# Design of triple band antenna for energy harvesting application

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**ABSTRACT**

Energy harvesting is a fast-expanding topic in many scientific and engineering-related disciplines due to the extreme necessity to discover answers to the world's power challenges. This paper focuses on the design of a novel antenna that will operate at frequencies of 2.45 GHz, 4.5 GHz, and 5.725 GHz. The study shows the improvement of the current triband antenna for energy harvesting applications by varying the antenna parameters. The return loss, the voltage standing wave ratio (VSWR) and the radiation pattern for the antenna at all frequencies 2.45 GHz, 4.5 GHz, and 5.725 GHz have been compared in the results. The scope of this project development comprises the antenna design utilizing simulation software, computer simulation technology (CST) 2019 and vector network analyzer (VNA) test instrument for physical testing. During the design process, fundamental antenna characteristics were estimated and validated to determine optimal performance of an antenna for this project.



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## 1. INTRODUCTION

Wireless power transfer technology is now widely used in mobile, industrial, and medical applications. Wireless power transfer technology can eliminate the need for cables and batteries. As a result, it is extremely easy and secure for all users [1]. Wireless local area networks (WLAN) and worldwide interoperability for microwave access (WiMAX) are type of wireless power transfer that have significant roles in today's wireless communication system. WLAN is a wireless communication technology that can be used to replace the previous copper wire based local area network. WiMAX is a wireless data network protocol that supports high speed data transmission [2], [3].

To achieve current wireless power transfer technology demand, researcher developed various design of antennas, and method to improve the performance of the antenna. The various type of existing antenna is classified into different kind of parameters and other applications. Rectangular shape and circular shape of microstrip antenna are the common type of antenna that the researcher use to improve the signal transmission antenna [4]. This project employs the microstrip patch antenna (MPA) technology, which has several advantages over alternative substrates, such as low profile, low cost, lightweight, compactness, and compatible. It is a better option for developing an energy harvesting antenna [5], [6]. In addition, the antenna's performance is affected by the antenna's physical configuration and the material qualities of its elements. This paper involved simulation and measurement part, in which the antenna was designed using computer simulation technology (CST) in 2019 and the fabricated antenna were tested using vector network analyzer (VNA) in the laboratory. In this paper, a triband antenna is designed with small size and good radiation characteristic. By using calculation, a simple design of MPA can produced three resonant frequencies. The radius of flower shaped antenna design and the notch gap is varied to get a smooth and ideal return loss frequency.

This study includes radio frequency (RF) energy harvesting, which converts the received RF ambient signal into a useable form, permits the efficient use of available spectrum, and offers an effective method for powering low-power wireless devices [7]. Energy may be received from several digital and analogue RF sources, such as analog/digital TV broadcasting stations, frequency modulation/amplitude modulation (FM/AM) radio towers, WLAN access points, and cellular base stations. Although just a little amount of energy can be extracted from these RF sources, it can be used to power low power devices, potentially alleviating the battery replacement issue [8]–[11]. Figure 1 illustrates the system block diagram for RF energy harvesting.

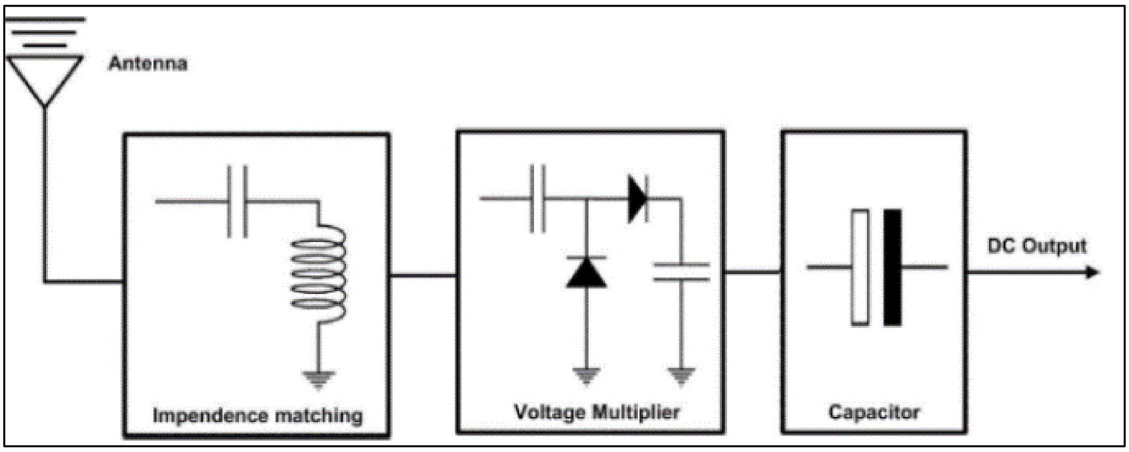


Figure 1. RF energy harvesting general architecture [7]

The antenna design of this project is aimed to operate at WLAN and WiMAX for energy harvesting. This is because the antenna will combine with the rectifier to scavenge low input power. Antenna is a crucial component for energy harvesting since it has a direct effect on the radiation-to-AC harvesting efficiency, which can alter the amount of power harvested [12]. While rectifier function is to capture RF energy from the surrounding environment and transmit it to the circuit. This delivers superior microwave-to-electrical energy conversion efficiency [13]–[15]. The concept of utilising RF energy to operate low-power electronic devices as a method to replace batteries and reduce maintenance costs has gained popularity. Wireless energy harvesting through the use of rectifying antenna (rectenna) technology is a viable option for converting ambient RF power to useable DC power. The rectenna, the most widely utilised technology for wireless power transmission (WPT) and energy harvesting, has seen significant improvement during the past decade [16].

## 2. METHOD

The antenna is designed in accordance with past research and a survey of the literature, as detailed in Table 1. The antenna will operate at 2.45 GHz, 4.5 GHz, and 5.725 GHz. The FR-4 substrate with a dielectric constant, $\varepsilon_r$=4.3, height of substrate, h of 1.6 mm, and height of conductor, t of 0.035 mm is employed in this research. The triband antenna's design specs are listed in Table 2.

### 2.1. Calculation of antenna design

Designing the MPA involved some calculation. The formula state is obtained from the antenna book. Below shows basic calculation to design the antenna [17]. Using this equation, the width of a rectangular MPA may be computed:

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

The value speed of light defined as $C = 3 \times 10^8 ms^{-1}$, resonant frequency, $fr = 2.45\ GHz$ and the dielectric constant as $\varepsilon_r = 4.3$:

$$W = 37.6\ mm$$

Table 1. Literature review from previous research

| Author | Research title | Analysis: Purpose | Analysis: Techniques | Application (GHz) |
|---|---|---|---|---|
| In 2016, Li *et al.* [18] | A compact triple-band printed monopole antenna for WLAN/WiMAX applications | The authors propose a printed monopole antenna for WLAN and WiMAX networks. | Design a forkshaped strip antenna that is etched on a modified rectangular ring and a rectangular-defected ground plane with size is 34×18 mm, however, the radiation pattern has bigger side lobe and back lobe | 2.5, 3.5, and 5.5 |
| In 2018, Shafqat *et al.* [19] | A compact uniplanar tri-band antenna for wearable smart watches | The authors propose a uniplanar antenna for smart watch application. | The antenna is composed of an edge tapered, bent monopole element with capacitively couple inverted L shorting strip support. The size is miniature for wearable application but still lack in gain | 2.4, 3.8, and 5.8 |
| In 2019, Jin *et al.* [2] | Design of triband antenna for WLAN and WiMAX application | A coplanar waveguide (CPW) design that groove with three symmetrical L-shaped slot and one rectangular ring slot. | The design of antenna is unique and suitable to apply to any application especially for wearable, but the return loss is unsatisfactory | 2.5, 3.5, and 5.2 |
| In 2018, Chandravanshi *et al.* [20] | Design of triple band differential rectenna for RF energy harvesting | The author popose a triple band differential rectenna for RF energy harvesting applications. | The antenna is design with reflector to improve the performance when connected with rectifier design. However, the return loss is not in ideal condition. | 2, 2.5, and 3.5 |
| In 2022, Elkorany *et al.* [21] | Implementation of a miniaturized planar tri-band microstrip patch antenna for wireless sensors in mobile applications | The author presents a MPA with two F-shaped resonators. | The design of the F shaped antenna produced a good bandwidth however still lack in antenna gain. | 1.8, 3.5, and 5.4 |

Table 2. Specification of antenna design

| Parameter specification | Value of parameter |
|---|---|
| Frequency of resonance, $fr$ (GHz) | 2.45 GHz, 4.50 GHz, and 5.75 GHz |
| Copper conductor's height (mm) | 0.035 mm |
| Substrate height (mm) | 1.6 mm |
| Material of substrate | FR-4 with $\varepsilon_r$ of 4.3 |

In (2) is used to calculate the effective dielectric constant, $\varepsilon_{eff}$.

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

When computing the value of antenna width, $W = 37.6\ mm$ , and height of substrate, $h$=1.6 $mm$ and dielectric constant, $\varepsilon_r$=4.3, the value of effective dielectric constant, $\varepsilon_{eff}$ is as shown in:

$$\varepsilon_{eff} = 3.992$$

The equation to calculate the value of effective length, $L_{eff}$ is:

$$L_{eff} = \frac{c}{2fr\sqrt{\varepsilon_{eff}}} \quad (3)$$

If the value of $C = 3 \times 108\ ms - 1, fr = 2 \cdot 45\ GHz, \varepsilon_{reff} = 3.992$, the value of effective length is as:

$$L_{eff} = 30.64\ mm$$

In (4) shows how to calculate the fringing length, $\Delta L$;

$$\Delta L = 0.412h\left[\frac{(\varepsilon_{eff}+0.3)\left(\frac{w}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{w}{h}+0.8\right)}\right] \quad (4)$$

By substituting $W = 37.6\ mm, h = 1.6\ mm$ and $\varepsilon r = 4.3$. To get patch length, L may be calculated using this (5);

$$L = L_{eff} - 2\Delta L \tag{5}$$

$$L = 29.16\ mm$$

Since patch antenna for this project is in flower shape, the calculation for circular patch antenna design must be involved to obtain the radius of the circle. Below shows the formula of circle radius;

$$cr = \sqrt{\frac{(w+h)\ x\ (l+h)}{2}} \tag{6}$$

By substitute W=37.6 $mm$, $L = 29.16\ mm$ and $h$=1.6 $mm$;

$$cr = 24.55\ mm$$

The cr value is divided by two since the design of flower shape consist of two different circle at left and right.

$$cr_{new} = \frac{24.55\ mm}{2}$$

$$cr_{new} = 12.275\ mm$$

In (7) and (8) for width of feedline is;

$$fw = \frac{2h}{w}\{B[1 + \ln(2B - 1)]\} + \frac{\varepsilon_r}{2\varepsilon_r}\left\{\ln(B - 1) + 0.3 - \left(\frac{0.61}{\varepsilon_r}\right)\right\} \tag{7}$$

$$B = \frac{377\pi}{2Zo\sqrt{2\varepsilon_r}} \tag{8}$$

The length of microstrip feedline is calculated as;

$$y_o = 10^{-4}(0.16922\varepsilon_r^{\ 7} + 0.13761\varepsilon_r^{\ 6} - 6.1783\varepsilon_r^{\ 5} + 93.187\varepsilon_r^{\ 4} - 682.69\varepsilon_r^{\ 3} + 2561.9\varepsilon_r^{\ 2} - 4043\varepsilon_r + 6697)\ x\ \frac{L}{2} \tag{9}$$

By substitute the value of $\varepsilon_r = 4.3$ and L =29.16 mm;

$$y_o = 15.5\ mm$$

For notch gap, the calculation as shown in:

$$g = \frac{v_o}{\sqrt{2\varepsilon_{eff}}}\ x\ \frac{4.65\ x\ 10^{-12}}{fo\ (in\ GHz)} \tag{10}$$

By substitute $v_o = 3 \times 10^{11} mm/s, \varepsilon_{eff} = 3.992$ and $fo = 2.45\ GHz$;

$$g = 0.244\ mm$$

Since ground and subtrate of the antenna design is same, the value is determined as shown in:

$$w_g = 6h + w \tag{11}$$

$$l_g = 6h + l \tag{12}$$

### 2.2. Structure of antenna

Figures 2 and 3 shows the view of the simulated patch antenna for this project from the front side and back side. The front side view consists of the design of flower shaped antenna. The back side view shows the ground for the antenna design which the length and width size are same as the subtrate. Table 3 shows the dimension value of antenna design.

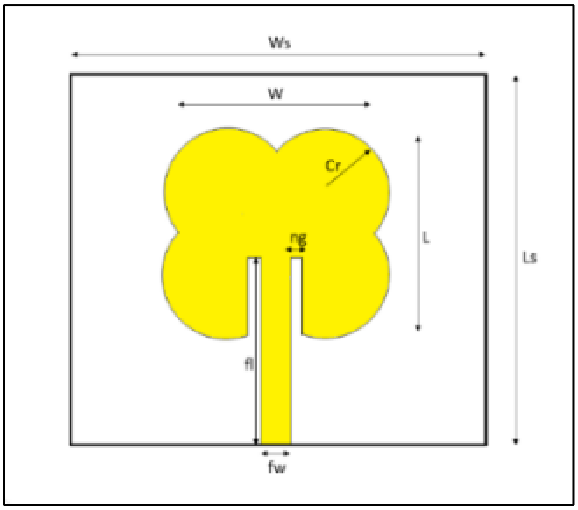


Figure 2. Front side view of antenna

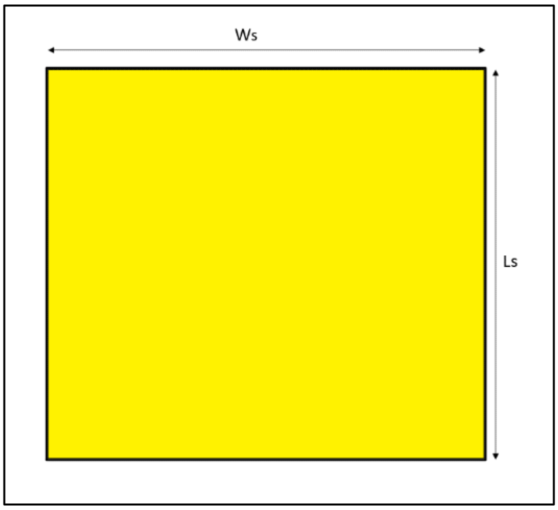


Figure 3. Back side view of antenna

Table 3. Parameter of patch antenna

| Parameter | Value (mm) |
|---|---|
| Width of substrate (Ws) | 57.600 |
| Length of substrate (Ls) | 49.160 |
| Height of substrate (h) | 1.600 |
| Circle radius (cr) | 10.680 |
| Height of patch (ph) | 0.035 |
| Width of patch feedline (fw) | 2.000 |
| Length of patch feedline (fl) | 15.500 |
| Gap of the notch (ng) | 0.244 |

## 3. RESULTS AND DISCUSSION

CST is used to design and simulate the MPA. In general, this programme analyses 3D and multilayer configurations. From the simulation, return loss, VSWR, farfield, and radiation pattern has been found and recorded in this research. However, the design of MPA has been fabricated in laboratory using FR-4 board. From the measured result using VNA, return loss of antenna has been recorded and compared with the simulation result.

### 3.1. Return loss

Figure 4 shows that the return loss of the flower shaped antenna from CST 2019 at frequency 2.45 GHz, 4.5 GHz, and 5.725 GHz. Return loss describes the input and output of the signal sources. It occurs when the load is not properly matched or when not all of the generated power is supplied to the load [22]. From simulation design, the value of return loss found as -15.109 dB, -27.225 dB, and -24.593 dB respectively. This shows the antenna has good reflection coefficient because it can radiate the signal less than -10 dB.

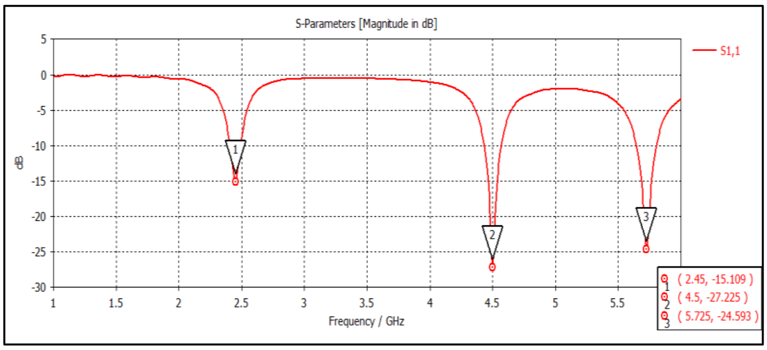


Figure 4. Results of S-parameter

However, in Figure 5 shows that there is a little different of return loss between simulation and measurement result. When the fabricated antenna is tested using the VNA equipment, the return loss found as -9.963 dB, -18.528 Db, and -20.064 dB respectively. This is conceivable because to the fact that in practice, the antenna is connected using a subminiature version A (SMA) cable but in the CST 2019 software, antenna is design using a waveguide port. Material loss, near field scattering objects, feed connection losses, and coaxial cable losses all have an effect on the antenna's responsiveness and fabrication tolerance [23].

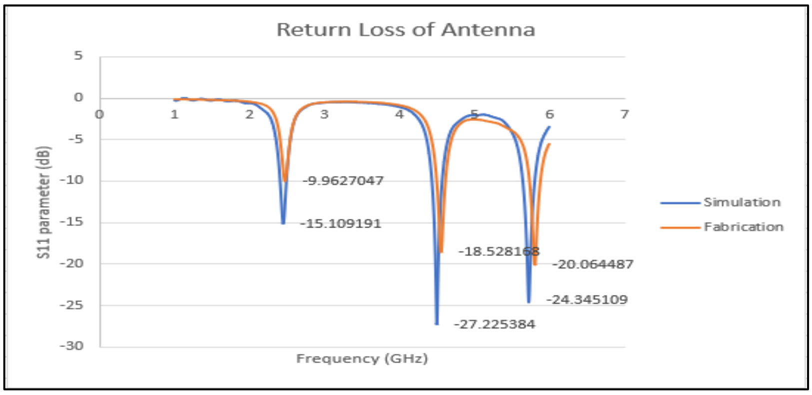


Figure 5. Comparison from simulation and measurement

### 3.2. Voltage standing wave ratio

Figure 6 shows the result of VSWR. The VSWR displays the antenna's compatibility with the line impedance. The VSWR represents the quantity of energy that is reflected or transmitted into the cable. The VSWR of an antenna that properly matched would be 1:1. This indicates that the antenna design is optimal for power transmission into the cable. The minimal VSWR value is 1.0, which is the optimal value for a broadcast signal since no power is reflected from the antenna [24]. According to the simulation result, antenna signal resonated within 1.426 VSWR at 2.45 GHz, 1.091 VSWR at 4.5 GHz, and 1.1253 VSWR at 5.725 GHz. The results show antenna resonated perfectly where all the VSWR value lower than 2 [25], [26].

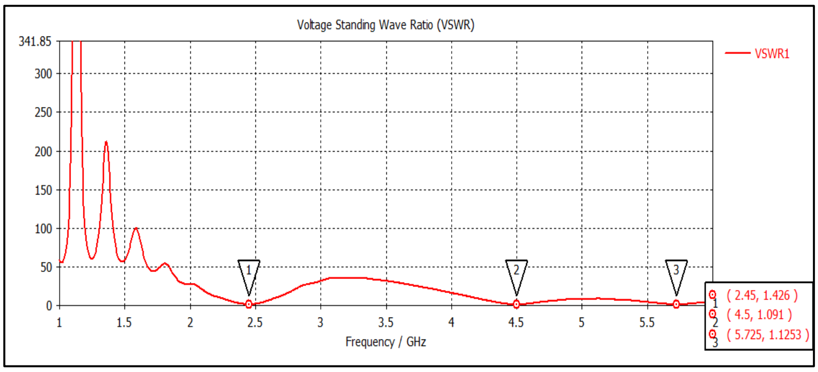


Figure 6. VSWR value at frequency 2.45 GHz, 4.5 GHz and 5.725 GHz

### 3.3. Farfield of the antenna and radiation pattern

Figure 7 shows the 3D view of radiation pattern for the simulation antenna at certain frequency and obtained different directivity. From simulation, radiation pattern at 2.45 GHz shows the value of directivity is around 6.101 dBi and the efficiency at -3.758 dB. The radiation at 4.5 GHz obtained directivity 6.099 dBi and efficiency -4.690 dB while radiation at frequency 5.725 GHz obtained directivity 5.233 dBi and efficiency -7.791 dB. Figure 8 show the radiation pattern in polar coordinate. As shown in the figure, the main lobe covers a larger area compared to sidelobes. Hence, this antenna design has maximum radiation power and minimum wasted power.

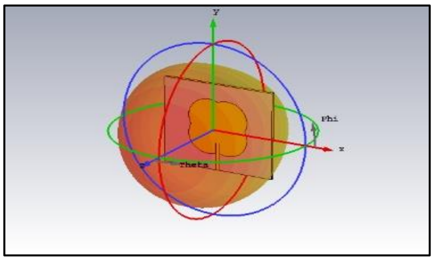


Figure 7. Farfield result for 2.45 GHz, 4.5GHz, and 5.75 GHz

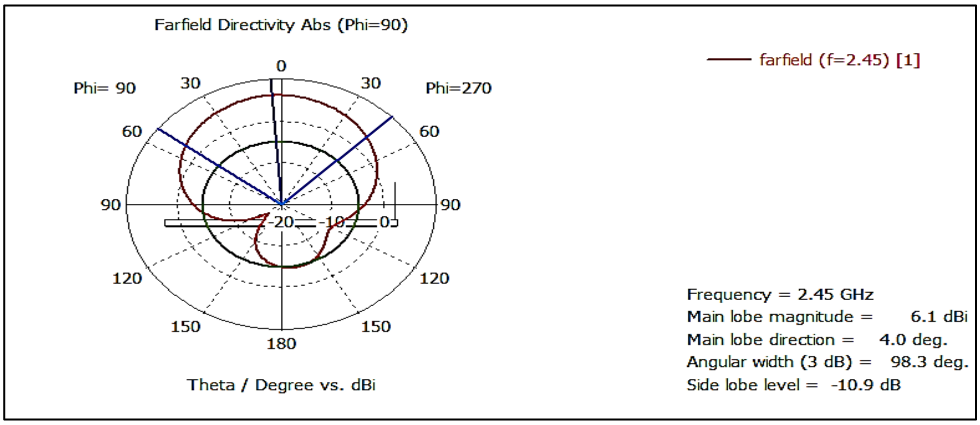


Figure 8. The pattern in polar coordinate at frequency 2.45 GHz

## 4. CONCLUSION

This work presents a design for a tri-band antenna that satisfies the required size limitation. The results obtained indicate that the antenna's performance can be improved by altering the structure of the patch antenna, and that this can be accomplished by modifying the structure of the patch antenna. The return loss, the bandwidth, the VSWR, the directivity, and the polar gain of the antenna are among the parameters that are being investigated. When compared to the simulation and measurement result, the antenna can transfer more data at frequency 4.5 GHz and 5.75 GHz because it can radiate the signal less than -10dB and shows that the antenna has good reflection coefficient. Through the experiments, the proposed design has been proven to be effective and efficient. Further investigation for this design is possible for triple band operation as well, but with a coplanar waveguide as the antenna design.

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