CO-AXIAL FED MICROSTRIP RECTANGULAR PATCH ANTENNA DESIGN FOR BLUETOOTH APPLICATION

Phani kumar TVB[1], Abhinay Kumar Reddy S[2], Aditya K[3],NagaRaju A[4]

[1] *Assistant Professor, ECE Department, IARE, A.P, India,* ***phanitvb@gmail.com***
[2]*PG Student, CSE Department, University of central Missouri, Missouri, USA,****santimallaabhinay@gmail.com***
[3]*Design Engineer Trainee, Avionics Department, InfoTech, Andhra Pradesh, India,* ***konthamaditya9@gmail.com***
[4]*UG Student, ECE Department, IARE, Andhra Pradesh, India,****nagaraju.a.514@gmail.com***

Abstract

Abstract: - A design procedure for Microstrip rectangular patch antenna for Bluetooth application is presented. In Bluetooth open wireless technology important constraints are size and installation of the antenna. In this paper the proposed antenna is designed using transmission line model and can create resonance at 2.45 GHz with in Bluetooth frequency range 2400-2485 MHz. Coaxial feed technique is used to excite the patch even though microstrip inset feed technique is present because of low radiation and ease of installation. Placement of co axial feed for this patch is taken almost one third of length from virtual ground line i.e., at the center line of the patch which is along the width lines and can creates resonance at 2.45 GHz with minimum reflection coefficient (s_{11}) at this feed position. Fabrication is done using photolithographic technique and is tested with Agilent Network Analyzer to measure VSWR and S_{11} parameters. S-parameters are used to measure the antenna performance and shown that S_{11} value is low at resonant frequency. Variation of input impedance as function of frequency is also presented using Smith Chart. Radiation patterns are drawn both in E-plane, H-plane in anechoic chamber and parameters like gain, beam width (both E and H planes) are measured. Designed antenna is simulated on FR4 substrate with loss tangent tanδ=0.02 using Agilent Advance Design System (ADS) software. Simulation and measurement results are compared and discussed.

Index Terms: *Transmission line model, Blue tooth communications, S-parameters, VSWR, Anechoic chamber.*

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1. INTRODUCTION

To exchange the data over a short distance communication a wireless technology called Bluetooth is used with in frequency range 2400-2485 MHz. So antenna is an essential device to transmit the data through unguided media. In wireless communication applications the major constraints are size, weight and ease of installation of antennas. These constraints are overcome by using a low or flat profile Microstrip Antenna(MSA). MSA is a simplest configuration of radiating patch of different shapes on one side of dielectric material whose dielectric constant lies in $4 < \varepsilon_r < 12$ and ground plane on the other side. It is a narrow band wide beam antenna. The conductors used for patch are generally copper and gold of different shapes. In order to simplify mathematical analysis and to predict patch performance at resonance frequency, conventional shapes like rectangular, square, circular etc. are generally preferred. Excitation of patch is done by using different techniques like inset feed, co-axial feed, aperture coupling etc. This paper describes designing procedure for rectangular patch antenna with co axial feed technique at 2.4 GHz resonant frequency and radiating characteristics are presented in both E and H planes.

In transmission line model, the microstrip antenna is represented by two slots of width W and height h, separated by a transmission line of length L. Most of the electric fields are reside in the substrate and parts of some lines are in air. Since microstrip line is a non homogeneous, it can not support Transverse Electromagnetic Mode (TEM) of transmission and because of phase velocities change in air and dielectric media, it can support quasi-TEM mode only. By considering the fringing effect and wave propagation, effective dielectric constant (ε_{reff}) is obtained rather than dielectric constant (ε_r) whose value is slightly less than ε_r. The length of the patch is slightly less than $\lambda_g/2$, where λ_g is guided wavelength in dielectric media ($\lambda_0/\sqrt{\varepsilon_{reff}}$) and λ_0 is free space wavelength to support TM_{10} mode.

Patch is treated as an open-end transmission line and hence current is minimum and voltage is maximum at open-end. At the center line of the patch along the width line, the voltage falls to minimum and almost becomes to zero, but current rises to maximum and forms virtual ground line. Beyond that line again voltage rises to maximum in reverse polarity and current falls to zero. So input impedance (Z_{in}) of the patch varies along length line and remains constant along width (W) lines. Normal and tangential components of electric fields are present at the edges of the patch with respect to ground. Since these two slots are separated by distance of $\lambda_g/2$, the normal electric field components are in opposite direction along the width at the two edges and hence they cancel with each other in broadside direction.

However, tangential components are in phase resulting combined electric field and maximum radiation normal to the substrate surface. Presence of the fringing fields along the radiating slots causes microstrip patch electrically greater than physical dimension. The extended length (ΔL) is given empirically by Hammerstad [1]. Fig 1 shows photographic negative of co-axial fed Rectangular patch antenna used for fabrication.

The loss tangent of dielectric media indicates the quantity of electric energy converted into heat by dielectric media itself. The antenna efficiency can be increased by having lowest possible loss tangent. The relative dielectric constant ε_r determines the physical dimension of antenna. Lower the value of ε_r larger the antenna size and vice versa. In this presentation antenna is designed with FR_4 material having ε_r=4.4, thickness h=1.6 mm and loss tangent $\tan\delta$=0.02. FR_4 is inexpensive and can be used for wireless communication applications. Moreover, it gives better results and cost is effective. SMA(Sub-Miniature) co-axial connector is chosen to excite patch antenna. The main application of SMA connector is on component for microwave systems.

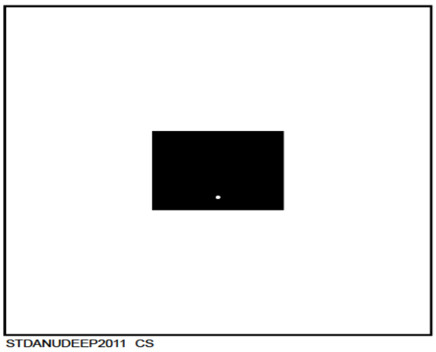

Fig-1: Photographic negative of patch antenna

2. ANTENNA DESIGN

The proposed antenna is designed with the specifications as Resonant frequency (f_o) = 2.45 GHz, dielectric constant (ε_r) = 4.4, height (h) = 1.6 mm. The width and effective length of the patch are given by the fallowing formulas [1] and calculated values for above specifications are

$$W = \frac{c}{2 f_o \sqrt{\frac{\varepsilon_r + 1}{2}}} = 37.26mm$$

$$L_{eff} = \frac{c}{2 f_o \sqrt{\varepsilon_{reff}}} = 32.92mm$$

Physical length of the proposed patch antenna can be calculated by considering effect of extended length ΔL due to fringing effects along the widths and is

$$\Delta L = 0.412h \frac{(\varepsilon_{reff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{W}{h} + 0.8\right)} = 0.7303mm$$

Where $\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2} = 4.08$

and finally the physical length is $L = L_{eff} - 2\Delta L = 28.84mm$

The input impedance of rectangular patch antenna is given [2] and is

$$Z_{in} = jX_f + \frac{R}{1 + 2Q\left(\frac{f}{f_o} - 1\right)} = 243\Omega$$

Since a coaxial cable of 50Ω impedance is used as input feed line of antenna, a 50 Ω impedance point on patch can be located by using the fallowing formula [1] and is given as

$$x = \frac{L}{\pi}\sin^{-1}\left(\sqrt{\frac{Z_i}{R_e}}\right) = 4.32mm$$

The dimensions for ground plane are selected in such a way that it can cover spurious radiation present at the edges of the patch and are given as L_g = L+6h = 38.44 mm and W_g = W+6h = 46.86 mm. The gain of the antenna is G = $4\Pi A/\lambda^2$ = 4.19 dB and beam widths in E and H planes are calculated [4] using fallowing formulas

$$\theta_{BE} = 2\cos^{-1}\left(\frac{7.08}{3\beta_0^2 W^2 + \beta_0^2 h^2}\right) = 73.66^0$$ and

$$\theta_{BH} = 2\cos^{-1}\left(\frac{1}{2\left(1 + \frac{W\beta_0}{2}\right)}\right)^{1/2} = 119.25^0$$

With above calculated values the antenna is simulated on FR4 material with loss tangent of 0.02 using Advanced Design System (ADS) software. The size of the antenna is 37.26X28.84 mm^2, which is suitable for Blue tooth communication. The co axial probe can carefully be inserted to reduce the radiation. Ease of insertion and low probe radiation is advantages of probe feeding as compared to microstip line feeding. Fig 2 shows the proposed structure of antenna using ADS software Layout.

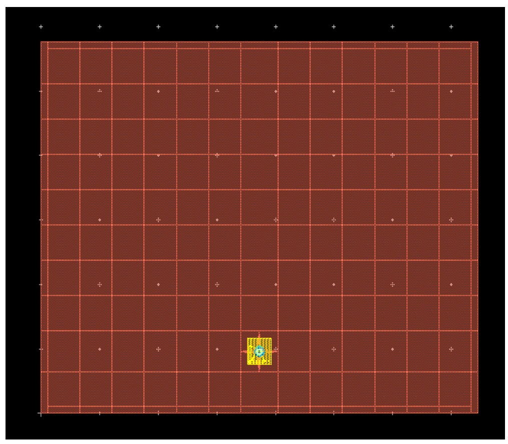

Fig-2: Layout of proposed antenna.

3. FABRICATION AND TESTING

The transformation of geometric shapes on a mask to the surface of FR4 wafer can be done by using photolithography and the steps involved in this process are wafer clearing, barrier layer formation, photoresist application, soft banking, mask alignment, exposure and development and hard banking. Below Fig 3, Fig 4 and Fig 5 shows the ground plane negative of proposed antenna, front and back photographic views respectively.

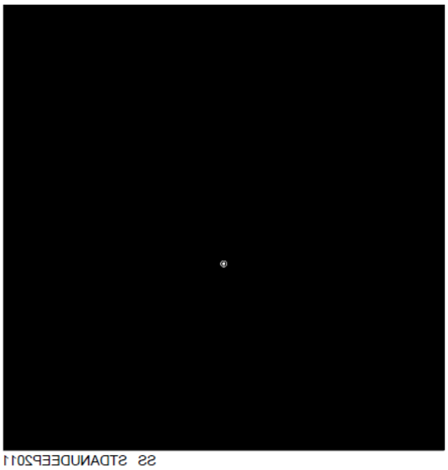

Fig-3:ground plane negative of proposed antenna.

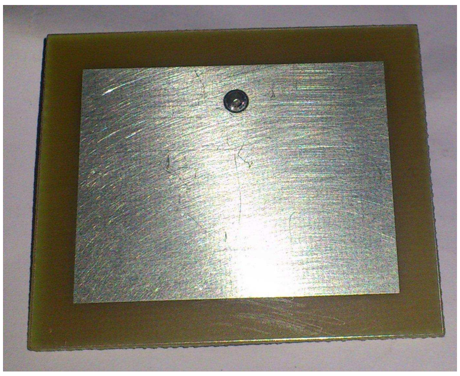

Fig-4: Front View of antenna

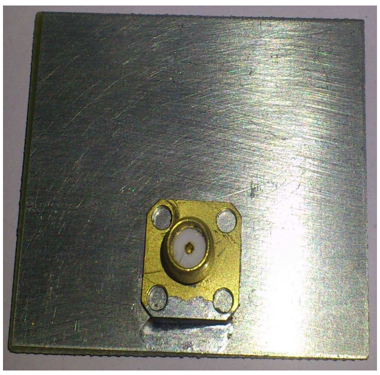

Fig-5: Back View of antenna

The performance of the designed antenna can be understood by measuring parameters like reflection coefficient (S_{11}), VSWR and input impedance (Z_{in}) measurement using Smith Chart. They have been measured by using two port vector Network Analyzer. Fig 6 shows testing of fabricated antenna using Agilent Network Analyzer.

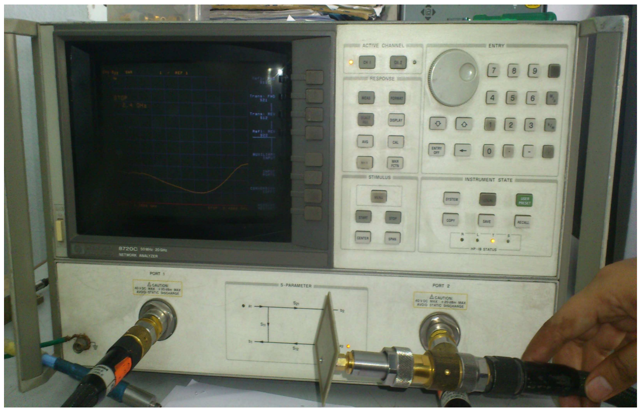

Fig-6: Testing of antenna using Network Analyzer

Radiation patterns are drawn by placing antenna in anechoic chamber as shown in Fig 7 which is a room designed to completely absorb reflections of either sound or electromagnetic waves. They are also insulated from exterior source of noise means that chamber is simulated as an open-space of infinite dimension.

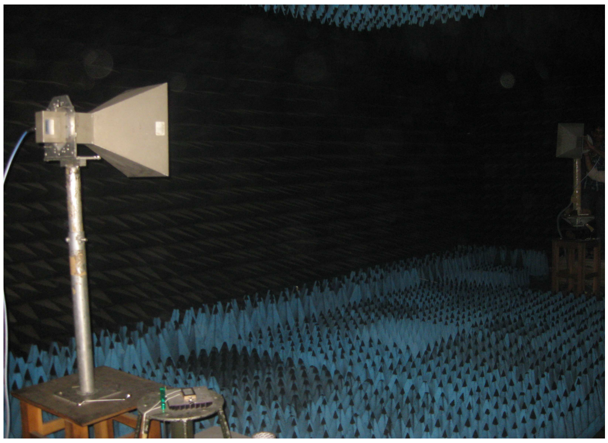

Fig 7: Testing of antenna in Anechoic Chamber

4. RESULTS AND DISCUSSIONS

Simulation and measured results of proposed microstrip rectangular patch antenna is presented in this section. Table 1 and Table 2 shows the dielectric specifications for antenna design and calculated values for patch design. In Fig 8 the simulation input return loss S_{11} which is about -12.529 dB at 2.417 GHz and is comparable with measured input return loss S_{11} as shown in Fig 9 and is -9.04 dB at 2.38GHz. The second major result of this antenna is VSWR $\leq$ 2 which is very important. The VSWR corresponding to the return loss as a function of frequency is given in Fig 10. The important parameter of the antenna is impedance matching and is achieved by using a co axial cable of 50 Ω and the variation of input impedance as a function of frequency is shown in Smith Chart and is about 54Ω at 2.38 GHz.

Table 1: Dielectric material specification for antenna fabrication

Substrate			Conductor	
Dielectric constant	Substrate thickness	Loss tangent	Copper thickness	Conductivity
4.4	1.6 mm	0.02	20 um	$5.8X10^7$

Table 2: Calculated parameters for patch design

Width (W)	37.26 mm
Effective permittivity(ε_{reff})	4.08
Effective length (L_{eff})	32.92 mm
Extended length (ΔL)	0.7303 mm
Length (L)	28.84 mm
Ground length (L_g)	38.44 mm
Ground width (W_g)	46.86 mm
Feed position (x)	4.32 mm

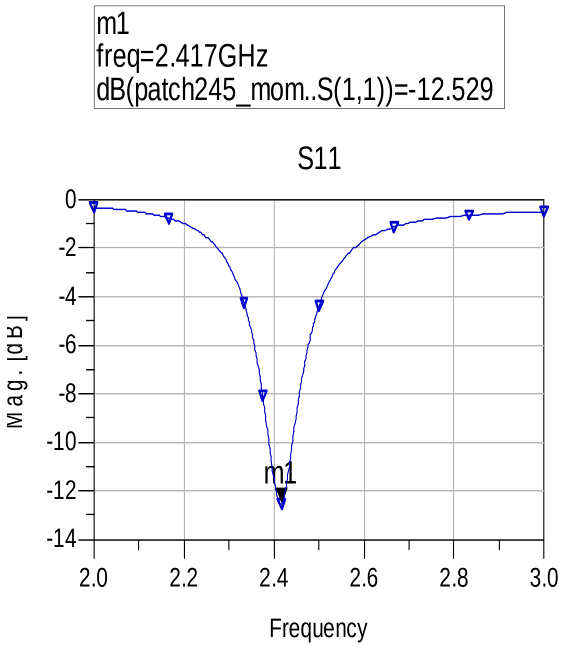

Fig-8: S_{11} parameter simulation using ADS

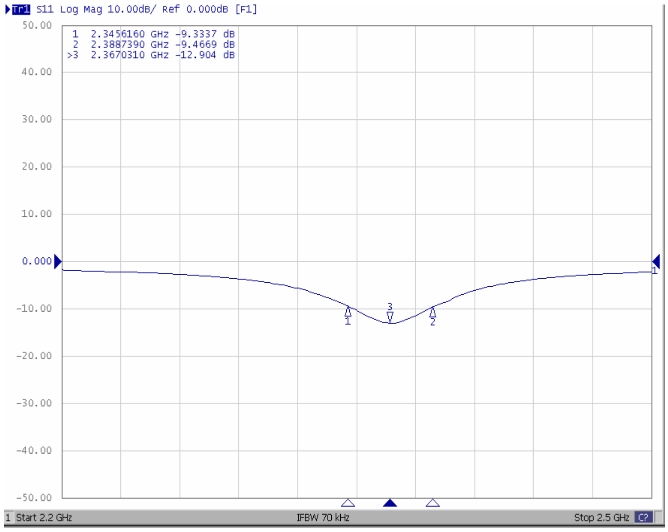

Fig-9: S_{11} parameter measured using Network Analyzer

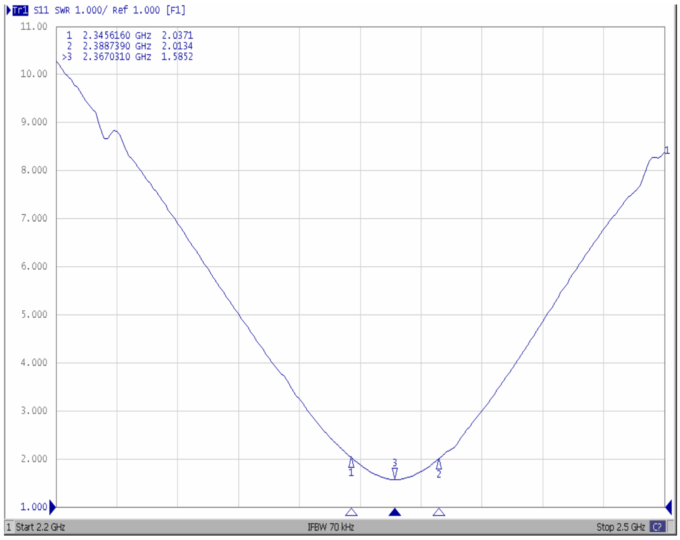

Fig-10: VSWR Variation measured using Network Analyzer

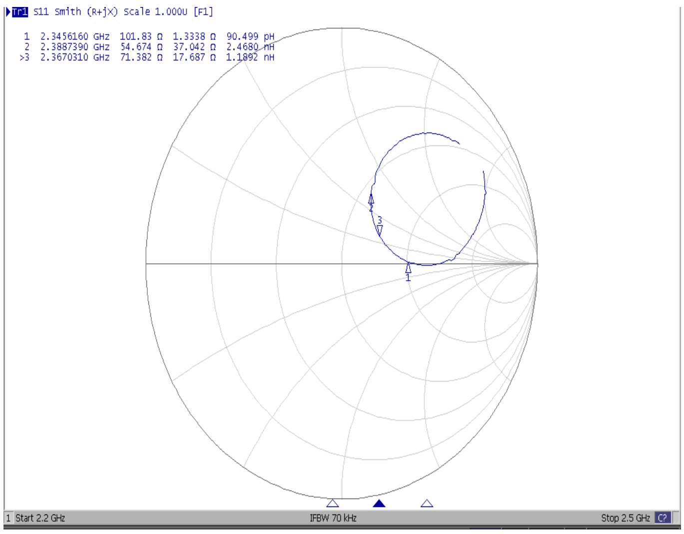

Fig-11: Input impedance variation using Network Analyzer

The drawn radiation patterns in both E and H plane in control room section of anechoic chamber are presented in Fig 12 and Fig 13 are in both rectangular and polar co ordinates respectively. The measured beamwidths are 92^0 and 114^0 in E and H planes respectively and are agreed with calculated and simulated values. The gain of the antenna is measured by using two element antenna method with standard Horn antenna of gain 16.9 dB. The gain of the proposed antenna is 3.4 dB at 2.35 GHz which is comparable with calculated and simulated results. Table 3 shows gain measurement.

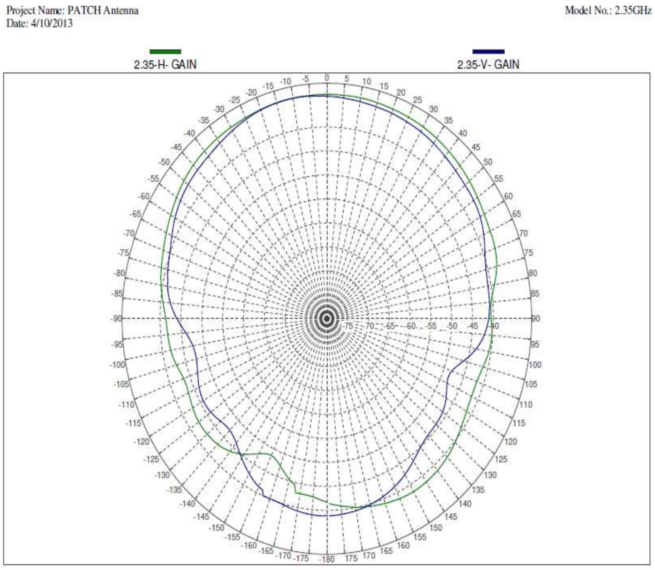

Fig-12: radiation patterns in polar coordinates

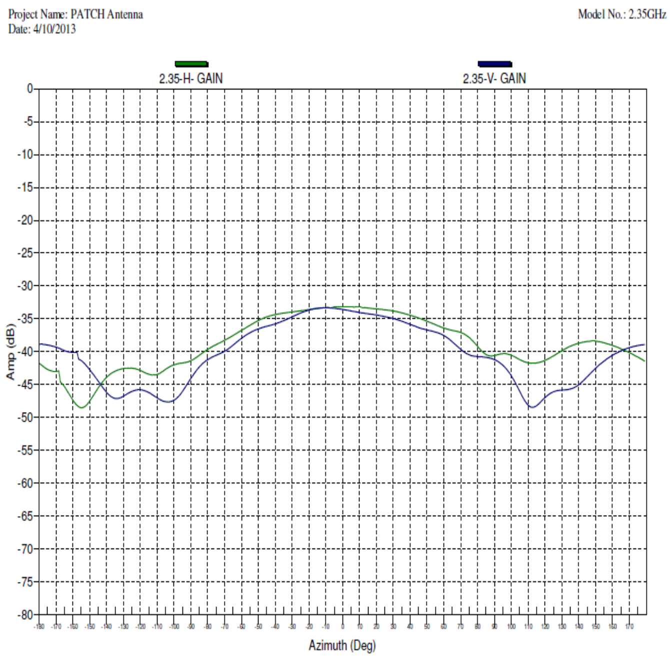

Fig-13: Radiation patterns (E and H Planes) in Rectangular Coordinates

Table-3: Gain Measurement

Frequency in GHz	STD Horn PrH (dB)	A.U.T PrA (dB)	Difference in Pr Level PrH-PrA	STD (SA) HORN Gain(dBi)	Gain A.U.T (dBi)
2.35	-19.8	-33.3	-13.5	16.9	3.4

Comparative results obtained by calculation, simulation and measurement are presented in below Table 4.

Table-4: comparison of proposed antenna parameters

Parameters	Calculated	Simulated	Measured
frequency	2450MHz	2417 MHz	2350MHz
Bandwidth	40.55MHz	39.32 MHz	43.1 MHz
Beam Width E-	73.67^0	81.8^0	92^0
Beam Width H-	119.25^0	105^0	114^0
Gain	4.19 dB	2.59 dB	3.4 dB

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CONCLUSIONS

This paper presents design procedure of a co-axial fed microstrip rectangular patch antenna at 2.45 GHz for Bluetooth application. Main parameters such as return loss (S_{11}), input impedance (Z_0), gain and radiation patterns have been studied and are agreed with measured results. This antenna can be used for Bluetooth application and it is fully utilizes the entire frequency range 2.4-2.48 GHz. The resonant frequency of proposed antenna is occurred at 2.38 GHz and also VSWR is ≤ 2 which are important results. Moreover, any patch antenna with co-axial feed technique with good resonant frequency can be designed with this procedure.

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BIOGRAPHIES

Phani Kumar completed his M.Tech in Microwave Engineering from Dept of ECE, Andhra university in 2007. His broad interested area of research is antenna design. Presently working as Asst Professor in ECE Dept, IARE, Hyderabad.