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Design and Analysis of Mobile Antennas for Different Applications

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ABSTRACT
In this paper we analyze antennas which operate for various applications at different frequencies. The growing technology in mobile devices requires multiple resonant frequencies for various applications like GSM, DCS, PCS, UMTS, Bluetooth, Wi-MAX and SDM broadcasting in a single antenna. Here, a PIN diode is used in a simplified antenna model to switch between Bluetooth (2.4 GHz) and Satellite DMB (2.6 GHz) technologies. To achieve reasonable gains at application center frequencies, a monopole antenna is composed with L-Strips as slot radiators and defected ground plane. The antenna model is simulated and analyzed in Ansoft HFSS 13 software.
Keywords: Internal antenna, Multiband antenna, PIN Diode, SDM, VSWR, Wi-MAX

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I. INTRODUCTION

Present day cellular handsets are required to operate at multiple frequency bands and also demands the antenna for high performance, low profile, compact size and light weight. As planar microstrip antennas occupy very less space, so they are suitable and attractive for slim cellular phones using today [1,2]. There has been speedy development in the fields of wireless communication from past few years. Initially Bluetooth is incorporated in the system by replacing cables, later the technology is further improved to gain speed. IEEE 802.11b technology for WLAN is developed which provides data speed upto 11 Mbps. Recently IEEE802.11a standard for Wi-MAX emerged to provide data rate up to 54 Mbps and also it is less interfering with 2.4 GHz ISM band [3]. In most of the modern cellular handsets 5.7 GHz band is not included. In this paper the mobile handset includes Wi-MAX (Worldwide Interoperability for Microwave Access) technology along with GSM (Global system for mobile communication), DCS (Digital Cellular System), PCS (Personal Communication System), UMTS (Universal Mobile Telecommunication Service) and Bluetooth. In antenna model 4, a PIN diode is used. When PIN diode is ON, it covers Bluetooth frequency range, when PIN diode is OFF, it covers Satellite DMB (Satellite Digital Mobile Broadcasting) frequency range.

The Federal Communication Commission (FCC) specified frequency bands for GSM (880-960 MHz), DCS (1710-1880 MHz), PCS (1880-1990MHz),

UMTS (1920-2170 MHz), Bluetooth (2400-2480 MHz), Satellite DMB (2605 - 2655 MHz) and Wi-Max (2.3-2.6 GHz / 5.7-5.85 GHz) [4,5]. GSM describes the protocols for second generation cellular networks. DCS integrates the standards of TDMA, CDMA,GSM. PCS provides both analog and digital services in wireless phones to provide high quality voice, video and data services. UMTS is a 3G based network based on GSM standard. Bluetooth helps to exchange data between two devices over a short distance. Satellite DMB is a direct digital delivery of audio and multimedia content via satellite and terrestrial means to consumers in a mobile environment and Wi-MAX is a broad connectivity across cities for internet access.

In designing of an antenna, it is quite challenging to enhance bandwidth and miniaturize size at the same time for internal antenna in mobile applications. Sometimes the size of the antenna is increased because of the low frequency application [6]. L-shaped slots, defected ground plane and a monopole radiator are etched on a rectangular patch to achieve tri-band operation in [7]-[9]. In [10], asymmetric M-shaped microstrip patch antennas achieved triple band whereas in [11], three circular-arc-shaped strips whose whole geometry looks like "ear"-type antenna is designed for tri-band operation. RF PIN diodes can be used as switches to aid in the design of frequency reconfigurable antennas [12].

Antenna designs and simulated results are discussed in the following sections.

II. ANTENNA DESIGN

The antenna models are composed with two substrates FR4 (ϵ_r=4.4) and air (ϵ_r=1) of thickness t (t=1.6mm). The antenna dimensions are 50×46 mm^2 in which the upper part is air substrate with the dimensions 50 mm x16 mm and the lower part is FR4 substrate with the dimensions 50 mm x 30 mm. The antenna is designed for mobile application which must provide Omni directional radiation pattern. So, to get the efficient radiation, ground is eliminated below the patch i.e., considered defected ground plane. As the antenna is a monopole, we applied microstrip feed at the center. The antenna is designed for 50Ω transmission line.

For efficient transmission of a signal, the antenna resonator length should be at least quarter signal wavelength λ/4.

$$L = \frac{c}{4f\sqrt{\epsilon}} \quad (1)$$

where $$\epsilon = \frac{\epsilon_r + 1}{2} \quad (2)$$

Here c is velocity of light, ϵ_r is relative permittivity of the substrate.

The width of the feed is calculated by the formula

$$\frac{W}{h} = \frac{8e^{A}}{e^{2A}-2} \quad \text{for } (W/h \le 2) \quad (3)$$

where $$A = \frac{Z_0}{60}\sqrt{\frac{\epsilon_r+1}{2}} + \frac{\epsilon_r-1}{\epsilon_r+1}(0.23 + \frac{0.11}{\epsilon_r}) \quad (4)$$

where W is width of the feed and h is thickness of the feed. The calculated width of the feed from the equation (3) is 2 mm.

II.I ANTENNA MODEL 1

Fig. 1 consists of two resonators which resonate at 930 MHz, 2.38 GHz. It covers GSM, DCS, PCS, UMTS, Bluetooth applications. To cover Wi-MAX band also, a small slot is introduced in Antenna model 2 to cover entire bands of mobile applications.

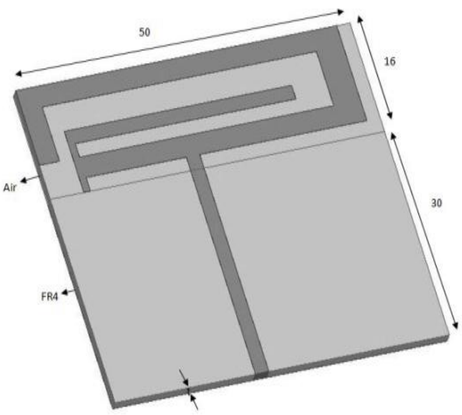

Fig.1 (a)

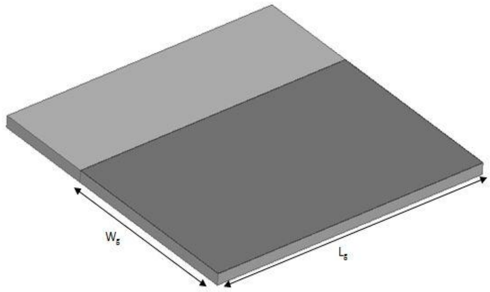

Fig.1 (b)

Fig. 1. Schematic diagram of antenna model 1 (a) Side View (b) Back View

II.II ANTENNA MODEL 2

Fig. 2 consists of three resonators which resonate at different frequencies.

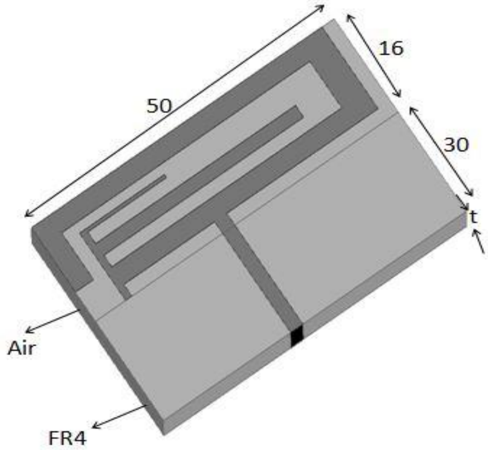

Fig. 2 (a)

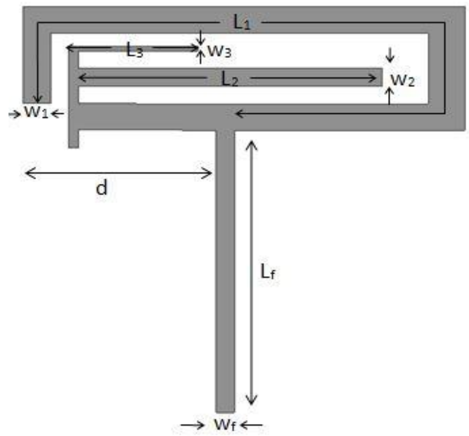

Fig.2(b)

Fig. 2. Schematic diagram of antenna model 2 (a) Side View (b) Front View

The calculated values from the equation (1) at 900MHz, 2GHz, 5.8 GHz are 85mm, 37mm, 13mm. But due to coupling effect, the values are to be adjusted to 93mm, 36 mm, 14 mm to cover entire frequency bands. In the Fig. 2 (b) L_1, L_2, L_3 and W_1, W_2, W_3 are the lengths and widths of the three resonators. L_g, W_g are length and width of the defected ground plane. L_f, W_f are length and width of the feed.

S. No	Parameters	Dimension (mm)
1	L_1	93
2	L_2	36
3	L_3	14
4	L_f	32
5	W_1	3
6	W_2	2
7	W_3	0.5
8	W_f	2
9	d	21
10	L_g	50
11	W_g	30

Table. I. Design parameters of the Antenna Model 2

II.III ANTENNA MODEL 3

In the Fig.3 (a), the complete outer resonator is considered. It resonates at 2.4 GHz for Bluetooth application

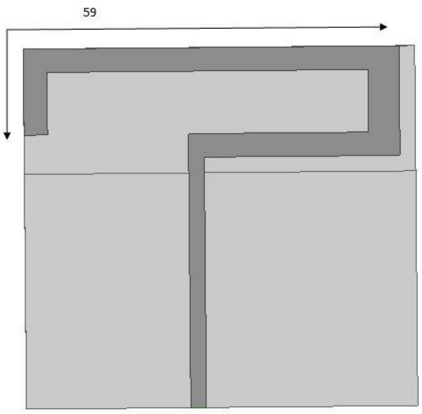

Fig. 3 (a)

In the Fig.3 (b), the partial outer resonator is considered. It resonates at 2.6 GHz for Satellite digital mobile broadcasting application

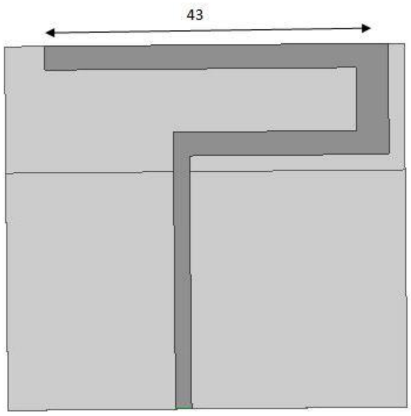

Fig.3 (b)

Fig. 3. Schematic diagram of antenna model 3 (a) with complete outer resonator (b) with partial outer resonator

II.IV ANTENNA MODEL 4 (SIMPLIFIED MODEL WITH PIN DIODE)

In the Fig.4 both applications of antenna model 3 are integrated in a single antenna i.e., Bluetooth and Satellite DMB applications in a single antenna using a PIN diode.

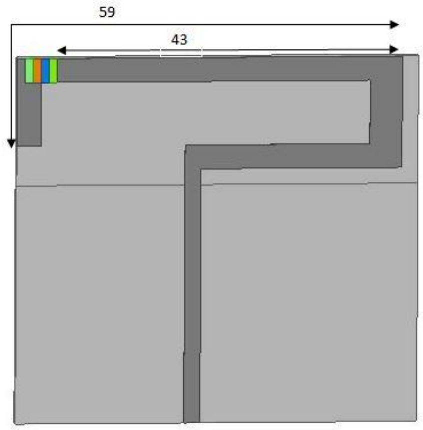

Fig. 4. Schematic diagram of antenna model 4 with PIN diode

The antenna resonates at low frequency, when the length of the resonator is more. When PIN diode is ON, the antenna considers entire length of the resonator. So, it resonates at low frequency 2.4 GHz. When PIN diode is OFF, the length decreases and therefore the antenna resonates at 2.6 GHz. PIN diode is a lumped RLC circuit, here one resistor, two capacitors and one inductor are considered. With specific values of R,L,C. Hence PIN diode is used as a switch to ON and OFF.

III. RESULTS

The return loss curve for -6dB and VSWR curve are observed from Fig. 5 and Fig. 6. If VSWR is 3, the reflected power will be 25% (reflected power in dB is -6 dB). For practical mobile applications -6dB cutoff is an optimal value.

III.I ANTENNA MODEL 1

Fig.5 shows Return loss curve which resonates at 900 MHz and 2.4GHz covers bands of GSM,DCS,PCS,UMTS and Bluetooth

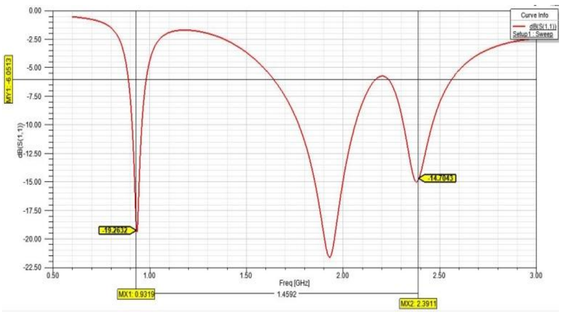

Fig. 5. Return Loss Curve in dB (S_{11})

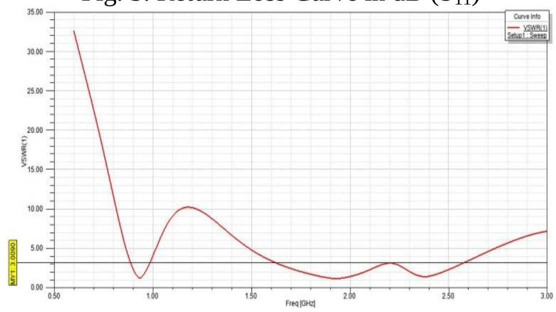

Fig. 6. VSWR Curve

The radiation patterns are observed from Fig.7 at application center frequencies

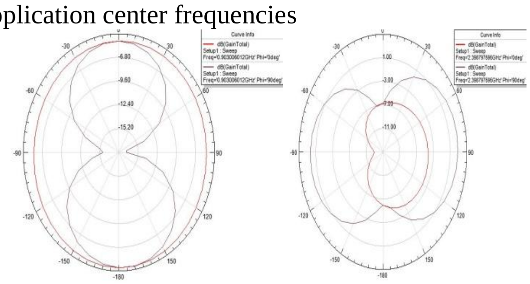

Fig.7(a) Fig.7(b)

Fig. 7. Radiation patterns at (a) 900 MHz (b) 2.4 GHz

The 3D polar plots are observed from Fig.8 at center frequencies of the mobile application i.e., 900 MHz and 2.4 GHz

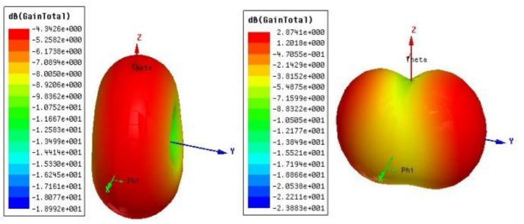

Fig.8(a) Fig.8(b)

Fig. 8. 3D polar plots at (a) 900 MHz (b) 2.4 GHz

III.II ANTENNA MODEL 2

From the Fig. 9 on observing return loss curve, the first resonance occurred at 900 MHz. It covered entire band of GSM (880-960 MHz). The second resonance occurred at 1.9 GHz. It covered the band from 1.6 GHz to 2.6 GHz. It implies the bands of DCS (1710 - 1880 MHz), PCS (1880-1990 MHz), UMTS (1920-2170 MHz), Bluetooth (2400-2480 MHz) are completely covered. The third resonance occurred at 5.8 GHz covering the band from 5.7 GHz to 7 GHz, which covered the WiMAX (2.3-2.6 GHz/5.7-5.85 GHz) band.

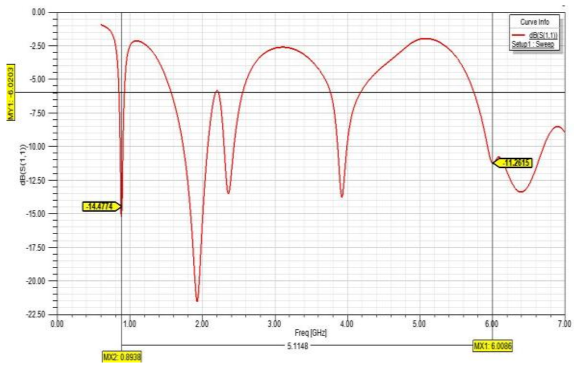

Fig. 9. Return Loss Curve (S_{11}) in dB

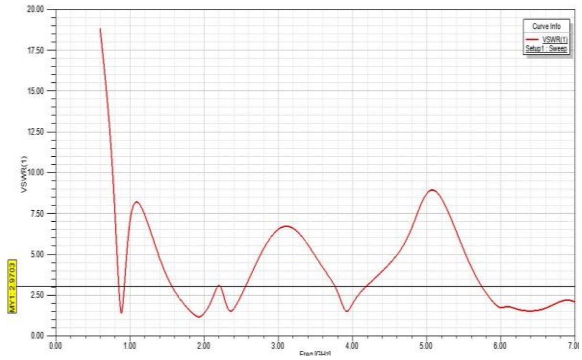

Fig. 10. VSWR curve

The radiation patterns are observed at the center frequency of the applications

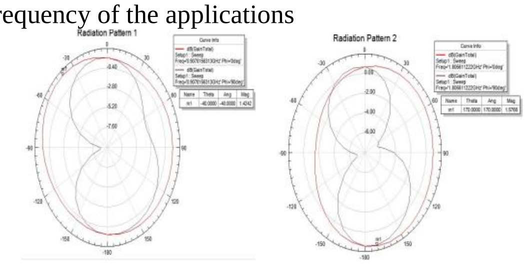

Fig. 11 (a) Fig. 11 (b)

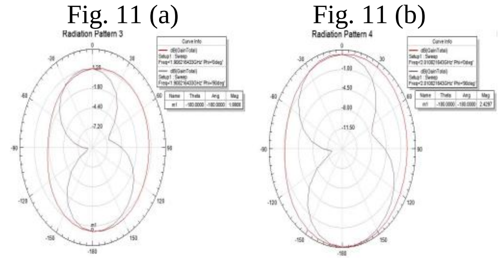

Fig. 11 (c) Fig. 11 (d)

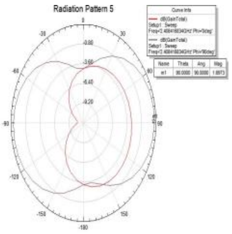

Fig. 11 (e)

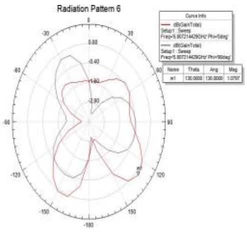

Fig. 11 (f)

Fig. 11. Radiation patterns at (a) 900MHz (b) 1800 MHz (c) 1900 MHz (d) 2000 MHz (e) 2400 MHz (f) 5.8 GHz

From Fig. 11(a), at 900 MHz, the maximum gain 1.42 dB observed in ϕ=0^0 , ɵ=40^0 direction. From Fig. 11(b), at 1800 MHz, the maximum gain 1.57 dB observed in ϕ=0^0 , ɵ=180^0 direction. From Fig. 11(c), at 1900 MHz, the maximum gain 1.99 dB observed in ϕ=0^0 , ɵ=180^0 direction. From Fig. 11(d), at 2000 MHz, the maximum gain 2.42 dB observed in ϕ=0^0 , ɵ=180^0 direction. From Fig. 11(e), at 2400 MHz, the maximum gain 1.69 dB observed in ϕ=90^0 , ɵ=90^0 direction. From Fig. 11(f),at 5.8 GHz, the maximum gain 1.07 dB observed in ϕ=0^0 , ɵ=130^0 direction.

The 3D polar plots are observed at the center frequency of the applications are shown below

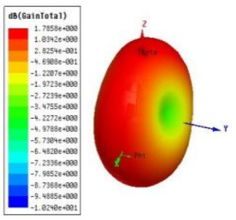

Fig. 12(a)

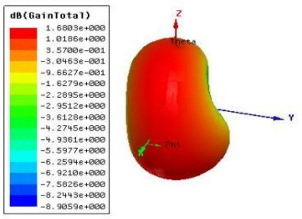

Fig. 12(b)

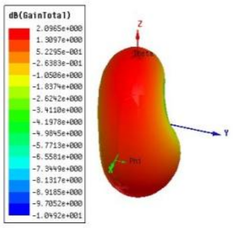

Fig. 12(c)

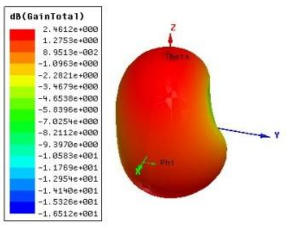

Fig. 12(d)

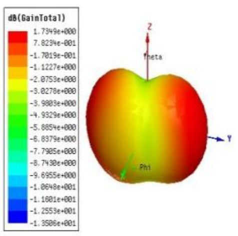

Fig. 12(e)

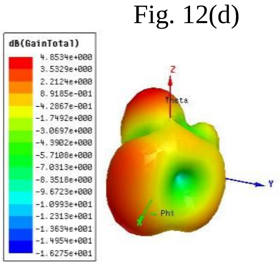

Fig. 12(f)

Fig. 12. 3D polar plots at (a) 900MHz (b) 1800 MHz (c) 1900 MHz (d) 2000 MHz (e) 2400 MHz (f) 5.8 GHz

S. No.	Center Frequency(Hz)	Obsreved Gain (dB)
1	900 MHz	1.78
2	1800 MHz	1.68
3	1900 MHz	2.09
4	2000 MHz	2.46
5	2400 MHz	1.73
6	5700 MHz	4.85

Table II Maximum gains observed

III.III ANTENNA MODEL 3

From Fig. 13 and Fig. 14, S_{11} plot and 3D polar plot for the antenna model 3(a) is observed. From Fig.13 the antenna resonates at 2.4 GHz covering the band from 2.2 GHz to 2.6 GHz. The -6dB impedance bandwidth is 400 MHz. From Fig. 14 the maximum gain observed is 3 dB at 2.4 GHz.

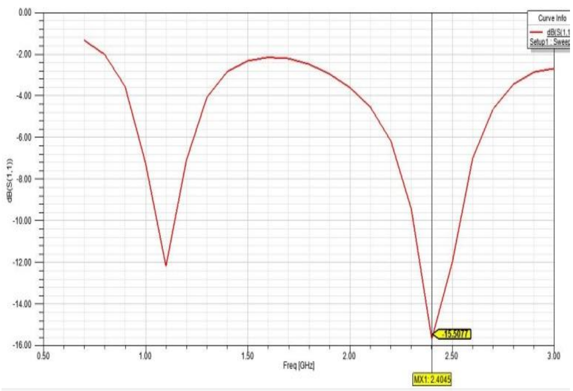

Fig. 13. Return Loss Curve (S_{11}) in dB

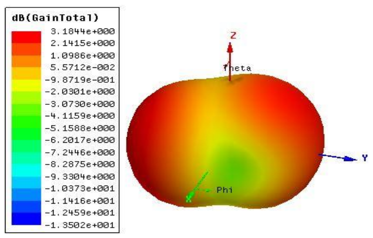

Fig. 14. 3D Polar plot at 2.4 GHz

From Fig. 15 and Fig. 16, S_{11} plot and 3D polar plot for antenna model 3(b) is observed. From Fig.15 the antenna resonates at 2.6 GHz covering the band from 2.4 GHz to 2.76 GHz. The -6dB impedance bandwidth is 385 MHz. From Fig. 16 the maximum gain observed is 2.9 dB at 2.6 GHz.

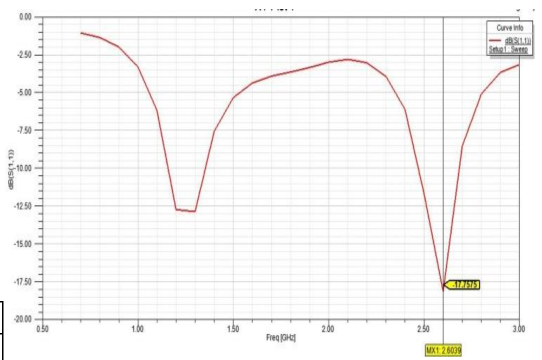

Fig. 15. Return Loss Curve (S_{11}) in dB

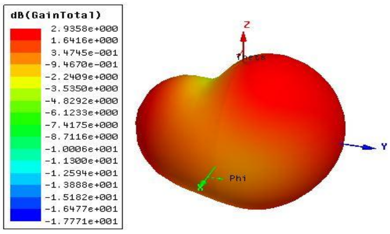

Fig.16. 3D Polar plot at 2.6 GHz

III.IV ANTENNA MODEL 4 (SIMPLIFIED MODEL WITH PIN DIODE)

Fig. 17. PIN diode is ON Return Loss Curve (S_{11}) in dB when PIN diode is ON

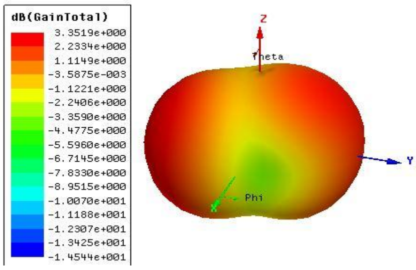

Fig. 18. 3D Polar plot at 2.4 GHz

From Fig.17 and Fig.18, S_{11} plot and 3D polar plot for the antenna model 4 when PIN diode is ON is observed. From Fig.17 the antenna resonates at 2.4 GHz covering band from 2.2 to 2.67 GHz. The -6dB impedance bandwidth is 470 MHz. From Fig.19.the maximum gain observed is 3.35 dB.

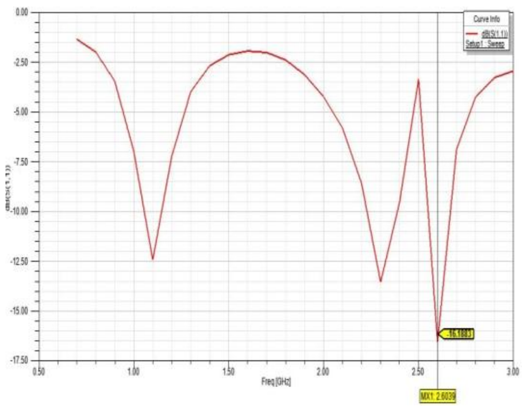

Fig. 19. Return Loss Curve (S_{11}) in dB when PIN diode is OFF

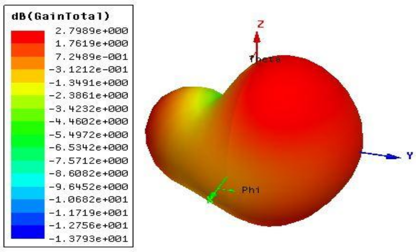

Fig. 20. 3D Polar plot at 2.6 GHz

From Fig. 19 and Fig. 20, S_{11} plot and 3D polar plot for the antenna model 4 when PIN diode is OFF is observed The antenna resonates at 2.6 GHz covering bands from 2.5 to 2.73 GHz. The -6dB impedance bandwidth is 217 MHz. From Fig. 20 the maximum gain observed is 2.79 dB.

IV. CONCLUSION

Comparing Antenna model 1 with antenna model 2, antenna model 2 shows another resonant frequency at 5.7 GHz covering Wi-MAX bands along with GSM, DCS, PCS,UMTS and Bluetooth. Comparing Antenna model 3 with model 4, antenna 3 requires two antennas for Bluetooth and Satellite DMB applications. By using PIN diode, we can use both applications in a single antenna. All the antennas with size 50 x 46 x 1.6 mm^3 i.e., 3.6 cm^3 is suitable for modern cellular phones and achieved reasonable gains at application center frequencies. The high performance antenna can be further be developed by integrating PIN diode in antenna model 2, so that it covers maximum frequency bands.

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