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Transmission Efficiency Analysis of Different Patch Antenna Design Configuration in Various Distance for Wireless Power Transfer

Muhamad Iskandar Naziri [1], Elfarizanis Baharudin[1]*

[1]Faculty of Electrical and Electronics Engineering,
Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, 86400, MALAYSIA

*Corresponding Author Designation

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Abstract: Wireless Power Transfer (WPT) is gaining popularity due to its potential use in charging portable electronic devices without cables, such as laptop computers, mobile phones, and other portable electronic devices. Nowadays, WPT uses microwave antennas to transfer power through the airspace. In the WPT system, direct current is converted into microwave radiation and sent from a transmitter antenna to a reception antenna. This project aims to design several different patch antennas and generate a frequency at 900MHz using CST studio to analyze the power transmission efficiency at various distances, from 1 cm to 12 cm. Another objective is to compare the simulated power transmission efficiency results from several design antennas. Three types of microstrip patch antenna have been designed: square microstrip patch antenna with inset, rectangular microstrip patch antenna with inset, and square microstrip patch antenna with a slot. The antenna design was assumed to be a transmitter and receiver antenna with a distance of 1 cm to 12 cm and simulated to analyze the power transmission efficiency. The best performance of power transmission efficiency is the rectangular microstrip patch antenna with inset, which at the minimum distance of 3 cm is 29.51% (-5.299 dB), and the maximum distance of 15 cm is 2.64% (-15.781 dB). In conclusion, the power transmission efficiency will increase when the receiver antenna is near the transmitter antenna. If the receiver antenna is far from the transmitter antenna, the power transmission efficiency will decrease in this experiment. It depends on the performance of a design antenna to receive power from the transmitter antenna.
Keywords: wireless power transfer, patch antenna, transmission efficiency

1. Introduction

WPT, also called Wireless Power Transfer, is gaining popularity due to its potential use in the charging of portable electronic devices such as laptop computers, mobile phones, and other portable electronic devices without cables. Technology of WPT has been proved in the experiment which is an evanescent resonant-coupling approach using coil to create efficient power transmission [1]. But now,

*Corresponding author: elfa@uthm.edu.my

WPT uses microwave antenna to transfer power through air space. In the WPT system, direct current is converted into microwave radiation and is sent from a transmitter antenna to a reception antenna, which then converts the microwave radiation back to direct current (DC) [2].

There are lot types of patch antenna designs, such as square patch antennas, circular patch antennas, H-slot patch antennas, etc. Each type of the microstrip patch antenna design has its own set of characteristics. If the patch antenna design configuration is changed, the antenna's characteristics parameter will also be changed, especially power transmission efficiency [3]. During signal transmission, the electromagnetic wave propagates between the transmitter and receiver station at a certain distance. The distance in transmitting the electromagnetic wave between transmitter and receiver will give low efficiency when both antennas are at the furthest distance. It is needed to transmit an optimum efficiency at a longer distance. The distance between patch antennas has always been a big challenge in wireless power transfer in various distances [3]. The power transfer efficiency will be low when the distance antenna is far and efficiency will be increased when the distance antenna is short distance [4].

There are several patch antennas need to design by using FR-4 material and operating 900 MHz to determine the characteristic of antenna, particular power transmission efficiency, *T*. By using CST Studio software, in order to construct several microstrip patch antenna design and analyses the wireless power transmission efficiency, *T* at various distances between 1 cm to 12 cm. After that, need to comparison of result power transmission efficiency from several microstrip patch antenna design.

2. Principle and Design

In this section, the design of microstrip patch antenna with the theoretical principal design are discussed.

2.1 Theory.

Microstrip antennas are utilized in a variety of practical applications. This is attributable to the fact that it has a low volume, is smaller in weight, has lost cost, is physically more inconsequential, and is easier to build and conform to the traditional microwave antenna. In order to construct the Microstrip patch antenna, the frequency resonant (f_r), dielectric constant (ε_r), and height (h) of the substrate must be understood. In order to create a basic Microstrip patch antenna, the following formulas were use:

i. The width of the patch, W [5]

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \qquad Eq. 1$$

ii. The effective dielectric constant, ε_{reff} [5]

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\frac{h}{W}\right)^{-\frac{1}{2}} \qquad Eq. 2$$

iii. The normalized extension in the length, $\triangle$L[5]

$$\triangle \mathrm{L} = 0.412h\frac{\left(\varepsilon_{reff} + 0.3\right)\left(\frac{w}{h} + 0.264\right)}{\left(\varepsilon_{reff} - 0.258\right)\left(\frac{W}{h} = 0.8\right)} \qquad Eq. 3$$

iv. The length of the patch, L[5]

$$L = \frac{C}{2f_r\sqrt{\varepsilon_{reff}}} - 2 \triangle \mathrm{L} \qquad Eq.4$$

v. The length of the quarter-wave, L_f is equal to the length of the single-section quarter-wave transformer.[5]

$$L_f = \frac{\lambda_g}{4}$$

Where, λ_g $\qquad Eq.5$

$$\lambda_g = \frac{c}{f_r\sqrt{\varepsilon_{reff}}}$$

vi. The characteristic impedance of a microstrip feed line[5]

For, $\frac{W_f}{h} < 2$

$$\frac{W_f}{h} = \frac{8e^A}{e^{2A} - 2}$$

Where, A $\qquad Eq.6$

$$A = \frac{z_o}{60}\sqrt{\frac{\varepsilon_r + 1}{2}} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1}\left(0.23 + \frac{0.11}{\varepsilon_r}\right)$$

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

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

Where, B $\qquad Eq.7$

$$B = \frac{377\pi}{2z_o\sqrt{\varepsilon_r}}$$

2.2 Design

They are three type of design microstrip patch antenna has been optimized which is square microstrip patch antenna with inset, rectangular microstrip patch antenna with inset and square microstrip patch antenna with slot. The parameter values had displayed in Tables 1, 2, and 3 show the dimension parameter of three type of design microstrip patch antenna has been optimized as shown in Figure 1, 2 and 3.

Table 1: Optimize parameter of the square patch antenna with inset

Item	Parameter Name	Variable Value	Unit or Dimension
1	Resonant frequency, f_r	900	MHz
2	Dielectric constant, ε_r	4.3	-
3	Substrate thickness, h	1.6	mm
4	Width of microstrip patch, W	77.8	mm
5	Length of Microstrip patch, L	77.8	mm
6	Characteristic impedance width of a microstrip feed line, W_f	3	mm
7	length of quarter wave feed line, L_f	36.6	mm
8	Length of inset feed, L_i	13	mm
9	Gap of inset feed, G_i	2	mm

Table 2: Optimize parameter of the rectangular patch antenna with inset

Item	Parameter Name	Variable Value	Unit or Dimension
1	Resonant frequency, f_r	900	MHz
2	Dielectric constant, ε_r	4.3	-
3	Substrate thickness, h	1.6	mm
4	Width of microstrip patch, W	63	mm
5	Length of Microstrip patch, L	78.2	mm
6	Characteristic impedance width of a microstrip feed line, W_f	3	mm
7	length of quarter wave feed line, L_f	41.82	mm
8	Length of inset feed, L_i	10.92	mm
9	Gap of inset feed, G_i	1.5	mm

Table 3: Optimize parameter of the square patch antenna with slot

Item	Parameter Name	Variable Value	Unit or Dimension
1	Resonant frequency, f_r	900	MHz
2	Dielectric constant, ε_r	4.3	-
3	Substrate thickness, h	1.6	mm
4	Width of microstrip patch, W	77.6	mm
5	Length of Microstrip patch, L	77.6	mm
6	Characteristic impedance width of a microstrip feed line, W_f	2	mm
7	length of quarter wave feed line, L_f	26.20	mm
8	Length of inset feed, L_i	5	mm
9	Gap of inset feed, G_i	5	mm

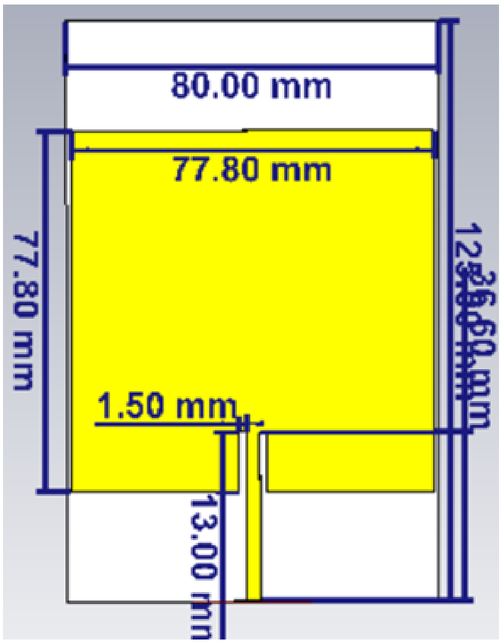

Figure 1: Dimension of square microstrip patch antenna with inset

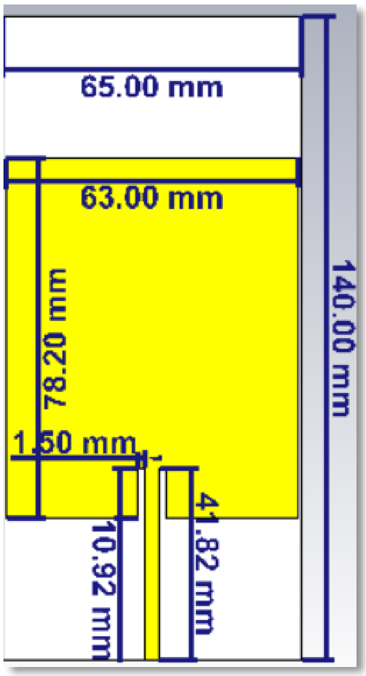

Figure 2: Dimension of rectangular microstrip patch antenna with inset

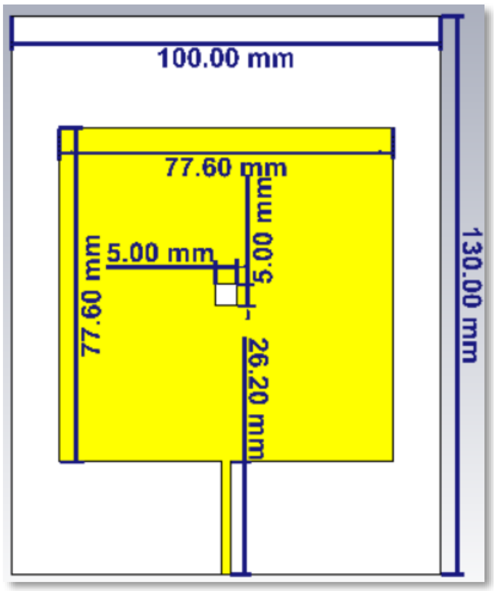

Figure 3: Dimension of square microstrip patch antenna with slot

3. Result and Discussion

The results of microstrip patch antenna by using CST Microwave Studio simulated are reported in this part based on S-parameter and power transmission efficiency. The outcome includes the setup simulation set up for wireless power transfer and the comparison simulation result of power transmission efficiency from each microstrip patch antenna design.

3.1 The Return loss, S_{11} parameter

The performance of the antenna has been optimized and analyzed by using Software CST studio. The return loss of the several microstrip patch antenna design at 900 MHz are shown in Figure 4,5 and 6. The better result for reflection coefficient is below -10 dB [6]. From the S_{11} parameter from square microstrip patch antenna with inset, it can be analyzed that optimum antenna has -19.76 dB at frequency 900MHz. While for rectangular microstrip patch antenna with inset, the S_{11} parameter antenna has -43.18 dB at frequency 900MHz. And the square microstrip patch antenna with slot result of the S_{11} parameter can be analyzed that optimum antenna has -37.702 dB at frequency 900MHz.

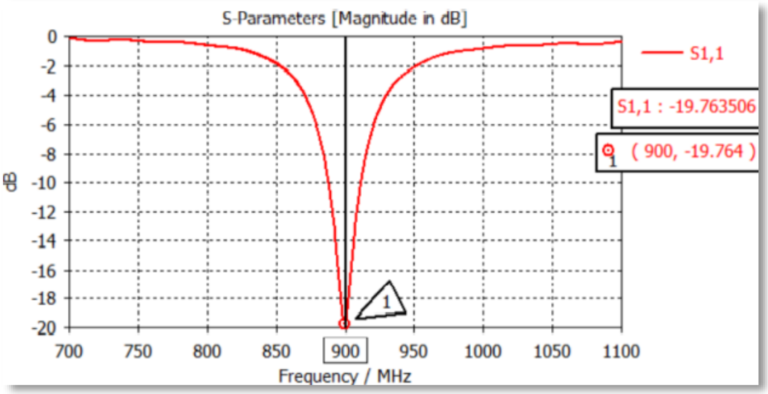

Figure 4: The return loss of the square microstrip patch antenna with inset

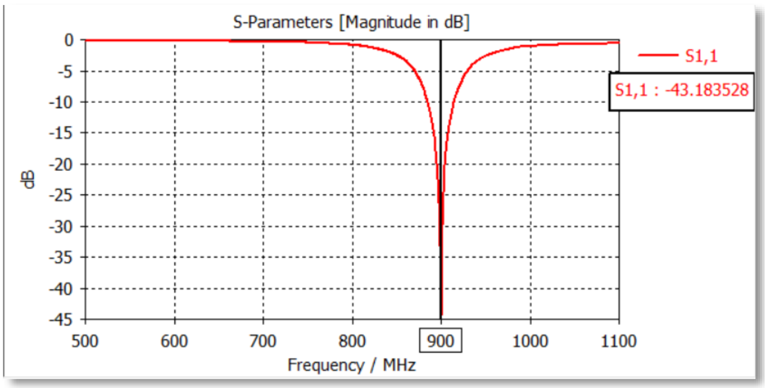

Figure 5: The return loss of the rectangular microstrip patch antenna with inset

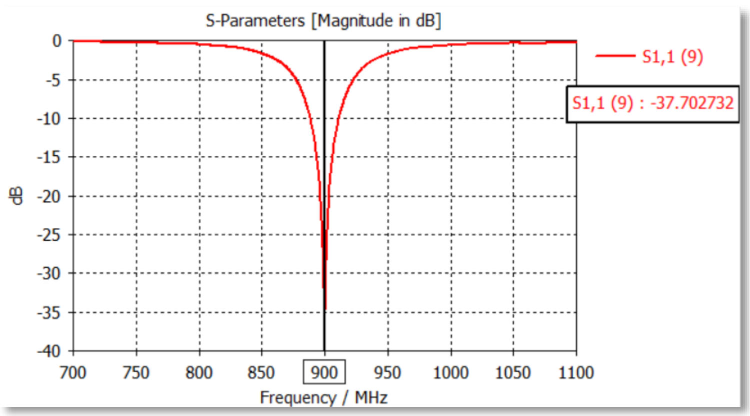

Figure 6: The return loss of the square microstrip patch antenna with slot

3.2 Simulation for wireless power transmission efficiency

This section simulates the measurement of two antennas via free space at distances ranging from 1 cm to 12 cm. This method has two antenna which is transmitter and receiver antenna. The transmitter and receiver antennas that have become transfer power devices in a free space situation has been to analyze the percentage of transmission efficiency. In this project has been simulated three antenna designs via free space in distance 1cm to 12cm as shown in Figure 7.

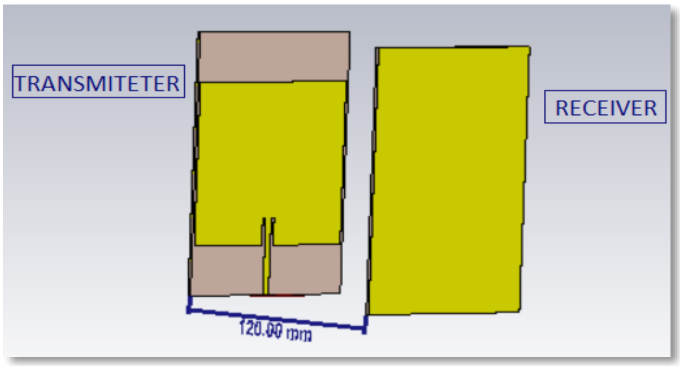

Figure 7: Simulation setup of microstrip patch antenna in 1cm to 12cm

3.3 Comparison simulation result of power transmission efficiency from each microstrip patch antenna design

Figure 8 shows the comparison simulation result of power transmission efficiency from three microstrip patch antenna design. The blue line is square microstrip patch antenna with inset, the orange line is rectangular microstrip patch antenna with inset and the grey line is and square microstrip patch antenna with slot. The parameter of power coefficient, S_{21}, can use to calculated the power transmission efficiency for analyses the result of wireless power transfer [7].

The power transmission efficiency, T [7]

$$T = 10^{\frac{|S_{21}|}{10}} \text{ X } 100\,\% \qquad Eq. 8$$

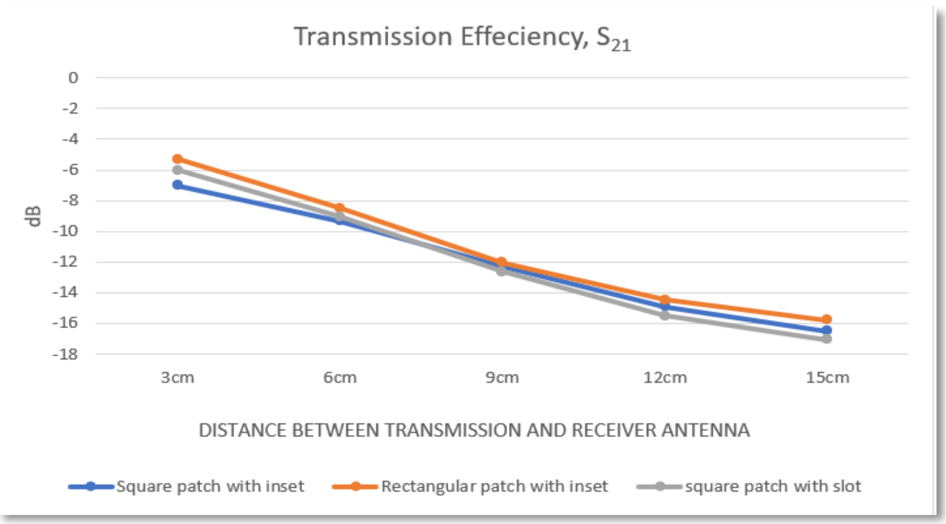

Figure 8: Simulation setup of microstrip patch antenna in 1cm to 12cm

Based on Table 4, the comparison result, the best performance of power transmission efficiency is rectangular microstrip patch antenna with inset, which is in minimum distance at 3cm is 29.51% (-5.299 dB) and maximum distance at 15 cm is 2.64% (-15.781dB). The lowest performance of power transmission efficiency is square microstrip patch antenna with slot, which is in minimum distance at 3cm is 25.10% (-6.0019 dB) and maximum distance at 15 cm is 1.97% (-17.0419 dB). When the receiver antenna near to transmitter, the power transmission efficiency is increase value. When the receiver antenna far away from transmitter, the power transmission efficiency will decrease value.

Table 4: The calculation parameter of power transmission efficiency

Antenna Design	3 cm in (dB)	3 cm in (percentage)	15 cm in (dB)	15 cm in (percentage)
Square microstrip patch antenna with inset	-6.33 dB	23.28%	-15.47 dB	2.837%
rectangular microstrip patch antenna with inset	-5.299 dB	29.51%	-15.781dB	2.64%
Square microstrip patch antenna with slot	-6.0019 dB	25.10%	-17.0419 dB	1.97%

4. Conclusion

In this paper, the microstrip patch antenna design configuration was proposed to improve the power transmission efficiency in various distance for wireless power transfer by using CST Studio software. Compared with the microstrip patch antenna, when the receiver antenna near to transmitter, the power transmission efficiency is increase value. When the receiver antenna far away from transmitter, the power transmission efficiency will decrease value. Specially, the configuration of rectangular microstrip patch antenna with inset can achieve higher efficiency at minimum distance and maximum distance than other antenna design. Recommendation for the future work, the design was implemented for this project is rectangular shape microstrip shape antenna where it's the basic design of the microstrip patch antenna. As recommendation, the improvement of the patch antenna design that possible to provide better performance of the characteristic antenna.

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