Design of Reconfigurable Antenna for RFID System

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Abstract. This paper proposes a reconfigurable antenna for RFID system which can operate between 860MHz to 960MHz frequency that belongs to ultra-high frequency (UHF) band used in Malaysia with the center frequency of 910MHz. One rectangular slot and two triangle-shaped slots are used in designing this antenna. A good circular polarization obtained from the slotted structure along the diagonal axis in the design. RF pin diodes are used as the switching mechanism of the antenna. However, in this work to proof the concept of switching mechanism, copper pins are used as artificial switches. Parasitic elements are deployed on the right and left side of the driven element to assist the radiation pattern reconfiguration. Overall, the proposed antenna able to steer the beam at approximately at -30°, -16°, and 10° with peak gain of 3.2dB and average gain of 2.5dB. With this result, overall coverage of UHF RFID reader antenna could be improved.

Keywords: Antenna and Propagation, Beamforming, Phased array antenna, Reconfigurable antenna

1.Introduction

Since its first application in the 1940’s, Radio Frequency Identification (RFID) has obtained more priority in recent year [1]. RFID equipment can be used in more area of applications due to its versatile technology [2]. Automatic Identification and Data Capture (AIDC) is a fast-moving technology in which it can identify objects, capture and can store objects into the server system [1]. For example, RFID tags can be used as flood warning detector [8]. RFID reader also useful in vehicle identification system [15]. For good tag localization, RFID readers can be used [7]. A microstrip antenna is a most well-known proposal to ultra-high frequency (UHF) RFID reader antennas [3]. To enable suitable RF power delivery, field focusing for energy harvesting applications in RFID tag was carried out [9].
integrated passive UHF RFID-based strain sensor platform also was developed for body movement-based controlling [10]. With RFID technology, 3D location system based on attitude estimation was done [11]. A concept of using sensor integrated RFID tag for wearable human body temperature measurement was reported in a research paper [13]. RFID tags were found to be useful in health monitoring systems too [14]. There are four bands in RFID which are low frequency, high frequency, ultrahigh frequency and microwave [4]. This work reports the design of reconfigurable antenna for RFID system to achieve the circular polarization. A reconfigurable antenna has the ability to change its operating parameters such as frequency, radiation pattern and so on. Reconfigurable antenna has to be integrated with RF switches and its reconfiguration capability is used to enhance the antenna performance. RFID system in the UHF bands is a fast-developing technology and used in many applications such as warehouse management, logistics tracking and industrial production [4]. For UHF RFID system, it requires variety of frequency ranges depends upon the standards needed all over the world [2]. Each country in this world has a specific operating bandwidth. For example, in Malaysia, the operating bandwidth is between 860MHz to 960MHz. Microstrip antenna is a popular approach to UHF RFID reader antennas with antenna patch, ground plane and substrate. Basically, in RFID system the gain of the antenna plays a vital role in read range distance [3]. The higher the gain is, the higher the read range distance of the antenna. In this project, the reconfigurable antenna for RFID reader will be developed using one rectangular slot and two triangular-shaped slots in order to achieve circular polarization. The proposed design operates at 860MHz-960MHz frequency range. The efficiency of the antenna might be sacrificed to have a trade-off between the antenna size and gain. RF pin diodes will be used as the switching mechanism of the antenna. The theoretical stimulations are conducted by means of CST platform.

2. Design and Analysis

The reconfigurable array antenna proposed in this work uses parasitic array concept [5]. A three-element reconfigurable antenna thus consists of one driven element and two parasitic elements. First, unidirectional driven element is designed according to work [6] and the design stages involved is presented in Figure 1. Figure 2 shows the three-element array antenna that is created with left and right parasitic elements. The antenna is designed using FR4 substrate with a relative permittivity of 4.4 and a height of 1.6 mm. The antenna layout is shown in Figure 2. The related parameters are tabulated in Table I. The coaxial probe is located at 17 mm from centre of the driven element. The parasitic elements are slightly smaller than the driven element. The size could be varied about 95-98% of the driven element size. The right and left function as director and/or reflector, thus the radiation will change moving right and left from center. The mutual coupling exist when the parasitic elements are placed nearby the driven element. This phenomena could help to change the radiation pattern of the antenna. Adding the rectangular and triangular slots will help in enhancing the impedance bandwidth and to achieve the circular polarization.

To investigate and perform the radiation pattern, shorting pins are placed in both right and left parasitic elements. SW1 and SW2 are the artificial switches (pin diodes) used to proof the concept. Figure 3 shows the three-element array antenna with shorting pins. In future work, this can be replaced with touch stone block that contains the S-parameter information of the RF switch at ON and OFF condition. At ON state, the switches adopts copper as the material of the shorting pin. On the other hand, the material changed to vacuum at OFF state. When the switch is ON, it connected to ground, thus the parasitic will act like reflector. While at OFF state, the parasitic is disconnected from the ground plane, hence acts as a director. This reconfiguration will help to perform the radiation pattern reconfiguration. The parasitic elements will act as reflector and director depends on the states of the switches.
Figure 1. Design stages involved in UHF circular polarization antenna (a) Creating the rectangular slot at rotation of 45° from Z-axis (b) Next step is to create the 1st triangular slot at the coordinate of (20.8, 20.8). (c) Then, the 2nd triangular slot at coordinate of Cb (-19.3, -20.3) was created.

Figure 2. Three-element array antenna
3. Result and Discussion

In this section, the results obtained from the simulation of the design were analysed. The simulation results were compared with and without use of slots. The use of the rectangular and triangular slots is to obtain the circular polarization. For the realization of circular polarization, the use of asymmetrical triangular slots is useful. Figure 4 shows the single directional antenna results with and without usage of the slots. Without the use of rectangular and triangular slots, the resonance frequency obtained after the simulation of the proposed antenna was 930MHz. From the graph, it can be seen that the result has a low bandwidth. With the use of the rectangular slot and two asymmetrical triangular slots in the design, it can be seen that the impedance bandwidth has increased at resonance frequency of 905MHz. This shows that use of slots in the design would help in getting greater impedance bandwidth and circular polarization.

Figure 5 shows the simulation result for single directional antenna with the use of slots. From figure 4, can be summarize that, for single directional antenna with just the usage of slots, the gain obtained is negative with highest tilt angle of one degree. As there is no reconfiguration of pin diodes, the tilt angle obtained is less as the antenna cannot steer to a certain beam. Figure 6 shows the axial ratio results for different angles of the rectangular slot. It is found that with the angle of T=0, good axial result, < 3dB is achieved.

Table 1. Dimensions of the Proposed MTM Unit Cell

| Parameter | Values |
|-----------|--------|
| Wg        | 80mm   |
| Lg        | 260mm  |
| Ws        | 7.6mm  |
| Ls        | 19mm   |
| Wp        | 76mm   |
| Lp        | 76mm   |
| a         | 25.4mm |
| b         | 12.8mm |
Figure 4. Single Directional Antenna Results

Figure 5. Simulation result for variation of frequency for single directional antenna with the use of slots.
The results of array antenna are based on its switching configuration. The switch operation is analysed with the $S_{11}$, axial ratio, tilt angle and gain results. With the aid of the reflector and director (pushing and pulling effect), the radiation pattern is tilted towards the director, or opposite to the reflector. The parasitic elements will act as reflector and director depends on the states of the switches. The simulation is carried out to determine the beam tilt produced by the configuration of the switches. Table 2 shows the four switching configurations used in this work.

![Figure 6. The permittivity ($\varepsilon$) values for different unit cell arrays.](image)

**Table 2. Switches state**

| Switch 1 | Switch 2 |
|----------|----------|
| ON       | ON       |
| OFF      | OFF      |
| OFF      | ON       |
| ON       | OFF      |

**A. Condition 1: Switch 1 ‘ON’ and Switch 2 ‘ON’ state**

Figure 7 shows the $S_{11}$ results when different gaps were used. As the gap between the patches increase, the $s11$ value is greater than -10 dB. When the gap is set at 4 mm, the $S_{11}$ obtained was -73 dB at 894MHz. The both switches considered to be in ‘ON’ state when the material used is copper for both of the switches. Figure 6 shows some parametric analysis carried out to see the effect on S11 result.
Figure 7. $S_{11}$ results for switches in (ON,ON) states for different gaps.

Figure 8. Comparison of simulation result at different frequencies for both switches in ‘ON’ state

Figure 8 shows the comparison of simulation result at different frequencies for both switches in ‘ON’ state. From result, it can be seen that the antenna can be steered to certain beam which are to 8 degree, 14 degree and 16 degree when both switches in ‘ON’ state. The highest tilt angle is achieved at 16 degrees at 890MHz and at 895MHz. The highest gain achieved is at 895Mhz which is 3.17 dB with 16 degree of tilt angle.

B. Condition 2: Switch 1 ‘OFF’ and Switch 2 ‘OFF’ state

Figure 9 shows the $S_{11}$ results for different values of gaps when both switches are in ‘OFF’ state. When gap is set to 4 , the $S_{11}$ obtained was -9 dB at 908 MHz. Figure 10 shows the comparison of radiation
pattern at different frequencies for both switches in ‘OFF’ state. It can be seen that the tilt angle is less as the both switches are in ‘OFF’ state. The highest tilt angle achieved is 3 degree at 880MHz with the highest gain of 1.38 dB. The gain obtained for this state is less than the gain obtained when both switches are in ‘ON’ state. During the both switches in ‘OFF’ state, the antenna is not able to steer and the tilt angle is lesser.

![Figure 9. $S_{11}$ results for switches in (OFF,OFF) state](image)

![Figure 10. Comparison of simulated radiation pattern result at different frequencies for both switches in ‘OFF’ state.](image)

**C. Condition 3: Switch 1 ‘OFF’ and Switch 2 ‘ON’ state**

Figure 11 shows that, at this condition, $S_{11}$ result is good where the $S_{11}$ bandwidth is from 892MHz to 918MHz at <-10 dB. Figure 12 shows respective radiation pattern result under this switching condition.
When switch 1 is in ‘OFF’ and switch 2 is in ‘ON’ state, the radiation pattern will be more concentrated on the right side. It can be summarized that the antenna able to steer a maximum of 10 degrees at 880MHz with the highest gain of 2.11 dB.
D. Condition 4: Switch 1 ‘ON’ and Switch 2 ‘OFF’ state

Figure 13 shows the $S_{11}$ results when switch 1 is in ‘ON’ state and switch 2 is in ‘OFF’ state. Figure 14 shows the comparison of radiation pattern result for switches in (ON,OFF) state.

![Figure 13](image1)

**Figure 13.** $S_{11}$ results when switch 1 is in ‘ON’ state and switch 2 is in ‘OFF’ state.

When switch 1 is in ON state and switch 2 is in OFF state, the radiation pattern will be more concentrated on the left side. It can be seen that the antenna able to steer a maximum of 30 degrees at 880MHz. The highest gain achieved at 890 MHz which is 2.65 dB.

![Figure 14](image2)

**Figure 14.** Comparison of simulation result for switches in (ON,OFF) state.

4. Conclusion

The project purpose is to design a reconfigurable antenna for RFID system. Adopting the use of the rectangular slot and two asymmetrical triangular slots in the design, it can be seen that the impedance bandwidth has increased at resonance frequency of 905MHz, with comparable axial ratio result. Then, three-element array antenna is designed with left and right parasitic elements. To investigate the
radiation pattern in simulation, shorting pins working as artificial switches are placed in both right and left parasitic elements. Overall, the proposed antenna able to steer the beam at approximately at \(-30^\circ\), \(-16^\circ\) and \(+10^\circ\) with peak gain of 3.2 dB and average gain of 2.5 dB. The usable switching conditions to achieve the steering angles are ON, ON; ON, OFF and OFF, ON. The circular polarization could be achieved with a single directional antenna but this characteristic could be retained in the radiation pattern reconfigurable antenna. This could be future challenge of the proposed work.

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