Rectangular and circular antennas design for Bluetooth applications

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ABSTRACT

The most researched and examined aspect of the communication system is the wireless connection. Without learning how to operate and use different types of antennas, your knowledge is incomplete. Microstrip patch antenna research has advanced significantly in recent years. When compared to standard antennas, microstrip patch antennas provide additional advantages and opportunities. It is of low volume, light weight, low cost, low appearance, compact and easy to manufacture. This study investigates the differences between rectangular and circular patch antennas. For Bluetooth applications, the center frequency of 2.4 GHz was chosen as the optimal resonant frequency. On a flame retardant (FR-4) epoxy substrate, the antenna dielectric constant is 4.4. Above the ground the base rises 3.6 mm. For the simulation process, high frequency simulation software (HFSS 15) is used as the program design. Antennas 1×1, 1×2, and 1×4 are designed for both circular and rectangular antennas. A comparison was made for both types of antennas and voltage standing wave ratio (VSWR), return losses, gain, directivity and half power beam width (HPBW) were found, and the feature of the rectangular antenna was shown.

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1. INTRODUCTION

An antenna is a portion of a transmitting or receiving system that is designed to emit or receive electromagnetic waves. It is an electrical conductor or a series of conductors. Because of their tiny size and low weight, in addition to their simplicity of manufacture and design robustness, micro-strip antenna technology patches have made great development in recent years. Micro-strip patch antennas have circular and dual polarizations, dual-frequency system, wide-bandwidth, and line-feed pliability [1]–[4].

A microstrip antenna is constructed composed of a thin ground dialectical substrate and a tiny metal conductor. Many current applications, including wireless local area networks (W-LAN), mobile phones, global positioning system (GPS), and other wireless terminals that may be available shortly, rely on microstrip patch antenna shrinking [5]–[7]. Because of their low profile (paper-thin), flatness and conformal structure, structural strength, and lightweight, micro strips or patches are increasingly useful, ease of manufacture using printed-circuit technology is possible, both linear and circular polarization (helpful for frequency - reuse) are possible [8], [9]. The modular designs are suitable; hence, solid-status components also can be directly integrated with the circuit into the microstrip antenna substratum. Feed lines and networks that match [10]–[12] dual-frequency performance is easy to achieve, arrays can be easily created to increase direction, they can easily be mounted without significant alterations on space vehicles, missiles and satellites and compatible with monolithic microwave integrated circuit (MMIC) designs [13], [14]. Patch antennas are highly essential in today's world of wireless communications networks [15], [16]. By engraving the antenna element pattern on a metallic trace and then attaching it to an insulating substrate, conventional microstrip antennas, for instance, a printed circuit board, are created using a metal layer bonded to the substrate's second side, which serves as a ground plane [17]–[19]. Micro-strip patch antennas are more commonly employed than the more well-known rectangular and circular antennas [20], [21]. Microstrip patch antennas, which may be utilized in communication and sensing applications, offer several advantages [17], [22]. The study in [23] is based on the notion that a rectangle patch antenna is higher than the reverse patch antenna loss when an enhanced voltage standing wave ratio (VSWR) value is 1.18 compared to the rectangular patch of the VSWR 1.27. Circular patch antenna presents an eighth percentage higher gain and a 2.0 dB lower side-lobe power than the rectangular patch antenna. The patch antenna structure decreases as the substrate dielectric constant increases, this leads to bandwidth absorption, impedance, and antenna efficiency. Simulated antennas are utilized for 3G communications because of the resonance frequency. A basic patch antenna with a 2.4 GHz operating frequency is given Mahmud *et al.* [24]. The developed process was performed by entering 2.3 of polyurethane (PU)-dielectric empty fruit bunch's (EFB) constant, using matrix laboratory (MATLAB) and high frequency simulation software (HFSS) software. There were a high return loss, low bandwidth, and good radiation efficiency in the antenna, respectively -21.98 dB, 0.28 dB, and 97.33 percent. Communication systems are rapidly expanding as a result of the revolution in antenna engineering [25]. Rectangular, circular, and microstrip patch antenna design, modeling, and analysis are presented. The suggested patch antennas are constructed with ansys HFSS software for dielectric 2.2 RT/droid 5880 material and have a 9 GHz resonance rate, which is inside the X band. An antenna patch for rectangular micro-streaming is included in an optimized circular and rectangular antenna [26]. This work aims to realize multi-band resonance in a flexible antenna for WLAN applications. 2.4 GHz and 4.38 GHz are the proposed design resonances. The antenna is 100 mm to 90 mm in size. The design and analysis of the proposed antenna were based on a full-wave simulation program. Mabaso and Kumar [27], an antenna is developed for a 3-band microstrip. The rectangular patch is burdened by the slots, and the ground is unfit for a three-band process. A Studio Suite 3D electromagnetic (EM) simulation and analysis software (CST) is used to optimize and simulate the suggested design. The triple mode's optimal design structure works at 1.2 GHz, 2.45 GHz, and 5.6372 GHz.

The design was created with the help of HFSS software, and the design operating frequency was set at 2.45 GHz. Rectangular and circular antennas were compared using simulation data and this study was divided into three parts the proposed antenna parameters were determined using the mathematical equations in the first part. The results are presented in part two, with a comparison of both circular and rectangular antennas. Furthermore, there is a brief conclusion in the final section.

2. MATHEMATICAL EQUATIONS

It is possible to simulate microstrip patch antennas in a number of different ways. In terms of popularity, rectangular patches are by far the most popular type of patches. With the gab and transmission line concepts, analyzing the situation is a breeze. This formula is used to calculate the rectangular substrate's parameters. Where C denotes the speed of light in open space.

a) The width (W)

$$W = \frac{C}{2f_o\sqrt{\frac{(\varepsilon_r+1)}{2}}} \tag{1}$$

b) Dielectric constant (effective) ε_{reff}

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+12\frac{h}{W}\right)^{-\frac{1}{2}} \tag{2}$$

c) The effective length

$$L_{eff} = \frac{c}{2f_o\sqrt{\varepsilon_{reff}}} \tag{3}$$

d) Fringe length (ΔL)

$$\Delta L = 0.412h \times \left\{\frac{(\varepsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)}\right\} \tag{4}$$

e) Determine the actual length L, as well as the ground's width and length. Typically, the input impedance is 50 ohms.

$$L = L_{eff} - 2 \times \Delta L, L_g = 2 \times L\ ;\ W_g = 2 \times W \tag{5}$$

f) The gap between an $inset\_fed$ and patch ($G\ fed$) is 1 mm.
g) The circular plane radius

$$R = F/\sqrt{(1 + 2h/(F\varepsilon\_r\ \pi)\ [\ln(\pi F/(2 \times h)) + 1.7726]\ )} \tag{6}$$

Where:

$$F = 8.791 \times 10^9 \times (f_o\sqrt{\varepsilon_r}\ )^{-1} \tag{7}$$

As a result of the (1)–(7), we can calculate the parameters in Table 1 and the Table 2 illustrate the proposed antenna's parameter values of array. The HFSS program was used to create rectangular and circular patch antennas. A substrate with (h) thickness, and a relative thickness permittivity, is used for the antenna development. Figure 1, Figure 2, Figure 3, Figure 4, Figure 5 and Figure 6 depict antennas created with HFSS. The circular and rectangular patch antennas are Figure 1 and Figure 2 with their design and measurements. Internal microstrip line feed supplies both patches. Both designs make use of a substrate with ε_r = 4.4, loss tangent ($tan\ \delta$ = 0.0001) and h = 3.6 mm thickness. In order to make a fair comparison, the same substrate (ε_r= 4.4 and thickness h = 3.6 mm) is utilized in a 2×1 array. Figure 3 and Figure 4 shows the 2×1 circular patch array and 2×1 circular patch array respectively. A quarter wave transformer is used to supply the components in a 4×1 array, which can be both rectangular and circular. A circular antenna array of 4×1 is Figure 5. Calculations were used to determine the size of the quarter-wave transformer. A rectangular patch antenna array of 4×1 is seen in Figure 6.

Table 1. Parameters of designed antennas

Parameters	Values (mm)
W	38
L	28
$Wfed$	3.13
L_g	70
W_g	70
$G\ fed$	1
The height of the conductor	0.035
The length of feed (L_f)	30
The height of the dielectric substrate	3.6
length of inset (f_i)	8.86

Table 2. The proposed antenna's parameter values (array)

Parameter	Definition	Value (mm)
D_1	Distance between two elements	62.5
L_1	Length of source$_1$	30
L_2	Length of source$_2$	3
W_1	Width of 50 Ω impedance line	3

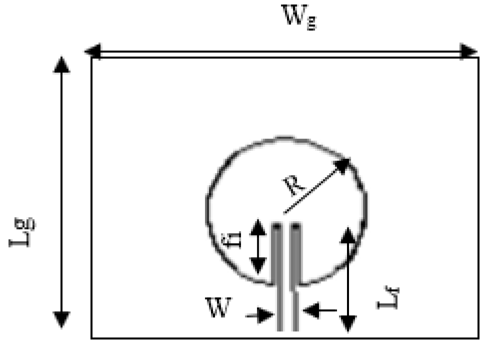


Figure 1. Circular patch designed

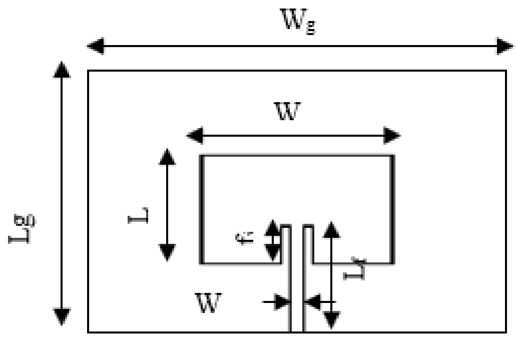


Figure 2. Rectangular patch designed

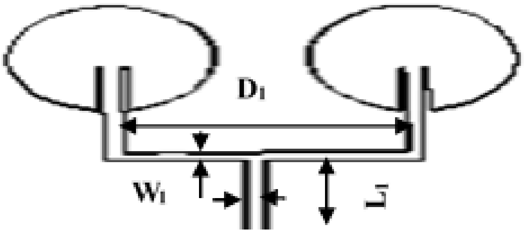


Figure 3. 1×2 Circular patch array designed

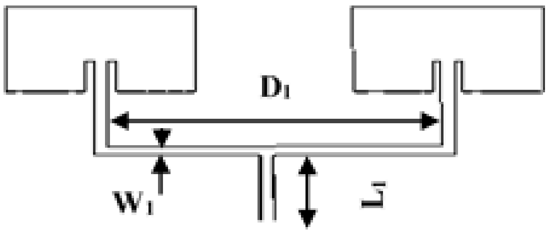


Figure 4. 1×2 Rectangular patch array designed

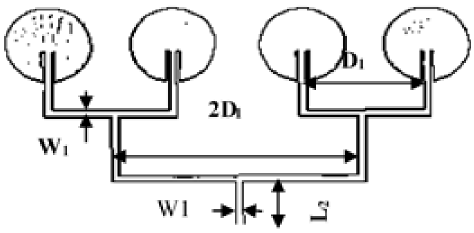


Figure 5. 1×4 Circular patch array designed

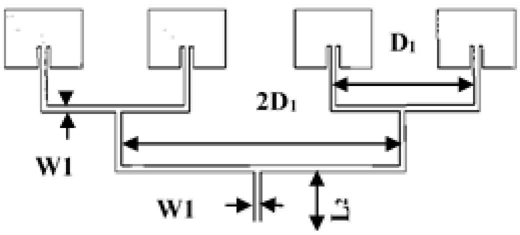


Figure 6. 1×4 Rectangular patch array designed

3. RESULTS AND DISCUSSION OF CIRCULAR AND RECTANGLE PATCH ANTENNA

Figure 7, Figure 8 and Figure 9 show the return loss for each of the designed antennas. As demonstrated in these Figures, a circular antenna has a smaller return loss than the rectangular antenna. Return losses that are negative provide better results, therefore a circular antenna performs better since it has a lower return loss. Figure 10, Figure 11 and Figure 12 respectively, VSWR of circular and rectangular microstrip antennas. Relying on these results, the circular patch antenna exceeds the rectangular patch antenna.

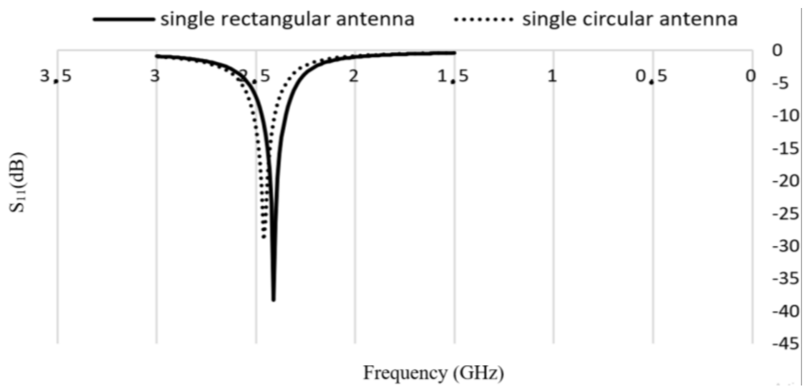


Figure 7. Return loss (S_{11} in dB) of the single circular and rectangular antenna

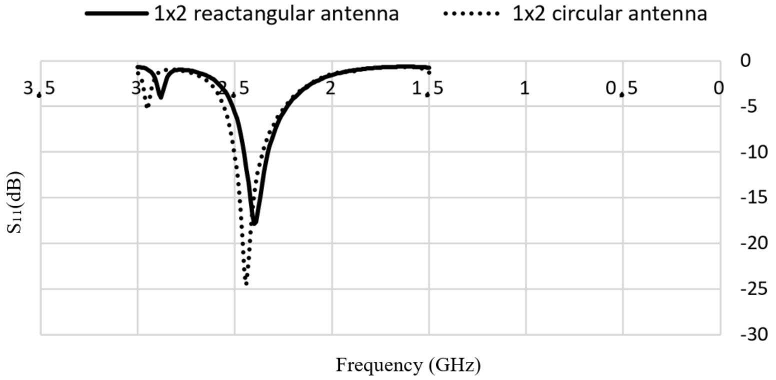


Figure 8. Return loss (S_{11} in dB) of 1×2 circular and rectangular array antenna

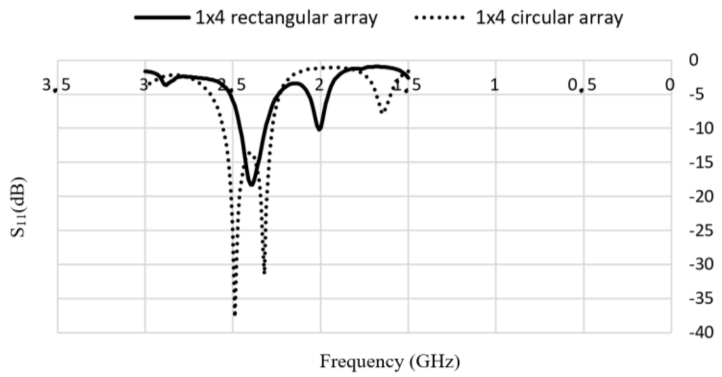


Figure 9. Return loss (S_{11} in dB) of 1×4 circular and rectangular array antenna

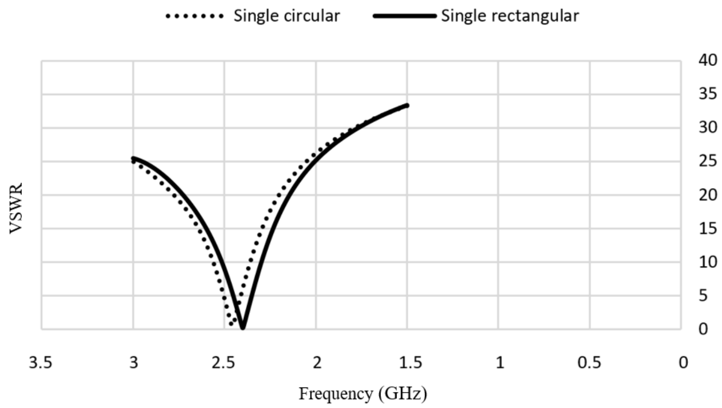


Figure 10. VSWR (in dB) of the single circular and single rectangular antenna

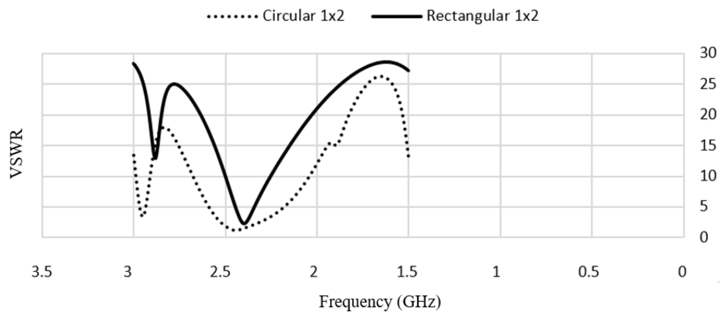


Figure 11. VSWR (in dB) of the (1×2) circular and (1×2) rectangular antenna

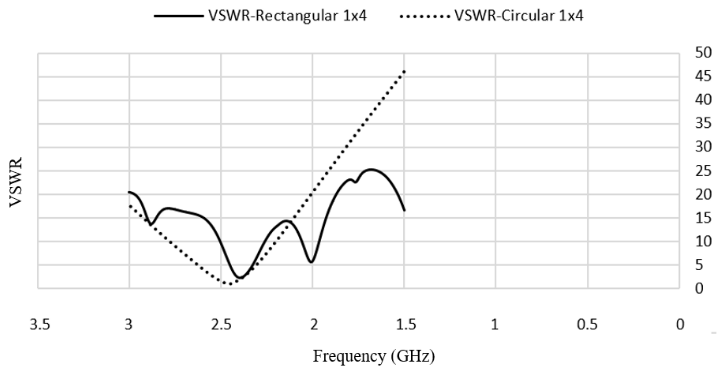
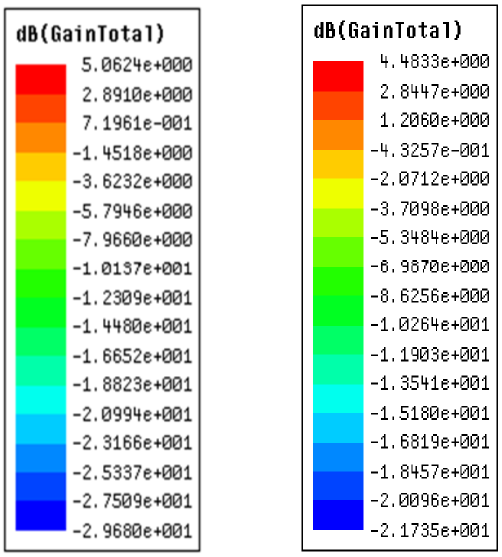


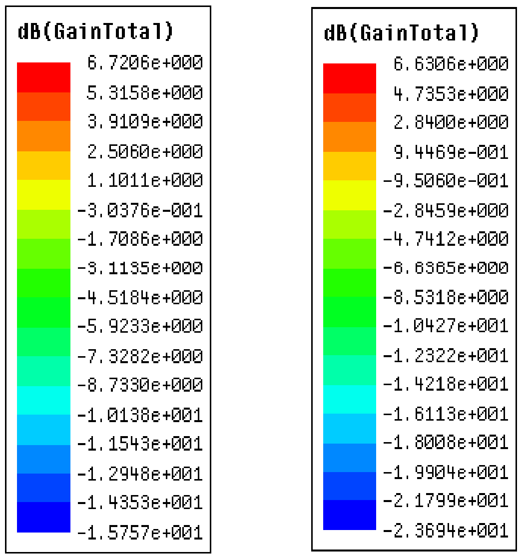
Figure 12. VSWR (in dB) of the (1×4) circular and (1×4) rectangular antenna

Figure 13(a) shows gain for single rectangular and Figure 13(b) gain for single circular patch antenna. Figure 14(a) illustrates gain for 1×2 rectangular and Figure 14(b) gain for 1×2 circular patch antenna while Figure 15(a) shows gain for 1×4 rectangular and Figure 15(b) gain for 1×4 circular patch antenna. Relying on these results, the rectangular patch antenna outperforms the circular patch antenna. Figure 16, Figure 17, and Figure 18 they show the preference of a rectangular antenna over a circular antenna, where Figure 16(a) shows directivity for single rectangular and Figure 16(b) directivity for single circular patch antenna. Figure 17(a) represents directivity for 1×2 rectangular and Figure 17(b) directivity for 1×2 circular patch antenna. As for the Figure 18(a), it shows directivity for 1×4 rectangular and Figure 18(b) directivity for 1×4 circular patch antenna.



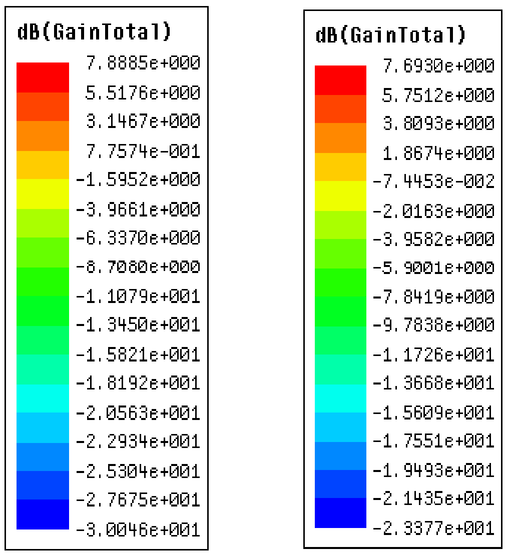
(a) (b)

Figure 13. Gain for single rectangular and single circular patch antenna: (a) for single rectangular and (b) for single circular patch antenna



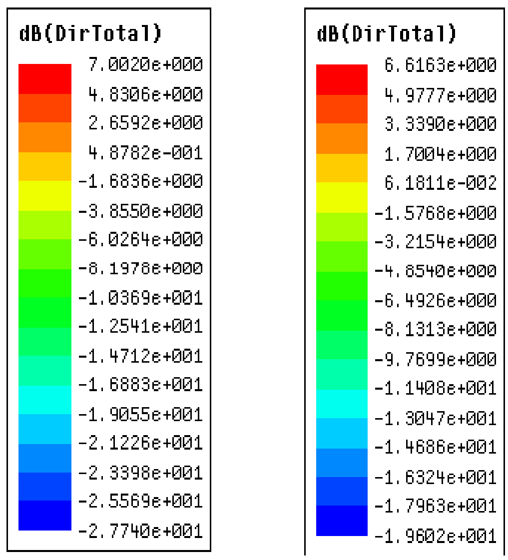
(a) (b)

Figure 14. Gain for 1×2 rectangular and 1×2 circular patch antenna: (a) for 1×2 rectangular and (b) for 1×2 circular patch antenna



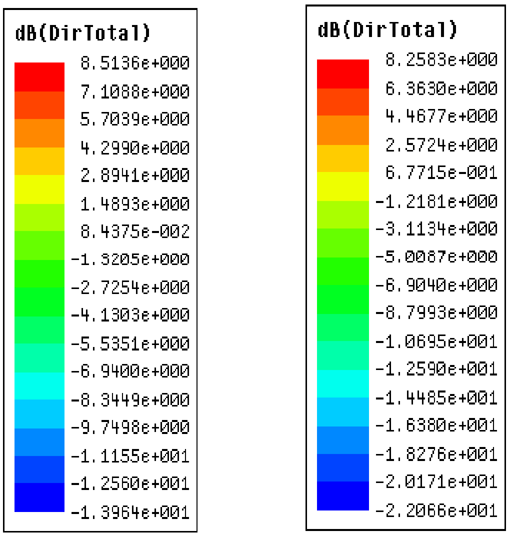
(a) (b)

Figure 15. Gain for 1×4 rectangular and 1×4 circular patch antenna: (a) for 1×4 rectangular and (b) for 1×4 circular patch antenna



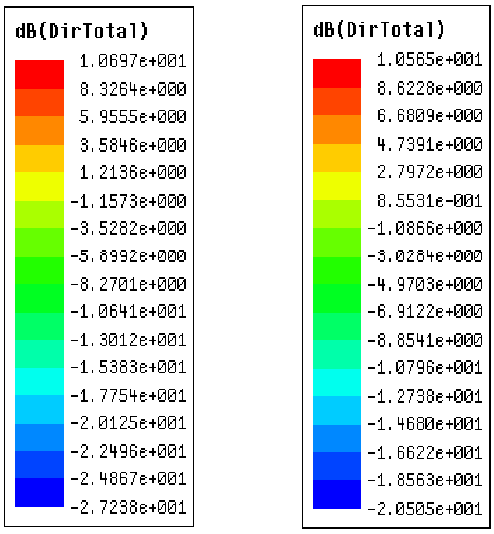
(a) (b)

Figure 16. Directivity for single rectangular and single circular patch antenna: (a) for single rectangular and (b) for single circular patch antenna



(a) (b)

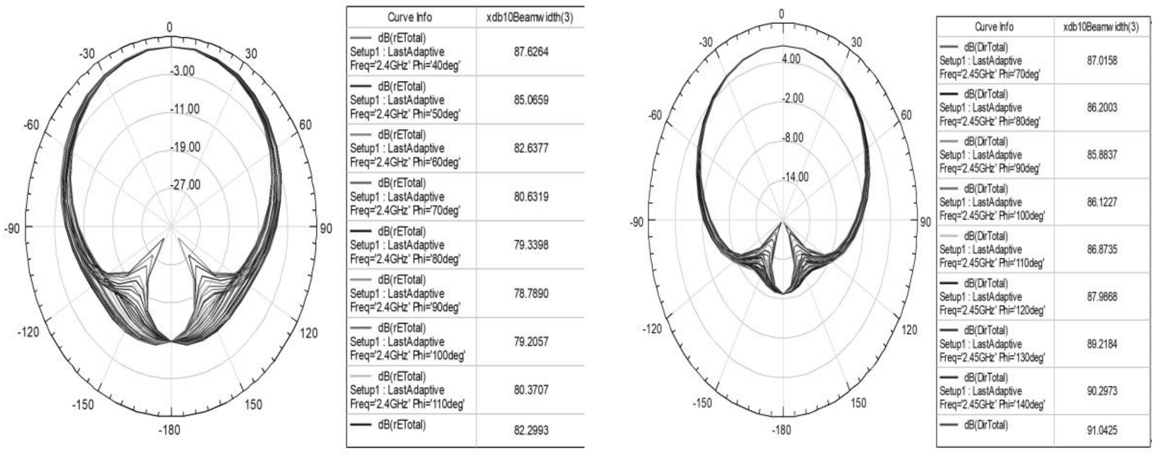
Figure 17. Directivity for 1×2 rectangular and 1×2 circular patch antenna: (a) for 1×2 rectangular and (b) for 1×2 circular patch antenna



(a) (b)

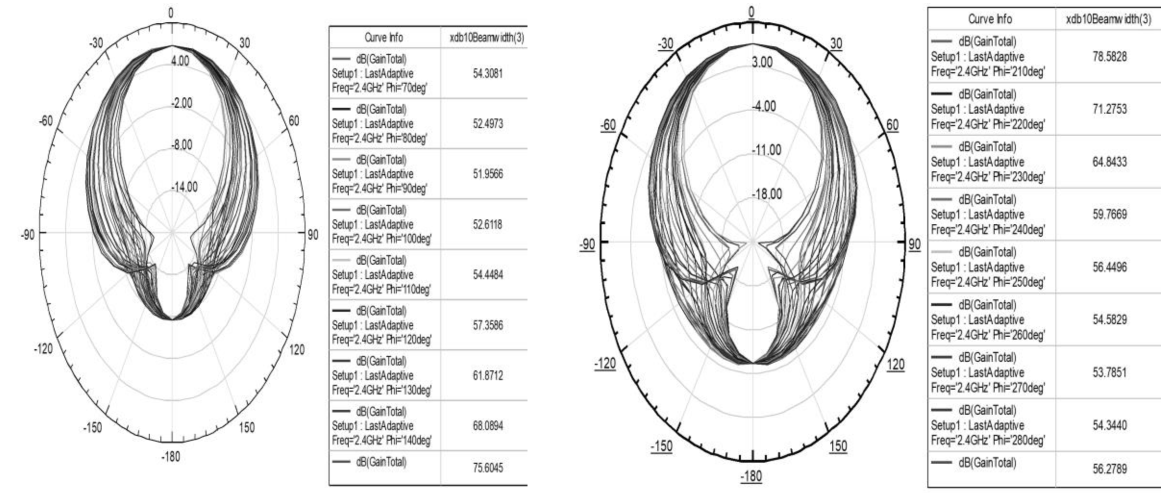
Figure 18. Directivity for 1×4 rectangular and 1×4 circular patch antenna: (a) for 1×4 rectangular and (b) for 1×4 circular patch antenna

Figure 19(a) illustrates half power beam width (HPBW) for single rectangular and Figure 19(b) HPBW for single circular patch antenna. Figure 20(a) shows HPBW for 1×2 rectangular and Figure 20(b) HPBW for 1×2 circular patch antenna, while Figure 21(a) explains HPBW for 1×4 rectangular and Figure 21(b) represents HPBW for 1×4 circular patch antenna. The following Table 3 and Table 4 compares several performance metrics between rectangular and circular antenna. The results for the rectangular patch are quite similar to those from the circular patch, as shown in Table 3 and Table 4. In the singular matrices of both shapes, the return loss is the best (rectangular and circular). When the value of the VSWR is close to one, it has the best value. The circular antenna has a superior VSWR, and the gain and directivity of both shapes (rectangular and circular) improve as the number of components grows, as does the side-lobe level. Finally, optimal radiation patterns are achieved when the HPBW value is low. The Table 5 displays the comparison of the proposed circular antenna and rectangular antenna with references [28]–[30] and [25] at frequency 2.4 GH. It was noted that the proposed circular and rectangular antennas were superior to the antennas in those references.



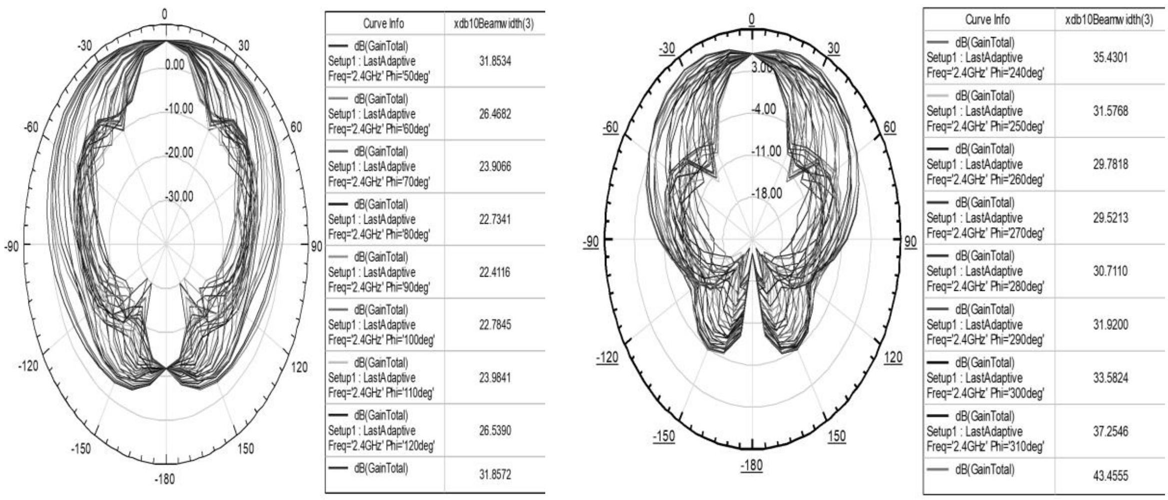
(a) (b)

Figure 19. HPBW for single rectangular and single circular patch antenna: (a) for single rectangular patch antenna and (b) for circular patch antenna



(a) (b)

Figure 20. HPBW for 1×2 rectangular and 1×2 circular patch antenna: (a) for 1×2 rectangular patch antenna and (b) for 1×2 circular patch antenna



(a) (b)

Figure 21. HPBW for 1×4 rectangular and 1×4 circular patch antenna: (a) for 1×4 rectangular patch antenna and (b) for 1×4 circular patch antenna

Table 3. Comparison of different performance parameters (rectangular)

Parameter	Single rectangular	1×2 rectangular	1×4 rectangula
S_{11}	-38.2830	-17.8783	-17.7506dB
VSWR	0.8325	2.23dB	2.2634dB
Gain	4.7357	6.7206dB	7. 8885 dB
Directivity	6.658	8.5136dB	10.697dB
HPBW	78.7890	51.9566	22.4112

Table 4. Comparison of different performance parameters (circular)

Parameter	Single circular	1×2 circular	1×4 circular
S_{11}	-29.0791	-24.5730dB	-17.6850 dB
VSWR	0.8904	1.0273 dB	2.2796 dB
Gain	4.4833	6.6306 dB	7.6930 dB
Directivity	6.6163	8.2583 dB	10.565 dB
HPBW	86.1227	53.7851	29.5213

Table 5. comparison of the proposed circular antenna and rectangular antenna with references [28]–[30], [25]

Parameter	Single rectangular antenna [28]	Single rectangular antenna [29]	Proposed single rectangular antenna	Single circular antenna [30]	Single circular antenna [25]	Proposed single circular antenna
S_{11}	-24.03	29.601	-38.2830	-26.7	-21.69	-29.0791
VSWR	1.14	1.58	0.8325	1.3	1.43	0.8904

4. CONCLUSION

The simulation results from HFSS Microwave Studio were employed to compare the performance of a rectangular patch antenna with a circular patch antenna. Each antenna designs perform wonderfully for Bluetooth spectrum applications. By comparing the single antennas, 1×2 and 1×4 for each of the circular and rectangular antennas, the preference of the rectangular antenna over the circular antenna at frequency 2.4 GHz was shown for all the proposed designs.

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