Scientific Research Publishing

Design Simulation and Fabrication of a Dual Band Frequency Reconfigurable Monopole Antenna for Wi-Fi and WiMAX Applications

Prasanna Paga[1], H. C. Nagaraj[2], T. S. Rukmini[2]

[1]Department of Electronics, NREA, NMIT, Bangalore, India
[2]Department of ECE, NREA, NMIT, Bangalore, India
Email: prasanna.paga@nmit.ac.in, principal@nmit.ac.in, rukminirvce.rao@gmail.com

Abstract

Nowadays, wireless systems require compact multi band antennas that can dynamically change some of its fundamental parameters such as frequency band, polarization and radiation pattern. The novelty of the proposed work lies in using two conducting strips that are perpendicular to each other. The longer strip resonates at 2.4 GHz and the shorter strip resonates at 3.5 GHz. The length and width of the Ground plane is made equal to length of the main arm and length of the side arm respectively. The results are obtained by simulating the antenna structure using simulation tool Ansoft HFSS v15.0. The Simulated antenna Gains were 6.2364 dBi and 7.1758 dBi for frequencies of 2.4 GHz and 3.5 GHz respectively. The antenna dimensions are $50 \times 25 \times 1.6$ mm³ on a 1.6 mm thick FR-4 substrate.

1. Introduction

Monopole antennas have become the most preferred choice in the domain of the Wi-Fi and WiMAX applications and other fields like Bluetooth cards and wireless communications. In the present work, Monopole classes of Antennas are selected which are compact in size and normally the gains are low. To excite dual bands, two conductors of different lengths are chosen that are perpendicular to each other. The length of the longer strip is designed for resonating at 2.4 GHz while the shorter strip is designed for 3.5 GHz. The novelty of the proposed work lies in making the length of the Ground plane equal to the length of the

main arm and the width of ground plane correspond to the side arm width of the. The main contribution of the research work is in getting a huge bandwidth of 2.16 GHz corresponding to 3.5 GHz, very high peak gains of 6.236 dBi and 7.17 dBi for Wi-Fi and WiMAX bands respectively. The measured radiation pattern is nearly omni-directional in both the E and the H planes for both 2.4 GHz and 3.5 GHz frequency bands.

In [1], a printed monopole antenna with a low profile on a FR4 substrate is proposed. The Antenna structure resembles a figure of T. The proposed Antenna results in a resonant frequency of 2.4 GHz and is very compact in size. In [2], a dual band printed Monopole Antenna resonating at two frequencies namely 900 MHz (GSM band) and 2.4 GHz (Wi-Fi band) has been proposed on a FR4 substrate. The proposed antenna resulted in a return loss of −33 dB and −35 dB for both the lower and the upper frequency bands respectively. The VSWR obtained is between 1 and 2 for both the bands. The Bandwidth of the proposed antenna was 104 MHz and 350 MHz for 900 MHz and 2.4 GHz band respectively. In [3], a novel 9-shaped multiband frequency reconfigurable monopole antenna for wireless applications, using 1.6 mm thick FR4 substrate and a truncated metallic ground surface, has been proposed. The designed antenna operates in single and dual frequency mode based on switching states. The antenna operates in WiMAX band resonating at 3.5 GHz when the switch is in the OFF state. The structure operates in 2.45 GHz and 5.2 GHz when the switch is turned ON. The antenna resulted in a Gain of 1.48 dBi, 2.47 dBi and 3.26 dBi for frequencies of 2.45 GHz, 3.5 GHz and 5.2 GHz respectively. The proposed antenna is compact in size with a dimension of $40 \times 35 \times 1.6$ mm^3, light weight, and highly efficient (84% - 92%). It can be used in Wi-Fi, WiMAX and WLAN based wireless applications. In [4], a tri-band monopole antenna has been proposed to resonate at 2.4 GHz, 3.5 GHz and 5.5 GHz Applications. The bandwidths reported were 340 MHz (2.4 - 2.74 GHz), 340 MHz (3.41 - 3.75 GHz), and 640 MHz (5.24 - 5.88 GHz), respectively, for 2.4 GHz, 3.5 GHz and 5.5 GHz indicating this antenna is suitable for WLAN and WiMAX applications. The antenna resulted in a return loss value less than −10 dB for all the three frequencies. Gain of proposed antenna was 2.08 dBi, 1.93 dBi and 2.48 dBi for 2.5 GHz, 3.5 GHz and 5.5 GHz respectively. The proposed antenna is compact in size and has nearly omni-directional radiation characteristics and constant gains over all the operating frequency bands. In [5], a compact antenna with a modified Ground structure is presented. The antenna gives a bandwidth of 400 MHz and 530 MHz for 2.5 GHz and 3.5 GHz respectively. It also gives a omni-directional pattern with a peak gain of 1.9 dBi and 2.7 dBi for the lower and upper frequency bands respectively. In [6], a compact triple-band printed monopole antenna for WLAN and WiMAX applications has been proposed. The Bandwidth reported in the Antenna was 100 MHz for 2.4 GHz, 500 MHz for 3.5 GHz and 610 MHz for 5.5 GHz. The radiation pattern of the Antenna is omni-directional in nature. The Antenna resulted in a Gain of 1.55 dBi, 1.6 dBi and 2.05 dBi for 2.45 GHz, 3.5 GHz and 5.6 GHz respectively. In [7], a Tri band Antenna with a modified
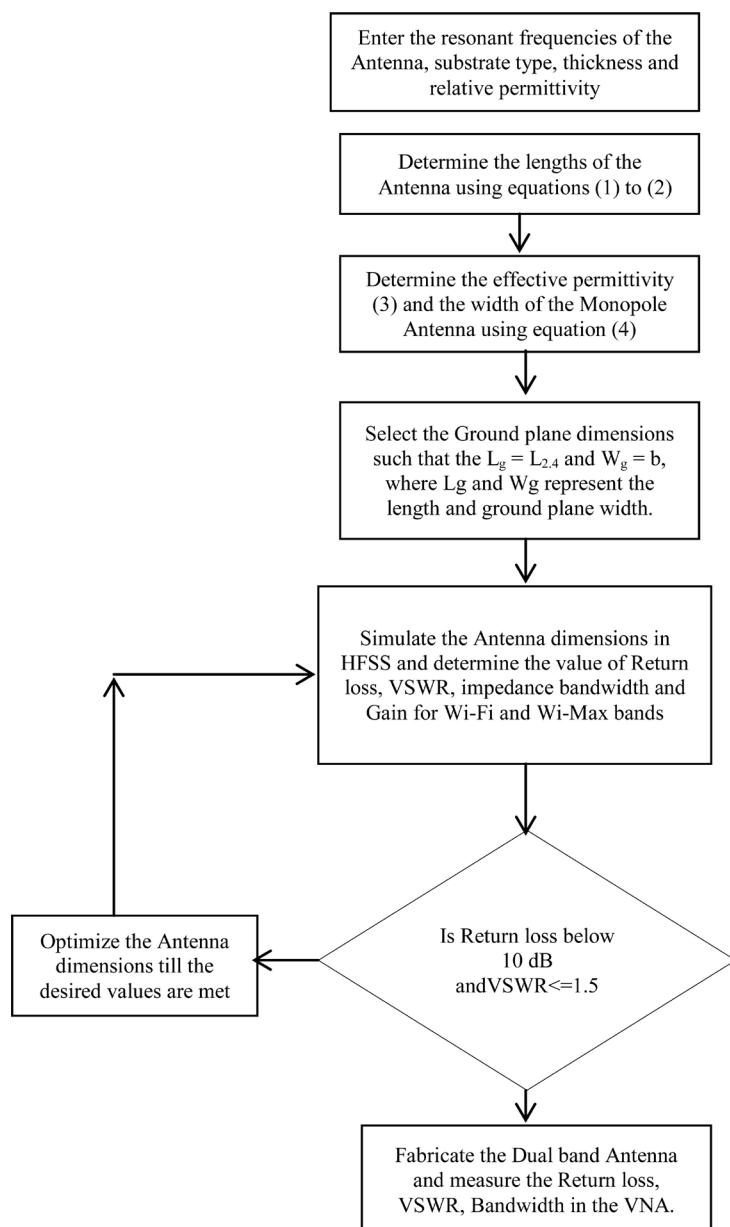
Ground plane has been proposed for WLAN and WiMAX applications. By inserting inverted L shaped strips and perturbations in the Ground plane resulted in a resonant frequency of 2.4 GHz, 3.5 GHz and 5.2 GHz. The structure size reported were 20 mm × 27 mm × 1 mm. The Bandwidth of the proposed antenna was 180 MHz, 380 MHz and 280 MHz covering both the 2.4, 5.2 GHz WLAN and 3.5 GHz WiMAX bands. The Antenna Gains reported were between 2.06 to 2.78 dBi for the lower band, 2.14 dBi for the 3.5 GHz and the 5.2 GHz bands respectively. In [8], a pentagonal shaped monopole Antenna with defected Ground structure is presented. The Antenna is etched on a FR4 substrate and compact in shape. The Antenna resonates at 1.8 GHz and 3.5 GHz. The antenna gives a gain of 0.611 dB and 3.56 dB for frequencies of 1.847 GHz and 3.474 GHz respectively. The Bandwidth of the proposed antenna was 90 MHz and 150 MHz respectively for DCS and WiMAX bands respectively. In [9], dual-band monopole antenna is presented for resonating at 900 MHz and 1.8 GHz covering the GSM 900 and GSM 1800 bands respectively. The proposed design can be used as an Energy Harvesting system. The Antenna was printed on a FR4 substrate. The return loss values were −30 dB and −25.5 dB for GSM 900 and 1800 bands respectively. The Gains reported were −1.64 dB and 0.85 dB for the lower and the upper bands respectively. Bandwidths of the proposed Antenna were 124 MHz and 196 MHz covering lower and upper GSM bands respectively.

In [10], a compact slotted multi-band monopole antenna has been proposed for WLAN and WiMAX applications. The proposed antenna has a size of 30 mm × 25 mm × 1 mm. The designed antenna obtained three frequency bands namely 2.4 GHz, 3.5 GHz and 5.8 GHz covering the WLAN and the Wi-Max bands. The current path is changed by using inverted E and C shaped slot. The structure resulted in a Bandwidth of 51 MHz, 450 MHz for the WLAN 2.4 GHz and 5.5 GHz and 251 MHz for the Wi-Max band. In [11], a simple multiband metamaterial-loaded monopole antenna suitable for WLAN and Wi-Max has been proposed. The rectangular Monopole antenna was originally designed to resonate at 5.2 GHz. When the inverted-L slot is etched, the antenna produces a second resonance at around 4.1 GHz. Then, with the addition of the metamaterial reactive loading, a third resonance covering the 2.4-GHz band occurs. Consequently, the antenna can cover the 2.4/5.2/5.8 GHz WLAN and 2.5/3.5/5.5 GHz WiMAX bands with a very compact size. In [12], design of a dual-band monopole antenna with microstrip fed for use in wireless devices in the WiMAX system is presented. The antenna radiator has a compact size of only 14.5 × 8.7 mm² and consists of a short stem and two branches resonating at around 2.4 GHz and 3.5 GHz for the WLAN and WiMAX bands. In [13], a circularly polarized planar monopole antenna is presented. By inserting the L and the C shaped strips on the patch, two frequency bands were obtained. The structure has a compact size of 40 × 47 × 1.5 mm³. The Bandwidths of the proposed Antenna were 380 MHz and 1240 MHz for the 2.4 GHz and the 5.2 GHz bands respectively. The patterns have the characteristic of bidirectional radiation, and the gains are stable in both bands. In [14], multi band Monopole Antennas, covering three frequencies using

Defective Ground plane structures were realized. The novelty of the proposed work lies in dual inverted L-shaped strips and is fed by a cross-shaped stripline. This technique resulted in creating additional bands and improved Bandwidth. The size of the Antenna reported were 20 mm × 30 mm^2, covering the WLAN and Wi-Max Applications. In [15], a multiband bow-tie monopole antenna with Co-planar waveguide feed is proposed. To cover different frequency bands, slots of different lengths were etched in the bow-tie patch. The Antenna resulted in a peak Gain of 3.75 dBi, 3.56 dBi and 3.93 dBi covering the 2.5 GHz, 3.5 GHz and 5.5 GHz bands respectively.

2. Design Methodology

In our proposed work, the main antenna is designed to resonate at 2.4 GHz

Enter the resonant frequencies of the Antenna, substrate type, thickness and relative permittivity

Determine the lengths of the Antenna using equations (1) to (2)

Determine the effective permittivity (3) and the width of the Monopole Antenna using equation (4)

Select the Ground plane dimensions such that the $L_g = L_{2.4}$ and $W_g = b$, where Lg and Wg represent the length and ground plane width.

Simulate the Antenna dimensions in HFSS and determine the value of Return loss, VSWR, impedance bandwidth and Gain for Wi-Fi and Wi-Max bands

Is Return loss below 10 dB andVSWR<=1.5

Optimize the Antenna dimensions till the desired values are met

Fabricate the Dual band Antenna and measure the Return loss, VSWR, Bandwidth in the VNA.

which is shown by the longer monopole of length $L_{2.4}$ and side arm is inserted towards the right of the longer monopole antenna so as to create an additional resonant frequency of 3.5 GHz. The substrate chosen here is a FR4 type which has a dielectric loss tangent of 0.02 and permittivity of 4.4. The substrate thickness is kept equal to 1.6 mm. The length and width of the ground planes are selected such that the antenna size becomes compact, with the length of the ground plane kept equal to $L_{2.4}$ and width of the ground plane is selected such that it is approximately equal to the length of the side arm of the monopole.

3. Antenna Design

In the proposed design, the Ground plane has been partially removed to give it a Monopole like structure.

4. Design Equations

Figure 1 shows the snap shot of the antenna designed in HFSS clearly indicating the substrate, the Antenna and the Ground plane. Figure 2 shows the fabricated
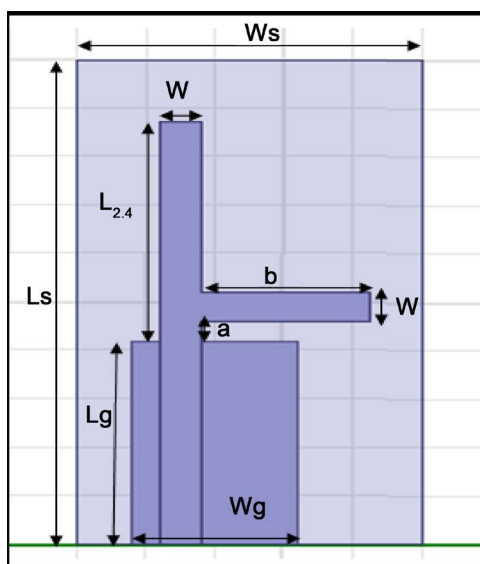
Keynote 1: $L_{2.4}$ represents the length of the monopole resonating at 2.4 GHz and b represents the section contributing for resonance at 3.5 GHz.

Figure 1. Snapshot of the proposed Dual frequency Monopole Antenna in HFSS.
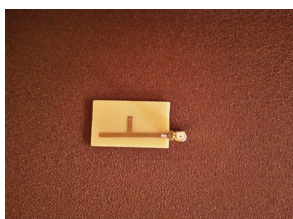
| (a) | (b) |

Keynote 2: Antenna dimensions are 50 mm by 25 mm on FR4 substrate of thickness 1.6 mm.

Figure 2. (a) Fabricated Dual band Antenna (b) Ground plane view.

prototype of the Antenna. The selection of the length and width of the Monopole has been done using the following equations [1] & [16]

$$L_{2.4GHz} = \frac{\lambda g}{4} \tag{1}$$

$$\lambda g = \frac{\lambda_0}{\sqrt{\varepsilon_{reff}}} \tag{2}$$

$$\varepsilon_{reff} = \left[\left(\frac{\varepsilon_r + 1}{2} \right) + \left(\frac{\varepsilon_r - 1}{2} \right) \left(1 + \frac{12h}{W} \right)^{\frac{-1}{2}} \right] \tag{3}$$

$$Z = \frac{60}{\sqrt{\varepsilon_{reff}}} \ln \left[\frac{8h}{W} + \frac{W}{4h} \right] \tag{4}$$

$$L_{3.5GHz} = a + b = \frac{\lambda g}{4} \tag{5}$$

$$Ls = 6h + L \tag{6}$$

$$Ws = 6h + W \tag{7}$$

where L_1 = Length of the Main Monopole resonating at 2.4 GHz.

λg = Guide wavelength.

ε_{reff} = Effective electrical permittivity of the dielectric substrate.

λ_0 = Free space wavelength corresponding to frequency of operation.

ε_r = Relative dielectric constant of the substrate.

W = Monopole Antenna width.

H = Substrate thickness = 1.6 mm.

Z = 50 Ohms (port Impedance).

W = Width of the Monopole.

a = Gap width.

b = Side Lengths of the Monopole.

Ls = Substrate Length.

Ws = Substrate Width.

5. Proposed Algorithm

(i) Select the Antenna dimensions require using Equations (1) to (3)

(ii) Select the substrate type required, thickness and relative permittivity

(iii) Determine the value of effective permittivity using (3)

(iv) Simulate the Antenna for 2.4 GHz with the theoretical length.

(v) Determine the values of Return loss, VSWR, Impedance bandwidth and Gain.

(vi) Is the Return loss well below −10 dB and VSWR < 1.5.

(vii) Optimize the antenna dimensions and repeat the steps (v) and (vi).

(viii) Insert a side arm perpendicular to the main arm using the theoretical length calculated for 3.5 GHz.

(ix) Repeat steps (v) to (vii) until all the parameters are as desired.

(x) Antenna is fabricated on a FR4 substrate. Simulated and measured results are compared.

6. Simulation & Measured Results

The Antenna has been simulated under HFSS version 15.0 and also fabricated and tested with VNA. The results are indicated as shown.

7. Results and Discussions

The Dual band Antenna resonating at Wi-Fi and Wi-Maxband which is reported here is fabricated and experimentally tested with dimensions as reported in Table 1. The substrate lengths and widths were set equal to 50 mm by 25 mm. The Length and width of the ground plane was theoretically set equal to quarter of the Guide wavelength corresponding to 2.4 GHz and 3.5 GHz respectively. The Length of the longer monopole arm was set equal to a quarter of the Guide wavelength corresponding to 2.4 GHz frequency and the side arm length which is perpendicular to main arm is set equal to quarter of the Guide wavelength corresponding to 3.5 GHz frequency. After theoretical calculations it was found to be 17.1 mm. The length of the side arm (a + b) was calculated at Quarter wavelength resonance condition to arrive at 11.7 mm. Further optimization was done on the longer arm and the side arm resulting in a length of 22.6 mm and 14.3 mm respectively. The width of the feed was calculated using Equation (4) taking the port impedance as 50 Ohms substrate height as 1.6 mm and effective permittivity as 4, to arrive at the feed width of 3.0 mm. Figure 3 and Figure 4 show the simulated and measured return loss of the proposed Antennas. The Return loss of the fabricated Dual band Antenna was measured using VNA MASTER MS2308C. Two resonant modes were excited 2.4 GHz and 3.5 GHz. The measured values were 2.7 GHz and 3.426 GHz with an impedance Bandwidth of 0.26 GHz and 2.16 GHz. The bandwidth reported in the upper band was the highest. The measured value of VSWR reported in the Wi-Fi band was 1.53 and that in the Wi-Max band was 1.09 indicating a good impedance match at the upper. The measured values as seen from Figure 4 were 2.7GHz and 3.426 GHz with an impedance Bandwidth of 0.26 GHz and 2.16 GHz as reported in Figure 9. The VSWR reported in Figure 5 is close to 1 indicating a good impedance match. The bandwidth reported in the upper band was the highest. From the Figure 6, the measured value of VSWR reported in the Wi-Fi band was 1.53 and that in the Wi-Max band was 1.09 indicating a good impedance match at the upper band compared to the lower band. Comparing Figure 7 and Figure 8, the simulated Bandwidth reported is 330 MHz and 412 MHz for Wi-Fi and the Wi-Max Frequency bands respectively. From Figure 10, peak value Gain is 6.23 dB for 2.4 GHz, and 7.17 dBi in the 3.5 GHz band. The measured radiation pattern as reported in Figure 13 and Figure 14, show that the pattern is omnidirectional for both the 2.4 GHz and the 3.5 GHz frequency bands respectively. Referring to Table 2, we see that the return loss value is more negative in the 2.4 GHz band

Table 1. Geometrical specifications of the Antenna.

| Antenna specifications	Theoretical Value	Optimized Value
Substrate Length (Ls)	50 mm	50 mm
Substrate Width (Ws)	25 mm	25 mm
Ground plane Length (Lg)	26.7 mm	21 mm
Ground plane width (Wg)	12.6 mm	12.0 mm
Feed width (w)	3.0 mm	3.0 mm
Length of longer arm ($L_{2,4}$)	17.1 mm	22.6 mm
Length of the side arm (a + b)	11.7 mm	14.3 mm
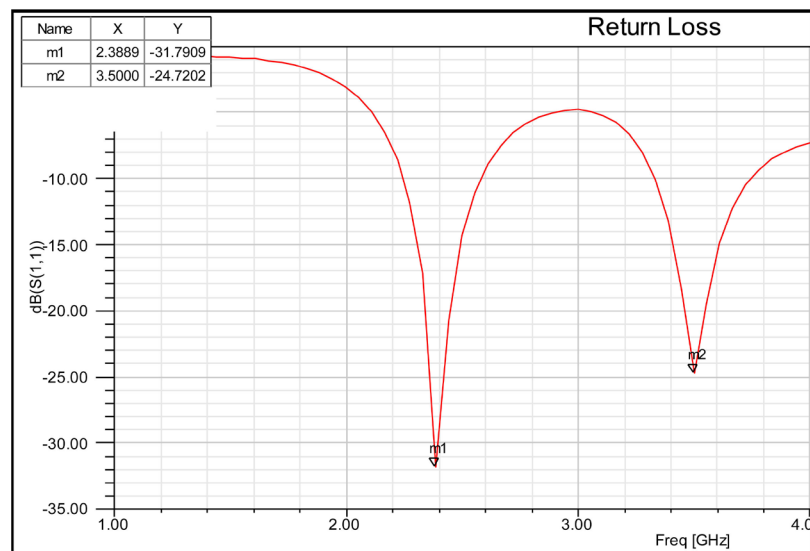
Keynote 3: markers m1 and m2 indicate a return loss of −31.79 dB & −24.72 dB for 2.4 GHz and 3.5 GHz.

Figure 3. Return Loss plot of the Monopole Antenna resonating at 2.4 and 3.5 GHz.
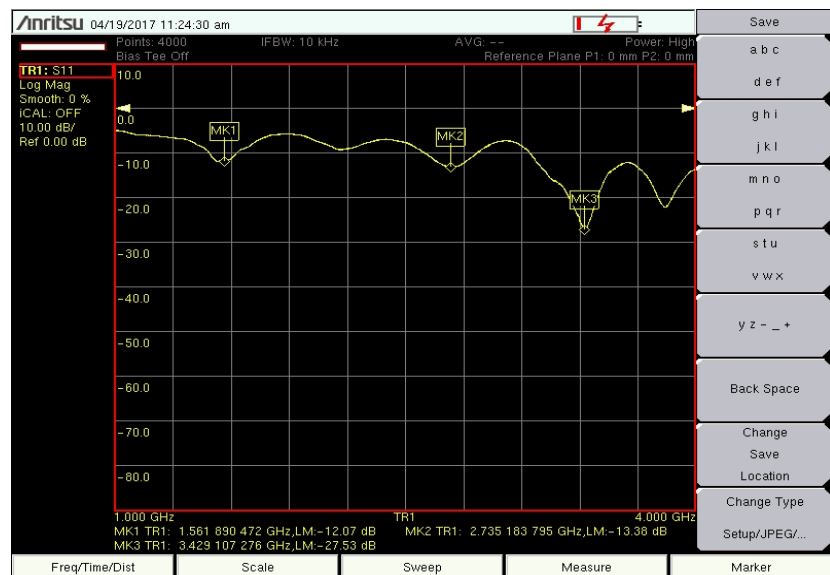
Keynote 4: The Horizontal Axis represents the Frequency in GHz and the vertical Axis represents the Return Loss in dB markers MK2 and MK3 represent 2.7 GHz and 3.5 GHz.

Figure 4. Measured Return Loss plot of the Fabricated Monopole Antenna. The Return loss value is −13.38 dB at 2.72 GHz as indicated by marker MK2 and −27.53 dB at 3.5 GHz corresponding to marker MK3.

Name	X	Y
m1	2.3889	1.0528
m2	3.5000	1.1233
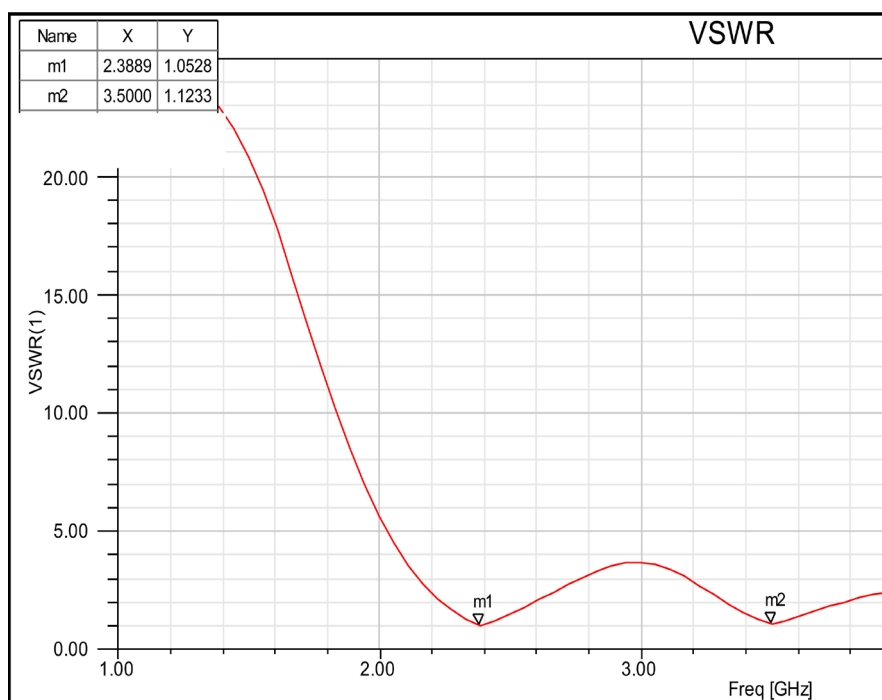
Keynote 5: Markers m1 and m2 indicate a VSWR value of 1.05 and 1.12 for 2.4 GHz and 3.5 GHz.

Figure 5. Simulated VSWR plot of the Monopole Antenna resonating at 2.4 GHz and 3.5 GHz. The corresponding values of VSWR are 1.05 and 1.12 as indicated by markers m1 and m2.
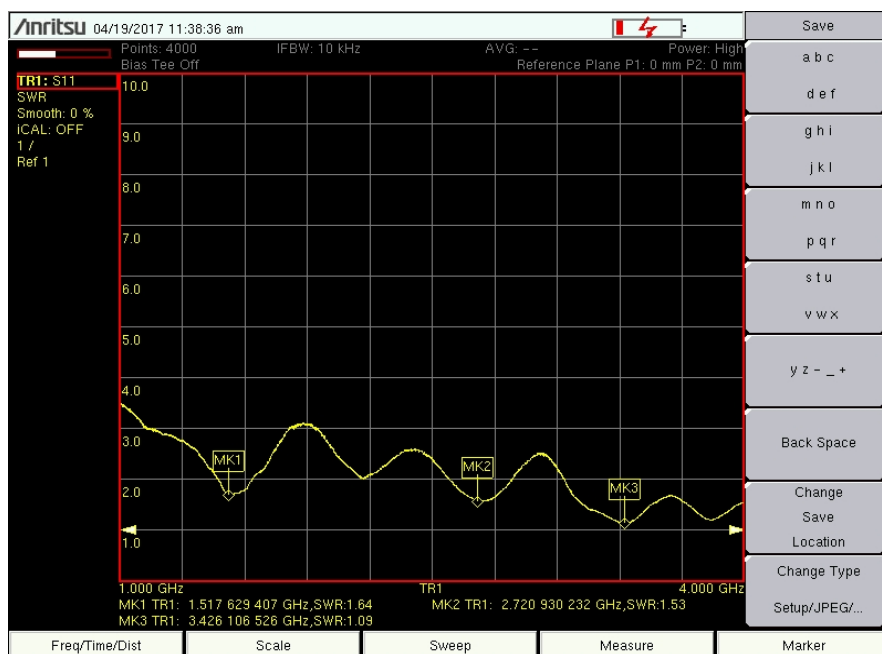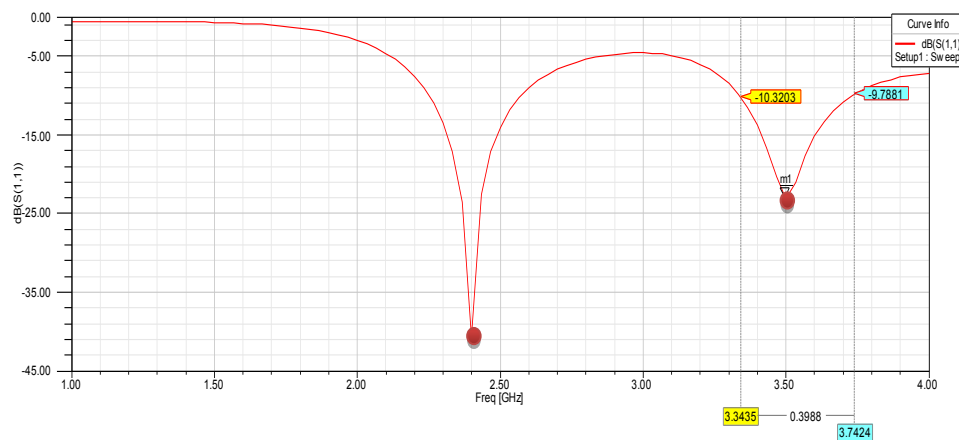

Keynote 6: The Horizontal axis represents the Frequency in GHz and the vertical Axis represents the VSWR. The markers MK2 and MK3 represent the VSWR corresponding to 1.53 and 1.09 for 2.7 GHz and 3.5 GHz.

Figure 6. Measured VSWR plot of the Monopole Antenna resonating at 2.4 GHz and 3.5 GHz as shown by markers MK2 and MK3. The corresponding values are 1.53 and 1.09 for lower and upper band respectively.

Figure 7. Simulated Bandwidth of the Monopole Antenna resonating at 2.4 GHz indicating a Bandwidth of 330.2 MHz.


Keynote 8: Horizontal Axis represents the Frequency in GHz and the Vertical axis represents the return loss in dB.

Figure 8. Simulated Bandwidth of the Monopole Antenna resonating at 3.5 GHz indicating a Bandwidth of 412.7 MHz. From the figure, the lower −10 dB frequency is 3.33 GHz and the upper −10dB frequency is 3.747 GHz and the difference gives the Bandwidth.
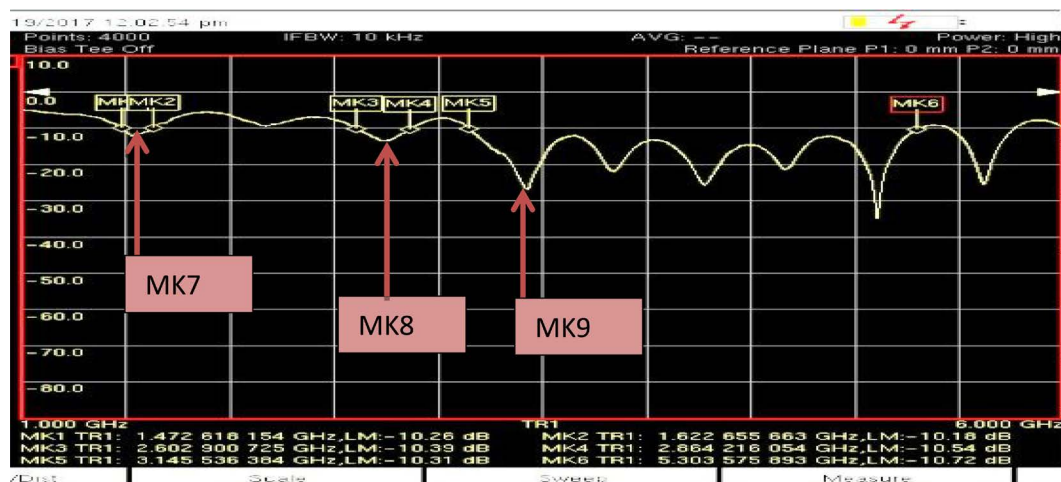
Keynote 9: Horizontal Axis represents the Frequency in GHz and the Vertical Axis represents the Return loss in dB.

Figure 9. Measured Bandwidth of the Dual band Antenna resonating at 2.4 GHz 3.5 GHz as shown by markers MK3, MK4, MK5 and MK6 indicating a Bandwidth of 262 MHz and 2.158 GHz for Wi-Fi and Wi-Max. The markers MK7, MK8 and MK9 indicate the resonant frequencies of 1.5 GHz, 2.7 GHz and 3.429 GHz.
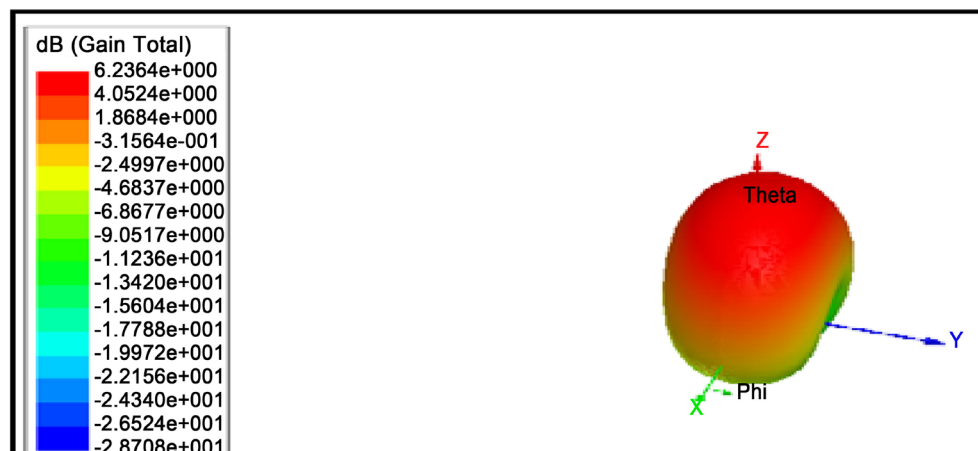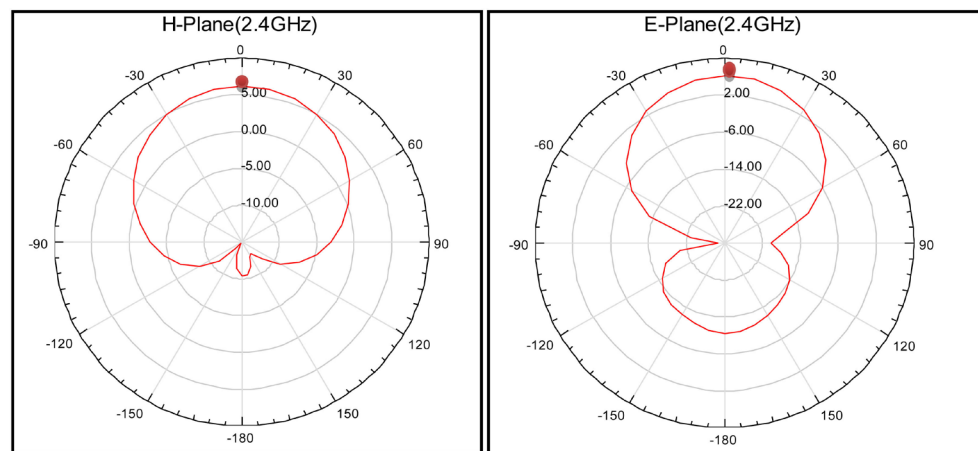
(a)
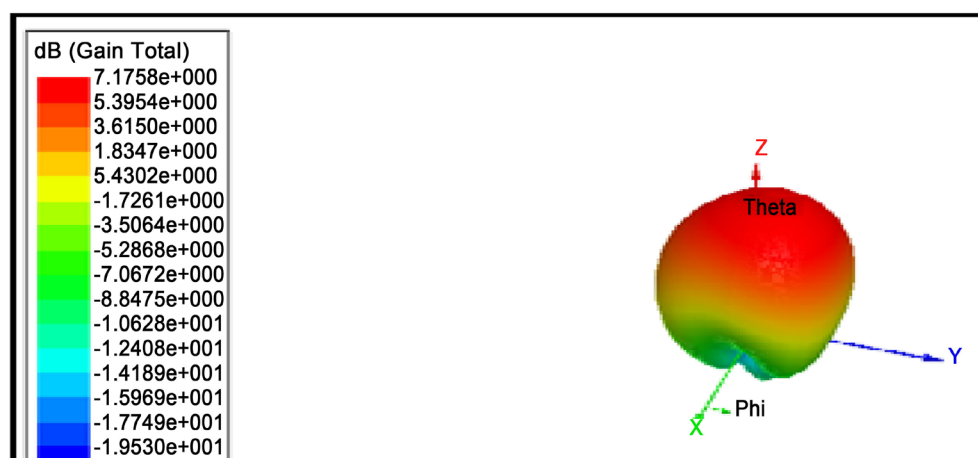
(b)

Figure 10. (a) Simulated Gain plot for 2.4 GHz. The peak; (b) Simulated Gain plot for 3.5 GHz indicating a Gain reported is 6.236 dB. peak Gain of 7.17 dBi.


(a)   **(b)**

Keynote 11: The vertical Axis represents a peak gain of 6.23 dBi for the E and H plane. The pattern is Hemispherical in H plane and figure of 8 in E plane.
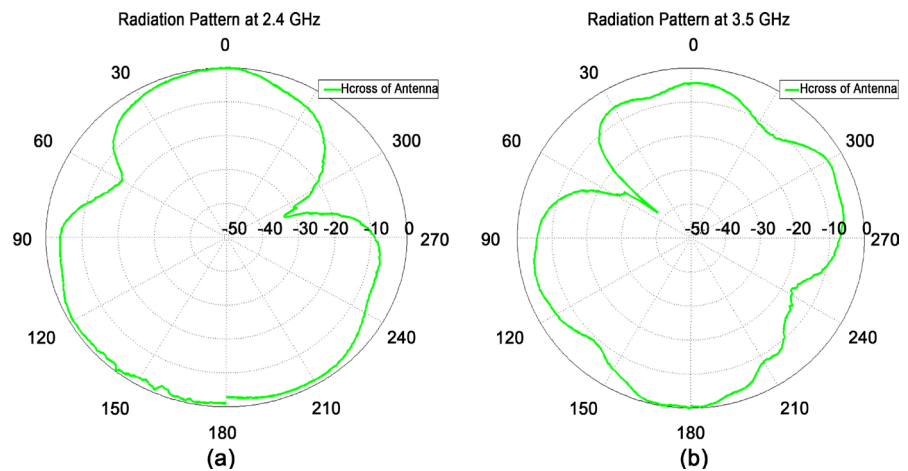
Figure 11. Simulated radiation pattern of Antenna at 2.4 GHz (a) under H plane and (b) under E plane.

compared to 3.5 GHz band indicating a good impedance match close to 50 Ohms in the lower band compared to the higher band. Both the Gain and the Bandwidths are increased by a factor of 0.9 dB and 88.5 MHz in the upper compared to lower band respectively. Comparing Figure 11, we see that the peak boresignt gain is 6.23 dBi under both E and the H plane at 2.4 GHz. But the pattern in H plane is Figure 8. Comparing Figure 12, we see that the peak boresight Gain is 6.5 dB and 7.17 dB under H and E planes. Referring to Table 3, we see that the measured Bandwidth reported is very high close to 2.16 GHz in the upper band compared to lower band and also there is a shift in the resonant Frequency from 2.4 GHz to 2.7 GHz in the lower band. Referring to Table 4 and Table 5, we see that both the Gain and Bandwidths reported in the present work are high compared to other designs reported in [6] [7] and [10] at 2.4 GHz and 3.5 GHz Frequency. Figure 15 indicates that there is a good improvement in the


(a) (b)
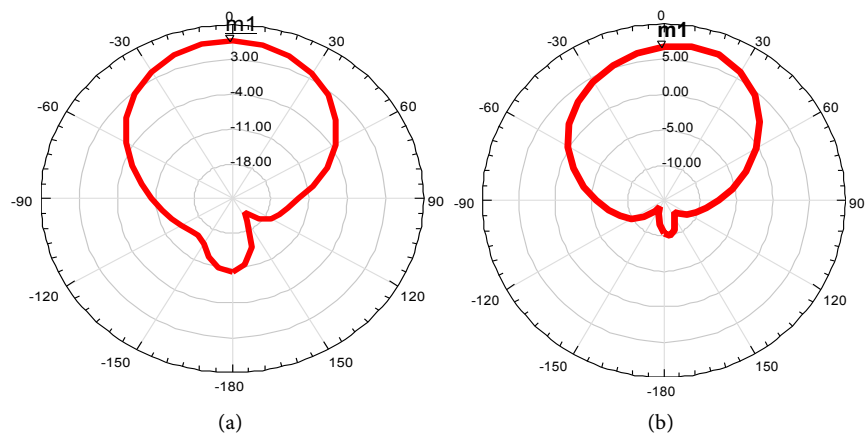
Keynote 12: the radiation pattern indicates a peak bore sight gain of 6.5 dB under H plane and 7.17 dB under E plane for 3.5 GHz.

Figure 12. Simulated radiation pattern of Antenna at 3.5 GHz (a) H plane (b) E plane. From the pattern it is clear that there are some side lobes are appearing at −180 degrees.

(a) (b)

Keynote 13: The measured radiation pattern is nearly omni directional in E plane for both the frequencies.

Figure 13. Measured Normalized E-plane radiation pattern of Antenna at (a) 2.4 GHz and (b) 3.5 GHz.
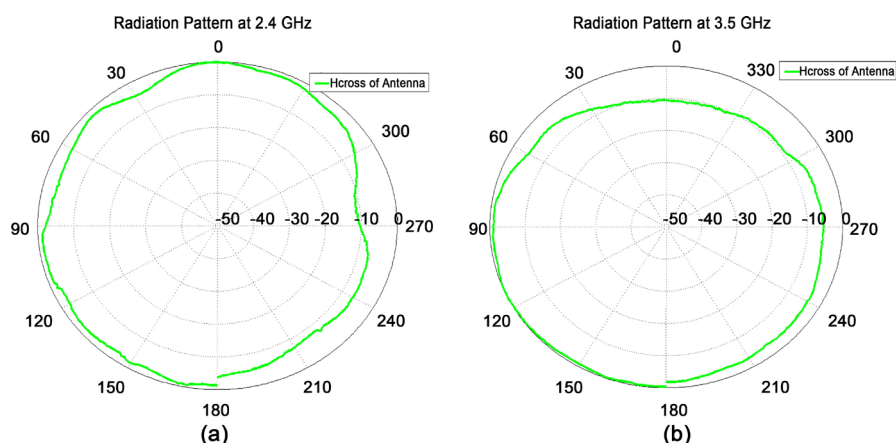
Keynote 14: The radiation pattern is nearly omni-directional for both the frequencies. The pattern is normalized to 0 dB.

Figure 14. Measured normalized H-plane radiation pattern of Antenna at (a) 2.4 GHz and (b) 3.5 GHz.

Table 2. Showing the comparison of the Simulated Antenna parameters at 2.4 GHz and 3.5 GHz.

	2.4 GHz	3.5 GHz
Return Loss	−31.79 dB	−24.72 dB
VSWR	1.058	1.123
Port Impedance	52.3825 Ohms	44.6874 Ohms
Bandwidth	330.2 MHz	412.7 MHz
Gain	6.2364 dBi	7.1758 dBi

Table 3. Showing the comparison of the Simulated and Fabricated Antenna Results.

	Simulated Results	Measured Results
Resonant Frequency	2.4 GHz and 3.5 GHz	2.72 GHz and 3.426 GHz
VSWR	1.058 (2.4 GHz) & 1.123 (3.5 GHz)	1.53 (2.72 GHz) & 1.09 (3.426 GHz)
Return Loss	−31.79 dB (2.4 GHz) & −24.72 dB (3.5 GHz)	−13.38 dB (2.72 GHz) & −27.53 dB (3.5 GHz)
Bandwidth	330.2 MHz(2.4 GHz) & 412.7 MHz (3.5 GHz)	0.26 GHz (2.4 GHz) & 2.16 GHz (3.5 GHz)

Table 4. Showing the comparison of the Simulated results reported in the paper with [6] [7] and [10] at 2.4 GHz.

| Antenna parameters	Present work	[6]	[7]	[10]
Return Loss	−31.79 dB	−18.0 dB	−32 dBi	−25 dB
Bandwidth	330.2 MHz	110.0 MHz	180 MHz	110 MHz
Gain	6.326 dBi	1.55 dBi	2.78 dBi	2.1 dBi

Table 5. Showing the comparison of the Simulated results reported in the paper with [6] [7] and [10] at 3.5 GHz frequency.

Antenna parameters	Present work	[6]	[7]	[10]
Return Loss	−24.72 dB	−17.5 dB	−29 dB	−17.5 dB
Bandwidth	412.7 MHz	700.0 MHz	380 MHz	260 MHz
Gain	7.1758 dBi	1.6 dBi	2.14 dBi	3.4 dBi
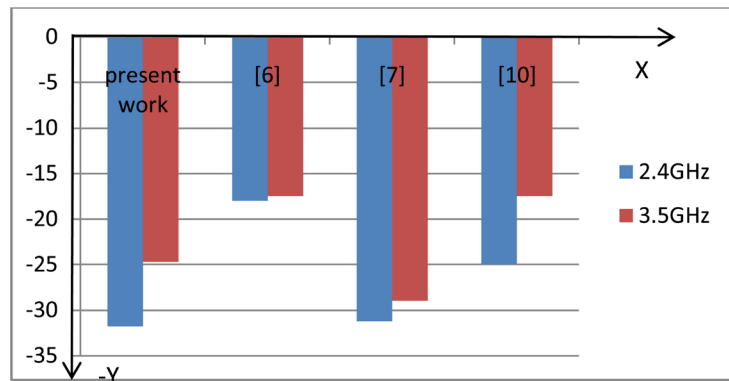
Keynote 15: X Axis represents the Reference papers and Y Axis represents the Return Loss in dB.
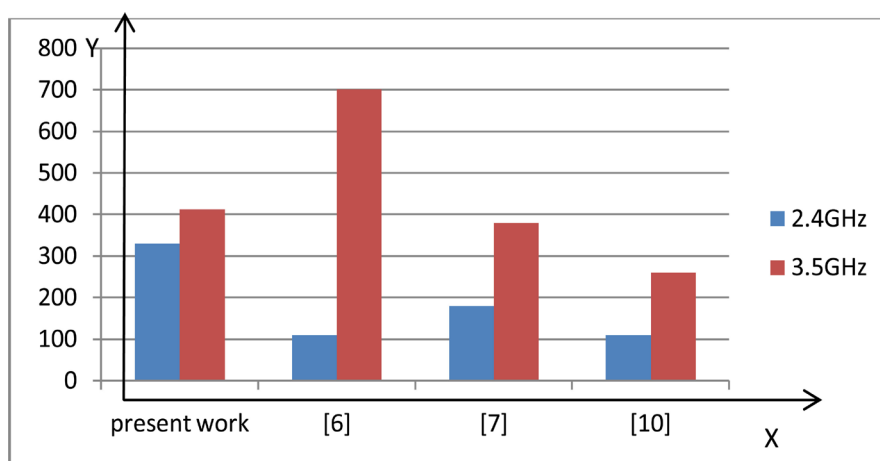
Figure 15. Showing the comparison of the Simulated results reported in the paper with [6] [7] and [10] at 3.5 GHz frequency.
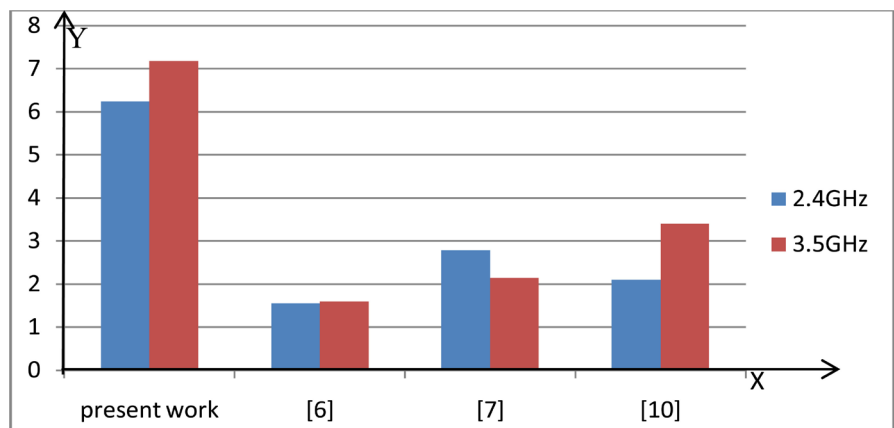
Keynote 16: X Axis represents the Reference papers and Y Axis represents the Gain in dBi.

Figure 16. Showing the comparison of the Gain reported in the present work with similar other works reported in [6] [7] and [10]. X Axis represents the Dual Frequency bands obtained in References [6] [7] & [10] and Y Axis represents the Gain in dBi.

Return loss, namely 13.79 dB and 6.79 dB compared to [6] and [10] for the Wi-Fi Frequency band of interest. But in the Wi-Max band, there is a 7.22 dB improvement in the return loss compared to [6] and [10]. From **Figure 16**, it is clear that there is a 3.546 dB and 4.226 dB improvement in the Gain compared to [7] and [10] in the lower frequency bands of interest. While in the upper band there is a 5.03 dB and 3.7758 dB improvement in the Gain compared to [7] and [10]. As far as the Bandwidth of the Antenna is concerned **Figure 17** shows that

Keynote 17: Y Axis represents the Bandwidth in MHz and X Axis represents the Reference papers.

Figure 17. Showing the comparison of the Bandwidth reported in the present work with similar other works reported in [6] [7] and [10]. X Axis represents the Dual Frequency bands obtained in References [6] [7] & [10] and Y Axis represents the Bandwidth in MHz.

there is a 200.2 MHz improvement in the Bandwidth reported in the present work compared to [6] & [10] at 2.4 GHz frequency band. But at 3.5 GHz frequency band, there is a 32.7 MHz and 152.7 MHz improvement in the Bandwidth at the upper frequency band of interest compared to [7] and [10].

8. Conclusion

A novel Antenna for Wi-Fi and Wi-Max band of frequencies has been proposed. It is etched on a FR4 substrate with a permittivity of 4.4. By employing two perpendicular strips, the Antenna has been made to resonate at the Dual band. The measured S11 were −13.38 dB and −27.53 dB for the 2.4 GHz band and the 3.5 GHz band respectively. The measured bandwidth of the proposed Antenna was 0.26 GHz and 2.16 GHz in the lower and upper band respectively. The size of the Antenna reported is 50 mm by 25 mm, thus making it compact in size.

Acknowledgements

References

[1] Prasanna Paga, Nagaraj, H.C., Rukmini, T.S. and Nithin, N.E. (2015) Design and Fabrication of Microstrip printed T monopole antenna for ISM applications. *International Conference on Microwave, Optical and Communication Engineering*, 18-20 December 2015, IIT, Bhubaneswar.
https://doi.org/10.1109/ICMOCE.2015.7489742

[2] Jithu, P., Paul, A., Pithadia, V., Misquitta, R. and Khot, U.P. (2013) Dual Band Monopole Antenna Design. *International Journal of Engineering and Technology* (*IJET*), **5**, 2297-2302. http://www.enggjournals.com/ijet/docs/IJET13-05-03-036.pdf

[3] Shah, I.A., Hayat, S., Khan, I., Alam, I., Ullah, S. and Afridi, A. (2016) A Compact, Tri-Band and 9-Shape Reconfigurable Antenna for WiFi, WiMAX and WLAN Applications. *International Journal of Wireless and Microwave Technologies*, **5**, 45-53. https://doi.org/10.5815/ijwmt.2016.05.05

[4] Huang, S.S., Li, J. and Zhao, J.Z. (2014) Design of a Compact Triple-Band Monopole Planar Antenna for WLAN/WiMAX Applications. *Progress in Electromagnetics Research C*, **48**, 29-35. https://doi.org/10.2528/PIERC13122202

[5] Li, L., Rao, S.-H., Tang, B. and Li, M.-F. (2013) A Novel Compact Dual-band Monopole Antenna Using Defected Ground Structure. *International Workshop on Microwave and Millimeter Wave Circuits and System Technology*, 24-25 October 2013, Chengdu. https://doi.org/10.1109/MMWCST.2013.6814645

[6] Wang, H.J. and Li, H. A Compact Triple-Band Monopole Antenna for WLAN/WiMAX.

[7] Wang, T., Yin, Y.Z., Yang, J., Zhang, Y.L. and Xie, J.J. (2012) Compact Triple-Band Antenna Using Defected Ground Structure for WLAN/WIMAX Applications. *Progress in Electromagnetics Research Letters*, **35**, 155-164. https://doi.org/10.2528/PIERL12082814

[8] Zahraoui, I., Errkik, A., Zbitou, J., Abdelmounim, E. and Mediavilla, A.S. (2016) A New Design of a Microstrip Antenna with Modified Ground for DCS and WiMAX Applications. *International Journal of Microwave and Optical Technology*, **11**, No. 4.

[9] Zakaria, Z., Zainuddin, N.A., Abd Aziz, M.Z.A., Husain, M.N. and Mutalib, M.A. (2013) Dual-Band Monopole Antenna for Energy Harvesting System. *IEEE Symposium on Wireless Technology and Applications* (*ISWTA*), Kuching, Malaysia, 22-25 September 2013. https://doi.org/10.1109/iswta.2013.6688775

[10] Zhang, S.M., Zhang, F.S., Li, W.M., Li, W.Z. and Wu, H.Y. (2012) A Multi-Band Monopole Antenna with Two Different Slots for WLAN and WIMAX Applications. *Progress in Electromagnetics Research Letters*, **28**, 173-181. https://doi.org/10.2528/PIERL11111505

[11] Huang, H., Liu, Y., Zhang, S. and Gong, S. (2015) Multiband Metamaterial-Loaded Monopole Antenna for WLAN/WiMAX Applications. *IEEE Antennas and Wireless Propagation Letters*, **14**, 662-665. http://or.nsfc.gov.cn/bitstream/00001903-5/320065/1/1000013482596.pdf https://doi.org/10.1109/LAWP.2014.2376969

[12] Sun, X.L., Cheung, S.W. and Yuk, T.I. (2013) Compact Dual-Band Monopole Antenna for 2.4/3.5 GHz WiMAX Applications. *Progress in Electromagnetics Research Symposium Proceedings*, Taipei, 25-28 March 2013. https://doi.org/10.1002/mop.27710

[13] Tan, M.-T. and Wang, B.-Z. (2016) A Dual-Band Circularly Polarized Planar Monopole Antenna for WLAN/Wi-Fi Applications. *IEEE Antennas and Wireless Propagation Letters*, **15**, 670-673. http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=7185377 https://doi.org/10.1109/LAWP.2015.2466596

[14] Liu, W.-C., Wu, C.-M. and Dai, Y. (2011) Design of Triple-Frequency Microstrip-Fed Monopole Antenna using Defected Ground Structure. *IEEE Transactions on Antennas and Propagation*, **59**, 2457-2463.

https://doi.org/10.1109/TAP.2011.2152315

[15] Wu, M.-T. and Chuang, M.-L. (2015) Multibroadband Slotted Bow-Tie Monopole Antenna. *IEEE Antennas and Wireless Propagation Letters*, **14**, 887-890.
http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=6990588
https://doi.org/10.1109/LAWP.2014.2383441

[16] Balanis, C.A. (2008) Modern Antenna Handbook. Wiley, New York.
https://doi.org/10.1002/9780470294154