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A rectangular CSRR based microstrip UHF reader patch antenna for RFID applications

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ABSTRACT

This paper presents a compact microstrip ultra-high frequency (UHF) reader patch antenna with complementary split ring resonator (CSRR) for radio frequency identification (RFID). The total size of the antenna is 208 × 208 × 1.6 mm^3. The proposed antenna is designed, fabricated and measured in order to verify the proposed concept. The characterization for radiation parameters, like return loss, radiation pattern and antenna gain have been done experimentally. The proposed antenna is operated at 921 MHz for and achieved a gain of 8.285 dBi. All simulations in this work have been carried out by means of the commercial computer simulation technology (CST) software. In compare to the simulated results, the measured outcomes are promised.

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1. INTRODUCTION

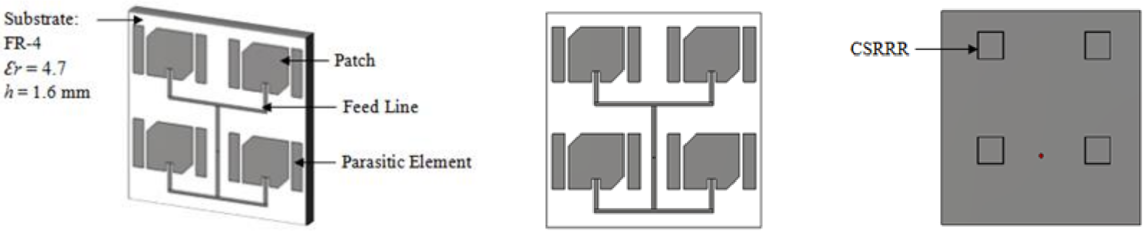
Radio frequency identification (RFID) is a technologies that provides wireless identification and tracking capability [1]. Antenna is a crucial part in the RFID system, which affects the whole performance of the RFID system [2]. Therefore, reader antenna is an important unit as they are integral part of RFID systems. Among the applications, ultra-high frequency (UHF) radio frequency identification (RFID) systems receives a lot of attention because of their potential in item-level tagging such as sensitive products tracking, pharmaceutical logistics, transport and medical products (blood, medicines, vaccines), bio-sensing applications, and so on [3-9]. UHF band has always been the pursuit of RFID systems, because the frequency band varies from country to country. In Malaysia, the permitted operating frequency is between 919 MHz – 923 MHz for UHF band [10, 11].

In many cases, the near field RFID system needs to have a larger reading range, just like commodity shelves. One challenge work in near field RFID application is to design one UHF band antenna with larger reading range. The metamaterial CSRR antennas is one among the growing research topic in the field of compatible antennas. These techniques has various advantages because of their improved performance in terms of the band of operation [11-15].

In this paper, a novel design of microstrip patch array antenna with CSRR elements for RFID reader and resonate on the UHF RFID bands of 860-960 MHz is presented. The theoretical simulations are performed using CST software.

2. ANTENNA CONFIGURATION AND DESIGN PROCEDURE

The proposed UHF reader antenna structure was designed and simulated on a FR-4 substrate along with $\mathcal{E}r$ = 4.7, h = 1.6 mm and δ = 0.019 which represent the dielectric constant, thickness and tangent loss respectively. Figure 1 shows the geometry of the UHF reader antenna structure. CSRR was implement on the ground plane as illustrated in Figure 1(c). Four of CSRR elements were added to the ground at the middle of every patches, which are presented in the 2 x 2 array configuration.



(a) (b) (c)

Figure 1. Design of proposed UHF reader antenna (a) 3D view, (b) front view, and (c) back view

The structure of the CSRR is shown in Figure 2. We have adopted the analytical equation for CSRR resonant frequency accomplished which is addressed in [16-24]. By using the (1-3), the average ring length (A), outer length (a_1), and inner length (a_2) of CSRR structure are correspondingly measured as follows:

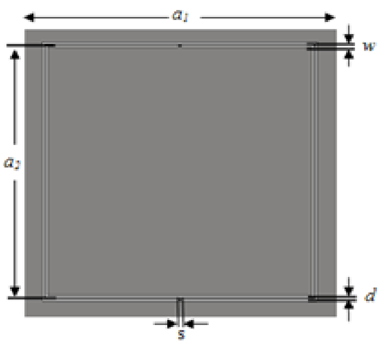


Figure 2. CSRR structure

The CSRR resonant frequency is expressed by:

$$F_{CSRR} = \frac{c}{2A\sqrt{\varepsilon_{eff}}} \quad (1)$$

Where c represents the light speed, the average ring length is represented by A and $\mathcal{E}_{eff}$ holds the effective dielectric constant value. The outer and inner length of the ring formula is presented in (2) and (3) respectively.

$$a_1 = \frac{A + s + 4w}{4} \quad (2)$$

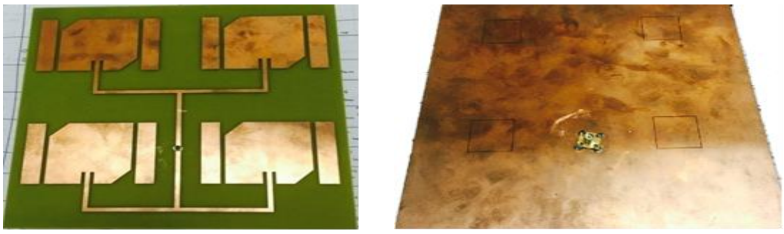
$$a_2 = a_1 - 2d - 2w \quad (3)$$

The dimension of the ring split (*s*) and width (*w*) was set to 0.2 mm. Furthermore, the value of *d* must not more than 0.1 mm due to the limitation of fabrication technology. The calculation dimensions of the CSRR element are tabulated and presented in Table 1.

The prototype of the proposed UHF reader antenna was fabricated. Therefore, due to the need of verifying the theoretical and simulation outcomes, antenna characteristics were measured. Figure 3 depict the front and back sides of the suggested UHF reader antenna structure which was implemented by CSRR element at the ground. It shows that the 2 x 2 truncated patches were located at the front, while 2 x 2 of CSRR elements were located at the back which also known as ground.

Table 1. Dimension of the CSRR Elements

CSRR Parameters	Calculation Dimensions (mm)
Average ring length, A	73.8
Outer length, a_1	18.7
Inner length, a_2	18.1



(a) (b)

Figure 3. The prototype of the UHF reader antenna structure (a) front view (b) back view with CSRR elements

3. RESULTS AND DISCUSSIONS

3.1. Reflection Coefficient Measurement

The measurement of the proposed UHF reader antenna structure was obtained by using reflection coefficient measurement equipment. The Rohde and Schwarz ZVA 40 instruments 10 MHz to 40 MHz Vector Network Analyzer (VNA) are used to calculate the reflection coefficient. Figure 4 shows the simulated and measured reflection coefficient responses. As for reflection coefficient results, the measured results show a shift to 918 MHz with -22.18 dB, compared to the simulated result 921 MHz with -27.76 dB. However, the shifted frequency was just slightly from the desired. Throughout antenna fabrication, there were some imperfections come out of the antenna. For instance, having misalignment once etching the shape of CSRR during positioning them onto substrate.

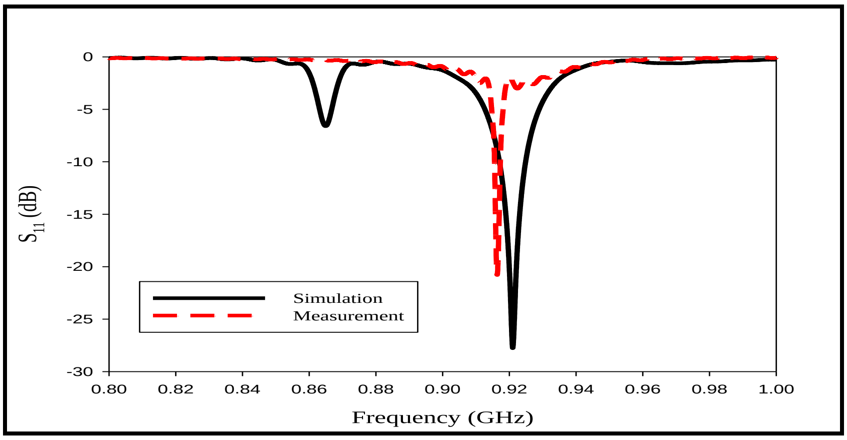


Figure 4. Comparison between simulated and measured outcomes of S_{11} for the proposed UHF reader antenna structure

3.2. Radiation Pattern Measurement

In an indoor anechoic chamber, the radiation pattern was measured by means of a near field measurement system along with an operating frequency 921 MHz. The simulated and measured radiation patterns of the proposed antenna have been conducted in two planes either in H-plane (x-z direction) with phi = 0º and E-plane (y-z direction) with phi = 90º. In comparison to the simulated results, the calculated radiation pattern shows a good agreement as illustrated in Figure 5. However, as shown in the measured results there were several minor discrepancies typically as a consequence of the similar reasons deliberated in the reflection coefficient measurement. The result among measured and simulated design of the radiation patterns obtained an acceptable agreement.

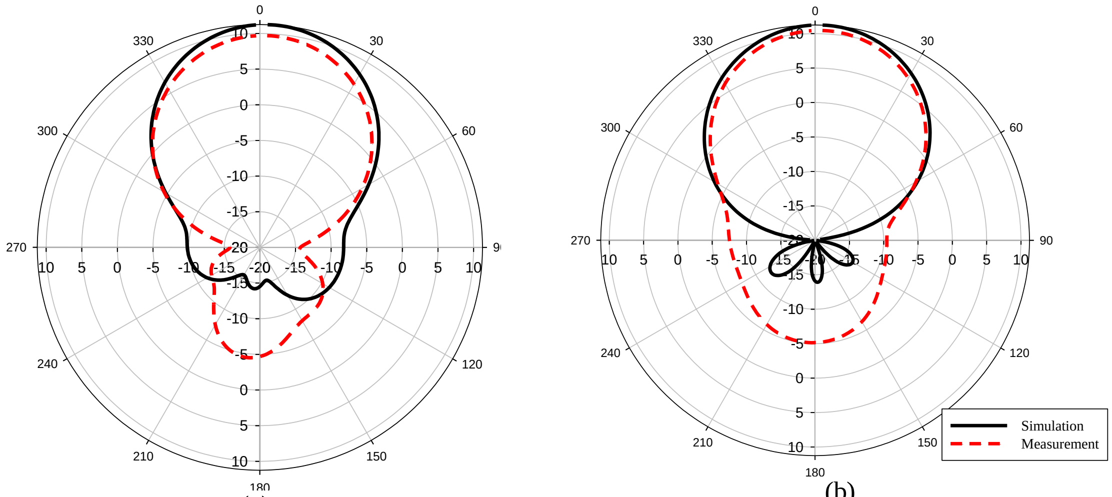


Figure 5. The simulated and measured radiation patterns of the proposed UHF reader antenna in polar plot during (a) E-plane (phi=90º) and (b) H-plane (phi=0º)

4. PRACTICAL INDOOR ANTENNA MEASUREMENT

Antenna's performance can be validated by testing the ability of the antenna in an indoor or outdoor measurement. Antenna-under test (AUT) is characterized by way of a transmitter in order to certify that the antenna has the capability to transmit both of the signals and waves to the receiver (Rx) side. Mutually, the AUT and Rx must be positioned face-to-face and bring into line towards each other at a height of 1 meter to achieve a line-of-sight (LOS) condition. As shown in Figure 6, the research [25-28] designed the AUT to be performed as the Rx. In addition, the experiment was conducted for indoor measurement. The aim is to investigate the capability of the AUT so that the antenna can transmit or receive the signal in order to verify that the AUT is not functioned as a dummy antenna.

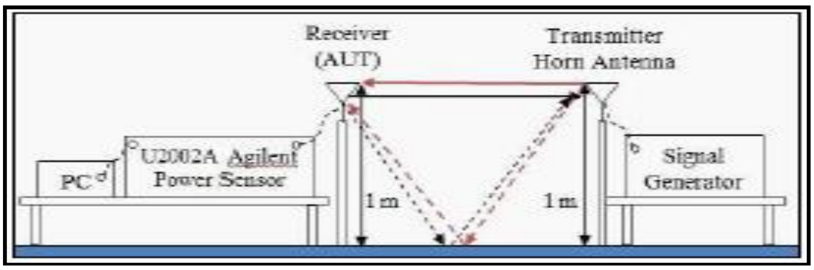


Figure 6. The arrangement experiment for indoor measurement

Figure 7 shows the considered losses and gains with the purpose of describing the power transmit, (*Pt*) or power receives, (*Pr*) signal of the AUT.

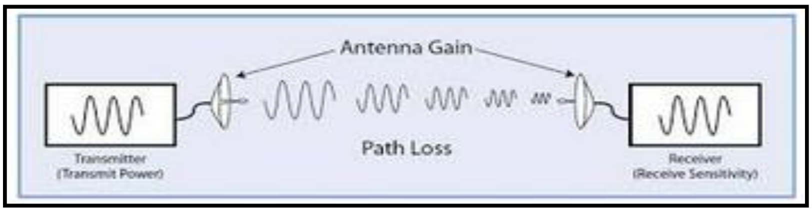


Figure7. The elements in a wireless communication system

As shown in (4) represents *Pr* with regard to the wavelength and the gains of the two antennas. However, this equation expresses the ratio of receiving power to transmit power *Pt* by the relation;

$$\frac{P_r}{P_t} = \frac{\lambda^2 G_t G_r}{16\,\pi^2 r^2} \tag{4}$$

where *r* represents the distance between the antennas in meters, λ is the wavelength in meters, *Gt* depicts the transmitting antenna gain in dBi, the receiving antenna gain in dBi is represented by *Gr*, *Pt* is the power transmitted in Watts, and *Pr* is the power received in Watts.

The above equation are transforms in decibels (dB) for better accuracy:

$$\frac{P_r}{P_t}(dB) = G_t(dBi) + G_r(dBi) - [32.44 + [20\log d] + [20\log f]] \tag{5}$$

where *Gr* is the receiver gain (dBi), *Gt* is the transmitter (AUT) gain (dBi), *d* holds the distance (km) value, *f* represents the frequency (MHz).

As derived from previous equation, the free path loss (*Lfs*) or path loss against the distance between the Tx and Rx which in theory is defined in the Ground Reflection (Two-Ray) propagation model and expressed as below:

$$L_{fs} = 32.44 + [20\log d] + [20\log f] - G_t - G_r + T_{other\,losses} \tag{6}$$

where;

$$L_{fs} = 10\log\left(\frac{P_t}{P_r}\right) \tag{7}$$

The floor, wall, and glass coefficient is the values of $T_{other\ losses}$. Given that losses of *Tglass* = 0.25 dB, *Twall* = 2.2 dB, and *Tfloor* = 13 dB respectively.

Therefore, the *Pr* can be formulated as:

$$P_r = \frac{P_t}{antilog(L_{fs}/10)} \tag{8}$$

To analyze the antenna performance, the *Pr* values between the measurement and theoretical are compared. As an outcome, it is confirmed functionality of the AUT and it is able to perform as a transmitter if the value of *Pr* is satisfactory and roughly comparable to the theory. As shown in Figure 8, the practical measurement was conducted at the corridor of the Antenna Research Group (ARG) laboratory, in Faculty of Electrical Engineering, UiTM Shah Alam. From this experiment the read range distance depending on the power transmit (*Pt*) signal was verified.

The real-world indoor antenna measurement was conducted at the laboratory corridor with the lowest power transmit, *Pt* of 0 dBm or 1 mW, provided to the AUT. The resulting formulas of (4) to (8) were implemented to operate the indoor experiment. In this experiment, there are losses have been deliberated such as the glass, wall and floor coefficient. The mentioned losses are assigned to the following values; *Tglass* = 0.25 dB, *Twall* = 2.2 dB, and *Tfloor* = 13 dB correspondingly [8]. This indoor measurement was in the empty space which is at the laboratory corridor, so that the floor loss (13 dB) is the only factor to be measured. Moreover, the transmit gain (*Gt*) represents the AUT throughout the simulation while the default receive gain (*Gr*) functions as a Horn antenna (Rx) with 10 dBi. Then, the *Pr* is calculated by (8). Next, the theoretical outcomes were related with measurement outcomes at the corridor of Antenna Research Group laboratory.

Figure 8. The real-world indoor measurement situation of the antenna

The power received signal (*Pr*) between the theoretical and measurement outcomes for proposed antennas is compared. The *Pr* values for proposed antenna between the theoretical and measurement are almost the same. Figure 9 shows once the measured distance between Tx and Rx is increased, the *Pr* signal is decreased. Based on the experimental outcomes of this research, the antenna is obviously can function as a transmitter due to the signal is able to be transmitted to the receiver side. However, a minimum distance of 8 m can be covered by the AUT. Moreover, it is proven that the gain value affect the distance. The results evidently demonstrations that the signal transmission ratio is being dropped when there is an obstacle.

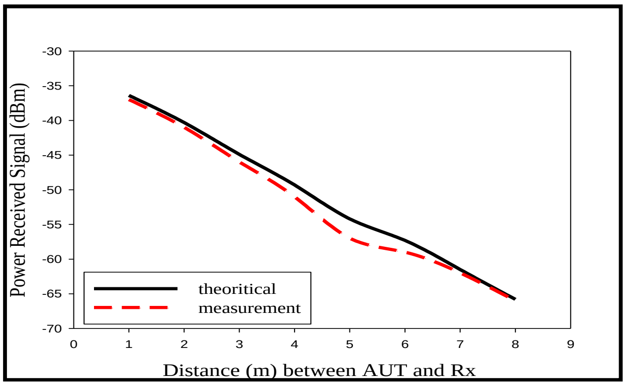


Figure 9. The comparison among theoretical and measurement results of the distance between AUT and Rx at the corridor of antenna research group laboratory

5. CONCLUSION

As a conclusion, a microstrip UHF reader patch antenna for RFID applications is implemented. The suggested antenna comprise of a complementary split ring resonator which the measured result of the antenna illustrated that the reflection coefficient measurement at the 921 MHz showed that the S_{11} magnitude being lower than -10 dB. The measured radiation pattern of antenna showed that the measured result was similar to the simulated results. It is confirmed that the antenna achieves a good agreement with the simulation. This paper gives a promising impact in the area of wireless communication in addition to its potential usage the in UHF RFID system applications, especially in Malaysia.

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