Circular Microstrip Patch Antenna for UHF RFID Reader

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***Abstract*—This paper presents an analysis of Circular shape patch antenna for Ultra High-Frequency Identification (UHF) Radio Frequency Identification (RFID) Reader Applications. The fabricated antenna has lightweight, simple structure, low profile and easy for fabrication due to the used of FR-4 materials with loss tangent 0.019, the dielectric constant of 4.7 and thickness of 1.6 mm. It can be operated for UHF RFID system in Malaysia with the frequency assigned from 919 MHz to 923 MHz. The antenna simulation was analysed by using CST Studio Suite 2016. From the results, the antenna has the reflection coefficient (S_{11}) less than -10dB together with the bandwidth of 90 MHz. Other results of antenna parameter such as voltage standing wave ratio (VSWR), circular polarized radiation pattern, return loss and gain were also discussed. The complete size of the proposed antenna is 120 mm x 120 mm x 1.6 mm. Thus, it is suitable for RFID portable reader applications.**

***Index Terms*—Microstrip Antenna; Radio Frequency Identification; Ultra High Frequency; Return Loss.**

I. INTRODUCTION

In recent years, radio frequency identification technology (RFID) has moved from unpopular technology into mainstream applications such as in agriculture product, electronics equipment, manufacturing products that produced in large quantity in order to track the location, delivery record and facilitate location [1].

RFID utilizes an electromagnetic field to electronically track and identify tags enclosed to objects and these tags contain electronically stored information [2]. RFID has many advantages over barcodes, for instance, in the operation of barcode reading, the scanner must be placed directly in front of each label and both need to be oriented to a very specific position to function properly [3-4]. On the other hand, RFID tags do not need strictly oriented to RFID readers right away because RFID uses radio waves to communicate and the RFID tag only needs to be in the reader reading range, which will vary depending on the types of handheld RFID reader used in the application [5]. With an improvement of the anti-collision element in RFID technology, readers can read multi-tag and identify multiple objects at the same time [6]. This will ensure the safeness and security of the object and also reduce the need for the time taken and manual personnel to identify the objects.

The RFID reader antenna designed in the (UHF) ultra-high frequency, (300MHz-3GHz) frequency band has been extensively used to detect objects rather than other frequency such as (LF), low frequency (30-300 kHz) and HF, high frequency (3 MHz-300 MHz) because it has advantages in term of better read range and can read many tags per second [7].

Nowadays, there are many categories of the designed antenna built for RFID readers such as monopole antenna [8], PIFA antenna [9], loop antenna [10], helical [11] and three elements printed Yagi antenna [12]. By implementing the same printed antenna approaches as mentioned above, this aimed antenna design takes benefits of the FR-4 substrate material.

Microstrip patch antennas (MPA) comprises of grounded patch and substrate of metallization. These are lightweight, low profile and most suitable for mobile applications and electronic integrated applications. Furthermore, microstrip patch antenna is usually designed at UHF and microwave frequencies because the dimension of the antenna is right away tied to the wavelength at the resonant frequency. There is a unique property for the microstrip patch antenna which is the capability to have a variant of polarization.

Circularly polarized (CP) antenna is a type of antenna with circular polarization. CP antenna is far better than linear polarization antenna since it is very effective in reducing fading or multipath interference [13]. Many designs have been built by the researchers to find this horizontal, vertical, right-hand circular polarization (RHCP) or left-hand circular polarization (LHCP) using a single feed point arrangement[14]. These advantages allow patch antennas to be adopted in different types of frequency bands that may have varied specifications.

The main disadvantages of microstrip patch antennas are narrow bandwidth, lesser gain and poor efficiency, which disturbed the efficiency of this antenna. Various researchers currently studied different shapes of antenna design for RFID readers by applying a varied approach of patch and ground geometry such as E shaped patch [15], U shaped patch [16], C shaped patch [17], L shaped patch [18]. Other modes to decrease these deficiencies are including the make use of notches [19], cutting various slots [20], antenna array [21], material thickness [22] and different substrate material [23] in the patch geometry.

This work discovers the potentiality of advancing the UHF RFID performance to any UHF reader module by focusing on increasing the read range and antenna gain in comparison with the state of the art. The aim of this study is to design a low profile circular patch antenna for an ultra-high frequency RFID based on Malaysia Frequency Allocation (921 MHz-923MHz). The communication between the fabricated antennas, RFID module and computers can enhance the potential of this study.

II. Antenna Geometry and Design

The antenna consists of a modified circular patch shaped microstrip element printed into the FR-4 substrate with a dielectric constant (ε_r) of 4.7, loss tangent of 0.019 and thickness of 1.6 mm. The patch and ground were used PEC material with the thickness of 0.0035 mm. Figure 1 shows the dimension and geometry of the antenna.

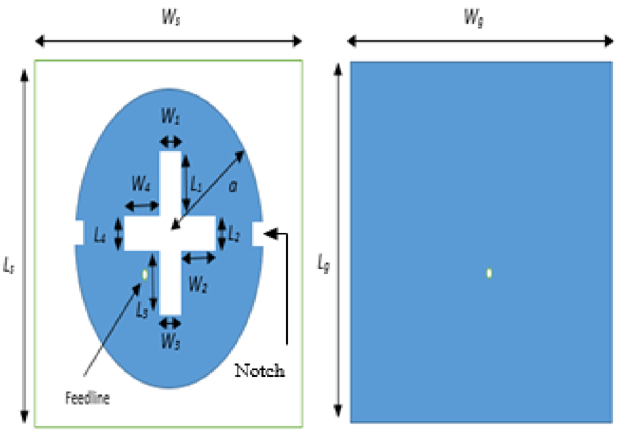

Figure 1: The geometry design of the proposed antenna.

The complying mathematical model has been analysed in designing the Circular Patched Microstrip antenna [24].

The relationship between the radius of circular patch radius (a), resonant frequency (f_r), dielectric constant (ε_r) and thickness of the substrate (h);

$$a = \frac{F}{\left\{1 + \frac{2h}{\pi\varepsilon_r F}\left[\ln\left(\frac{\pi F}{2h}\right) + 1.7726\right]\right\}^{1/2}} \tag{1}$$

where;

$$F = \frac{8.791\times10^{9}}{f_r\sqrt{\varepsilon_r}} \tag{2}$$

The condition above does not take into consideration over the fringing impact. Since fringing makes the patch electrically bigger, the effective radius (a_e) of the patch is utilized and can be defined as:

$$a_e = a\left\{1 + \frac{2h}{\pi a\varepsilon_r}\left[\ln\left(\frac{\pi a}{2h}\right) + 1.7726\right]\right\}^{1/2} \tag{3}$$

The relationship between the resonant frequency (f_r) and velocity of light (v_o) is given as;

$$(f_r)_{110} = \frac{1.8412 v_0}{2\pi a_e\sqrt{\varepsilon_r}} \tag{4}$$

The circular shaped microstrip antenna consists of four arms etched onto the metallised dielectric substrate. The ground plane covers one section of the dielectric, which does not fall directly beneath the monopoles. The antenna is probe fed via microstrip ground connected to the base circular patch. The default value of this antenna design is shown in Table 1.

Table 1
Dimension of the Antenna

Parameter	Symbol	Segment	Dimension (mm)
Patch	a	Radius	40
Notch	W_n	Width	3
	L_n	Length	7
Arm 1	W_1	Width	3
	L_1	Length	11
Arm 2	W_2	Width	11
	L_2	Length	3
Arm 3	W_3	Width	3
	L_3	Length	11
Arm 4	W_4	Width	11
	L_4	Length	3
Ground	W_g	Width	120
	L_g	Length	120
Substrate	W_s	Width	120
	L_s	Length	120
	h	Thickness	1.6
	ε_r	Dielectric Constant	4.7
SMA	Ω	Impedance	50

Figure 2: Fabricated Microstrip Antenna

III. Result and Discussion

A. *Result of simulation of the proposed antenna*

The simulation of important parameters prototype of the proposed antenna is done by using CST Microwave Design Studio 2016 software. It is worth mentioning that the used time domain simulation is useful to study the field propagation along the traces of FR4 such as reflection coefficient S_{11}, Voltage Standing Wave Ratio (VSWR) and directivity.

The comparison of simulated and measured S- Parameter is shown in Figure 3. The measured bandwidth and simulation bandwidth of this antenna is 90 MHz (915 MHz – 1005 MHz) and 30 MHz (908 MHz – 938 MHz) respectively.

Moreover, the desired of operating frequencies slightly change from 921 MHz (simulation) to 925 MHz (measured) and $|S_{11}|$ values shifted from -27.43 dB (simulation) to -13.78 dB (measured).

The Voltage Standing Wave ratio is important in order to find the good efficiency of the antenna design. In addition, VSWR always be used as an indicator of power reflected from the antenna. For practical application, the value of VSWR should be a real and positive number with values less than 2. Thus, in Figure 4, the VSWR is equal to 1.09 and this value satisfies the practical antenna design.

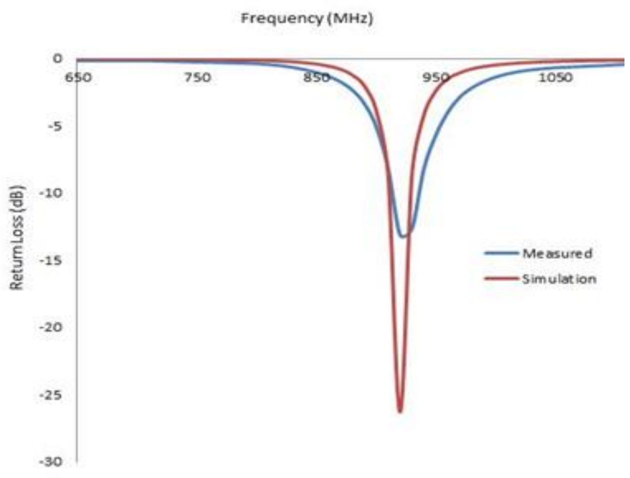

Figure 3: Simulated and measured of Return Loss S_{11}.

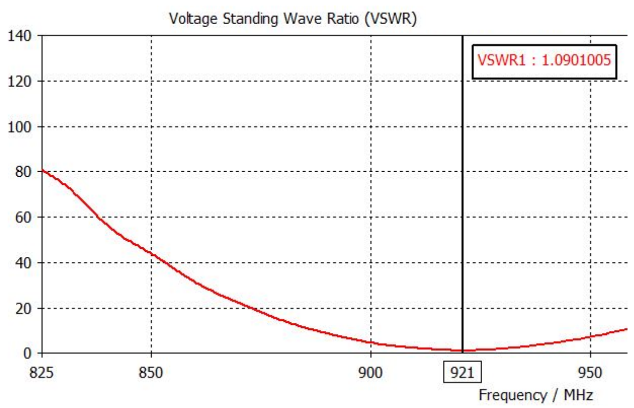

Figure 4: Simulated Voltage Standing Wave Ratio

Figure 5 shows the simulated radiation pattern in the 3D plot. The standard majority radiation is focused in one direction and can be achieved throughout the operating frequency of the antenna. The value of directivity for the antenna is at 5.970 dBi for 921 MHz.

Figure 6 shows the beamwidth was at 95.4 degrees when the main direction at 0 degree. Beamwidth is important to be considered because it shows the measurement of the area over which the antenna receives signal.

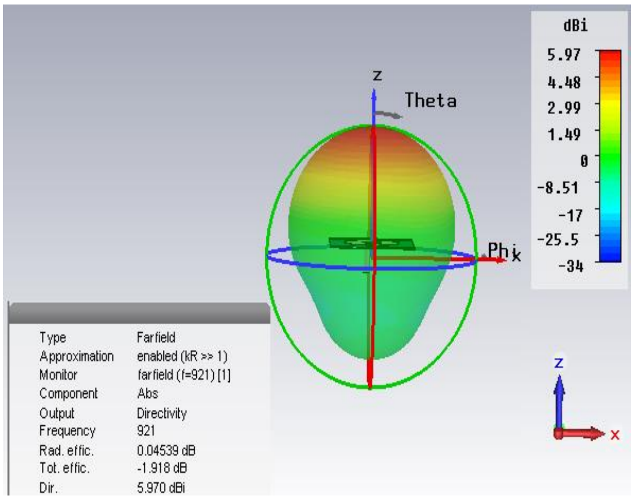

Figure 5: Simulated radiation pattern in the 3D plot for the proposed antenna.

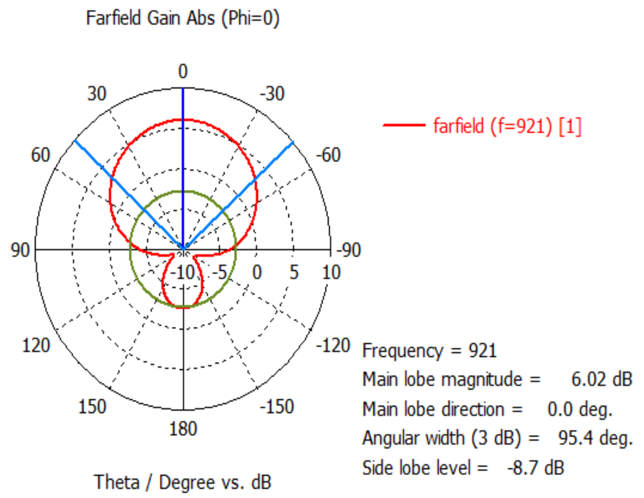

Figure 6: Simulated radiation patterns in polar plot for proposed antenna with Phi=0^0

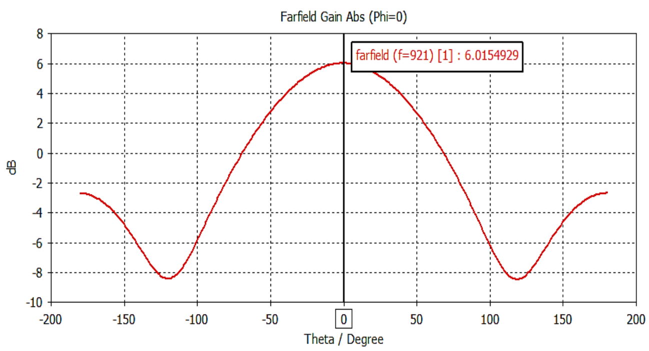

Figure 7: Simulated Gain in Cartesian Plot

It is also noticed that the simulated Gain in the Cartesian plot as in Figure 7 is also important to measure efficiency and directional capabilities of an antenna. The simulation gain value of this antenna is 6.015 dB for 921 MHz.

B. Parametric Studies of the Effect on Return Loss S_{11}

In order to view the effect of the return loss, characteristic value of the bandwidth and movement of the resonant frequency, a parametric study has been used by changing the dimension variation of the antenna.

There are three factors to be analyzed which are the change in diameter of patch, width and length of Arm 1 and Arm 3. Only one parameter is permitted to be changed at a time whereas other values are fixed. All of the dimension variation in the mentioned simulated graph are in millimeters (mm).

C. Diameter of Patch Effect

The diameter of the patch was simulated in four dimensions which are 80 mm (purple), 80.5 mm (orange), 81 mm (blue) and 81.5 mm (green). From Figure 8 (a), it has been found that by increasing the value of *a*, the resonance frequency of designed antenna slightly increased from 920 MHz to 923 MHz. Furthermore, the diameter of a patch with the value of 80 mm give higher return loss of -27.48 dB. Likewise in Figure 8 (b), it is observed from the axial plot that the minimum AR (axial ratio) point shift corresponding to the patch diameter. From figure 8 (b), the axial ratio is 2.87 dB at 921 MHz operating frequency. An antenna can be claimed as a circular polarized antenna when the axial ratio is less than 3 dB.

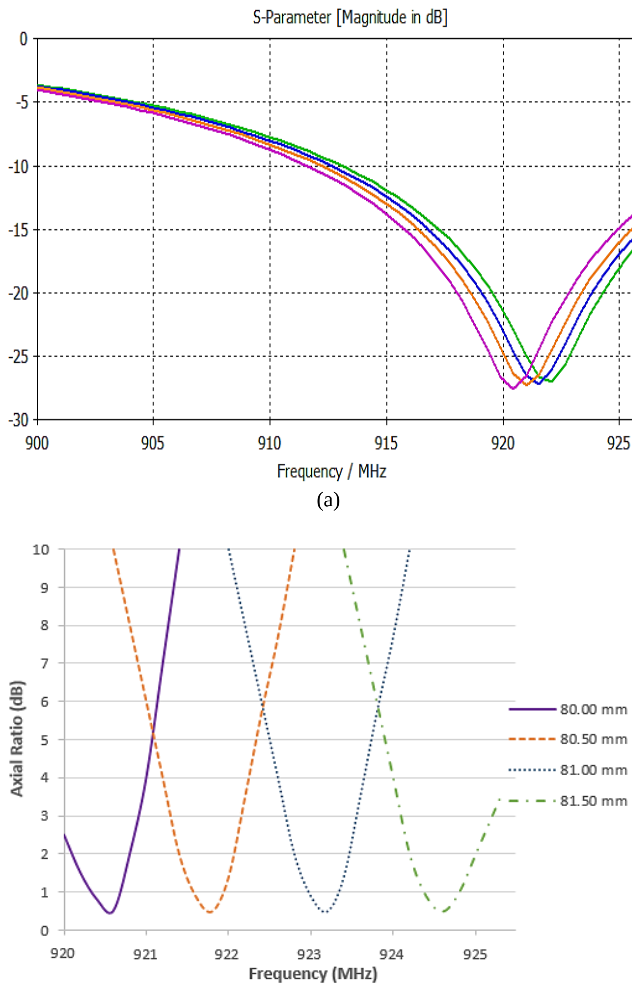

Figure 8: The effect of varying patch diameter (a) reflection coefficient (b) axial ratio.

D. Arm 1 and Arm 3 Slot Width Effect

The slot width of the arm 1 and arm 3 were simulated in four widths which are 0.5 mm (purple), 1 mm (blue), 2 mm (green) and 3 mm (orange) as in Figure 9. By using a value of 3 mm, an increment of the bandwidth is shown at 17 MHz (911 MHz - 928 MHz) compared to 0.5 mm that showing bandwidth at 7 MHz (910 MHz – 917 MHz). This bandwidth enhancement is probably because of the two possible paths of length L_2 and L_4, which contribute to the excitation of the two resonances at much closed frequencies and perform wide operating bandwidth.

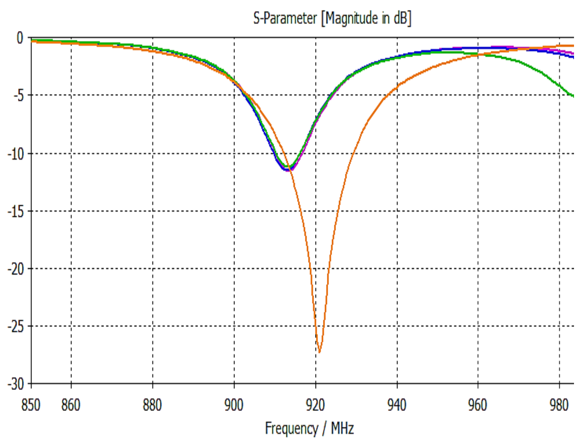

Figure 9: Arm 1 and arm 3 width effect vs Return Loss S_{11}

E. Arm 1 and Arm 3 slot length effect

Figure 10 shows the result of the variation in return loss with the respect to the Arm 1 and Arm 3 length size. Four lengths are simulated which are 11 mm (orange), 12 mm (green), 13 mm (blue) and 14 mm (purple).

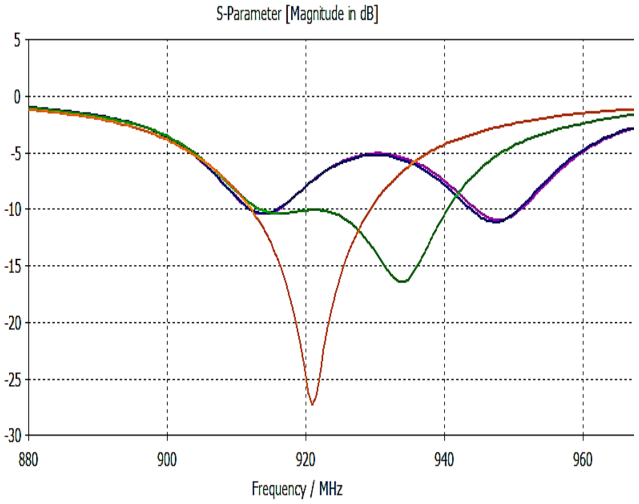

Figure 10: Arm 1 and arm 3 length effect vs Return Loss S_{11}

The arm length design is significantly important in antenna design because the S_{11} is sensitive to this variation effect. Based on the simulation, it shows that best result of S_{11} is at -27.43 dB with 11 mm length.

IV. CONCLUSION

An efficient and lightweight circular shaped antenna with arms has been designed and fabricated on FR4 substrate with a loss tangent of 0.019, the substrate thickness of 1.6 mm and dielectric constant of 4.7. The overall size of the antenna is designed with dimensions of 120 mm x 120 mm x 1.6 mm. This design is pin fed by 50 Ω SMA connector. In order to investigate the antenna reflection coefficient of S_{11}, the different modification of geometric dimensions on the circular patch, arm's length and width of the presented antenna have been studied. After analyzing all the simulations result, we can conclude that the designed antenna structure is in circular polarization and it can work in UHF RFID system in Malaysia which allocated frequency bands from 919 MHz to 923 MHz with return loss below than -10 dB.

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