EVOLUTION IN ELECTRICAL AND ELECTRONIC ENGINEERING
e-ISSN: 2756-8458

EEEE

Vol. 5 No. 1 (2024) 173-180
https://publisher.uthm.edu.my/periodicals/index.php/eeee

Design of a Dual Frequency Antenna for Energy Harvesting and WiMAX and WLAN Systems

Mustika Rawiah Azidin[1], Roshayati Yahya @ Atan[1]*

[1] *Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia, Batu Pahat, 86400, MALAYSIA*

*Corresponding Author: rhayati@uthm.edu.my
DOI: https://doi.org/10.30880/eeee.2024.05.01.022

Article Info

Received: 11 July 2023
Accepted: 10 October 2023
Available online: 30 April 2024

Keywords

Dual Frequency, Energy Harvesting, WiMAX, Microstrip Patch Antenna

Abstract

In recent decades, alternative energy sources have gained increasing attention as the need for power increases. This increase occurred as external energy sources have been harvested for various purposes. The development of Wireless Local Area Networks (WLAN) and Worldwide Interoperability for Microwave Access (WiMAX) systems has grown more relevant and necessary in recent years. Due to the surge in demand for the development of alternative energy resources and WiMAX and WLAN systems, an antenna with dual frequency has been designed in this study. This antenna is designed to operate at 2.45 GHz and 3.7 GHz frequencies. The simulated antenna is analysed by its gain performance. The antenna design has undergone several phases including optimization levels and choosing the suitable antenna design to obtain the dual frequency and fulfil the chosen applications. FR-4 substrate is chosen as the antenna's material. A microstrip patch antenna with a slotted gap technique is applied to increase the gain and obtain the desired frequencies of the antenna. CST Studio Suite Software is used in designing and obtaining the results for the antenna. The results obtained from this study are the values of S11, radiation pattern and gain. The gain obtained shows that the antenna has a positive gain of 2.45 GHz while obtaining a negative gain for a frequency of 3.7 GHz. Based on this analysis, it can be concluded that this antenna is operating well for energy harvesting applications. It needs improvement to operate at 3.7 GHz, to be utilized in WiMAX and WLAN systems.

1. Introduction

The high demand for wireless technologies has risen significantly in recent years. An increase in power sources contributes to a higher ambient wireless power density, due to widespread usage of Wi-Fi routers, mobile phones, and TV broadcasting. Consequently, a large amount of energy is wasted. For this reason, the demand for harvesting and recycling the ambient electromagnetic energy also increases. With the recent significant development of Wireless Local Area Network (WLAN) and Worldwide Interoperability for Microwave Access (WiMAX) systems, millions of customers in foreign markets where be unable to access the internet due to the cost and inconvenience of copper cables or coaxial cable are benefited from WiMAX. For fixed wireless broadband access in "last mile" scenarios, WiMAX and WLAN systems may thus be the answer. Therefore, antenna application is needed as antenna has the capability of sending and receiving electromagnetic energy. This work proposes a solution to overcome the mentioned problems.

© 2024 UTHM Publisher.
This is an open access article under the CC BY-NC-SA 4.0 license.

Antennas with dual or multi-band characteristics, ease of use, low-profile and lightweight, could satisfy the demand of covering the frequencies of these WLAN and WiMAX systems and also being utilized for RF energy harvesting have recently been made available. These antennas play a crucial role in integrating several communication standards into a single wireless communication system and in encouraging the expansion of wireless communication systems. Ways to imply the improvement can be done by choosing the best material when designing and consider the band gap of antenna [1],[2]. The slotted gap technique that is implied has been used in various applications, like sensors and electrical machines. This technique gives various advantages over other techniques, for example it enhances the antenna sensitivity in detecting any changes in the magnetic field. This improves the measuring accuracy and precision, highly recommended and suitable for application that required high sensitivity. Secondly, when compared to other methods, the slotted gap technique provides a greater signal-to-noise ratio. With a greater signal-to-noise ratio, this implies that the desired signal is superior in comparison to any unnecessary noise, resulting in an enhanced performance as well as dependability. Microstrip patch antennas are strongly recommended since it can support multiband operation. This benefits in utilizing the antenna for RF energy harvesting and WiMAX and WLAN systems application. Microstrip patch antenna is essentially a metallic copper patch made with a ground plane that is produced on top of a dielectric substrate.

The first objective for this work is to design an antenna that can function at frequency of 2.45 GHz and 3.7 GHz. The second objective is to analyze the simulated dual frequency antenna in terms of gain performance.

2. Materials and Methods

Table 1 shows the specification to design antenna. To ensure that the dual frequency antenna is functioning in good condition, the reflection coefficient must be less than -10 dB. By keeping the reflection coefficient below -10 dB, the VSWR of the antenna will be greater than 2, meaning that about 30% of the transmitted signal will not be affected by the reflected signals [3]. To send and receive signals, the radiation pattern is bi-directional. Gain must be greater than 1 dB to indicate that the antenna is in excellent condition. If the gain results are in negative dB, this indicates that the matching impedance is incorrect.

Table 1 *Specifications for antenna*

Parameters	Specification
Reflection coefficient, S11	< -10 dB
Radiation pattern	Bi direction
Gain	> 1 dBi
Material for substrate	FR-4

Table 2 *Antenna design parameters*

Parameters	Specification
Centre frequency, *f*	2.45 GHz
Substrate material	FR-4
Dielectric constant of substrate, *εr*	4.3
Thickness of substrate, *h*	1.6mm
Feed and Ground material	Copper
Thickness of copper, *ht*	0.035mm

To design an antenna, several parameters must be properly considered as shown in Table 2. In this work, the antenna dimensions are obtained from equations Eq.1 to Eq.3. The substrate material is FR-4, which has a dielectric constant, *εr* of 4.3. From the parameters above, formula of width and length of the microstrip patch antenna can be obtained from the following equations:

Formula to calculate the width of an antenna, w is written in equation Eq.1 where *f*, *c* and *εr* are frequency, speed of light and dielectric constant of the substrate, accordingly.

$$w = \frac{C}{2f\sqrt{\frac{(\varepsilon_r+1)}{2}}} \tag{1}$$

Formula for obtaining the effective dielectric constant, εeff is written in equation Eq.2, where *εr*, *h* and *w* are dielectric constant of substrate, thickness of substrate and width of antenna, accordingly.

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[\frac{1}{\sqrt{1+12(\frac{h}{w})}}\right] \tag{2}$$

Formula to find the length of patch antenna, L is as in equation Eq.3 where c, εeff, h and w are speed of light, dielectric constant of substrate, thickness of substrate and width of antenna, accordingly.

$$L = \frac{c}{2f\sqrt{\varepsilon_{eff}}} - 0.824h\left(\frac{(\varepsilon_{eff}+0.3)(\frac{w}{h}+0.264)}{(\varepsilon_{eff}-0.258)(\frac{w}{h}+0.8)}\right) \tag{3}$$

Based on the equations in equation (1) to (3), the preliminary result of the antenna is shown in Fig. 1 with the antenna specification dimension shown in Table 3.

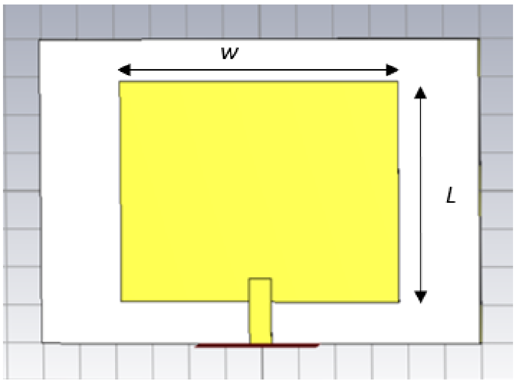

Fig. 1 *Microstrip patch antenna design*

Table 3 *Antenna specifications dimension*

Parameters	Dimension (mm)
ws	60
Ls	40
h	1.6
wp	38
Lp	29
ht	0.035
wf	3
k	6.8

Fig. 2 shows the flowchart for the simulated dual frequency antenna. Firstly, the antenna will be designed based on a microstrip patch antenna with slotted gap to obtain dual frequency. Then, if the antenna does not obtain the desired frequency, it will go thorough optimization with increasing feed size. The antenna is then constructed on an FR-4 substrate after the optimization of antenna is simulated. After the simulation process, an analysis of the simulated antennas will be presented following the collection of results as mentioned in the design specifications previously.

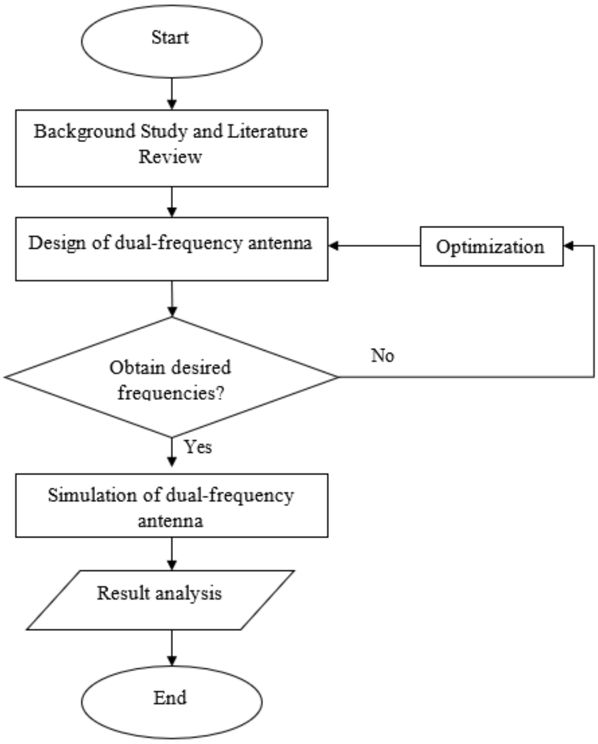

Fig. 2 *Flowchart for the simulated dual frequency antenna*

Before deciding on the proposed design of the dual frequency antenna, the antenna has to go through a few optimization levels in order to obtain the desired frequencies. Fig. 3 shows the designs of antenna that have been simulated before finalizing the antenna design. The antenna design begins with a no-feed antenna, but with the same other parameters as the final antenna design. Then, the feed size is increased by 0.5 mm, until the suitable feed width equal to 3.0 mm is chosen as the finalized antenna. The antenna design with feed width of 3.0 mm is chosen as the proposed antenna design due to its S11 result, H-field and E-field radiation pattern and gain is the best among all the design.

ws	=	*60*
Ls	=	*40*
wp	=	*38*
Lp	=	*29*
wf	=	*3.0*
k	=	*6.8*

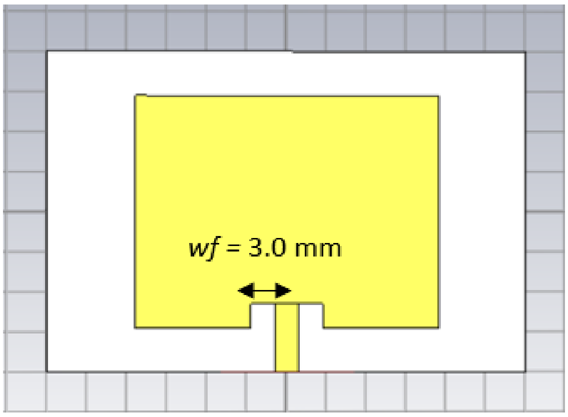

Fig. 3 *Antenna with 3.0 mm feed*

3. Results and Discussion

The dual frequency antenna has been simulated in CST Studio Suite software. All the results obtained for its reflection coefficient, radiation pattern and gain are discussed in this section.

3.1 Reflection Coefficient, S11

The frequency that is used for the simulation in CST Studio Suite software is 50 GHz. For the reflection coefficient results of the dual frequency antenna shown below, it can be observed that the proposed antenna design with 3.0 mm feed size has the lowest S11 value, occurred at -16.05 dB and -25.42 dB. S11 value below than -10 dB indicates that the antenna is working in a good condition. Fig. 4 illustrates the simulated result for S11 while Fig. 5 illustrates the result of the S11 for the proposed antenna.

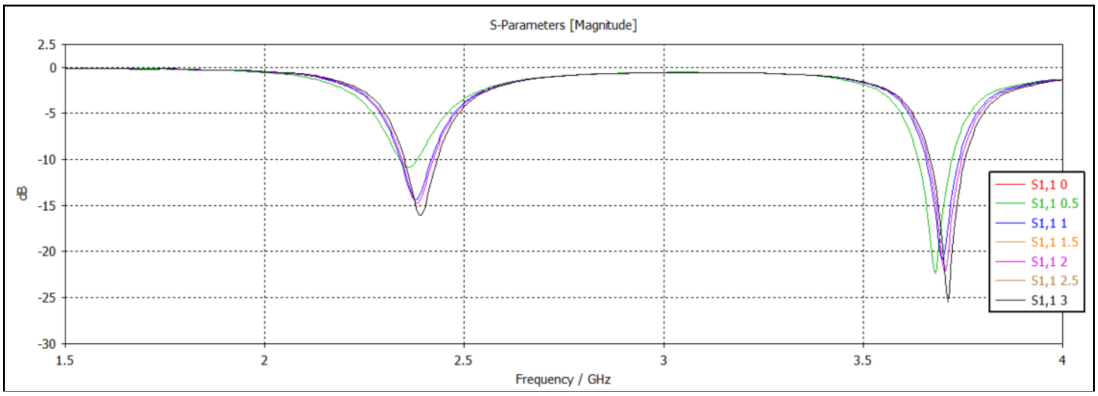

Fig. 4 *Simulated S11 for all feed width values*

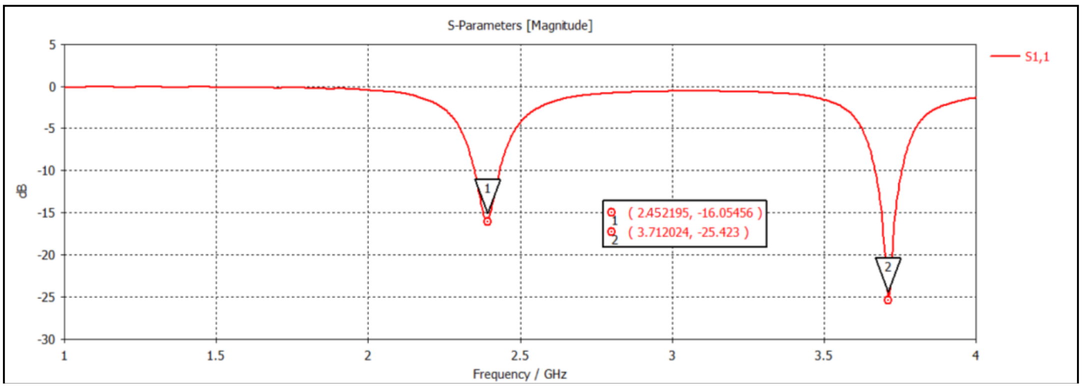

Fig. 5 *S11 for the proposed antenna with feed size = 3.0 mm*

3.2 Far Field Radiation Pattern

Fig. 6 to 9 show the E-Field and H-Field radiation pattern for the dual frequency antenna at two different frequencies; f=2.45 GHz and f=3.7 GHz. The E-field and H-field radiation patterns shown are at Theta = 90.

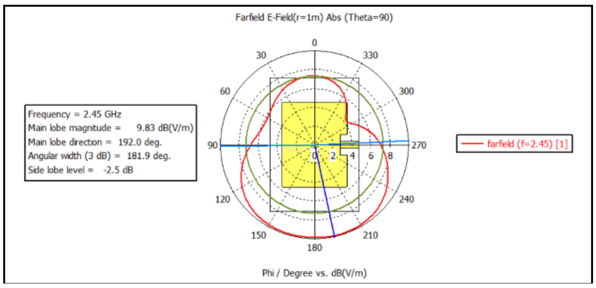

Fig. 6 *Result for E-field radiation pattern at f =2.45 GHz*

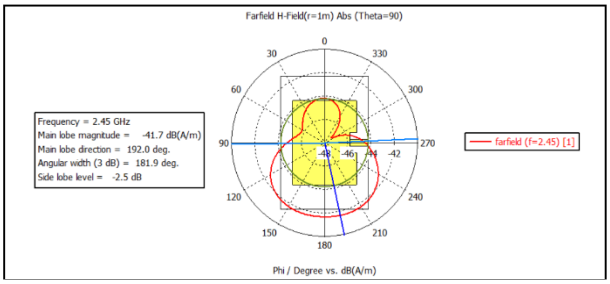

Fig. 7 *Result for H-field radiation pattern at f =2.45 GHz*

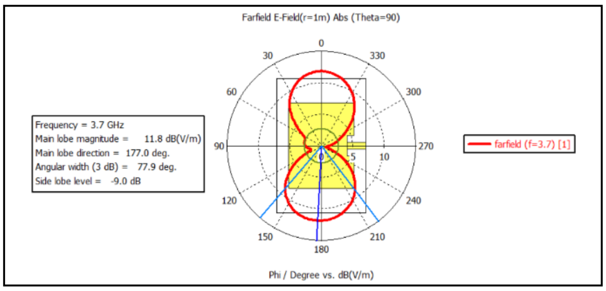

Fig. 8 *Result for E-field radiation pattern at f =3.7 GHz*

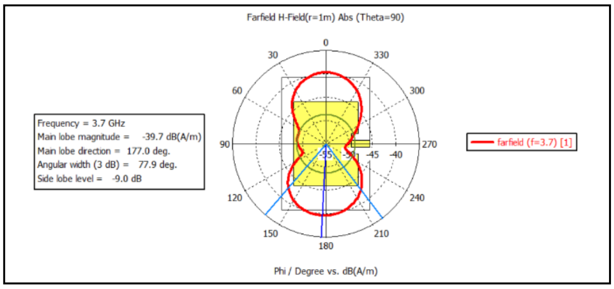

Fig. 9 *Result for H-field radiation pattern at f =3.7 GHz*

The diagram of the radiation pattern is bidirectional in all frequencies in E-plane and the H-field. In Fig. 6, when the frequency is 2.45 GHz, the main lobe magnitude is equal to 9.8.3 dB(V/m) with main lobe direction at 192°. From this radiation pattern result, it can be said that the electric field density is higher at the 181.9° region with angular width of -2.5 dB. For 3.7 GHz E-field pattern, the main lobe magnitude is equal to 11.8 dB(V/m) with main lobe direction at 177°. The angular width of 3 dB for this frequency is 77.9°.

In Fig. 7, for the H-field radiation pattern, at frequency is equal to 2.45 GHz, the magnetic field is mainly distributed in the 181.9° region with main lobe magnitude equals to -41.7 dB(A/m) and main lobe direction is at 192°. From Fig. 8, with a main lobe magnitude of -39.7 dB(A/m) and a main lobe direction of 177°. The 3dB angular width is 98.6° for frequency equals to 2.45 GHz and 77.9° for frequency equals to 3.7 GHz. From this result, the antenna may be more focused or directional at the higher frequency since the 3dB angular width is lower at the higher frequency, 77.9° at 3.7 GHz as compared to 98.6° at 2.45 GHz.

The angular width (3 dB) refers to Half Power Beam Width or HPBW, an angular width that is measured in degrees, identified on the primary lobe of an antenna radiation pattern at half-power points, i.e. when the signal power is half of its highest value. The half power points are located at the 3 dB positions on the antenna's primary lobe. These locations are located at a distance of -3 dB from the amplitude peak. Half power beam width is the angle in the antenna's effective radiated field where the relative power is greater than 50% of the peak power. This is regarded as the portion of the antenna output that has the most constancy and usefulness and is intimately tied to the antenna gain [4].

3.3 Far Field Gain

The ratio between the intensity in a particular direction and the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotropically is known as the gain of an antenna. The power input by the antenna divided by 4π determines the radiation intensity that corresponds to the isotropically radiated power [5].

For f equals to 2.45 GHz, the gain of antenna obtained is 2.399 dBi. This value is reasonable to take as the gain as the gain for antenna to radiate in excellent condition is usually more than 1 dBi. However, for frequency equals to 3.7 GHz, the simulated gain is -0.449 dBi. This gain value cannot be considered as it lies below 1 dBi. The simulation for f=2.45 GHz and f=3.70 GHz can be seen in Fig. 10 and 11, respectively. Table 4 summarizes the simulation results.

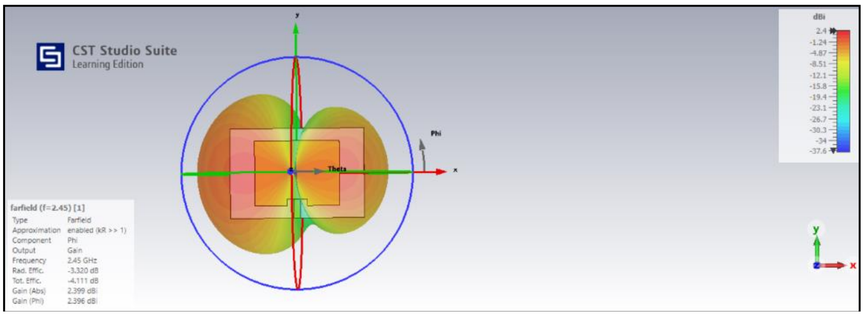

Fig. 10 *3-D Far field gain at f =2.45 GHz*

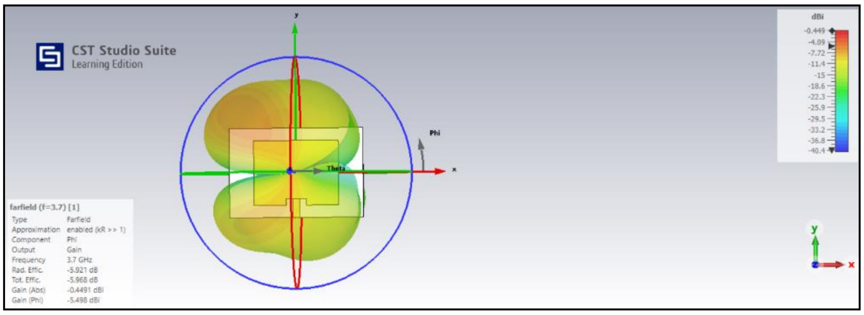

Fig. 11 *3-D Far field gain at f =3.7 GHz*

Table 4 *Gain for f=2.45 GHz and f=3.70 GHz*

f(GHz)	Gain (dBi)
2.45	2.399
3.70	-0.449

3.4 Discussions

According to the results, the simulation results acquired from the CST Studio Suite software are reasonable although a few results obtained indicate that the dual frequency antenna does not function in higher frequency of 3.7 GHz. The negative gain obtained might be due to the antenna has high losses at particular direction that causes the antenna cannot radiate in 3.7 GHz frequency. Comparing the result with the earlier research papers, the frequency band for WLAN and WiMAX obtained for the antenna to function well and efficient are in range of 1.43 to 2.78 GHz with glass epoxy as its dielectric substrate [6]. The negative gain also indicates that the matching impedance is incorrect. Despite the fact that negative gain appears illogical, it is a valid concept in antenna theory and has its uses. For instance, it can be useful in assessing an antenna's effectiveness in a particular setting and in antenna design to enhance the antenna's emission pattern for particular uses.

4. Conclusion

In conclusion, the microstrip patch antenna is designed to be functional on frequency of 2.45 GHz and 3.7 GHz. From the simulation results obtained, the gain is only positive when the frequency is equal to 2.45 GHz whilst at frequency of 3.7 GHz, the gain happened to lie below 1 dBi, obtaining the negative gain value. This can happen when the antenna's impedance is not correctly matched or due to high losses of antenna in particular direction. From the result, it can be clearly said that changes of frequency will affect the output gain. The dual frequency antenna has been successfully designed in CST Studio Suite software using FR-4 substrate. Due to the gain is only positive for 2.45 GHz, this antenna is suitable for RF energy harvesting application and needs improvement for it to be suitable to function for WiMAX and WLAN system applications.

Acknowledgement

The authors would also like to thank the Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia for its support.

Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

References

[1] Shaza, E., Zamel, M., Hendi, H., Moataza, Zekry, Attiya, A., Ahmed, “Gain enhancement of a millimeter wave antipodal vivaldi antenna by epsilon-near-zero metamaterial,” Progress in Electromagnetics Research C, 85. 105-116. 10.2528/PIERC18050302, 2018.

[2] Abdulhameed, Isa, M., Ibrahim, M.S., Mohsen, I., Hashim, M., and Attiah, S. “Improvement of Microstrip Antenna Performance on Thick and High Permittivity Substrate with Electromagnetic Band Gap,” Journal of Advanced Research in Dynamical and Control Systems, Vol. 10, 04-Special Issue, 2018.

[3] Saria, S. (2023) Tutorial: Why return loss > -10DB and VSWR <2 for antenna design, Electronics For You [Online]. Available at: https://www.electronicsforu.com/technology-trends/antenna-return-loss-vswr, 2023.

[4] Team, E. (2021) Everything RF, everything RF [Online]. Available at: https://www.everythingrf.com/community/what-is-half-power-beam-width, 2021.

[5] Poljak, D., Cvetković, M. Chapter 2 - Theoretical Background: an Outline of Computational Electromagnetics (CEM), Human Interaction with Electromagnetic Fields, Academic Press, Pages 21-52, ISBN 9780128164433, 2019.

[6] Rawat, Amit & Singh, V. (2014). Slotted Design of Microstrip Antenna for WLAN/WiMax Applications. Applied Physics Letter (ISSN: 2349-1108). 1. 23-26.