Rectangular Microstrip Patch Antenna at 5.8 GHz for RFID Reader Applications with High Directivity and Gain

C. Ruptanu (260673074)
ruptanu.chowdhury@mail.mcgill.ca

M. Rizvi (260508974)
murtaza.rizvi@mail.mcgill.ca

I. INTRODUCTION

Radio Frequency Identification Technology is part of the electronic identification which is based on radiofrequency connections, allowing identification without any physical contact. This technology can identify an object equipped with a tag capable of transmitting data using radio waves at a long distance[1]. Thus in this paper, it depicts a detailed design of a 5.8 GHz two elements rectangular Microstrip Patch Antenna for use in the RFID Reader applications[1].

Four frequency bands are mainly used by Radio Frequency Identification Technology Devices (RFID), ranging from low frequencies of 125 kHz to microwave frequencies of 5.8 GHz. Each frequency band, whose characteristics give the RFID devices unique properties in terms of reading distance, or propagation of waves in a particular medium, i.e. water, metal, etc. corresponds to specific applications[2]. RFID has two primary components, transponder, and reader.

A. How RFID Works

RFID uses radio waves for identification and collecting data with little or no human supervision. In simple, RFID system consists of three parts: tag, reader and antenna. RFID tags contain an integrated circuit and an antenna, which are used to transmit data to the RFID reader. The reader then converts the radio waves to a more usable form of data. Information collected from the tags is then transferred through a communications interface to a host computer system, where the data can be stored in a database and analyzed. The communication between the two components of the RFID system is generally done by a predefined communication protocol[3][4]. The RFID system assembly depends on the performance of the antenna like return loss, gain, directivity, and bandwidth.

B. Goal of the Project

This paper compares the simulation results of a single patch antenna with a 2×1 array patch antenna in terms of gain, directivity, return loss, radiation pattern and adaptation. Thus the main goal of this project was to design a 2×1 array patch antenna of rectangular shape, with high radiation performances, to identify objects or living things in motion that are at further distances from RFID readers.

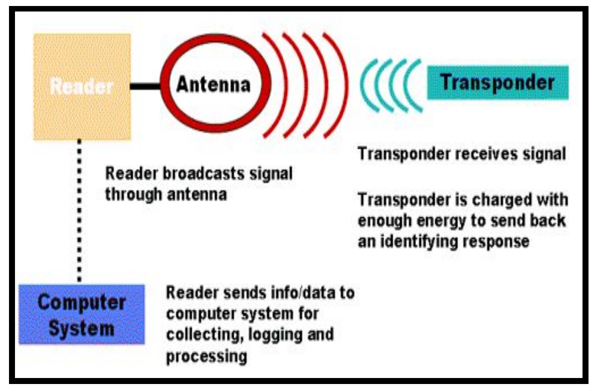

FIG. 1. PRINCIPLE OF AN RFID SYSTEM OPERATION

II. ANTENNA DESIGN

Microstrip antennas are considered in the field of RFID because of its low profile, lightweight, the small size of the structure and also a low cost of production. It's designed by two conductors radiating element and ground plane mounted in parallel and separated by a substrate with an ideal range of permittivity value of $2.2<\varepsilon_r<12$, which has a ground plane on the other side[6]. Hence below are the parameters for Single patch antenna and 2×1 array antenna.

SINGLE PATCH ANTENNA DESIGN

A. Length and Width of Substrate

For the substrate, we have used RT/Duroid-5880 with a dielectric constant of 2.2 and a loss tangent of 9×10^{-4}. Also, the thickness was accounted for as $1.56\ mm$ which was fed by 50 microstrip line. We have used the dimension of $L_{sub1} = 25.54\ mm$ and $W_{sub1} = 29.44\ mm$.

B. Length and Width of Patch

For the design of an antenna patch, the width and length were calculated using (1) [6][7].

$$W_p = \frac{c}{2*f_r} * \sqrt{\frac{2}{\varepsilon_r+1}} \tag{1}$$

Where c = velocity of light in free space
W_p = width of microstrip patch
ε_r = Dielectric constant of the substrate
f_r = operating frequency

Thus using equation (1) the width of the simple antenna patch used for simulation is $W_p = 20.44\ mm$.

In order to find effective permittivity ε_{reff}, we used (2)

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2\sqrt{1+\frac{12h}{W_p}}} \tag{2}$$

Patch length was calculated using equations (3)-(5).

$$L_{eff} = \frac{c}{2*f_r*\sqrt{\varepsilon_{riff}}} \tag{3}$$

$$\Delta L = 0.412 * h * \frac{(\varepsilon_{reff}+0.3)(\frac{W_p}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{W_p}{h}+0.8)} \tag{4}$$

$$L_p = L_{eff} - 2 * \Delta L \tag{5}$$

Thus the result is $L_p = 16.54\ mm$.

C. Feed Line Width

The physical size of the antenna derived from the microstrip transmission line, the microstrip antenna is modeled as a length of transmission line of characteristics[10][11] impedance given by (6) and (7).

$$Z_0 = \frac{60}{\sqrt{\varepsilon_{reff}}} * ln[\frac{8h}{W_f} + \frac{W_f}{4h}] \quad if\ \frac{W_p}{h}<1 \tag{6}$$

$$Z_0 = \frac{120\pi}{\sqrt{\varepsilon_{reff}}*[\frac{W_f}{h}+1.393+0.667*ln(\frac{W_f}{h}+1.444)]} \quad if\ \frac{W_p}{h}>1 \tag{7}$$

Where Z_0 is the characteristic impedance of the inserted microstrip line, and h is the substrate thickness of $1.56\ mm$. Thus for the single antenna, we used $W_f = 4\ mm$.

D. Feed Line Depth

The depth of the feed line, $Y_0 = 5\ mm$ was calculated using (8) [8].

$$Y_0 = \frac{L_p}{2*\sqrt{\varepsilon_{reff}}} \tag{8}$$

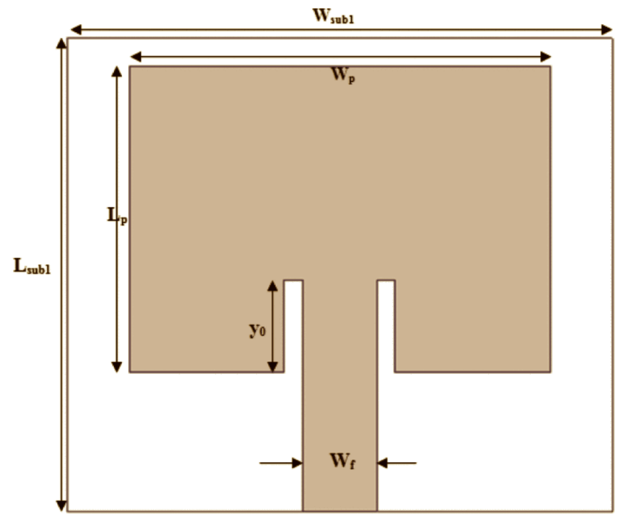

FIG. 2. GEOMETRY OF THE PROPOSED ANTENNA.

Variables	Values (mm)
L_{sub1} (simple antenna)	25.54
W_{sub1} (simple antenna)	29.44
L_p	16.54
W_p	20.44
W_f	4
Y_o	5

TABLE I. DIMENSION OF SINGLE ELEMENT ANTENNA

2×1 ARRAY ANTENNA DESIGN

It is important to design an antenna with high radiation performances (gain, directivity) and to achieve the long distance communication requirements, For the 2×1 array antenna, all the dimension as mentioned before for single patch antenna was used. Only the following changes where made.

A. Length and Width of Substrate

Just as the single antenna, we have used the same substrate but modified the dimension as $L_{sub2} = 38.47\ mm$ and $W_{sub2} = 59.44\ mm$.

B. Feed Width

For the 2×1 array antenna for the second patch width, we used $W_2 = 3.23\ mm$.

C. Feed Line Network

In order to compose the antenna both the element were identical and for exciting the proposed antenna a power divider was used. Thus the feed line parameter was maintained at $Z_1 = 50\Omega$ for the initial feed line which splits into two ones with impedance $Z_1 = 100\Omega$.

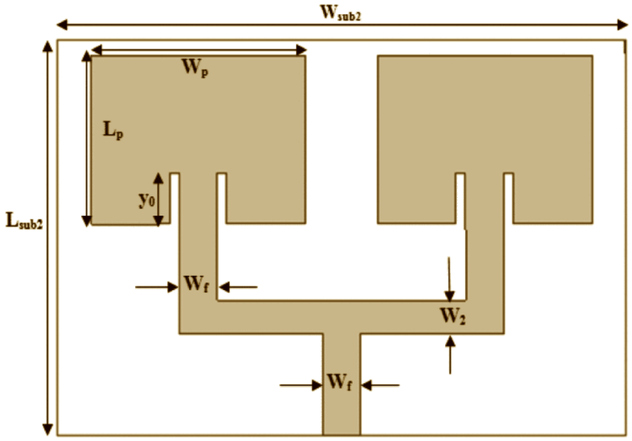

FIG. 3. GEOMETRY OF 2×1 ARRAY ANTENNA

Variables	Values (mm)
L_{sub2} (2×1 array antenna)	38.77
W_{sub2} (2×1 array antenna)	59.44
W_f	4
W_2	3.23

TABLE II. DIMENSION OF 2×1 ARRAY STRUCTURE

III. SOFTWARE

For the simulation, we have used ANSYS High-Frequency Structure Simulator (HFSS)[12]. The student version of the software, fulfilled our requirements to see certain parameters such as radiation pattern, input impedance, and loss[11]. Thus helping us to get to a conclusion to support the idea presented in the paper.

IV. SIMULATION RESULT AND DISCUSSION

We used ANSYS HFSS to design and perform a comparative simulation for both the simple antenna and a 2×1 array patch antenna at 5.8 GHz resonant frequency. Return loss, Voltage Standing Wave Ratio (VSWR), Input Impedance, Radiation Patterns, Gain and Directivity were some of the factors taken into consideration while conducting the performance analysis.

A. Return Loss

Return loss is a measure of loss of power in the reflected signal after the device is connected to a transmission line or optical fiber[10]. This loss can occur by a discontinuity in the line resulting from an impedance mismatch. Return loss is expressed as:

$$R_L(dB) = 10\ log_{10} \frac{P_i}{P_r} \tag{9}$$

A comparison of the simulated results of return loss for both the simple antenna and 2×1 array patch antenna is shown in Fig. 4. The value of return loss is found to be -30.58 dB for the simple antenna -40.11 dB for the 2×1 array antenna. The proposed design of the 2×1 array antenna reduces the return loss by 9.53 dB as compared to the simple antenna design.

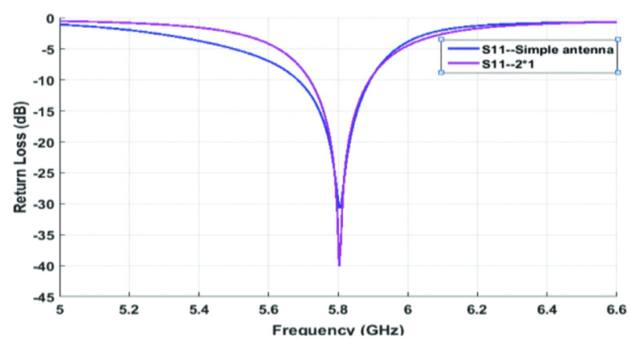

FIG. 4. RETURN LOSS VS FREQUENCY

B. Voltage Standing Wave Ratio

VSWR is the ratio of the maximum to minimum voltage along the transmission line. It is expressed as a function of the reflection coefficient Γ, which describes the power reflected from the antenna. VSWR is expressed as:

$$VSWR = \frac{1+|\Gamma|}{1-|\Gamma|} \tag{10}$$

The VSWR is always a real and positive number for antennas. The smaller the VSWR is, the better the antenna is matched to the transmission line and the more power is delivered to the antenna. The minimum VSWR is 1.0. In this case, no power is reflected from the antenna, which is ideal. Often the adaptation quality of an antenna is defined by its VSWR at the resonance frequency, and an antenna is considered to be well adapted if its VSWR is less than 2[9]. Fig. 5. shows the VSWR variance for the two designs.

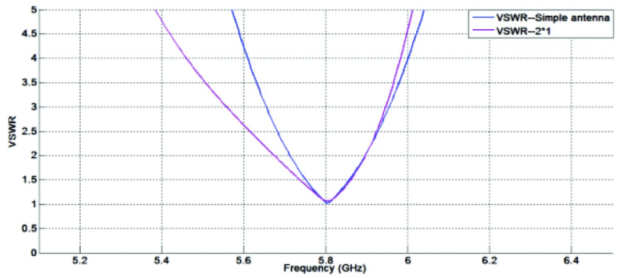

FIG. 5. VSWR PATTERN VS FREQUENCY

For the simple antenna, we found VSWR = 1.01 at 5.8GHz, and for the 2×1 array antenna, we found VSWR = 1.06 at 5.8GHz. It is impressive that the value of VSWR over the specified frequency range is less than 2 for both antennas, therefore, proving that each of the proposed designs is well adapted to its transmission line.

C. Input Impedance

In the addition of the VSWR, the input impedance is considered as an important parameter to study the antenna adaptation. Impedance relates the voltage and current at the input to the antenna. The real part of the antenna impedance represents the power that is either radiated away or absorbed within the antenna. The imaginary part of the impedance represents the power that is stored in the near field of the antenna, and it is the non-radiated power. An antenna is said to be resonant if its input impedance is only real with zero imaginary part[11].

Generally, the transmission line transforms the impedance of an antenna, making it very difficult to deliver power, unless the antenna is matched to the transmission line. Fig. 6. shows the values obtained of input impedance for the simple antenna and the 2×1 array antenna. It can be seen that at the resonance frequency of 5.8 GHz, $Z_{in} = 49.44 - j0.8\ \Omega$ for the simple antenna and $Z_{in} = 50.68 - j1.43\ \Omega$ for the 2×1 array antenna. These results depict reasonably acceptable impedance matching and confirm that both antennas are well adapted for 50Ω impedance.

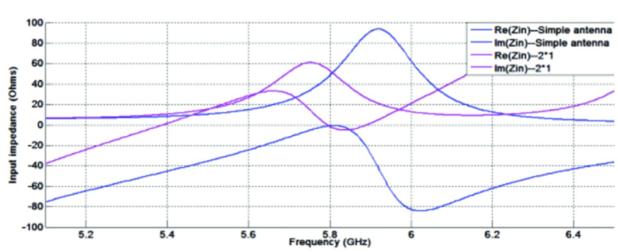

FIG. 6. INPUT IMPEDANCE PATTERN

D. Radiation Pattern

The radiation pattern of a microstrip patch antenna is the power radiated or received by the antenna, and it is another characteristic which helps determine antenna behavior[10]. It is the function of angular position and radial distribution from the antenna. The radiation pattern in both, the E-plane $\phi = 0°$, and H-plane $\phi = 90°$, for the simple antenna and the 2×1 array antenna, is shown in Fig. 7. and Fig. 8. respectively.

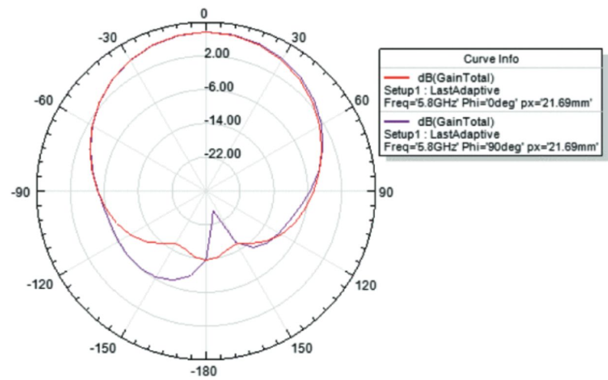

FIG. 7. THE RADIATION PATTERN OF A SIMPLE ANTENNA

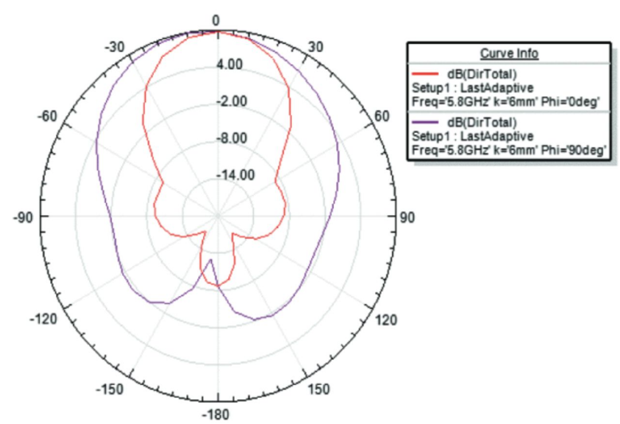

FIG. 8. THE RADIATION PATTERN OF A 2×1 ARRAY ANTENNA

Fig. 7. and Fig. 8. show that at 5.8 GHz operating frequency, the simple antenna offers a directional radiation pattern with a maximum gain of 7.67 dB and the 2×1 array antenna offers a directional radiation pattern with a maximum gain of 9.88 dB. A comparison of the two radiation patterns concludes that the 2×1 array antenna produces more intensity in the center of the radiation pattern than the simple antenna.

E. Gain

The gain of the antenna is the quantity which describes the performance of the antenna or the capability to concentrate energy through a direction to give a better picture of the radiation performance[10]. This is expressed in dB and can simply be referred to as the direction of the maximum radiation. A comparison between the gain of the simple antenna and the 2×1 array antenna is presented in Fig. 9.

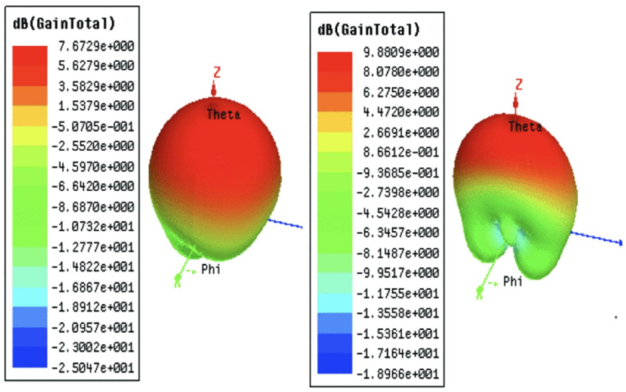

FIG. 9. GAIN PATTERN OF ANTENNAS

The simulation results show that for the simple antenna, the maximum possible achievable gain is 7.67dB and for the 2×1 array antenna, the maximum possible achievable gain is 9.88 dB. The results confirm that the 2×1 array antenna has higher gain.

F. Directivity

The directivity of an antenna quantifies how much it concentrates energy in one direction in preference to radiation in other directions. Increased directivity implies a more focused or directional antenna[12]. A comparison between the directivity of the simple antenna and the 2×1 array antenna is presented in Fig. 10.

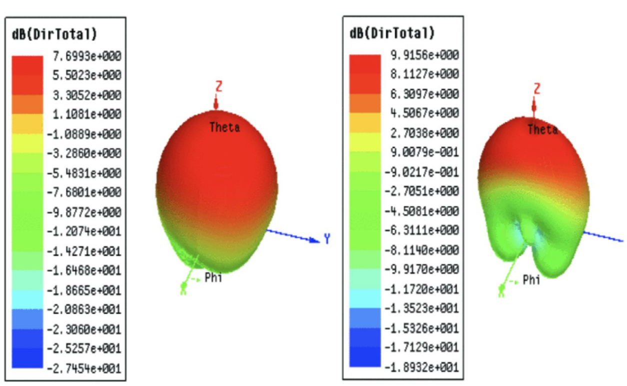

FIG. 10. DIRECTIVITY PATTERN OF ANTENNAS

It can be seen from the simulation results that the directivity for the simple antenna and the 2×1 array antenna is 7.69 dB and 9.91 dB respectively. Similar to the gain, these results also show that using two elements has increased the antenna directivity as compared to using the simple element.

Our proposed array antenna design provides significant advantages over the two antennas we used as a reference. The following table presents the advantages of our proposed array antenna comparing to others in the literature. Our proposed array antenna is miniaturized and represents a significant gain and a good adaptation.

Our proposed 2×1 array antenna provides a significantly greater gain, better adaptation quality, and reduced size. These results are presented in Table III.

Antenna	**Return Loss** (dB)	**Gain** (dB)	**Size** (mm^2)
Proposed antenna	-40.11	9.88	38.7×59.4
Reference antenna [9]	-31.42	6.51	105×165.5
Reference antenna [10]	———	5.05	63×68

TABLE III. COMPARISON WITH OTHER ANTENNAS

V. CONCLUSION

The comparative simulation results between a simple microstrip patch antenna and a 2×1 array microstrip patch antenna, at 5.8 GHz resonant frequency were analyzed in this paper using ANSYS HFSS. Our results showed that a 2×1 array antenna provides better gain and directivity, and a smaller return loss. Our simulations confirm that increasing the number of patches improves radiation performance and helps obtain a more directive beam. However, to avoid mutual coupling, special consideration must be given when choosing the position of patches in an array antenna.

VI. REFERENCES

[1] S. B. Miles, S. E. SARMA and J. R. Williams, "RFID Technology and Applications," Cambridge University Press, 2008.

[2] D. Paret, "RFID at ultra and super high frequencies: theory and application," Wiley and sons, 2009

[3] Hafid TIZIYI, Fatima RIOUCH, Abdelwahed TRIBAK, Abdellah NAJID, "Compact Dual-band Microstrip Antenna for Handheld RFID Reader", International workshop on RFID and adaptive Wireless Sensor Networks, 2015.

[4] Du Yongxing, Bai Wenhao "The Design of High Gain and Miniaturization Microstrip Antenna Array for RFID Reader", Inner Mongolia University of science and technology, College of Information Engineering, Baotou, China, IEEE 2015.

[5] C. Varadhan, J. K. Pakkathillam, M. Kanagasabai, R. Sivasamy, R. Natarajan and S. K. Palaniswamy, "Triband Antenna Structures for RFID Systems Deploying Fractal Geometry", IEEE Antennas and Wireless Propagation Letters, Vol. 12,2013, pp. 437-440.

[6] O. Ouazzani, S. D. Bennani, M. Jorio "Design and Simulation of 2*1 and 4*1 Array Antenna for Detection System of Objects or Living Things in motion", International Conference on Wireless Technologies, Embedded and Intelligent Systems, WITS-2017.

[7] C. A. Balanis, "Antenna Theory: Analysis and Design", 3rd edition, John Wiley & Sons, 2013.

[8] Yassine Gmih, Younes El Hachimi, El Mostafa Makroum, Abdelmajid Farchi, "Design of a Miniaturized Patch Antenna with Reverse U- Shaped Slots for 2.45/5.8 GHz RFID Applications", International Journal of Engineering Research & Technology (IJERT), Vol. 5 Issue 11, November-2016.

[9] Bhushan Bhimrao Dhengale and Deepak C. Karia," A 5.8 GHz ISM band microstrip antenna for RFID application" International Conference on Nascent Technologies in the Engineering Field (ICNTE-2015) pp.1- 4, Jan.2015.

[10] Veeramani. A, Vijayakrishnan. J, Afsane Saee Arezomand, Ferdos B. Zarrabi, " Compact S-shaped EBG Structures for Reduction of mutual coupling", International Conference on Advanced Computing & Communication Technologies, 2015.

[10] C. Balanis, Antenna Theory; Analysis and Design, 3thd edition, Wiley and Sons, New York, 2006.

[11] David M. Pozar "Microwave Engineering", John Wiley & Sons, Inc. Third Edition, 2005.

[12] www.ansys.com/products/electronics/ansys-hfss