Design of X-shaped Multi Band Printed Antenna for GSM-1800, Bluetooth, Wi-MAX and WLANApplications With Improved Gain

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Abstract*— A multiband rectangular printed antenna fed by coaxial feeding technique is proposed. This design of antenna is realized by cutting two rectangular shaped slots at appropriate positions at corners of the patch. Further, the X-shaped multiband antenna for quad band operation is obtained by cutting two triangular slot at the upper and lower edge of the patch followed with a two quarter rectangular slots above the feed and below the feed. The Proposed antenna is designed using FR-4 dielectric substrate which has a dielectric constant of 4.4 and loss tangent of 0.02 with dimensions of 46x38mm^2. The proposed antenna calculations are done for the frequency 2.4GHz. The proposed antenna simulated and studied using EM simulation software CAD FEKO suite (7.0). This antenna covers four bands of operation which includes GSM (1.79-1.83 GHz), Bluetooth (2.395-2.493GHz), Wi-Max (3.468-3.546GHz) and WLAN (5.1743-5.2949GHz) with Return loss ≤-10dB. Further in order to improve the gain of antenna, analysis of antenna for varying height of substrate has been done and achieving the positive gain for all the frequency bands. The overall simulation results shows that the antenna gives good impedance matching at desired frequencies with VSWR≤2. Also the radiation pattern, efficiency, gain and impedance for all four frequencies are investigated using simulation results.

***Keywords*— CADFEKO, Microstrip, Coaxial-feed, Multiband antenna**

I. INTRODUCTION

Usually a single antenna cannot operate at all of the frequency bands of Mobile communication; multiple different antennas covering multiple bands separately should be used. On the other hand usage of many antennas is usually limited by the volume and cost constraints of the applications [1]. As a result multiband and wideband antennas are essential to provide multifunctional operations for mobile communication. A Multibandantenna designed to operate on several bands [2].Mostly multiband micro strip antenna is realized by cutting slots like, U-slot, half U-slot, rectangular slot and step slot at a proper position inside the patch. Most of the reported literature on broadband slot cut MSAs, slot is said to introduce an additional resonant mode near the fundamental patch mode when its length equals either half wave or quarter wave in length [3]-[4]. There are countless numbers of approaches to obtain multiband antennas [9]-[11]. In this paper, the Design of quad band X shaped Rectangular Printed multiband Antenna is proposed for GSM, Bluetooth, Wi-MAX and WLAN Applications. Proposed antenna is designed using FR-4 dielectric substrate which has a dielectric constant of 4.4 and loss tangent of 0.02 with dimensions of 46x38x3.5 mm^3. The proposed antenna calculations are done for the frequency 2.4GHz. The proposed antenna simulated and studied using EM simulation software CAD FEKO suite (7.0). This antenna covers four bands of operation which includes GSM (1.79 - 1.83 GHz), Bluetooth (2.395-2.493GHz), Wi-MAX (3.468-3.546GHz) and WLAN (5.1743-5.2949GHz) with Return loss≤-10dB. Firstly single band antenna for Bluetooth applications is designed. The position of coaxial feed point is found in such a way that the Bluetooth band will resonate with center frequency of 2.44GHz. After earning the Single band antenna, surface current distribution is observed at 3.5GHz. For dual band antenna a rectangular quarter wavelength slot of length and width is 8×2mm is added to below feed position to get Wi-MAX band [4]. After that again from current distribution, A rectangular quarter wavelength slot of length and width is 10×2mm is added to left side of feed position to get GSM band And also we have optimized width of the patch and finding proper feed position for matching input impedance for resonating antenna for GSM band. For quad band operation surface current distribution is observed at 5.2GHz. A rectangular quarter wavelength slot of length and width is 7.2×2mm etched in to the upper corner of the radiating patch to resonate over WLAN band. After getting all four bands, Further in order to improve the gain of antenna, analysis has been done for antenna for varying height of substrate from 1.6 to 3.2mm and achieving the positive gain for all the frequency band at h=3.2mm.

II. ANTENNA DESIGN

The Proposed micro strip patch antenna geometry for quad band operation is printed on a FR4 Substrate with height of substrate h=1.6mm and dielectric constant $\varepsilon_{r=4.4}$ with loss tangent of 0.02. The antenna is feed by coaxial feeding technique of 50Ω. The antenna is designed with full ground having dimensions same as FR-4 substrate .The dimensions of proposed antenna geometry are of 46x38mm^2. The feed point for the proposed antenna from the center are (6, 7)[7]. Fig.1

shows the whole Modified X shaped geometry of antenna is modified for height of the substrate equal to 3.2mm, for getting improved gain. It consist X-shaped slot followed with two rectangular radiating quarter wavelength slots of dimensions that is, Slot 1 has dimensions of length and width equal to Lslot1=7mm and Wslot1=2mm and slot2 has dimensions of length and width equal to Lslot2=7mm and Wslot2=2mm respectively. Slot cutting totally based on current distribution at that particular notching frequency.

A. Design of the Single band RMSA (Bluetooth)design

The design of a single band MSA is mainly based on the proper feed position. The geometry of the single band MSA is as shown in Fig.2 (a). The designed antenna is realized using co-axial feed on a 1.6mm thick FR-4 dielectric substrate with 46mm x 38mm surface area and feed by a Co- axial feed of 50Ω.The antenna is designed with full ground having dimensions same as FR-4 substrate [7]. The relative permittivity and loss tangent of the substrate is 4.4 and 0.02 respectively. Coaxial feed is applied to the proposed antenna. To achieve a single band operation using Co-axial feed, it is very important that at which point we are feeding to the antenna patch. Hence after performing number of simulations for various feed positions, then at X = 2mm and Y = 7mm from the center of the radiating patch, a Bluetooth band from 2.414-2.476 GHz is achieved with a maximum reflection coefficient (S11) of -37dB [7]. Feed [7] points are optimized and placed at desired locations inside the patch in order to match with its inputimpedance. The feed points were calculated using formulae (1)-(2).

Distance of feed point from LP (X):

$$X = \frac{\mathrm{LP}}{2\sqrt{\varepsilon reff}} \tag{1}$$

Distance of feed point from W_P (Y):

$$Y = \frac{WP}{2} \tag{2}$$

B. Design of Dual Band RMSA with single slot (Bluetooth and Wi-MAX)

After earning the Single band antenna we have designed dual band antenna for Bluetooth and Wi-MAX applications. The geometry of the dual band MSA is as shown in Fig.2 (b). The antenna design is mainly based on the fact of the surface current distribution. After earning the Single band antenna, surface current distribution is observed at 3.5 GHz. It has been seen that there is very less current in the lower region or region below feed point of the radiating patch as shown in Fig.3 (a) [8]. After performing number of simulations for various slot lengths and widths of a rectangular quarter wavelength, a slot of Lslot1×Wslot1=11×2 is etched in to the lower region of the radiating patch to resonate over Wi-Max band (3.4-3.6 GHz) to get dual band operation. For Wi-Max band (3.4-3.6 GHz): center frequency (f_W) = 3.5 GHz and λ/4 = 12.98 mm. where, λ is calculated using formula (3).

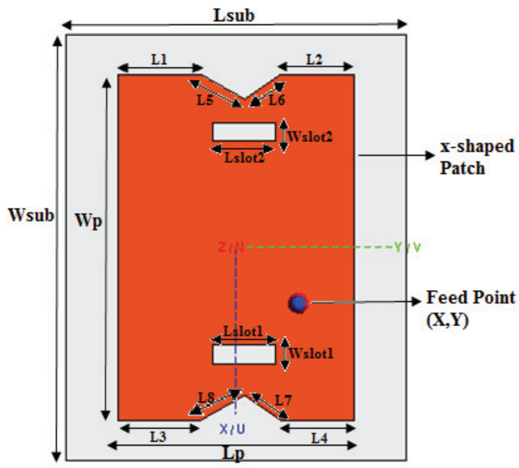


Fig 1. Geometry Of Quad Band Antenna [Lsub=38mm,Wsub= 46mm,,Lp=26.2mm,Wp=37.2mm,(X=6,Y=7)mm]

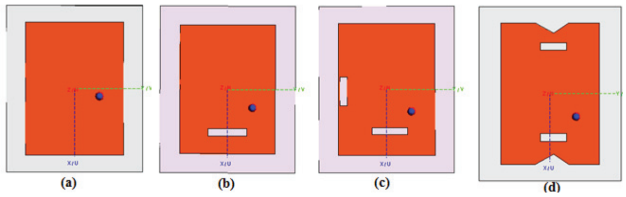


Fig 2.Geometry of antenna (a) Single band, (b) Dual band, (c) Tri band (d) Quad band antenna

The [4] initial length of a rectangular quarter wavelength slots are calculated using the formula, where f_w is notching frequency,

$$\lambda = \frac{c}{4 * fw\sqrt{\frac{\varepsilon r+1}{2}}} \tag{3}$$

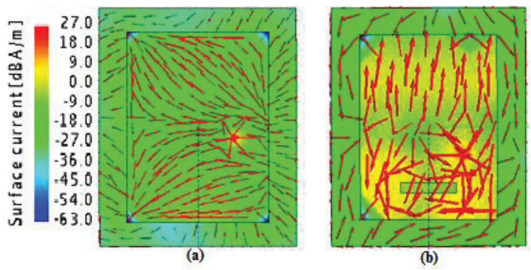


Fig.3.Surface current distribution at 3.5 GHz (a) Before adding slot1 (b) After adding slot1.

C. Tri Band antenna with two slots (GSM, Bluetooth and Wi-MAX)

The antenna design is mainly based on the fact of the surface current distribution. Current distribution is observed at 1.8 GHz as shown in Fig.4 (a). It has been seen that there is very less current in the left side of the feed point region of radiating patch [8].So we have added a slot at the left side of feed point.

After performing number of simulations for various slot lengths and widths of a rectangular quarter wavelength, a slot of 10x2 we have got the GSM band as shown in Fig.2(c).

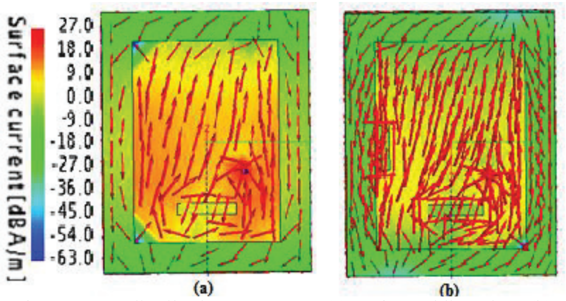


Fig.4.Surface current distribution at 1.8GHz (a) Before adding slot2 (b) After adding slot2.

D.Quad band X-shaped antenna with two slots (GSM, Bluetooth,Wi-MAX andWLAN)

After earning the triple band antenna we have designed quad band antenna for GSM, Bluetooth,Wi-MAX and WLAN applications. The geometry of the quad band MSA is as shown in Fig.2 (d). The antenna design is mainly based on the fact of the surface current distribution. After earning the triple band antenna, surface current distribution is observed at 5.2 GHz. It has been seen that there is very less current in the upper region or region above feed point of the radiating patch as shown in Fig.5(a). After performing number of simulations for various slot lengths and widths of a rectangular quarter wavelength is shown in Fig.4, a slot is etched in to the upper middle region of the radiating patch to resonate over WLAN band. For WLAN band center frequency (fw) = 5.24 GHz and $\lambda/4$ = 8.696 mm [8]. Where, λ is calculated from equation (3).Current distribution for at 5.24GHz center frequency is shown in Fig. 3(d). After that we have cut two triangular slots from the patch where current distribution is very less. After cutting these two triangular shape slots we have got x shaped slot with two rectangular slots. That cutting of two triangular slots does not affect the frequency bands but it slightly affects the gain parameter. So by adding these two slots we can get gain improvement and compactness. So again after that, we have done optimization of Lp for getting exact resonant frequencies as shown in Fig.7. Also we have done substrate h Para to get improved gain, bandwidth, efficiency as shown in Fig.13.

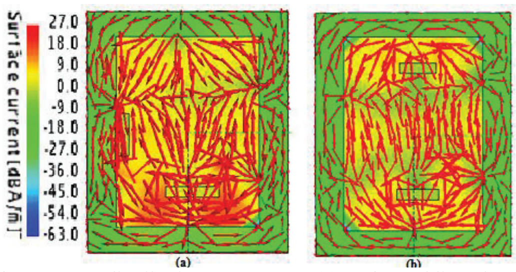


Fig.5.Surface current distribution at 5.24GHz (a) Before adding slot2 at upper side (b) After adding slot 2 at upper side of patch.

The values of optimized parameter of antenna are shown in Table I.

TABLE I. OPTIMIZED PARAMETER OF X-SHAPED ANTENNA

Parameter	Dimensions(mm)
Lp	26.20
Wp	37.20
Lsub=Lg	38
Wsub=Wg	46
Feed point(X,Y)	(6,7)
Lslot1×Wslot1	(7×2)
Lslot2×Wslot2	(7×2)
L1=L3	9.1
L2=L4	8.1
L5=L8	4.77
L6=L7	5.63

III. SIMULATION RESULTS AND ANALYSIS

The antenna designs were simulated in the CAD-FEKO suite 7.0. For proposed antenna, effects of different structures on resonant frequency is observed. Simulated S_{11} parameter using different radiating slot cases for quad band rectangular printed antenna are shown in Fig 6. From Fig.6, we can say that comparison of S11 parameter withoutslot, with slot 1 and slot 2, resonating bands for without slot is 1, then for slot 1 is twoand for slot1 and slot2, it is 4. Then the effect of different parameters of proposed antenna structure is studied. So we have [14] studied effect of variation in width of the patch, variation in feed position, variation in patch length, variation in slots lengths and width. Also height of the substrate parametric analysis is done to improve the gain and bandwidth. Then achieved simulated results are analysed. We have considered Reflection Coefficient (S_{11}) versus Frequency to judge the performance of the antenna. Fig.7 shows the parametric analysis of various feed positions. Coaxial probe feed affects the impedance matching of antenna, so by varying the feed position inside the patch we can achieve impedance matching of antenna. From Fig.7 we can say that, it affects return loss, and bandwidth but not resonant frequency. The effect of feed position on impedance is shown in Fig.8. Impedance variation is seen when we vary the feed position. Parametric analysis of patch length is shown in Fig.9. As we know that Lp controls the resonant frequency. As we increases the Lp, inductive reactance increases and resonant band shifted down that is from 2.31 to 2.5 GHz for Bluetooth band. It does not affect remaining three bands i.e. Wi-MAX, WLAN, GSM.So at Lp=26.2mm, we have got fr=2.44 GHz for Bluetooth band[9]. Patch width variation affects the resonant frequencies and bandwidth for GSM, WIMAX, WLAN as current distribution for these bands are along Wp as shown in Fig.20. Theoretical calculated width of the patch is 38mm but patch width of 37.20mm, we have achieved exact resonant frequencies for GSM, Bluetooth, Wi-MAX and WLAN. So we can see from Fig.8. that when we increases Wp 36.8 to 38.8 mm resonant frequency shift for GSM, Wi-MAX and WLAN are 1.81 to1.76 GHz,3.51 to 3.37 GHz,5.22to 5.03GHz respectively. And when we decreased it from 36.8 to 35.8 the resonant frequencies shifted to right side of resonant band [9].In this we have done the parametric analysis of length of the slot1 shown in Fig.11, from that we can say that the Wi-

MAX band is varied by varying its length. As we increase the length of slot1 center frequency of Wi-MAX band shifted to left and as we decreases the length it shifted to right side of Wi-MAXband. Similarly if we vary the length of slot 2 WLAN band shifted according to increase or decrease the length of slot2as shown in Fig.11.So we can say that Wi-MAX band is resonated due to slot 1 of length 7x2mm and WLAN due to slot2 [14]. Also we have done width of slot1 and slot 2 parametric analysis for optimization of width for both the slots as shown in Fig.12 and Fig.14. Slot width controls the return loss.

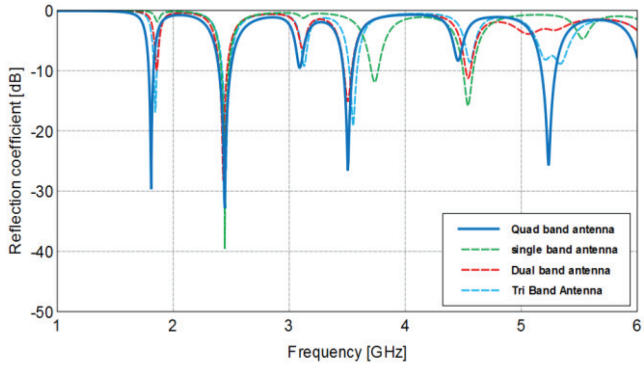


Fig. 6.Simulated S_{11} using different radiating slots cases for quad band antenna.

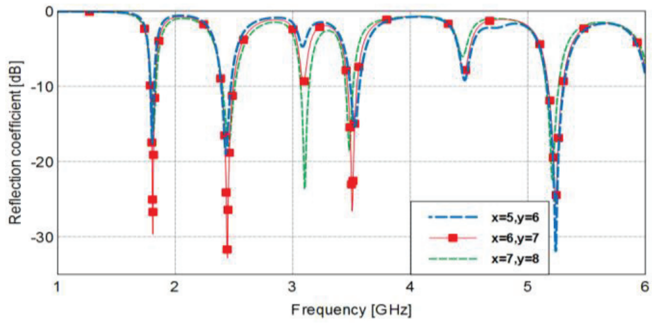


Fig.7. Graph of Reflection coefficientvs. Frequency for various feed positions.

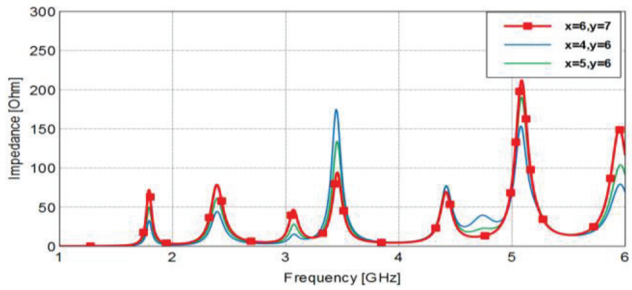


Fig.8.Graph of Impedance vs. Frequency for quad band Antenna for various feed positions

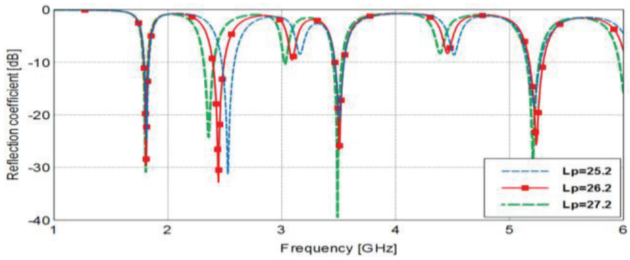


Fig 9. Reflection coefficient vs. Frequency graph for the variations of Length of patch (Lp)

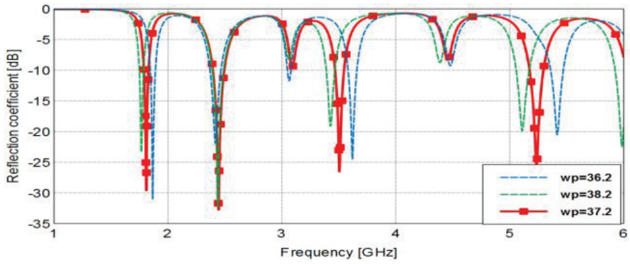


Fig 10. Reflection coefficient vs. Frequency graph for the variations of Widthof patch (Wp)

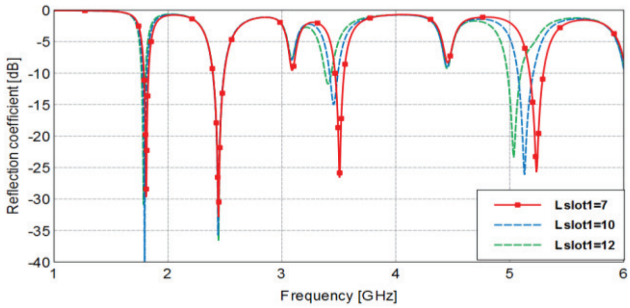


Fig.11.Reflection coefficient vs. Frequency graph for the variations of length ofrectangular slot1.

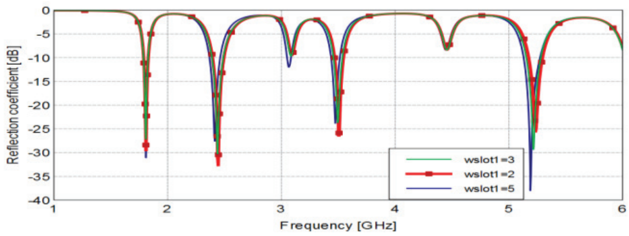


Fig.12.Reflection coefficient vs. Frequency graph for the variations of width ofrectangular slot1

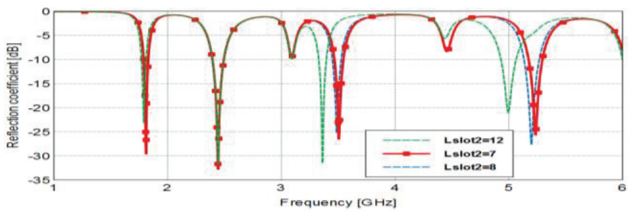


Fig.13. Reflection coefficient vs. frequency graph for the variations of length ofrectangular slot2.

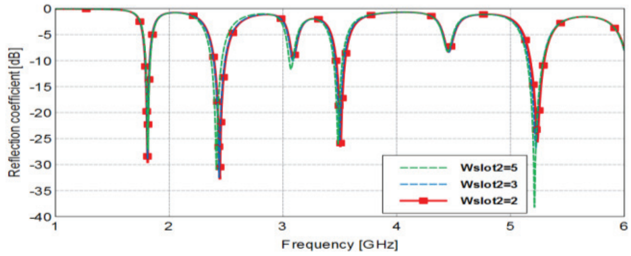


Fig.14.Reflection coefficient vs. frequency graph for the variations of width ofrectangular slot2

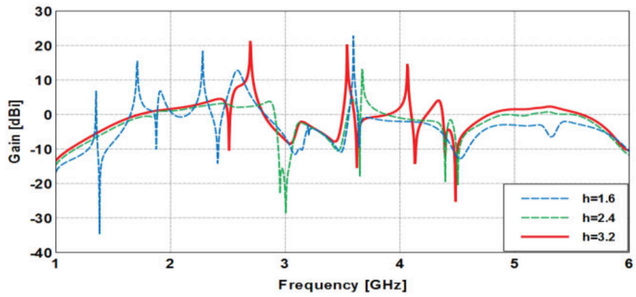
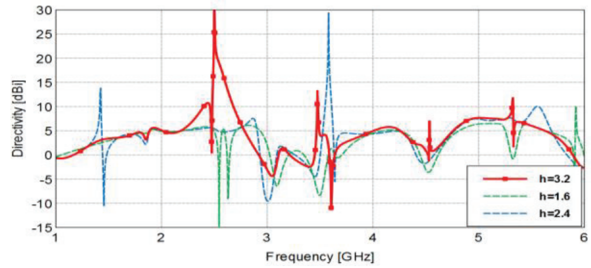


Fig .15.Graph of Gain vs. Frequency for Quad Band Antenna for various substrate height



. Fig .16.Graph of Directivityvs. Frequency for Quad Band Antenna for various height of substrate.

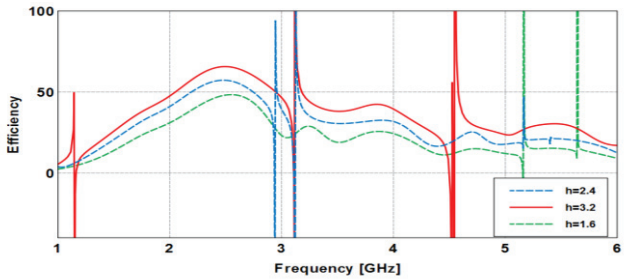


Fig .17.Graph of efficiencyvs. Frequency for quad Band Antenna for various height of substrate

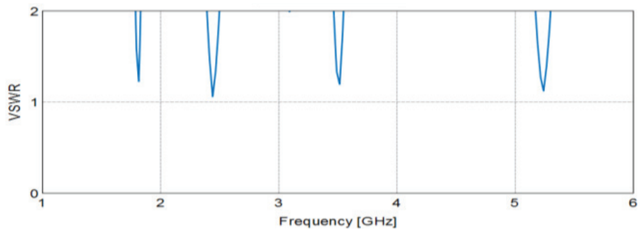


Fig.18.Simulated Graph of VSWR vs. Frequency for quad Band Antenna,at 1.81 GHz, 2.44 GHz, 3.5GHzand 5.24GHz.

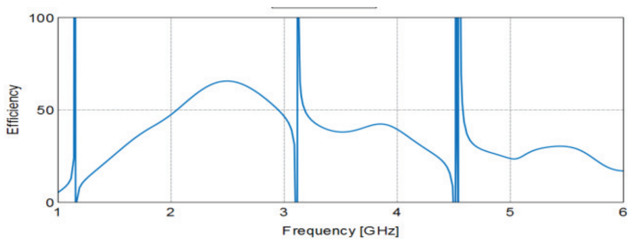


Fig.19. SimulatedGraph of Efficiency vs. Frequency for quadBand Antenna.

For improving gain, bandwidth and efficiency of the antenna we have done height of the substrate parametric analysis [9]. As we know that as height increases, open end fringing fields are increased and therefore effective length of patch increases therefore radiation bandwidth and efficiency increases. Also dissipation loss decreases with increase in h. From that we have seen from Fig.15 that if we vary the height of the substrate from 1.6 to 3.2 at h=3.2 we havegot better gain and directivity. For h=1.6, where εr=4.4 tanδ=0.02, bandwidth for GSM band is 1.58% ,for Bluetooth it is 2.578%, for Wi-MAX is 1.45%and for WLAN is 1.833%.And also gain for GSM band 0.869dBi and for Bluetooth is -1.85 dBi and for Wi-MAX it is -7.66dBi & for WLAN it is -3.07dBi. Also efficiency for all the four bands are 26.3%, 47.2%, 18.9%, 20.4% respectively. Directivity for all four bands are 4.51dBi, 5.81dBi, -6.28dBi, 6.47dBirespectively. For h=2.4, where εr=4.4 tanδ=0.02, bandwidth for GSM bad is 1.9%, for Bluetooth it is 3.2% ,for Wi-MAX is 1.8% and for WLAN is 2.33%. And also gain for GSM band -0.541dBi and for Bluetooth is 3.2dBi and for Wi-MAX it is -76.33dBi & for WLAN it is 0.509dBi. Also efficiency for all the four bands are 34.1%, 56.6%, 30.5%, 20.5% respectively. Directivity for all four bands are 3.39dBi, 5.49dBi, 2.26dBi, 7.3dBi respectively[20]. For h=3.2, where εr=4.4 tanδ=0.02, bandwidth for GSM bad increased from 1.58 to 2.2%, for Bluetooth it is increased from 2.578% to 4.01%, for Wi-MAX it is increased from 1.45 to 2.22% and for WLAN it is increased from1.833%to2.30%.And also gain for GSM band at h=3.2 is 0.68dBi and for Bluetooth it is increased up to 4.51dBi and for Wi-MAX it is 2.88dBi & for WLAN it is 2.01dBi. Also efficiency for all the four bands are 40%, 65.5%, 38%, 30% respectively. Directivity for all four bands are 4.58dBi, 10.08dBi, 3.92dBi, 7.33dBi respectively.

Fig.18 shows VSWR≤2 for all four bands are 1.29, 1.08, 1.22, and 1.14 respectively. Fig.19 shows the efficiency vs. frequency graph of the quad band antenna. Here it has been seen that for Bluetooth band, antenna efficiency is approximately 65.40% as shown in the Fig.18. And it is decreased after 3GHz. Fig.21 Shows the radiation pattern for elevation plane (E-plane or ≤=90) and azimuth plane (H-plane or ≤=0) at f=1.81GHz, f=2.44 GHz, f= 3.5 GHz and f=5.24GHz. It describes how an antenna directs the energy it radiates [11]. It shows an Omni-directional radiation pattern along the H-plane and a directional radiation pattern along the E-plane.

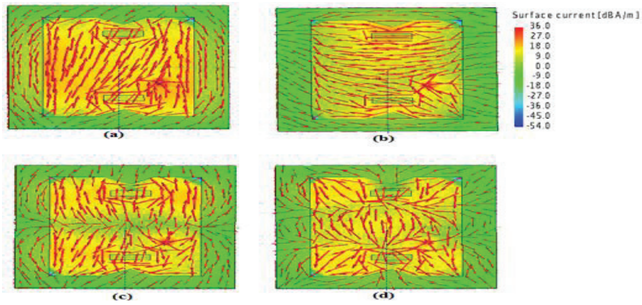


Fig.20. Surface current distribution (a) at 1.81 GHz (b) 2.44GHz(c) 3.5GHz (d) 5.24GHz

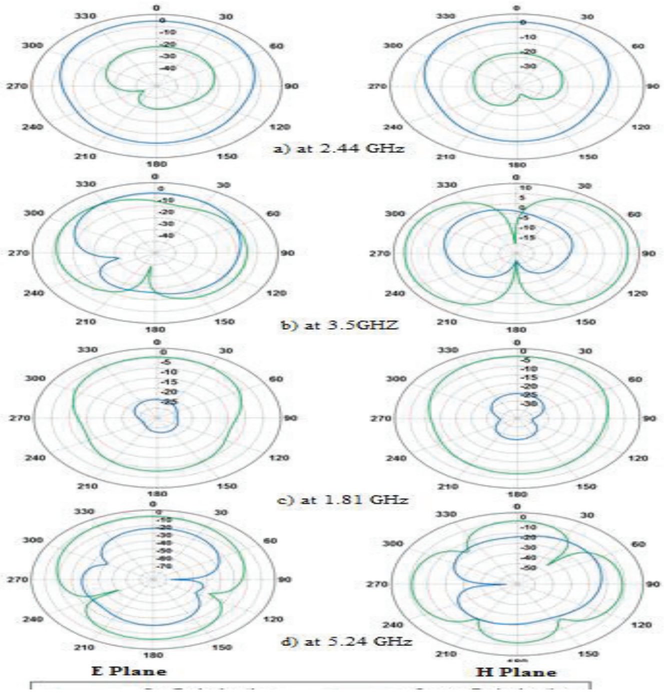


Fig.21.Simulated radiation patterns observed in E-plane and H-plane at (a) 2.44GHz (b) 3.5GHz(c) 1.81 GHz and (d) 5.24 GHz.

IV. CONCLUSION

In this paper, Design of Multi Band Rectangular Printed Antenna for GSM, Bluetooth, Wi-Max and WLAN Applications is presented. This antenna covers four bands of operation which includes GSM (1.79-1.830GHz), Bluetooth (2.395-2.493GHz), Wi-MAX (3.468-3.546GHz) and WLAN (5.1743-5.2949GHz) with Return loss≤ -10 dB . The proposed antenna operates over the frequency range of 1-6 GHz with VSWR ≤ 2. For achieving four band operations two rectangular slots are etched from radiating patch and the location of feed point optimized in such way that the antenna operates in four frequency bands. Also optimization of various parameters of antenna is done Such as height of substrate for getting improved gain, bandwidth and efficiency; it is found that as we increases the substrate height up to 3.2mm we have got improved gain, bandwidth and efficiency for all four bands.

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