

Design of a dual-band antenna for energy harvesting application

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ABSTRACT

This report presents an investigation on how to improve the current dual-band antenna to enhance the better result of the antenna parameters for energy harvesting application. Besides that, to develop a new design and validate the antenna frequencies that will operate at 2.4 GHz and 5.4 GHz. At 5.4 GHz, more data can be transmitted compare to 2.4 GHz. However, 2.4 GHz has long distance of radiation, so it can be used when far away from the antenna module compare to 5 GHz that has short distance in radiation. The development of this project includes the scope of designing and testing of antenna using computer simulation technology (CST) 2018 software and vector network analyzer (VNA) equipment. In the process of designing, fundamental parameters of antenna are being measured and validated, in purpose to identify the better antenna performance.

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1. INTRODUCTION

There are variety of antenna currently existing that can be classified into deferent type of parameters and different applications [1]. Unlike some of antenna such as dipole and monopole antenna which possess narrow bandwidth characteristics, it radiates only into the space above the ground plane, or half the space of a dipole antenna, a monopole antenna will have a gain of twice (3 dB greater than) the gain of a similar dipole antenna, and a radiation resistance half that of a dipole. This project is using microstrip patch antenna (MPA) technique that implies the features of low profile, low cost, lightweight, compactness, and compatibility makes it a better option in designing a better antenna for energy harvesting compare to another substrate [2]. Besides that, the physical configurations of the antenna and the material properties of elements also contribute to the performance of the antenna. This project is divided into two main parts, software, and hardware. For the software part, the antenna is developing using computer simulation technology (CST) 2016. Then for hardware part, vector network analyzer (VNA) is used with the microstrip patch antenna [3]-[11].

Energy scavenging or power harvesting is the changes of surrounding energy sources from the human activity environment to electric power, purposely to power compact autonomous devices of electronic wirelessly. Harvesting of power energy wirelessly context is defined. Two main subsystems involved in energy harvesting system. The receiving antenna is the first component in the energy harvesting system. All the ambient energy can be from magnetic fields or stray electric or radio waves from nearby electrical equipment will be captured by the

receiving antenna and the integrated embedded system will be power up by this energy. This concept and technology also provide improved reliability and also creates significant cost savings for a long period of time monitoring applications. This type class of antenna design would be useful in any transmission systems whenever the increase of ambient RF energy sources can be tolerated, and also when the RF-DC power conversion efficiency are primary concerns, such as in the case of emergency relief, agricultural sensors, structural health monitoring, and battery charging. For example, the prototype antenna design in this study together with rectifying circuit is best implemented in healthcare wireless sensor such as body temperature sensor, pulse and oxygen in blood sensor, patient position sensor, air flow sensor and electrocardiogram sensor in line with energy harvesting application [12]-[25].

2. RESEARCH METHOD

The process of the design in this work starting with research and literature review of some previous authors as stated in Table 1 as shown in. The antenna is required to be functioning a frequency 2.4 GHz and 5.4 GHz. As for the board of antenna, FR4 substrate is chosen to fabricate the antenna due to the availability product in UTeM's lab. The dielectric constant of this substrate is, ϵ_r of 4.4, dielectric height, h of 1.6 mm and the copper conductor with height, t of 0.035 mm. The design specifications of the dual-band antenna is shown in Table 2.

Table 1. Several researchers involved in dual-band antenna designs

(Author (s), Year)	Research's Title	Summary of Finding		Application
		Purpose	Method and result	
Yuan Zhu, Min Quan Li, Hong Qing He. 2016 [2]	A Compact Dual-band Monopole Antenna for 4G LTE and Wifi Utilizations	The proposed antenna contains a U- slot in the circular patch with gradually varied ground.	To improve the impedance match, and it occupies a compact size $42*28.38*1.5\text{mm}^3$ however, still lack of gain.	2.28GHz - 2.82 GHz 3.87 GHz - 6.00 GHz
See Yan, Ping Jack Soh, Guy A. E. Vandenbosch. 2015 [10]	Wearable dual-band magneto-electric dipole antenna for WBAN/WLAN applications	A wearable dual-band magneto-electric dipole antenna is proposed. Two U-shaped slots are introduced on a dipole and the resulting electric and magnetic resonances are combined with the aim to produce a dual band with wideband characteristics	The higher cross polarization in the upper band is caused mainly by the feeding pin, which has a considerable length compared to the wavelength. The measured forward realized gain is at least 4.7 dB and 3 dB in the lower and upper frequency band. The radiation efficiency: 50 % and 60 %	2.4 GHz and 5 GHz
Jhe-Sheng Yang, Jeen- Shee Row, 2017 [11]	Dual-band circularly polarized Microstrip antenna	A design for dual-band circularly polarized microstrip antennas with different radiation patterns is described. The proposed single-feed dual-band CP designs are achieved by inserting four T-shaped slits at the patch edges or four Y-shaped slits at the patch corners of a square microstrip	A patch size until 36% for the proposed design but still lack of gain.	1.57 GHz and 2.44 GHz

Table 2. Design specifications

Parameter	Value
Resonant Frequency, f_r (GHz)	2.4 GHz and 5.4 GHz
Height of Copper Conductor (mm)	0.035 mm
Height of Substrate (mm)	1.6 mm
Substrate Material	FR4 with ϵ_r of 4.4

2.1. Design calculation

The calculation for width rectangular patch antenna: [1]

$$W = \frac{c}{2fr\sqrt{\frac{\epsilon_r+1}{2}}} \quad (1)$$

Where the speed of light $C = 3 \times 10^8 \text{ms}^{-1}$, $fr = 2 \cdot 4 \text{GHz}$ and $\epsilon_r = 4.4$

$$W = 38.04 \text{ mm}$$

The effective dielectric constant, ϵ_{reff} are to be determine using this [1]

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[1 + 12 \left(\frac{h}{w} \right) \right]^{-0.5} \tag{2}$$

By substituting $W = 38.04 \text{ mm}$, and $h = 1.6 \text{ mm}$ and $\epsilon_r = 4.4$

$$\epsilon_{reff} = 4.0858$$

The calculation of the effective length, L_{eff} using this [1]

$$L_{eff} = \frac{c}{2f_r \sqrt{\epsilon_{reff}}} \tag{3}$$

Where speed of light $= 3 \times 10^8 \text{ ms}^{-1}$, $f_r = 2.4 \text{ GHz}$ and $\epsilon_{reff} = 4.0858$

$$L_{eff} = 30.92 \text{ mm}$$

Proceeding to the fringing length, ΔL is calculate using the formula;

$$\Delta L = 0.412h \frac{(\epsilon_{reff} + 0.3) \left(\frac{w}{h} \right) + 0.246}{(\epsilon_{reff} - 0.258) \left(\frac{w}{h} \right) + 0.8} \tag{4}$$

By substituting $M = 38.0363 \text{ mm}$, $h = 1.6 \text{ mm}$ and $\epsilon_r = 4.4$

Lastly the actual length of the patch, L can be determined by using;

$$L = L_{eff} - 2\Delta L$$

$$L = 29.44 \text{ mm}$$

The width of the feedline is;

$$B = \frac{377\pi}{2Z_0\sqrt{\epsilon_r}} \tag{5}$$

$$wf = \frac{2h}{\pi} \left[B - 1 - \ln(2B - 1) + \left(\frac{\epsilon_r - 1}{2\epsilon_r} \right) (\ln(B - 1) + 0.39 - 0.61\epsilon_r) \right] \tag{6}$$

The antenna width and length of antenna is determined by the;

$$w_g = w + 6h \tag{7}$$

$$L_g = L + 6h \tag{8}$$

2.2. Antenna structure

Figure 1 and Figure 2 show the front and back view of the simulated antenna. Figure 3 and Figure 4 show the front and back view of the fabricated antenna. The front view and back view parameters of the simulated antenna are listed in Table 3 and Table 4.

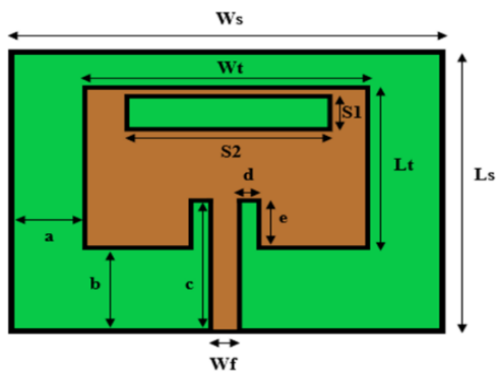


Figure 1. Front view of antenna

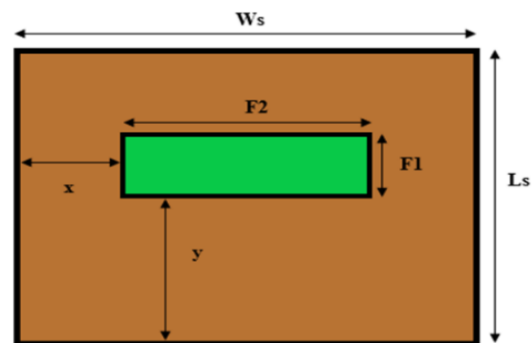


Figure 2. Back view of antenna

Table 3. Front view parameters

Parameter	Value (mm)
Ws	44.00
Ls	41.00
h	24.00
Lt	21.00
Wf	2.96
S1	4.50
S2	20.00
a	10.00
b	10.00
c	15.20
d	2.00
e	5.20

Table 4. Back view parameters

Parameter	Value (mm)
Ws	44.00
Ls	41.00
F1	10.00
F2	22.00
x	11.00
y	16.00



Figure 3. Front view

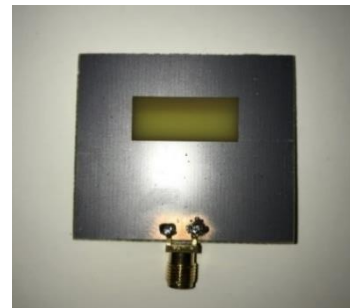


Figure 4. Back view

3. RESULTS AND DISCUSSION

3.1. Farfield results

Based on Figure 5, the simulation of the radiation pattern of the antenna at frequency 2.4 GHz shows that the directivity is 4.623 dBi with the efficiency of -2.576 dB. Based on Figure 6, the simulation of radiation pattern of the antenna at frequency 5.4 GHz shows that the directivity is 6.345 dBi with the efficiency of -3.194 dB.

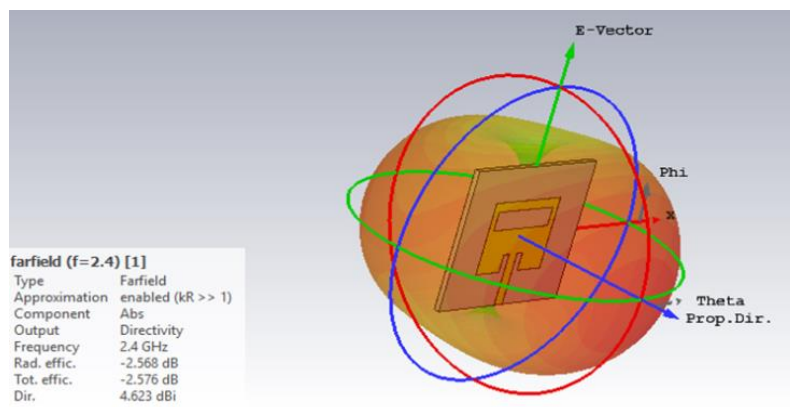


Figure 5. Farfield result at 2.4 GHz

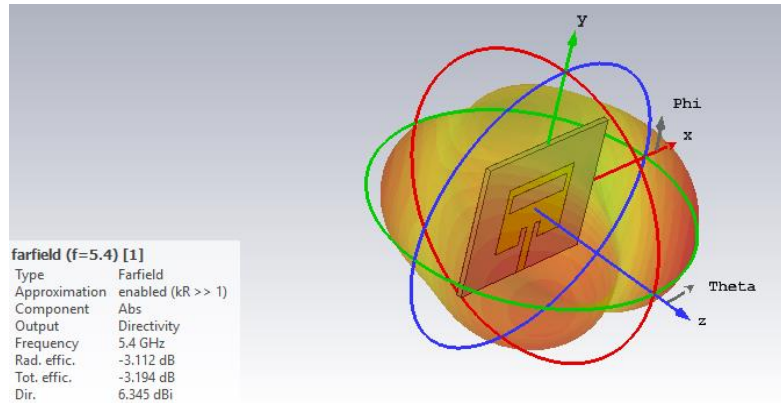


Figure 6. Farfield result at 5.4 GHz

3.2. Gain results

Based on Figure 7 and Figure 8, the gain for frequency 2.4 GHz is 2.03 dB and for frequency 5.4 GHz is 3.236 dB.

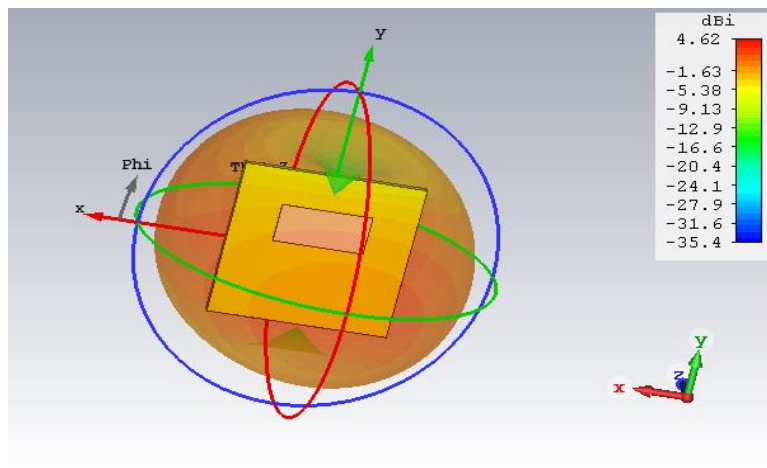


Figure 7. Gain Result for frequency 2.4 GHz

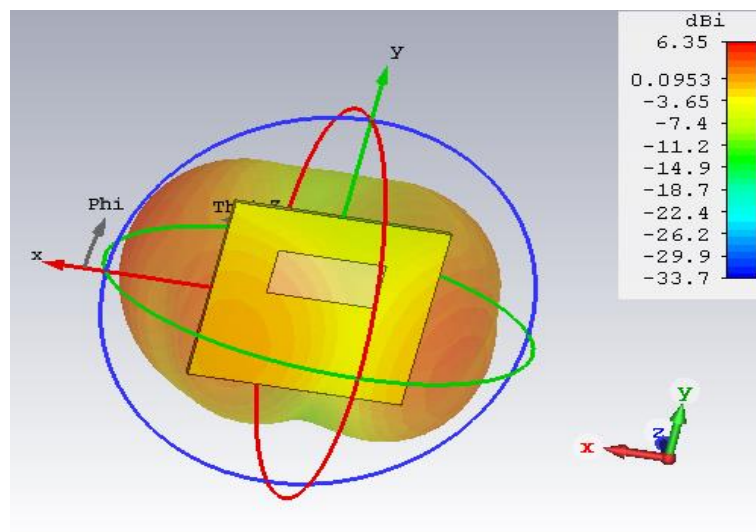


Figure 8. Gain result for frequency 5.4 GHz

3.3. Result for voltage standing wave ratio (VSWR)

Figure 9 shows the results of VSWR plot. The results show that the antenna resonated within 1.091 VSWR for 2.4 GHz and 1.3163 VSWR for 5.4 GHz.

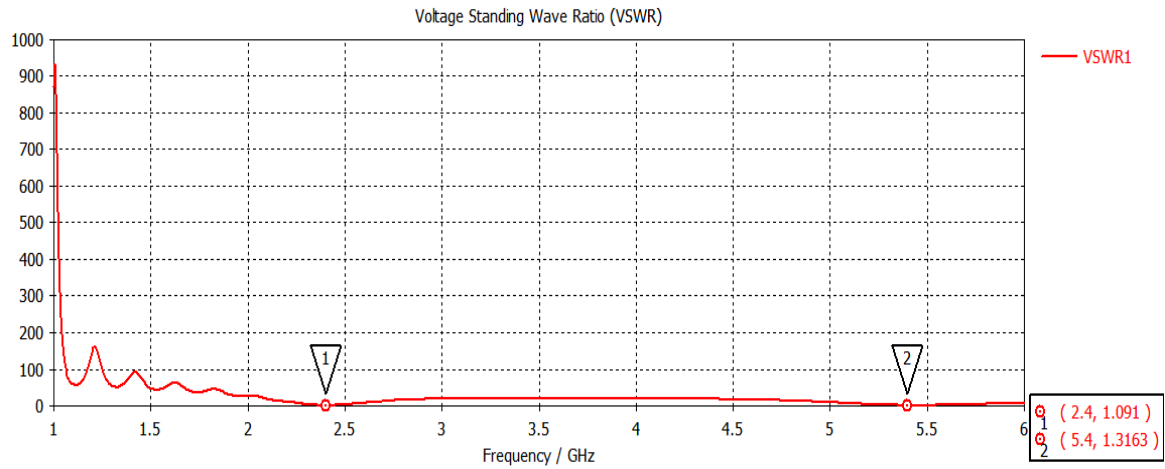


Figure 9. Result for voltage standing wave ratio (VSWR)

4. COMPARISON BETWEEN SIMULATION AND MEASUREMENT RESULTS

Figure 10 displays the comparison of simulated dual-band antenna at 2.4 GHz and 5.4 GHz designated frequencies. The simulation bandwidths for both frequencies were measured by:

$$\text{Bandwidth for 2.4 GHz is } \frac{2.4506 - 2.3556}{2.4} \times 100\% = 3.96\% \tag{9}$$

$$\text{Bandwidth for 5.4 GHz is } \frac{5.5528 - 5.3407}{5.4} \times 100\% = 3.93\% \tag{10}$$

The measured bandwidths for both frequencies were calculated by:

$$\text{Bandwidth for 2.4 GHz is } \frac{2.4582 - 2.3983}{2.4} \times 100\% = 2.50\% \tag{11}$$

$$\text{Bandwidth for 5.4 GHz is } \frac{5.5536 - 5.351}{5.4} \times 100\% = 3.75\% \tag{12}$$

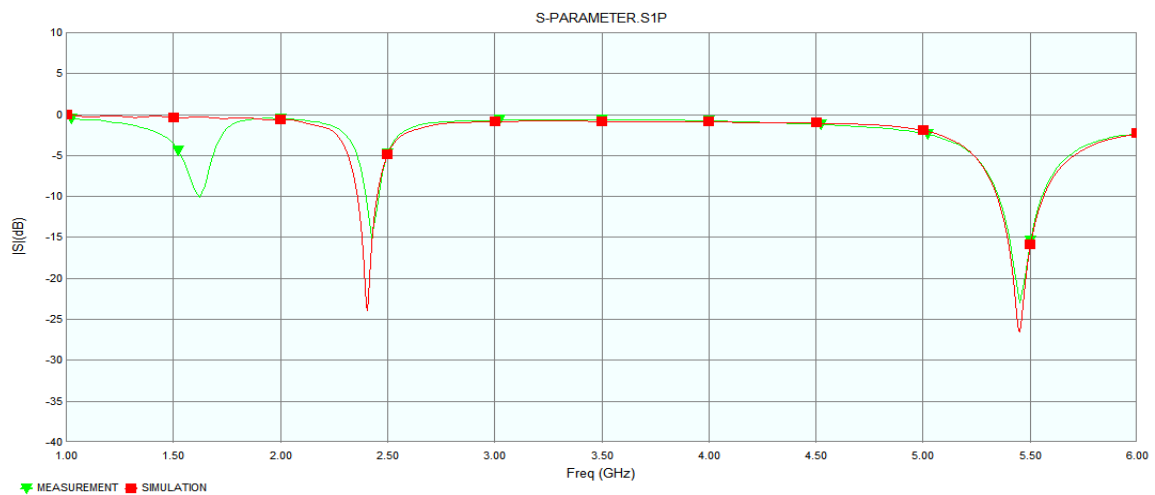


Figure 10. Comparison S-parameters results

Table 5 shows simulation result versus measurement result for the dual-band antenna. This return loss results are acceptable for the antenna to operate. There is slight difference between the simulated antenna when compared to the measured value. This is happened maybe because in the simulation, the antenna is excited using a waveguide port, but practically the antenna is excited using the SMA connector. The connector loss has an effect on the response of the antenna, material loss, the near field scattering objects, the losses due to the feed connector and the coaxial cable also affect the response on the antenna performance and fabrication tolerance. Figures 11 and 12 show the E-plane and H-plane co-polarization at 2.4 and 5.4 GHz of the antenna during measurement. Both radiation patterns are observed to have monopole-like pattern.

Table 5. Simulation result versus measurement result

Parameter	Simulation	Measurement
First Frequency, (f)	2.4 GHz	2.4 GHz
Second Frequency, (f)	5.4 GHz	5.4 GHz
First Return Loss (dB)	-27.23	-15.056
Second Return Loss (dB)	-30.477	-22.967

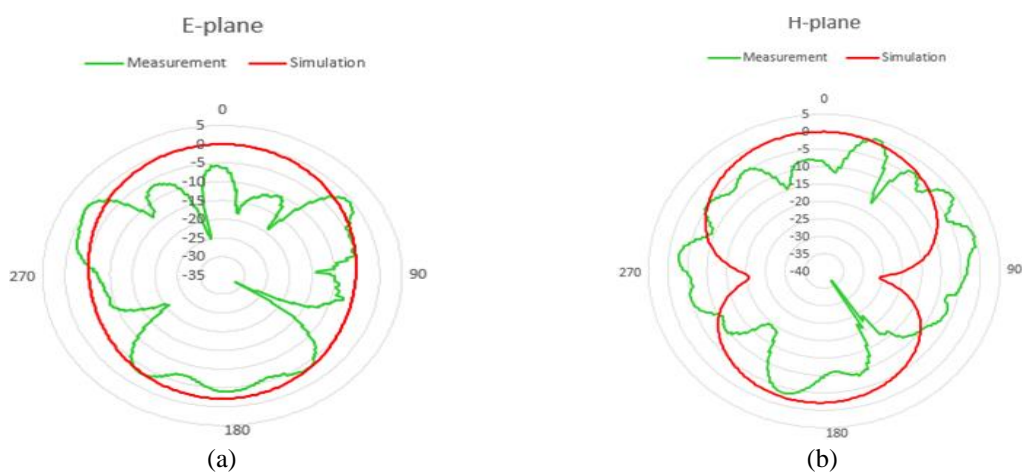


Figure 11. These figures are, (a) E-plane, (b) H-plane Co-polarization at 2.4 GHz

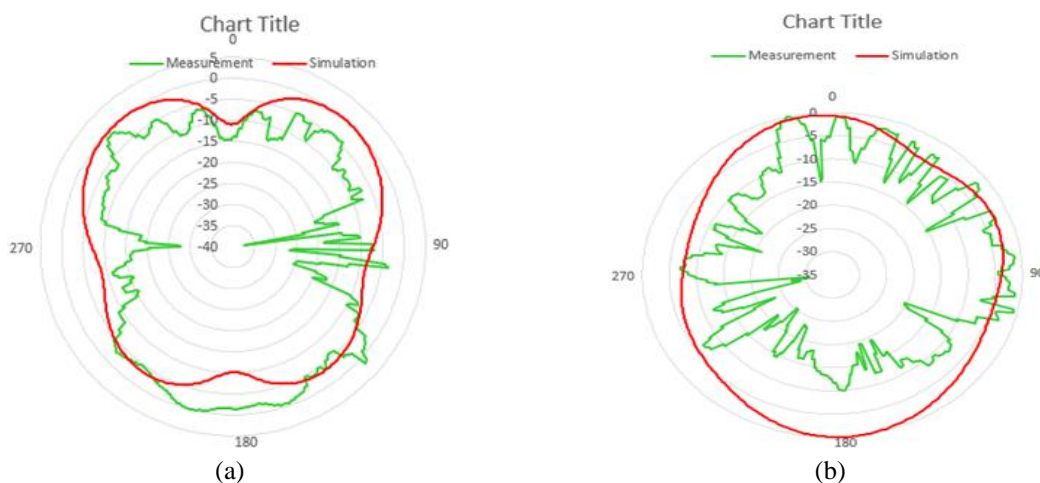


Figure 12. These figures are, (a) E-plane, (b) H-plane Co-polarization at 5.4 GHz

5. CONCLUSION

The purpose of this project is to investigate and develop a new dual-band antenna for energy harvesting application. Besides that, to validate the antenna frequency for dual-band antenna. The results that have obtained will indicate the performances of antenna thus the improvement of the antenna by changing the structure of the patch antenna is done. The parameters are analysed includes the return loss, the bandwidth,

the directivity, polar gain, and VSWR of the antenna. At 5.4 GHz, more data can be transmitted compare to 2.4 GHz. However, 2.4 GHz has long distance of radiation, so it can be use when far away from the antenna module compare to 5.4 GHz that has short distance in radiation. The proposed design has been validated through an experiment work. The obtained results show good agreement between simulated dan measured results. Further research on this design can be carried out for triple-passband and introduce a new metamaterial antenna.

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