Science and Technology Publishing (SCI & TECH)
ISSN: 2632-1017
Vol. 8 Issue 1, January - 2024

Design Of 2.4 GHZ Single Band Inset-Fed Rectangular Microstrip Patch Antenna

Tim, Peter Oritsetimeyin[1]
Department of Computer Engineering university of Calabar
Cross Rivers State, Nigeria
timopet4real@gmail.com

Ifeanyi Fredrick Obiadi[2]
Department of Electrical and Electronic Engineering
University of Uyo, Uyo, Akwa Ibom State, Nigeria
honfrerick@yahoo.com

Promise Uchenna Nwadike[3]
Department of Electrical and Electronic Engineering
Imo State University, Owerri,
Imo State, Nigeria

Abstract— **This work presents the design of 2.4 GHz single band inset-fed rectangular microstrip patch antenna. The major aspects of the procedure utilized in the design include specification of key parameters of the antenna, determination of key parameters of the patch and then the determination of the dimensions of the feed network. Afterwards, the parameter values obtained are used to carry out the simulation of the antenna in Computer Simulation Technology (CST) Microwave Studio. Specifically, the key design parameters specified include resonant frequency of 2.45 GHz, substrate dielectric constant, of 4.2 and the loss tangent, of 0.019. From the simulation, results on the antenna performance parameters are obtained such as the return loss, Voltage Standing Wave Ratio (VSWR), directivity for the H-plane (φ = 90°), directivity for the E-plane (φ = 0°) and 3-D gain plot. The simulation results show minimum return loss of -26.394 dB with a bandwidth of 68.3 MHz. The results also show that the antenna achieved a Voltage Standing Wave Ratio (VSWR) of 1.4032 at 2.4 GHz. The directivity results show that the H-plane (φ = 90°) directivity for the insert-fet antenna at 2.4 GHz has main lobe magnitude of 6.09 dBi, main lobe direction value of 3^o and half power beamwidth value of 97.2^o. Directivity results for the E-plane (φ = 0) achieved a gain of 6.08 dBi. The 3-D gain plot at 2.4 GHz showed a gain of 4.85 dB. In all, the results show that the designed antenna has good performance parameter values.**

Keywords— Single Band Antenna, Return Loss, Inset-Fed Antenna, Voltage Standing Wave Ratio (VSWR), Rectangular Microstrip Patch Antenna, Directivity, Bandwidth

1. INTRODUCTION

Over the years, wireless communication technologies have advanced and gained wide adoption that they have become the dominant technologies in the telecommunication industry [1,2,3]. In any case, wireless communications rely on the use of electromagnetic spectrum [4,5,6]. The antenna has the ability to radiate and receive electromagnetic signals [7,8,9]. As such, antennas are needed at the tranmitting end and also at the receiveing end of wireless communication systems [10,11,12].

With the myriad of wireless smart devices springing up in number in recent time, the need for a comprehensive antenna design and analysis to compliment the growing tech trend in order to give engineers and technicians options to choose from cannot be over emphasized. Accordingly, in this work, the design of 2.4 GHz single band inset-fed rectangular microstrip patch antenna is presented [13,14,15,16]. In its most basic form, a microstrip patch antenna consists of a radiating patch on one side of a dielectric substrate and a ground plane on the other side [17,18]. The patch is generally made of a conducting material such as copper or gold and can take any possible shape, but regular shapes are generally used to simplify analysis and performance prediction [19]. The radiating patch and the feed lines are usually photo-etched on the dielectric substrate. Microstrip patch radiate due to the fringing fields between the patch edge and ground plane.

The major aspects of the procedure utilized in the design include specification of key parameters of the antenna, determination of key parameters of the patch and then the determination of the dimensions of the feed network. Afterwards, the parameter values obtained are used to carry out the simulation of the antenna in Computer Simulation Technology (CST) Microwave Studio. Specifically, the key design parameters specified include resonant frequency of 2.45 GHz, substrate dielectric constant, of 4.2 and the loss tangent, of 0.019.

2. METHODOLOGY

The procedure employed in the design of the single band inset-fed RMSA can be broken down as follows; specification of key parameters of the antenna, determination of key parameters of the patch and then the determination of the dimensions of the feed network. After the parameter values obtained are used to carry out the simulation of the antenna in Computer Simulation Technology (CST) Microwave Studio. From the simulation, results on the antenna performance parameters are obtaibed such as the return loss, Voltage Standing Wave Ratio (VSWR), directivity for the H-plane (φ = 90°), directivity for the E-plane (φ = 0°) and 3-D gain plot.

2.1 Specification and determination of key design parameters for the single band inset-fed RMSA

In the design of the single band inset-fed RMSA, some key desing parameters are specified while others are computed based on the specified parameters.

i. The values of the following parameters are specified;
   a) the resonant frequency, f_r (in this study f_r =2.45 GHz),
   b) substrate dielectric constant, ε_r of the substrate ((in this study $\varepsilon_{r=}$ = 4.2)
   c) the loss tangent, tanδ (in this study tanδ = 0.019)

ii. The substrate thickness (h) is calculated as follows;

$$\lambda_0 = \frac{c}{f_r} \qquad (1)$$

$$h \leq 0.3 \text{ x } \frac{\lambda_0}{2\pi\sqrt{\varepsilon_r}} \qquad (3)$$

where $\varepsilon_r = 4.2$, $c = 3 \times 10^8 m/s$ and f_r =2.45 $\times 10^9$ Hz hence, $\lambda_0 = \frac{3 \times 10^8}{2.45 \times 10^9} =$ 122 mm and $h \leq 0.3 \text{ x } \frac{0.122}{2\pi\sqrt{4.2}} = 2.8\ 44m$. A value of h = 1.6 mm is chosen for this study.

iii. The width (W_P) of the patch is calculated as follows;

$$W_P = \frac{c}{2f_r\sqrt{\frac{(\varepsilon_r+1)}{2}}} \qquad (3)$$

Then, $W_P = \frac{3 \times 10^8}{2(2.4 \times 10^9)\sqrt{\frac{(4.2+1)}{2}}} = 37.97$ mm

iv. Effective dielectric constant (ε_{reff}) is calculated as follows;

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1 + 12\left(\frac{h}{W_P}\right)\right]^{-1/2} \qquad (4)$$

Hence;

$$\varepsilon_{reff} = \frac{4.2+1}{2} + \frac{4.2-1}{2}\left[1 + 12\left(\frac{0.0016}{0.03797}\right)\right]^{-1/2} = 3.90$$

v. Effective Length (L_{eff}) is calculated as follows;

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} \qquad (5)$$

Hence; $L_{eff} = \frac{3 \times 10^8}{2(2.4 \times 10^9)\sqrt{3.90}} = 31$ mm

vi. Extension length (ΔL) is calculated as follows;

$$\Delta L = 0.412h\frac{[\varepsilon_{reff}+0.3]\left[\frac{W}{h}+0.264\right]}{[\varepsilon_{reff}-0.258]\left[\frac{W}{h}+0.813\right]} \qquad (6)$$

Hence; $\Delta L = 0.412(1.6)\frac{[3.90+0.3]\left[\frac{0.03797}{0.0016}+0.264\right]}{[3.90-0.258]\left[\frac{0.03797}{0.0016}+0.813\right]} =$ 0.74 mm.

vii. Actual patch length (L_P) is calculated as follows;

$$L_P = L_{eff} - 2\Delta L \qquad (7)$$

L_P = 0.031 – 2(0.0074) = 29.52 mm.

viii. Ground plane dimensions (Lg and Wg) are calculated as follows;

$$Wg = W_P + 6h \qquad (9)$$

$$Lg = L_P + 6h \qquad (8)$$

Hence; Lg = 0.02952 + 6(0.0016) = 39.12 mm and Wg = 0.03797 + 6(0.0016) = 47.57 mm

ix. Patch thickness (t) is selected based on the following expression ;

$$t << \lambda_0 \qquad (10)$$

So, given thta λ_0 = 122 mm a value of t = 0.2 mm is selected.

2.2 Determination of the dimensions of the feed network for the single band inset-fed RMSA:

The computational formulas and procedure used to determine the dimensions of the feed network for the single band inset-fed RMSA are presented as follows:

Step 1: Determine the notch width, g using the expression (Ramil, Salleh, Ali and Md Tan, 2011);

$$g = \frac{c\, f_r \times 10^{-9} \times 4.65 \times 10^{-9}}{\sqrt{2\varepsilon_{reff}}} \qquad (11)$$

Hence, $g = \frac{30 \times 4.65 \times 10^{-9} \times 2.4 \times 10^{-9}}{\sqrt{2 \times 3.90}} = 1.20$ mm.

Step 2: Determine the resonant input resistance R_{in} as follows;

$$R_{in}(y = y_o) = \frac{1}{2(G_1 + G_{12})}\cos^2\left(\frac{\pi y_o}{L_p}\right) \qquad (12)$$

The characteristic impedance Z_o is defined as follows;

$$Z_0 \begin{cases} \frac{60}{\sqrt{\varepsilon_{reff}}}\ln\left[\frac{8h}{W_f} + \frac{W_f}{4h}\right] & \frac{W_f}{h} \leq 1 \\ \frac{120\pi}{\sqrt{\varepsilon_{reff}}}\left[\frac{W_f}{h} + 1.393 + 0.667\ln\left(\frac{W_f}{h} + 1.444\right)\right] & \frac{W_f}{h} \geq 1 \end{cases} \qquad (13)$$

In this study, the value of $\frac{W_f}{h} = \frac{3.30}{1.6} = 2.0625 > 1$. As such, the second expression in Equation 13 applies.

$$k = \frac{2\pi}{\lambda_{air}} \qquad (14)$$

where $\lambda_{air} = \lambda_0 =$ 122 mm, then $k = \frac{2\pi}{122} = 0.0515$.

$$I_1 = -2 + \cos(X) + XS_i(X) + \frac{\sin(X)}{X} \qquad (15)$$

$$X = k(W_p) \qquad (16)$$

Hence; X = 0.0515 × 37.97 = 1.955455 ≈ 2.00. Thus;

$I_1 = -2 + \cos(2) + [(1.912 \times S_i(2)] + \frac{\sin(2)}{2}$ = 1.1895 mA

$$G_1 = \frac{I_1}{120\pi^2} \qquad (17)$$

Hence, $G_1 = \frac{1.1895}{120 \times \pi^2} = 10.043 \times 10^{-4}$ siemens.

$$G_{12} = \frac{1}{120\pi^2}\int_0^{\pi}\left[\frac{\sin(\frac{kW_p}{2}\cos\theta)}{\cos\theta}\right]^2 J_o(kL_p\sin\theta)\sin^3\theta d\theta \quad (18)$$

where J_o is Bessel function of the first kind of order zero. Specifically, in this study, G_{12} is resolved using MATLAB-based program developed for the calculation of rectangular microstrip antenna parameters. Which retured the value $G_{12} = 5.905 \times 10^{-4}$ siemens.

$$R_{in(edge)} = \frac{1}{2(G_1 + G_{12})} \quad (19)$$

Hence; $R_{in(edge)} = \frac{1}{2(10.043\times 10^{-4} + 5.859 \times 10^{-4})} = 306.95\ \Omega$. In this work, inset feed technique is used with input impedance of 50 Ω.

Step 3: Determine the inset feed recessed distance y_0 and width of the transmission line W_f using Equation 20 and Equation 21:

$$Z_0 = R_{in(edge)}\cos^2\left(\frac{\pi}{L_p}y_0\right) \quad (20)$$

$$y_0 = \frac{L_p}{\pi}\cos^{-1}\left[\sqrt{\frac{Z_0}{R_{in(edge)}}}\right] \quad (21)$$

Hence, $y_0 = \frac{29.52}{\pi} \times \cos^{-1}\left[\sqrt{\frac{50}{306.95}}\right] = 11.12$ mm. According to Pozar, (2012), the width of the transmission line, W_f is calculated as follows:

For $\frac{W_f}{h} > 2$;

$$\frac{W_f}{h} = \frac{2}{\pi}\left[B - 1 - \ln(2B-1) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\left\{\ln(B-1) + 0.39 - \frac{0.61}{\varepsilon_r}\right\}\right] \quad (22)$$

Where, $B = \frac{377\pi}{2Z_0\sqrt{\varepsilon_r}}$ (23)

Hence; $B = \frac{377\pi}{2\times 50\times\sqrt{4.2}} = 5.78$

$$\frac{W_f}{h} = \frac{2}{\pi}\left[5.78 - 1 - \ln(\{2\times 5.78) - 1) + \frac{4.2 - 1}{2\times 4.2}\left\{\ln(5.78 - 1) + 0.39 - \frac{0.61}{4.2}\right\}\right]$$

= 2.06 mm

Therefore, $W_f = 2.06 \times 1.6 = 3.30\ mm$

3. RESULT AND DISCUSSION

The geometry of the designed 2.4 GHz RMSA is depicted in Figure 1. The designed inset-fed RMSA at 2.4 GHz in CST Studio is presented in Figure 2.The patch dimensions used are presented in Table 1.

Table 1: Feed dimensions of 2.4 GHz single band inset-fed RMSA

Parameter	Value (mm)
Microstrip line dimensions:	
Width of transmission line, W_f	3.30
Inset fed gap, g	1.20
Inset fed distance, y_o	11.12
Length of 50 Ω line, L_f	4.80
Resonance Frequency, f_r	2.40 GHz

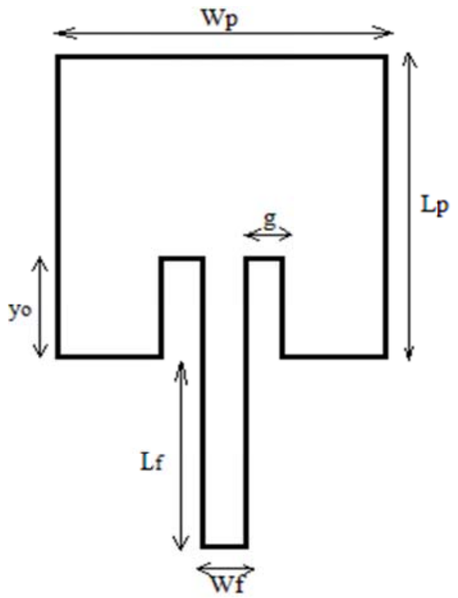


Figure 1: Dimensions of the designed single band inset-fed RMSA antenna.

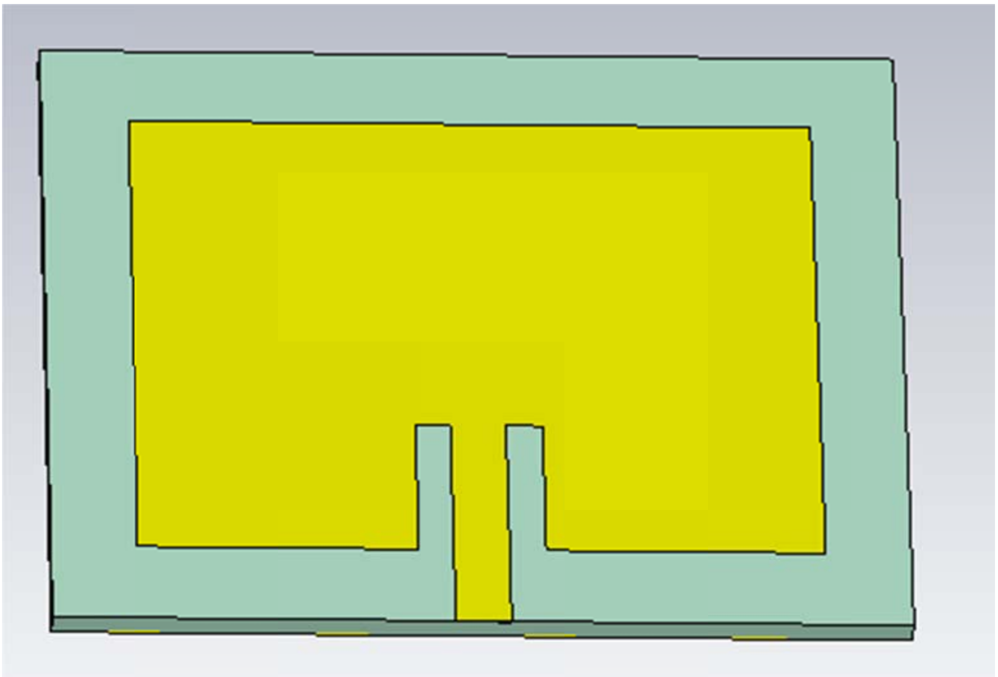


Figure 2: The screenshot of the 2.4 GHz inset-feed single band RMSA designed using the Computer Simulation Technology Microwave Studio**.**

The results of the return loss plot of the inset-fed single band antenna at 2.4 GHz is shown in Figuire 3 and it has a minimum return loss of -26.394 dB with a bandwidth of 68.3 MHz. The results in Figure 4 show that the antenna achieved a Voltage Standing Wave Ratio (VSWR) of 1.4032 at 2.4 GHz. The directivity results (in Figure 5) also show that the H-plane (φ = 90°) directivity for the insert-fet antenna at 2.4 GHz has main lobe magnitude of 6.09 dBi, main lobe direction value of 3^o and half power beamwidth value of 97.2^o. Directivity results for the E-plane (φ = 0°) is shown in Figure 6 where it achieved a gain of 6.08 dBi. The 3-D gain plot (in Figure 7) for the single band insert-fed antennas at 2.4 GHz showed a gain of 4.85 dB.

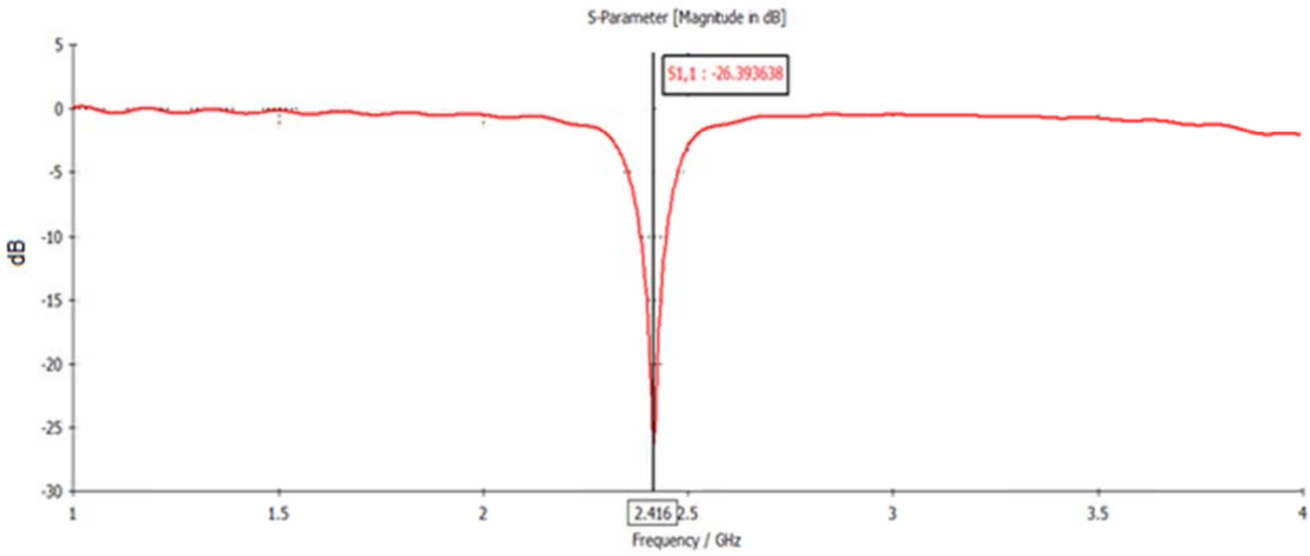


Figure 3: Return loss plot of inset-fed single band antenna at 2.4 GHz.

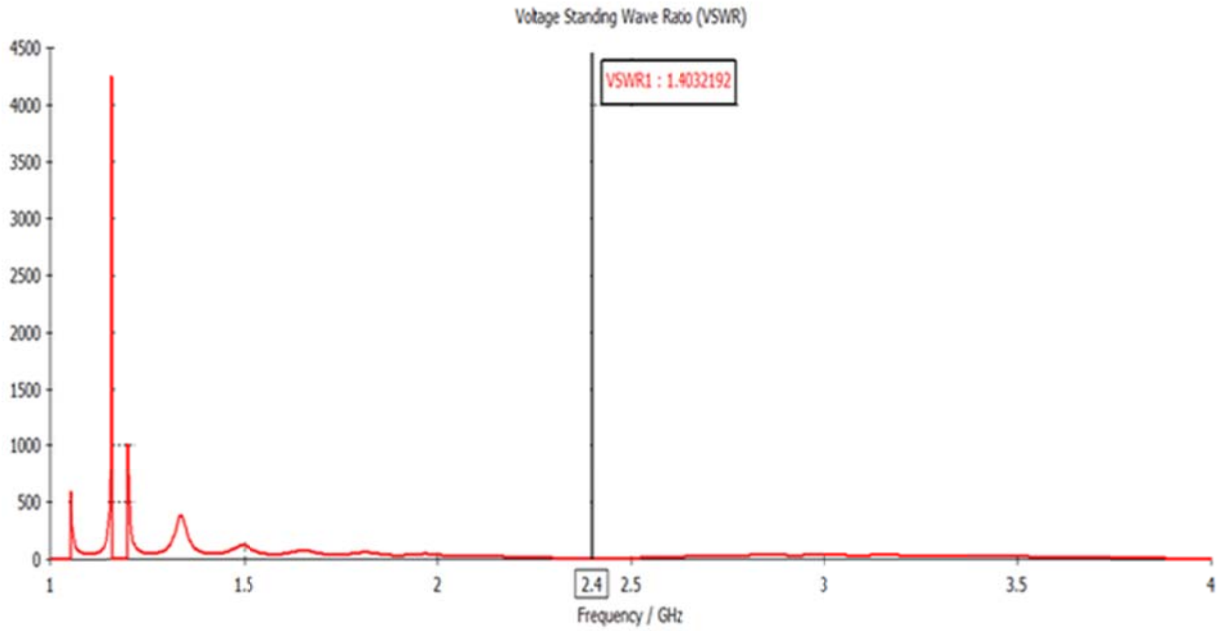


Figure 4: VSWR of inset-fed single band antenna 2.4 GHz.

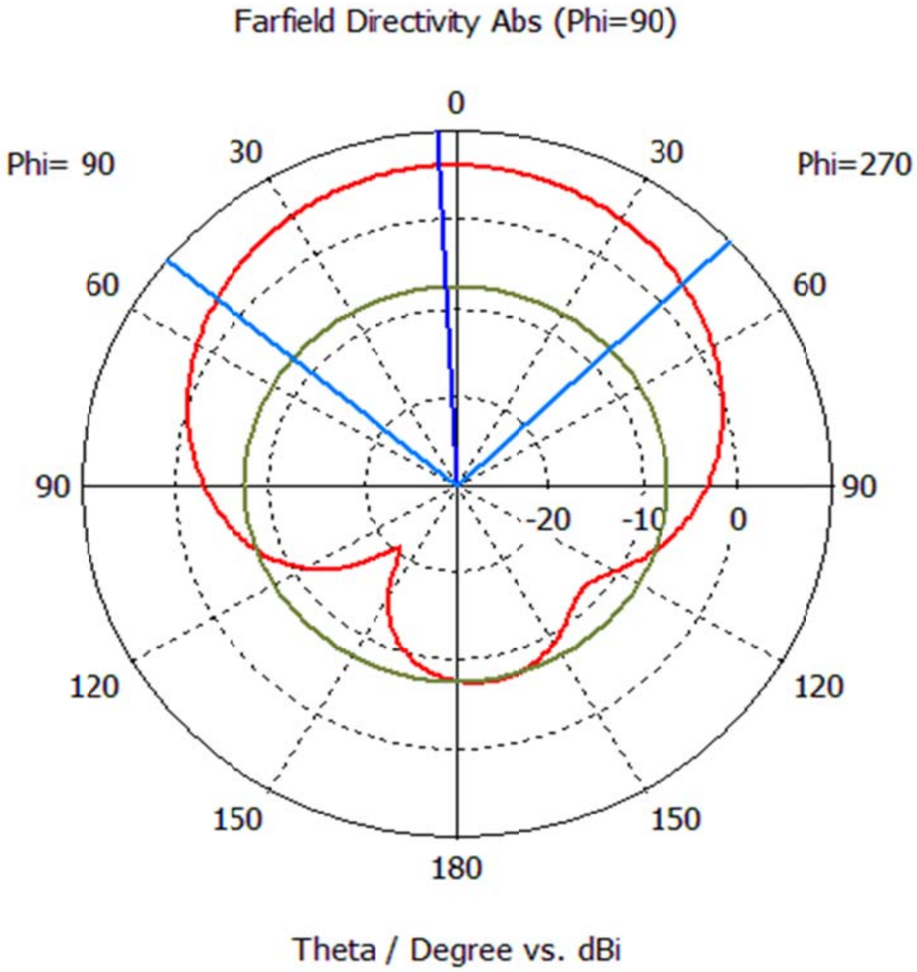
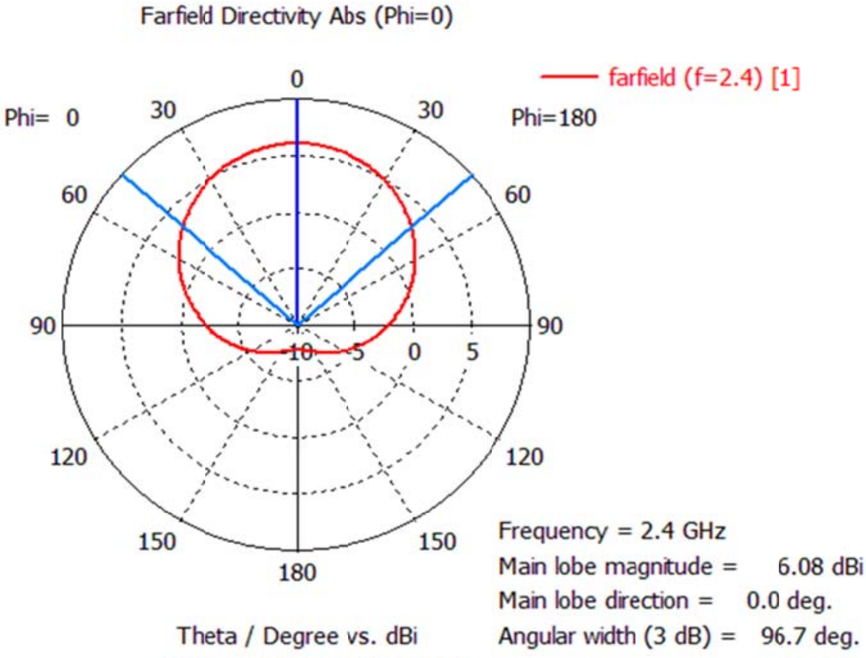


Figure 5: Directivity of single band insert-fed single band antennas at 2.4 GHz in H-plane (φ = 90°).



(b) Inset-fed single patch

Figure 6: Directivity of single band insert-fed single band antennas at 2.4 GHz in E-plane (φ = 0°).

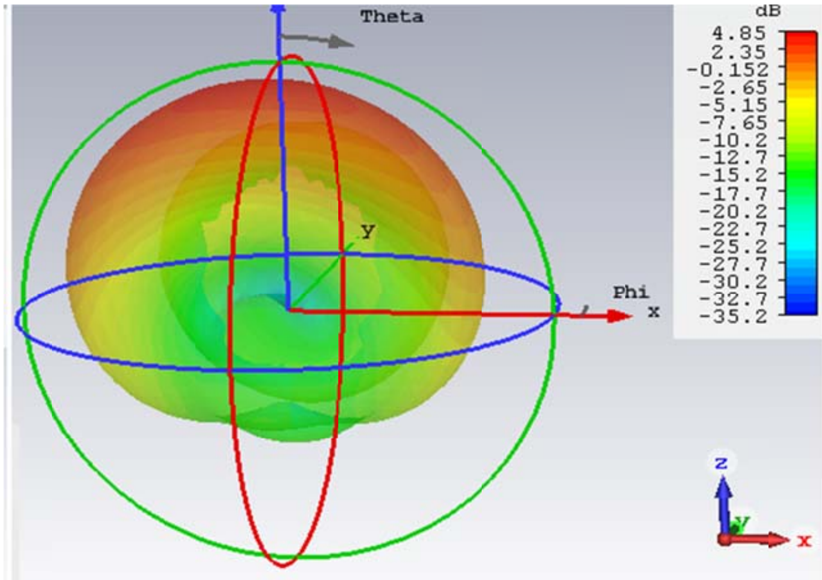


Figure 7: The 3-D gain plot for the single band insert-fed antennas at 2.4 GHz

4. CONCLUSION

A single band inset-fed rectangular microstrip patch antenna that resonated at 2.4 GHz is presented. The major aspects of the procedure utilized in the design include specification of key parameters of the antenna, determination of key parameters of the patch and then the determination of the dimensions of the feed network. Afterwards, the parameter values obtained are used to carry out the simulation of the antenna in Computer Simulation Technology (CST) Microwave Studio. In all, the results of the computations and simulations show good performance in respect of return loss, Voltage Standing Wave Ratio (VSWR), directivity, bandwidth and gain.

REFERENCES

1. Akpakwu, G. A., Silva, B. J., Hancke, G. P., & Abu-Mahfouz, A. M. (2017). A survey on 5G networks for the Internet of Things: Communication technologies and challenges. *IEEE access*, *6*, 3619-3647.
2. Chowdhury, M. Z., Shahjalal, M., Ahmed, S., & Jang, Y. M. (2020). 6G wireless communication systems: Applications, requirements, technologies, challenges, and research directions. *IEEE Open Journal of the Communications Society*, *1*, 957-975.
3. Alsabah, M., Naser, M. A., Mahmmod, B. M., Abdulhussain, S. H., Eissa, M. R., Al-Baidhani, A., ... & Hashim, F. (2021). 6G wireless communications networks: A

comprehensive survey. *Ieee Access*, *9*, 148191-148243.

4. Akyildiz, I. F., Kak, A., & Nie, S. (2020). 6G and beyond: The future of wireless communications systems. *IEEE access*, *8*, 133995-134030.
5. Bushberg, J. T., Chou, C. K., Foster, K. R., Kavet, R., Maxson, D. P., Tell, R. A., & Ziskin, M. C. (2020). IEEE committee on man and radiation—COMAR technical information statement: Health and safety issues concerning exposure of the general public to electromagnetic energy from 5G wireless communications networks. *Health Physics*, *119*(2), 236-246.
6. Bushberg, J. T., Chou, C. K., Foster, K. R., Kavet, R., Maxson, D. P., Tell, R. A., & Ziskin, M. C. (2020). IEEE committee on man and radiation—COMAR technical information statement: Health and safety issues concerning exposure of the general public to electromagnetic energy from 5G wireless communications networks. *Health Physics*, *119*(2), 236-246.
7. Allen, J., Herscovici, N., Kramer, B., Wu, B. I., & AIR FORCE RESEARCH LAB WRIGHT-PATTERSON AFB OH SENSORS DIR. (2015). New Concepts in Electromagnetic Materials and Antennas. *Air Force Research Laboratory*.
8. Kumar, P., Ali, T., & Pai, M. M. (2021). Electromagnetic metamaterials: A new paradigm of antenna design. *IEEE Access*, *9*, 18722-18751.
9. Chaloupka, H. J., & Kornev, V. K. (2022). Antennae. In *Handbook of Superconductivity* (pp. 619-639). CRC Press.
10. Yang, G., Ho, C. K., & Guan, Y. L. (2015). Multi-antenna wireless energy transfer for backscatter communication systems. *IEEE Journal on Selected Areas in Communications*, *33*(12), 2974-2987.
11. Huang, W., Chen, H., Li, Y., & Vucetic, B. (2015). On the performance of multi-antenna wireless-powered communications with energy beamforming. *IEEE Transactions on Vehicular Technology*, *65*(3), 1801-1808.
12. Albreem, M. A. (2015, April). 5G wireless communication systems: Vision and challenges. In *2015 International Conference on Computer, Communications, and Control Technology (I4CT)* (pp. 493-497). IEEE.
13. Selvi, N. T., Pandeeswari, R., & Selvan, P. N. T. (2018). An inset-fed rectangular microstrip patch antenna with multiple split ring resonator loading for WLAN and RF-ID applications. *Progress In Electromagnetics Research C*, *81*, 41-52.
14. Chemkha, H., & Belkacem, A. (2020, June). Design of new inset fed rectangular microstrip patch antenna with improved fundamental parameters. In *2020 IEEE International Conference on Design & Test of Integrated Micro & Nano-Systems (DTS)* (pp. 1-4). IEEE.
15. Matin, M. A., & Sayeed, A. I. (2010). A design rule for inset-fed rectangular microstrip patch antenna. *WSEAS Transactions on Communications*, *9*(1), 63-72.
16. Shankar, S., & Chaurasiya, H. (2015, September). Inset feed microstrip patch antenna. In *2015 International Conference on Computer, Communication and Control (IC4)* (pp. 1-3). IEEE.
17. Khan, M. U., Sharawi, M. S., & Mittra, R. (2015). Microstrip patch antenna miniaturisation techniques: a review. *IET Microwaves, Antennas & Propagation*, *9*(9), 913-922.
18. Singh, I., & Tripathi, V. S. (2011). Micro strip patch antenna and its applications: a survey. *Int. J. Comp. Tech. Appl*, *2*(5), 1595-1599.
19. Kumar, A. and Gupta, R. (2013). Series microstrip patch antenna array for wireless communication. *International Journal of Engineering Research & Technology (IJERT),* 2(3): 1 – 5.