Performances of Symmetric and Asymmetric T-slot Microstrip Antennas for Bluetooth Communication

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ABSTRACT—*Bluetooth is a short distance unlicensed wireless communication technology operating at 2.4 GHz band and primarily used for data transfer between portable devices. In this paper, small size microstrip patch antennas, loaded by symmetric and asymmetric T-shaped slots are designed and a comparative study of their performance at Bluetooth frequency band is presented. High frequency structure simulator (HFSS) software is used for antenna simulation. Improved bandwidth, uniform radiation pattern and good gain of the antenna are achieved using asymmetric T-slot microstrip antenna compared to symmetric T-slot microstrip antenna. The dimension of asymmetric T-slot microstrip antenna is 75% less than the symmetric T-slot microstrip antenna. Performance of the antennas, through parametric studies, related to the dimensions of the symmetric and asymmetric T-slots, is also presented.*

Keywords— Microstrip antenna, T-slot, Bluetooth, bandwidth, gain

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1. INTRODUCTION

Bluetooth is a short range wireless communication technology and it uses very low power. It operates at 2.4-2.484GHz band and is license-free [1-3]. Devices like cell phones, mice, laptop and headphones can be connected to each other wirelessly by Bluetooth technology for data transfer. Miniaturized integrated antennas with small size are the primary requirement for small devices for Bluetooth communication [4-6]. Advantages like light weight, low profile, dual and multiple frequency operation, capability and low fabrication cost make microstrip patch antenna very popular in communication system. Apart from these advantages, microstrip patch antenna have major disadvantages of narrow bandwidth, low power handling capability, low gain, low efficiency and extraneous radiations from feed. Various efforts have been taken by the researchers to overcome these limitations [7]. Structures with different substrates and with different feeding techniques have been proposed. Feeding techniques, used, are aperture-coupled feeding, co-axial feeding, proximity coupled feeding and Microstrip line feeding [7]. Various structures have been investigated in order to overcome the limitations of microstrip antenna. To achieve small size, antenna structures, like, U-shaped patch [8], E-shaped patch [9], double C-shaped antenna [10] etc. are investigated. A comparative study on aperture-coupled microstrip antennas excited by cross slot and T-slot is reported [11] where foam is used for better performances of the antennas. Recently, design of a T-stub coupled circularly polarized microstrip antenna is reported [12].

In this paper, a microstrip patch antenna with asymmetrical T-slot is designed. For an asymmetrical T-slot on microstrip patch, two arms of the T-slot are unequal. This gives flexibility in antenna design where by choosing appropriate lengths of the two arms required performance of the antenna can be achieved. HFSS software is used for antenna design. The designed antenna has sufficient bandwidth, more than 3 dB gain and is found suitable for Bluetooth application.

2. BASIC DESIGN EQUATIONS FOR MICROSTRIP ANTENNA

Microstrip patch antenna, in its basic form, consists of a conducting patch on one side of a dielectric substrate (of thickness h and dielectric constant ε_r) and separated by a ground plane. Generally, microstrip antenna is fed by a coaxial SMA connector (Fig. 1).

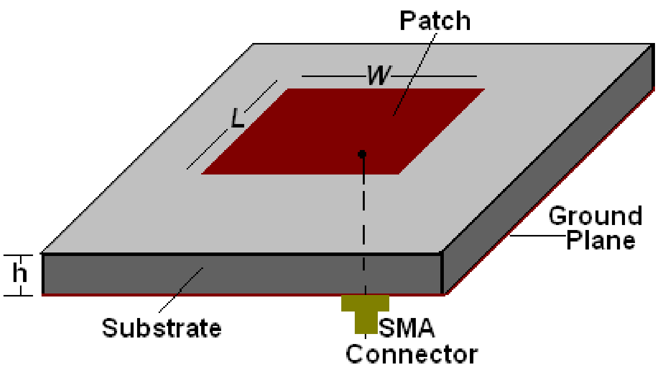


Figure 1: Microstrip Antenna Configuration

In order to calculate the dimension of a microstrip patch (without T-slot) at Bluetooth frequency, the following design formulas are used. The effective length of the patch L_{eff} can be obtained by using the formula [13]

$$L_{eff} = \frac{c}{2 f_0 \sqrt{\varepsilon_{reff}}} \tag{1}$$

Where f_0 is operating frequency, '*c*' is the velocity of light, ε_{eff} is the effective dielectric constant and the width (*W*) of the antenna can be calculated by using the formula

$$w = \frac{c}{2 f_0 \sqrt{\frac{\varepsilon_r + 1}{2}}} \tag{2}$$

Similarly the effective dielectric constant (ε_{reff}), the length extension (ΔL) due to fringing fields and the length of the patch (L) can be obtained by using the following formula [13]

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}[1 + 12\frac{h}{w}]^{-\frac{1}{2}} \tag{3}$$

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

$$L = L_{eff} - 2\Delta L \tag{5}$$

In HFSS simulation, first the dimensions of patch antenna without T-slot are calculated at Bluetooth frequency using the formula, given by (1) to (5). Then the T-slot is incorporated on the patch and the new dimensions of the slotted patch, feed position etc. are obtained for desired resonance frequency, bandwidth and gain using HFSS software.

3. DESIGN OF SYMMETRIC AND ASYMMETRIC T-SLOT MICROSTRIP ANTENNAS

3.1 Symmetric T-slot Microstrip Antenna

Configuration of the proposed T-slot microstrip patch antenna is shown in Fig. 2. T-slot has uniform width of 'd' with T-slot dimensions of 'a' and 'b'. Radiating patch has width and length of 'W' and 'L' respectively. The length of the T-slot is 'c'. If for a T-slot, a=b, the T-slot is symmetric and if $a \neq b$, the T-slot is asymmetric. Ansoft HFSS software, which is based on finite element method (FEM), is used for design of the antenna. FR-4 substrate with dielectric constant ε_r =4.4, substrate thickness h=1.6mm and loss tangent tanδ=0.02 is used for antenna design. The antenna is designed to operate at Bluetooth frequency band of 2.45 GHz.

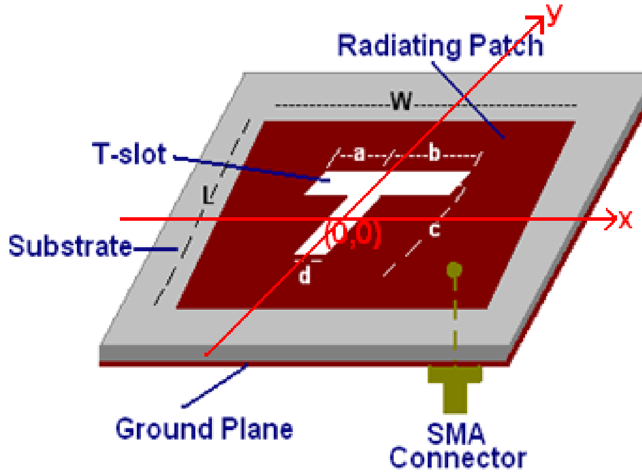


Figure 2: T-slot Microstrip Antenna

Initial dimension of the patch is chosen according to the design formulas presented in section 2. Then using symmetric T-slot on the patch a large number of simulations is done by varying the different dimensions of the patch and T-slot and final dimensions are obtained for 2.45 GHz frequency with sufficient gain of the antenna. The final dimensions of the patch antenna with T-slot on the patch, after simulation using HFSS are:

Length of patch(L)=53.4mm, width of patch(W)=73.4mm, T-slot dimension a=b=10mm, T-slot length 'c'=20mm, slot width 'd'=2mm. Coaxial feeding technique is used and feed is at point x = -11mm and y = -10mm (Fig.2). The simulation result for S_{11} parameter of symmetric T-slot microstrip patch antenna is shown in Fig. 3.

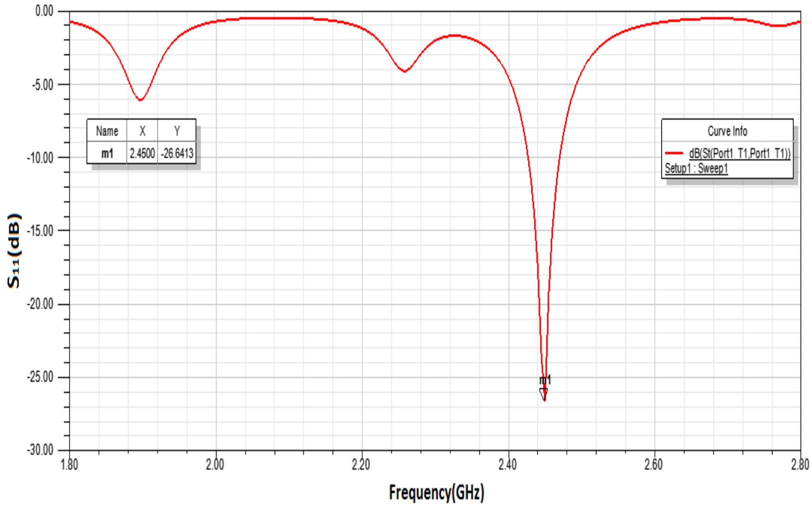


Figure 3: Return Loss Plot of the Symmetric T-slot Microstrip Antenna

10dB return loss bandwidth is 2.42 GHz to 2.47GHz (50 MHz) which is less than the required bandwidth for Bluetooth communication 2.4 GHz to 2.484 GHz. Impedance matching is obtained with S_{11}= -27dB. The radiation pattern of the symmetric T-slot microstrip patch antenna is shown in Fig.4 which shows broadside radiation pattern.

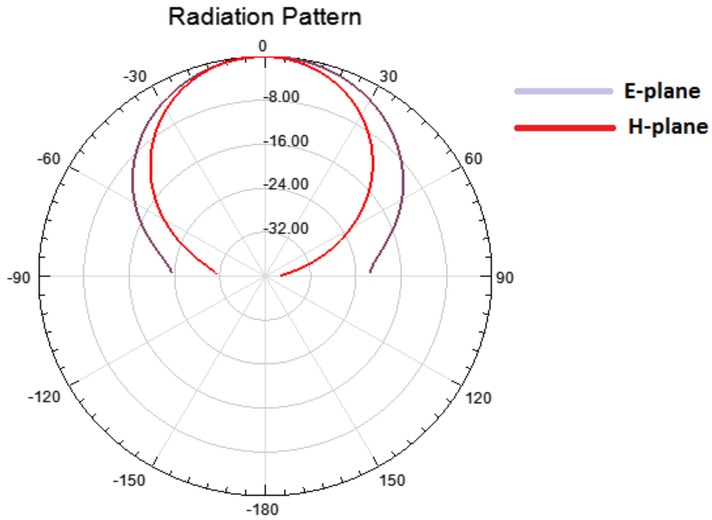
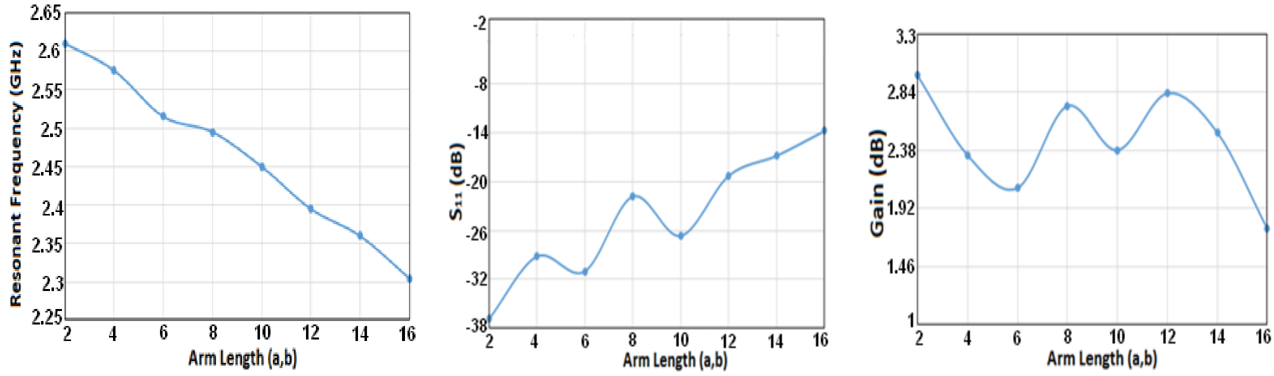


Figure 4: Radiation Pattern Plot for the Symmetric T-slot Microstrip Antenna

For parametric studies, the dimensions of two arms of the T-slot are varied and length ‘c’ is kept constant. This is to investigate the effect of arm length i.e. ‘a’, ‘b’ and length ‘c’ on the characteristics of symmetric T-slot microstrip patch antenna. The variations of resonant frequency, S_{11} and Gain with arm length are plotted in Fig. 5(a) to Fig. 5(c) respectively. The results are also tabulated in Table 1.



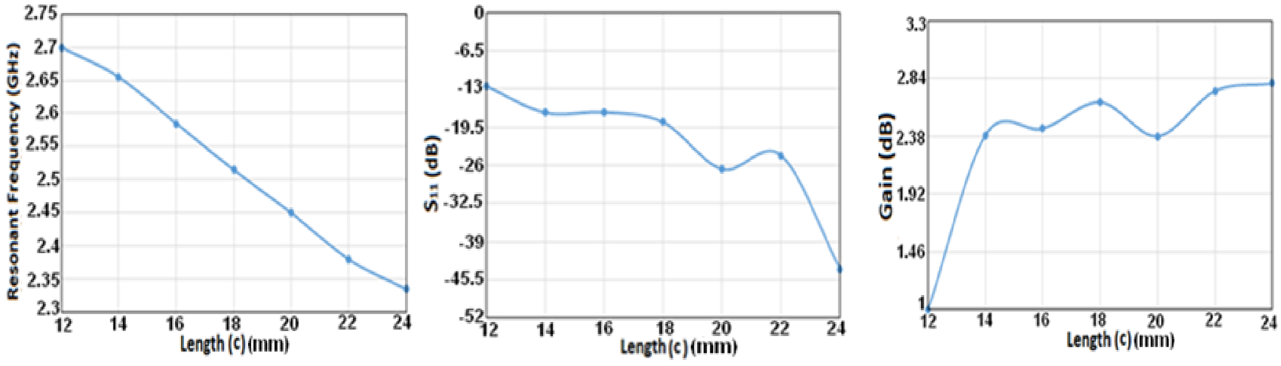
(a) (b) (c)

Figure 5: Variation of Antenna Parameters with Arm Length (a,b) of Symmetric T-slot Microstrip Antenna

Table-1: Variations of antenna parameters with arm length ‘a’ & ‘b’ of T-slot (length c=20mm)

Slot arm length(a=b)	Resonance frequency	S_{11}at resonance frequency	Gain
a=b=2mm	2.61 GHz	-36.8dB	2.9dB
a=b=4mm	2.57 GHz	-29.1dB	2.3dB
a=b=6mm	2.51 GHz	-30.9dB	2.1dB
a=b=8mm	2.50 GHz	-21.8dB	2.7dB
a=b=10mm	2.45 GHz	-26.6dB	2.38dB
a=b=12mm	2.40 GHz	-19.2dB	2.8dB
a=b=14mm	2.40 GHz	-16.8dB	2.5dB
a=b=16mm	2.30 GHz	-13.7dB	1.7dB

In parametric studies, for variation of antenna parameters with dimension ‘c’ keeping arm lengths dimensions ‘a’ and ‘b’ constants, are plotted in Fig. 6(a) to Fig. 6(c). The results are also tabulated in Table 2.



(a) (b) (c)

Figure 6: Variation of Antenna Parameters with Length (c) of Symmetric T-slot Microstrip Antenna

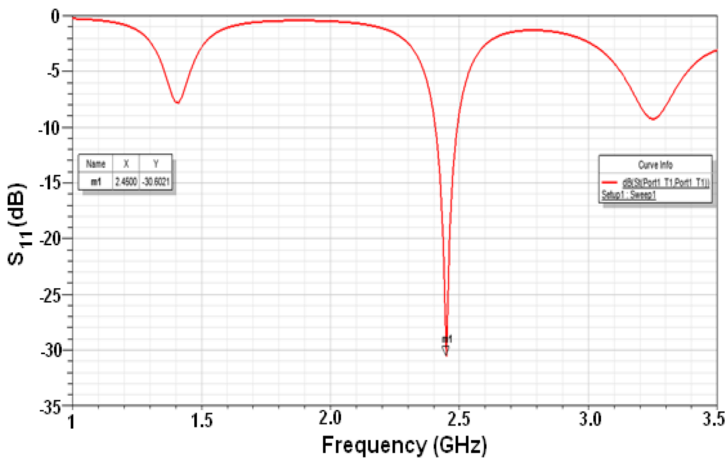
Table-2: Variations of antenna parameters with length ‘c’ of T-slot (arm length a=b=10mm)

Slot length(c)	Resonance frequency	S_{11}at resonance frequency	Gain
c=12mm	2.70 GHz	-12.5 dB	1.0 dB
c=14mm	2.65 GHz	-17.0 dB	2.4 dB
c=16mm	2.58 GHz	-16.9 dB	2.4 dB
c=18mm	2.51 GHz	-18.6 dB	2.6 dB
c=20mm	2.45 GHz	-26.6 dB	2.4 dB
c=22mm	2.38 GHz	-24.3 dB	2.7 dB
c=24mm	2.33 GHz	-43.6 dB	2.8 dB

3.2 Asymmetric T-slot Microstrip Antenna

For asymmetric T-slot microstrip antenna,. The final dimensions of the patch, after a large number of simulations using HFSS, are:

Length of patch (L)= 26.7mm, width of patch(W)= 36.7 mm, T-slot dimension ‘a’=6mm, T-slot dimension ‘b’=10mm, T-slot length ‘c’=20mm, slot width ‘d’=2mm. The simulation result for S_{11} parameter of asymmetric T-slot microstrip patch antenna is shown in Fig. 7.



Figur 7: Plot of Reflection Coefficient for the Asymmetric T-slot Microstrip Antenna

10dB S_{11} bandwidth is 2.38 GHz to 2.5GHz (120 MHz) which is more than the required bandwidth for Bluetooth communication 2.4 GHz to 2.484 GHz. Also good impedance matching is ontained (S_{11}= -31dB). The radiation pattern of the asymmetric T-slot microstrip patch antenna is shown in Fig. 8, which shows broadside radiation pattern.

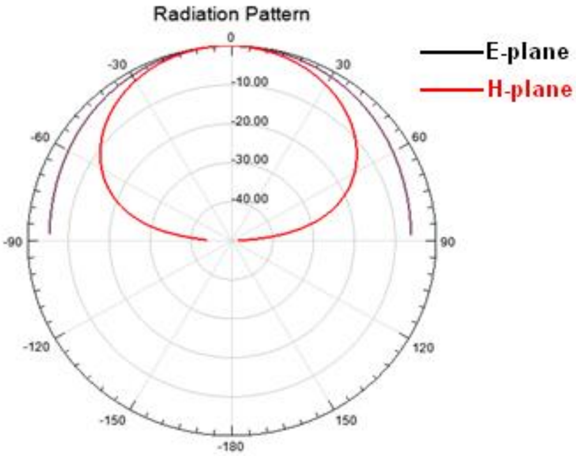
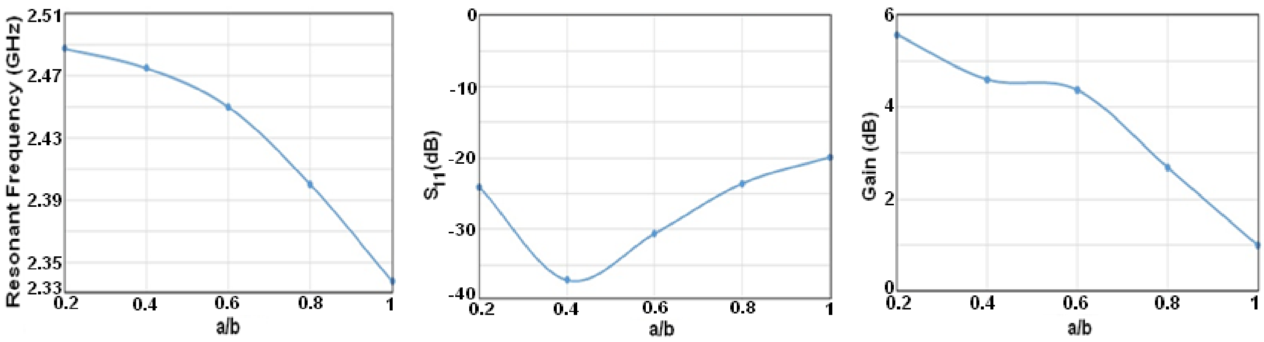


Figure 8: Radiation Pattern of the Asymmetric T-slot Microstrip Antenna

The simulated gain of the proposed antenna at 2.45 GHz is 4.4dB. For parametric studies, the value of one of the two slots is kept constant and the dimensions of other slot are varied. This is to investigate the effect of slot arm length ratio i.e. 'a/b' ratio on the characteristics of asymmetric T-slot microstrip patch antenna. The variations of resonant frequency, S_{11} and gain with a/b ratio are plotted in Fig. 9(a), Fig. 9(b) and Fig. 9(c) respectively.



(a) (b) (c)

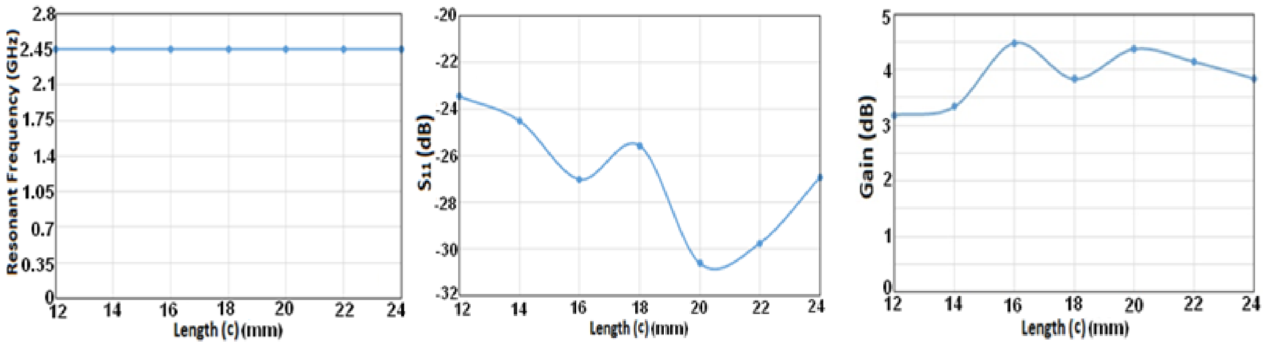
Figure 9: Variation of Antenna Parameters with Arm Length Ratio (a/b) of Asymmetric T-slot Microstrip Antenna

The variations of antenna parameters with a/b ratio are tabulated in Table 3.

Table 3: Variations of antenna parameters with arm length ratio (a/b) of T-slot

Slot length 'b'(constant)	Slot length 'a'(varying)	Slot length ratio 'a/b'	Resonant frequency	S_{11}at resonance frequency	Gain
10mm	2mm	0.2	2.48 GHz	-24.1 dB	5.6 dB
10mm	4mm	0.4	2.47 GHz	-37.1 dB	4.6 dB
10mm	6mm	0.6	2.45 GHz	-30.6 dB	4.4 dB
10mm	8mm	0.8	2.4 GHz	-23.6 dB	2.7 dB
10mm	10mm	1.0	2.33 GHz	-19.9 dB	1.0 dB

Fig. 9 and Table 1 show that appropriate value of a/b ratio is important to achieve required antenna parameters for a particular application. The variations of antenna parameters with length 'c' of the T-slot, keeping a=b=10mm constant, are shown in Fig. 10(a) to Fig. 10(c). The corresponding simulated results are tabulated in Table 4.



(a) (b) (c)

Figure 10: Variation of Antenna Parameters with Length (c) of Asymmetric T-slot Microstrip Antenna

Fig. 10 shows that resonance frequency remains unchanged with the variation of slot length whereas S_{11} and gain of the antenna depend on slot length.

Table 4: Variations of antenna parameters with length ‘c’ of asymmetric T-slot (a=b=10mm)

Slot length (c)	Resonance frequency	S_{11} at resonance frequency	Gain
c=12mm	2.45 GHz	-23.5 dB	3.2 dB
c=14mm	2.45 GHz	-24.5 dB	3.3 dB
c=16mm	2.45 GHz	-27.0 dB	4.5 dB
c=18mm	2.45 GHz	-25.6 dB	3.8 dB
c=20mm	2.45 GHz	-30.6 dB	4.4 dB
c=22mm	2.45 GHz	-29.7 dB	4.1 dB
c=24mm	2.45 GHz	-26.9 dB	3.8 dB

3.3 Comparison of Performances between Symmetric and Asymmetric T-slot Microstrip Antennas

Comparison of performances between symmetric and asymmetric T-slot microstrip antennas is tabulated in Table 5.

Table-5: Comparison of antenna parameters between symmetric and asymmetric T-slot patch antennas

Antenna structures	Resonant frequency	S_{11} at resonance frequency	Bandwidth	Gain	Patch area
Symmetric T-slot patch	2.45GHz	-26.6dB	50MHz	2.38dB	53.4x73.4=3919.6 mm^2
Asymmetric T-slot patch	2.45GHz	-30.6dB	120MHz	4.4dB	26.7x36.7=979.9 mm^2

In Table 5, at 2.45 GHz frequency, in case of symmetric T-slot patch antenna, the area of the microstrip patch is 53.4x73.4=3919.6 mm^2 and in case of asymmetric T-slot patch antenna, the area of the microstrip patch is 26.7x36.7=979.9 mm^2. Therefore, in using asymmetric T-slot patch antenna, size is reduced by about 75%. Also gain and bandwidth are increased in case of asymmetric T-slot patch antenna.

4. CONCLUSIONS

A small size microstrip antenna with asymmetric T-slot is designed for the application in Bluetooth communication and the performances of this antenna are compared with the performances of symmetric T-slot microstrip antenna. HFSS software is used for antenna design. At 2.45 GHz band the microstrip antenna with asymmetric T-slot has gain of 4.4 dB which is about 2 dB more than the gain of microstrip antenna with symmetric T-slot. The asymmetric T-slot microstrip antenna for Bluetooth application is designed whose area is reduced by 75% than a microstrip antenna with symmetric T-slot. The bandwidth of asymmetric T-slot microstrip antenna covers the whole frequency band of Bluetooth which can not be achieved by using symmetric T-slot microstrip antenna. Parametric studies show that the dimensions of the T-slot are very important for desired performance. The future work is to reduce the dimension of asymmetric T-slot microstrip antenna further by using shorting pin.

5. REFERENCES

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