Notably this pattern underscores its bidirectional nature by showcasing maximum field intensity at the patch's periphery.

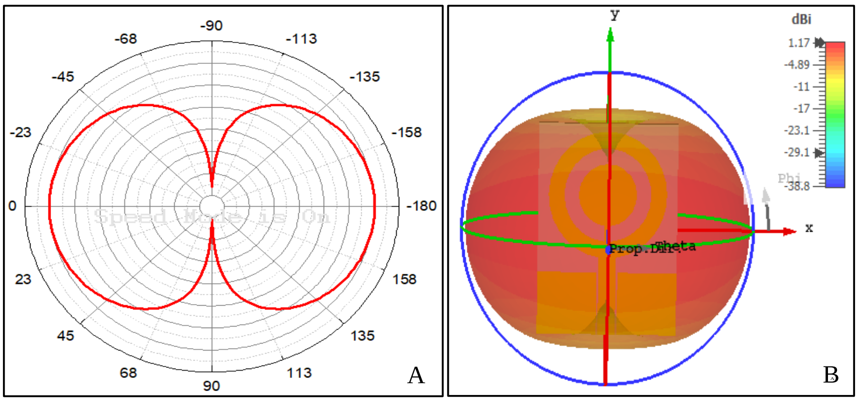


Figure 8. Simulated radiation patterns at 2.4 GHz (A view polar and B view 3D)

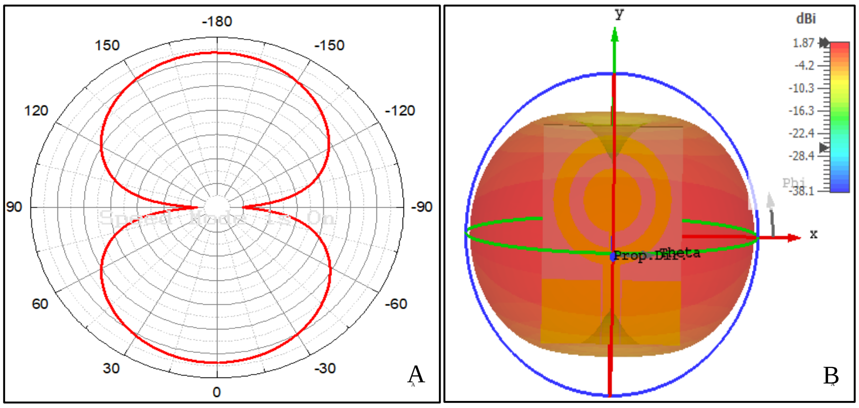


Figure 9. Simulated radiation patterns at 3.5 GHz (A view polar and B view 3D)

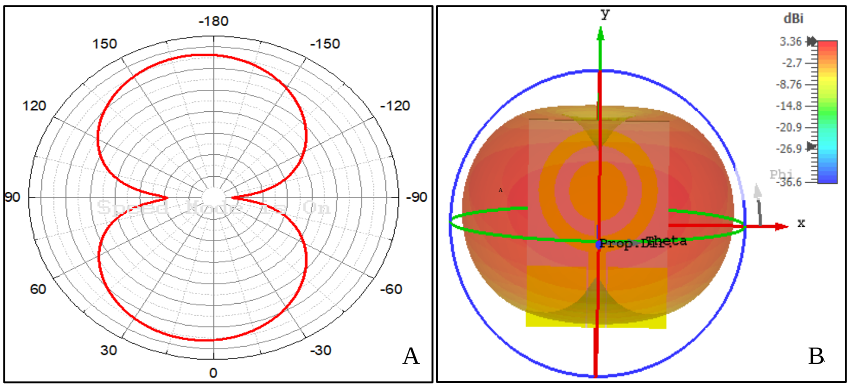


Figure 10. Simulated radiation patterns at 5.2 GHz (A view polar and B view 3D)

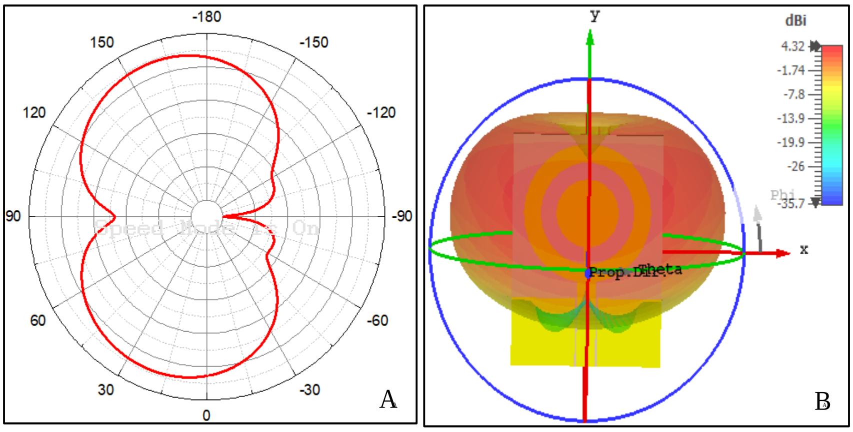


Figure 11. Simulated radiation patterns at 5.8 GHz (A view polar and B view 3D)

Table 2 we examine how the directivity parameter compares at frequencies 2.4 GHz, 3.5 GHz, 5.2 GHz, and 5.8 GHz. It is clear that as the increases the directivity also increases correspondingly. Tables 3 and 4 provide a comparison of parameters such as VSWR. S11 and gain for two radii Rin and Rout of the proposed antenna. These parameters are analysed for frequencies of 2.4 GHz, 3.5 GHz, 5.2 GHz, and 5.8 GHz. It is clear that changing the radius has an impact on the antenna characteristics.

Table 2. Comparison of directivity for different frequency

| Frequency (GHz) | Directivity |
|---|---|
| 2.4 | 1.48 |
| 3.5 | 2.44 |
| 5.2 | 3.47 |
| 5.8 | 3.87 |

Table 3. Comparison of different performance parameters (Rin)

| Frequ(GHz)/ Rin(mm) | Return loss (dB) | S11(dB) | Gain (dB) |
|---|---|---|---|
| 2.4/Rin 5 | 9.66 | -9.62 | 1.17 |
| 3.5/Rin 5 | 25.658 | -25.46 | 1.86 |
| 5.2/Rin 5 | 10.581 | -10.55 | 3.05 |
| 5.8/Rin 5 | 18.783 | -18.86 | 2.89 |
| 2.4/Rin 5.3 | 16.131 | -15.96 | -2.26 |
| 3.5/Rin 5.3 | 26.281 | -25.81 | 1.87 |
| 5.2/Rin 5.3 | 10.581 | -10.57 | 3.04 |
| 5.8/Rin 5.3 | 19.085 | -19.05 | 2.86 |
| 2.4/Rin 5.5 | 6.341 | -6.33 | -4.71 |
| 3.5/Rin 5.5 | 26.281 | -26.05 | 1.85 |
| 5.2/Rin 5.5 | 1.636 | -10.58 | 3.03 |
| 5.8/Rin 5.5 | 19.40 | -19.19 | 2.84 |
| 2.4/Rin 5.7 | 3.697 | -3.69 | -0.52 |
| 3.5/Rin 5.7 | 26.44 | -26.34 | 1.85 |
| 5.2/Rin 5.7 | 10.65 | -10.60 | 3.03 |
| 5.8/Rin 5.7 | 19.40 | -19.67 | 2.79 |

Table 4. Comparison of different performance parameters (Rout)

| Frequ(GHz)/ Rout() | Return loss(dB) | S11(dB) | GAIN (dB) |
|---|---|---|---|
| 2.4/Rout 7.5 | 9.66 | -9.43 | 1.17 |
| 3.5/Rout 7.5 | 25.66 | -25.47 | 1.86 |
| 5.2/Rout 7.5 | 10.58 | -10.56 | 3.05 |
| 5.8/Rout 7.5 | 18.78 | -18.68 | 2.89 |
| 2.4/Rout 7.3 | 22.12 | -20.97 | -0.43 |
| 3.5/Rout 7.7 | 26.44 | -25.99 | 1.85 |
| 5.2/Rout 7.7 | 10.44 | -10.43 | 3.03 |
| 5.8/Rout 7.7 | 20.08 | -20 | 2.75 |
| 2.4/Rout 7.9 | 12.41 | -13.01 | -3.41 |
| 3.5/Rout 7.9 | 26.44 | -26.38 | 1.84 |
| 5.2/Rout 7.9 | 10.30 | -10.31 | 2.98 |
| 5.8/Rout 7.9 | 22.61 | -22.28 | 2.54 |
| 2.4/Rout 8.1 | 4.24 | -4.35 | -4.03 |
| 3.5/Rout 8.1 | 27.32 | -26.55 | 1.86 |
| 5.2/Rout 8.1 | 10.16 | -10.13 | 2.86 |
| 5.8/Rout 8.1 | 29.42 | -28.56 | 2.02 |

## 5. CONCLUSION

The aforementioned proposed circular geometry patch antenna is designed and accurately simulated at the resonance frequencies of 2.4 GHz, 3.5 GHz, 5.5 GHz, and 5.8 GHz using CST software covering both the Bluetooth band (2.4–2.48 GHz) and the FCC band (2.4–5.8 GHz). The methodology employed in the design of these antennas entails the integration of a “circular metamaterial” into the radiating patch. This integration facilitates the manipulation of surface currents on the radiating plate thereby inducing resonance within the Bluetooth frequency band. The antenna meets all the FCC-recoended radiation characteristics. The next antenna will be fabricated and the results of the simulation will be compared to the results of the experiment.

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