Wideband slotted microstrip patch antenna for UHF-RFID reader

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Abstract. This paper is focused on the development of wideband microstrip patch antenna for Ultra High Frequency (UHF) Radio Frequency Identification (RFID) Reader application. This RFID reader can read information from tags and allow the detection of objects. Usually, the RFID Reader has narrow bandwidth and can be used in certain country only. Therefore, this proposed antenna is designed with wideband frequency, low cost and simple structure which can be used worldwide. The operating frequency range for worldwide operation is between 860 MHz to 960 MHz. The structure of the antenna is composed of a Z-shaped feedline on the upper side of FR-4 substrate and a slotted patch on the lower side. The cutting slot method has been used in this antenna design in order to improve the antenna bandwidth as well as the size of the antenna. This RFID Reader was designed and simulated using CST Microwave Studio. The overall size of the proposed UHF RFID antenna is 100 × 100 × 1.6 mm$^3$. The proposed RFID Reader antenna has the reflection coefficient ($S_{11}$) below than -10 dB and has wideband frequency from 845 MHz to 1.09 GHz in simulation result. The measured and simulated result was compared in order to analyse the performance of the designed antenna. Other antenna parameters such as radiation pattern, bandwidth and gain has also been evaluated and analysed.

1. Introduction
Nowadays, the demand for wireless communication system is increasing rapidly since it can benefit people and ease the daily life activities. Wireless data transfer technology that widely being used in the communication fields are Near Field Communication (NFC), Radio Frequency Identification (RFID), Bluetooth and Infrared [1]. Each of these applications have different working principle and range of operating frequencies. Due to demands in wireless data transfer communication system, RFID becoming more popular for exchange data between tag and reader [2].

Recently, RFID has moved along with the latest technology and has been improved from time to time. RFID is a wireless identification system that use radio frequency (RF) wave to exchange the data [2]. RFID has been widely used in various applications including animal tagging, supply chain management, object and also document tracking. RFID system normally consists of a reader, tag, computer host, communication network and data that process the system [3]. A reader acts as a transceiver which can transmit as well as receive the RF wave [4]. The RFID Reader will read information from tags and allow the detection of objects [5].

RFID has more advantages compared to barcode in terms of accuracy and efficiency. Besides that, RFID Reader can read and detect multiple information at one time [5]. The frequency range between 860 MHz until 960 MHz is the worldwide operating frequency for Ultra High Frequency (UHF) RFID...
Meanwhile, in Malaysia the allocated operating frequency is between 919 MHz until 923 MHz. UHF band usually offer higher data transfer and better reading range as compared to High Frequency (HF) band from (3 MHz to 300 MHz) and Low Frequency (LF) band from (30 kHz to 300 kHz). Usually Low Frequency band is used in animal tracking, while for High Frequency band is used for detection of objects in a closed range up to 1.5 meters. In RFID system, RFID reader antenna plays a vital role in determining the efficiency of the RFID system. High performance of reader antenna will contribute to the high efficiency of the RFID system. There are many designed that has been proposed in recent years for RFID reader antenna such as loop antenna, PIFA antenna and microstrip antenna.

Microstrip patch antenna consists of patch antenna at the front and the ground side. Microstrip patch antenna usually being used because of these advantages such as low fabrication cost, low weight, simple structure and suitable for many applications. However, there are also some limitations including smaller gain and narrow bandwidth. A lot of study has been done by the researchers to overcome these disadvantages for instance by using a substrate with low dielectric constant, increase the thickness of the substrate and also by cutting various slots and notches in the patch geometry. Therefore, in this paper, a microstrip patch antenna with Z-shaped feedline on the upper side of FR-4 substrate and a slotted patch on the lower side has been proposed for universal UHF-RFID reader. The proposed antenna has a wide bandwidth, make it suitable to be used in all countries including Malaysia country.

2. Antenna Geometry and Design
The elements that need to be considered in designing the UHF-RFID reader antenna are the operating frequency and the antenna structures.

2.1. Operating frequency
The frequency range for UHF-RFID system worldwide is from 860 MHz until 960 MHz, while for Malaysia country the frequency range is allocated from 919 MHz until 923 MHz. Therefore, this antenna has been designed with the operating frequency of 921 MHz, which is the centre frequency for Malaysia country. Since the antenna has been designed to be operated worldwide, the minimum bandwidth that the antenna should cover is between 860 MHz until 960 MHz.

2.2. Antenna structure
The design of the proposed UHF-RFID Reader antenna consists of Z-shaped feedline on the upper side of FR-4 substrate and a slotted patch on the lower side as shown in Figure 1 and Figure 2 respectively. The slotted patch and the Z-shaped feedline has been used to increase the bandwidth of the reader antenna. According to [11], the insertion of slots over the patch will increase the patch inductance, thus reduce the Q factor of patch antenna. Since Q factor is inversely proportional to the bandwidth, decreasing the value of Q factor will increase the bandwidth of the patch antenna.

\[
Q = \frac{R}{\omega L}
\]

\[
\text{Bandwidth, } BW = \frac{1}{Q \sqrt{2}}
\]

The proposed reader antenna has been simulated using CST Microwave software. The antenna is using microstrip inset feed method with standard input impedance of 50 Ω. Figure 3 shows the prototype of the proposed antenna using FR-4 substrate. The overall dimension of the proposed reader antenna is 100 × 100 × 1.6 mm³, which is smaller as compared to other reader antenna. The small size of the antenna is also due to the existence of the slotted element on the patch. According to [14-15], when the slots are created on the radiating patch, the length of the current path will increase, thus leading to the increase of the overall capacitance and the resonant frequency will be shifted to the lower frequency. In order to shift back the resonant frequency to the operating frequency, the size of the antenna should be reduced. The parameters and dimension of the proposed UHF-RFID Reader are as listed in Table 1.
Resonant frequency, \( f = \frac{1}{2\pi \sqrt{LC}} \)  \hspace{1cm} (3)

**Figure 1.** Upper side of proposed UHF-RFID Reader antenna

**Figure 2.** Lower side of proposed UHF-RFID Reader antenna

**Figure 3.** Upper side and lower side view of fabricated UHF-RFID antenna with FR-4 substrate

**Table 1.** Parameters of the UHF RFID Reader antenna

| Parameter | Value (mm) | Parameter | Value (mm) |
|-----------|------------|-----------|------------|
| S1        | 100        | L11       | 5          |
| S2        | 100        | L12       | 2          |
| L1        | 25         | W1        | 7          |
| L2        | 40         | W2        | 54         |
| L3        | 58         | W3        | 45         |
| L4        | 15         | W4        | 17         |
| L5        | 0.5        | W5        | 17         |
| L6        | 10         | W6        | 24         |
| L7        | 45         | W7        | 2          |
| L8        | 52         | W8        | 12         |
| L9        | 5          | W9        | 17         |
| L10       | 11         | W10       | 18.5       |
3. Parametric Studies
A parametric study has been carried out in order to obtain optimum performance of the RFID reader antenna. Firstly, the comparison between the conventional patch antenna with the proposed antenna has been done. Figure 4 shows the design of the conventional patch antenna with the rectangular patch on the upper side of FR-4 substrate and full ground plane at the lower side. From the simulation results illustrated in Figure 5, it shows that the conventional patch antenna produces a very narrow bandwidth (20 MHz), which make it applicable for Malaysia country only. In contrast, the proposed reader antenna successfully achieves a wide bandwidth (245 MHz), which has covered the worldwide frequency range from 860 MHz until 960 MHz. The wide bandwidth is achieved due to the introduction of slots on the ground plane and the modification of the radiating patch to Z-shape. Any disturbances to the ground plane may change the current distribution, which leads to the increase of inductance and capacitance value, thus increase the bandwidth as well.

![Figure 4. Upper side and lower side view of conventional patch antenna](image1)

![Figure 5. Return loss results for conventional and proposed antenna](image2)

Other elements that has been analysed are different type of substrate, different length of L2 at the ground plane and different length of W9 at the front side. The substrate that has been used for the analysis of length L2 and W9 is FR-4 substrate, since the antenna using this substrate has been used as a reference in this study. From the parameter change, the effect on bandwidth and return loss has been studied. Only one parameter has been changed at one time and the others are fixed.

3.1. Different type of substrate
Different dielectric constants of the substrate will give different performance to the antenna. A low dielectric constant of substrate will provide better efficiency, larger bandwidth and better radiation. [16-18] Therefore, two substrate materials have been used to design the proposed reader antenna, which are FR-4 and Rogers RT Duroid 5880. The properties of the substrate are listed in Table 2.
Table 2. Properties of different substrate

| Material             | Dielectric Constant, $\varepsilon_r$ | Thickness, h (mm) |
|----------------------|--------------------------------------|------------------|
| FR-4                 | 4.3                                  | 1.6              |
| Rogers RT Duroid 5880| 2.2                                  | 1.6              |

Figure 6 shows the simulation result of antenna return loss with respect to the frequency for FR-4 and Rogers RT Duroid substrate. From the graph it can be seen that the operating frequency for both antennas with different substrates occurred at 921 MHz, but the return loss values are different. From the result, it shows that the Rogers RT Duroid 5880 substrate has smaller return loss as compared to FR-4 substrate with the return loss value of 43.63 dB and 18.95 dB respectively. Other than return loss, it can also be seen that the bandwidth for the antenna with Rogers substrate is wider as compared to FR-4 substrate. This prove that lower dielectric constant will contribute to better antenna performance.

![Figure 6. Return loss value with different substrate.](image)

3.2. Variation of length L2

Figure 7 shows the return loss result with the variation of length L2 from the proposed UHF-RFID reader antenna. Three different lengths that has been simulated are 30 mm, 35 mm and 40 mm. The lengths L2 has been chosen for the parametric study because it gives large effect to the resonant frequency and return loss value with different values of L2. From the results obtained in Figure 7, it shows that when the value of the length is decreased, the bandwidth will be decreased, and the resonant frequency is shifted to the lower frequency. The optimum value for L2 is 40 mm, where the bandwidth obtained is 245 MHz, which is from 845 MHz to 1.09 GHz. The value of bandwidth with respect to the length L2 are documented in Table 3.

![Figure 7. Return loss value with different length L2.](image)
Table 3. Bandwidth value with different length L2

| Length of L2 (mm) | Bandwidth            |
|------------------|----------------------|
| 30               | 799 - 840 MHz (41MHz) |
| 35               | 790 - 900 MHz (110 MHz) |
| 40               | 845 - 1.01 GHz (245 MHz) |

3.3. Variation of width W9

Figure 8 shows the return loss results with the variation of width, W9. Three different widths that have been simulated are 15 mm, 16 mm and 17 mm. The width W9 has been chosen for the parametric study because to see the effects of changing the arms of Z-shaped feedline to the bandwidth. From the results obtained in Figure 8, it shows that the antenna bandwidth will be decreased when the value of the width W9 is decreased. Therefore, it is proven that the Z-shaped feedline will contribute to the wide bandwidth of the antenna. The optimum value for W9 is 17 mm, which results to the bandwidth value up to 245 MHz. Different value of bandwidth with respect to the width W9 is documented in Table 4.

Table 4. Bandwidth value with different length W9

| Width of W9 (mm) | Bandwidth            |
|------------------|----------------------|
| 15               | 853 MHz – 1.01 GHz (157 MHz) |
| 16               | 847 MHz – 1.03 GHz (183 MHz) |
| 17               | 845 MHz – 1.09 GHz (245 MHz) |

4. Result and Discussion

The measurement of S-Parameter, $S_{11}$ was carried out using Vector Network Analyzer (VNA) as shown in Figure 9. Figure 10 shows the measurement setup for antenna radiation pattern in an anechoic chamber. The measured return loss and radiation pattern has been compared with the simulation results. Meanwhile, the antenna power gain has been evaluated from the simulation result only due to some limitation of the equipment.
4.1. S-Parameter, $S_{11}$

The simulated and measured $S_{11}$ results for the proposed reader antenna with FR-4 substrate is shown in Figure 11. The measured resonant frequency is shifted around 6% to the lower frequency from the simulation with the $S_{11}$ value of -39.21 dB at 860 MHz. Meanwhile, the resonant frequency from the simulation is at 921 MHz with the $S_{11}$ value of -18.95 dB. Although the measured result has shifted from the simulated result, it is still in the range of UHF-RFID frequency which is from 860 MHz to 960 MHz [6].

Other than that, the bandwidth of the reader antenna obtained from the measurement result is narrower as compared to the simulation, which is 140 MHz, meanwhile from the simulation is 245 MHz. The deviation of the measured result from the simulated result is due to some inevitable error that occurred while soldering the SMA connector to the antenna port as well as error during fabrication process such as etching.
Figure 11. Simulated and measured return loss value with respect to frequency.

4.2. Antenna gain and radiation pattern
Figure 12 illustrates the radiation pattern of the simulated and measured reader antenna at the operating frequency of 921 MHz. Both results show similar radiation pattern, which are almost omni-directional pattern. Figure 13 shows the 3D radiation pattern for the simulated reader antenna. From the simulation, the antenna has shown relatively high gain, which is 3.325 dB.

Figure 12. (a) Simulated and (b) measured antenna radiation pattern

Figure 13. 3D radiation pattern for simulated UHF RFID Reader antenna.
5. Conclusion
A wideband UHF-RFID reader antenna, which can operate worldwide is proposed, designed and measured. The simple structure of the reader antenna with Z-shaped feedline on the upper side of FR-4 substrate and slotted patch on the lower side result to the wide bandwidth and good performance of the antenna. The overall size of the antenna is $100 \times 100 \times 1.6 \text{ mm}^3$ which is quite small as compared to the existing reader antenna. The small size of the reader antenna is due to existence of the slotted structure on the antenna radiating patch. From the simulation, the antenna resonates at the frequency of 921 MHz with the bandwidth of 245 MHz. Meanwhile, from the measurement the antenna resonates at the frequency of 860 MHz, which is still in the UHF-RFID range with the bandwidth of 140 MHz. The measurement results agree well with the simulation result.

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