Design and Analysis of a RFID Reader Microstrip Array Antenna for IoT Applications in Smart Cities

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ABSTRACT

This paper presents the design of 2*1 and 4*1 RFID reader microstrip array antenna at 2.4GHz for the internet of things (IoT) networks which are Zigbee, Bluetooth, and WIFI. The proposed antenna is composed of identical circular shapes radiating patches printed in FR4 substrate. The dielectric constant εr and substrate thickness h are 4.4 and 1.6mm, respectively. The 2*1 and 4*1 array antennas present a gain improvement of 27.3% and 61.9%, respectively. The single, 2*1, and 4*1 array antennas were performed with CADFEKO.

KEYWORDS

Gain, IoT, Microstrip Array Antenna, Radiation Pattern, RFID

INTRODUCTION

Over the past few years, the IoT is a paradigm that uses information and communication technologies to make the interconnection of all objects in various domains such as healthcare, urban infrastructure, transportation, and energy. The IoT makes a large contribution in developing smart cities, most smart city applications use IoT devices equipped with sensors, actuators, and a limited computing capability (Fahmy et al., 2019; Khardioui et al., 2020; Varum et al., 2018).

To monitor physical objects while they are steady or on the move in smart city application, the Internet of Things employs various technologies to create a communication network between all this object such as radio-frequency identification (RFID) and near-field communication (NFC) (Khardioui et al., 2020).

The RFID is a smart technology that uses radio waves to monitor, identify, and follow objects. The RFID system contains a reader and a tag, which communicate between them by the air. The antenna is an important component of RFID systems. The RFID system depends on its performances such as gain and bandwidth(A.El Alami et al., 2019; Ali El Alami et al., 2005; Chen & Qing, 2010; Ikram et al., 2017; Ouazzani et al., 2017).

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Recently various Research Projects microstrip antenna for IoT applications have been published, in (K. A. Nate et al., 2015)aperture coupling-fed antenna designed to be used in wireless sensors for IoT. A stretchable, flexible loop antenna operating at 2.4GHz ISM band, as a wearable solution for health and IoT applications is presented in (K. Nate & Tentzeris, 2015). A dual-band microstrip antenna is presented in(Katoch et al., 2015) for IoT applications. In (Dong et al., 2017)a compact and novel printed antenna based on a folded strip is designed for 2.4 GHz WLAN applications with extended bandwidth. A microstrip patch antenna array for IoT applications is presented in (Giay & Alam, 2018). In Microstrip Antenna for IoT/WLAN applications in Smart Homes at 17GHz(Varum et al., 2018). However, all these research results present a low gain.

The aim of this work is to design a circular2*1 and 4*1 array antennas for RFID reader which operates at 2.4GHz, which will be used for IoT applications. The development of this array antenna improves the gain of the antenna.

In the first section, a single circular patch antenna was performed by CADFEKO, in the following sections, two and four elements of patch array antennas are studied and performed.

SINGLE MICROSTRIP CIRCULAR PATCH ANTENNA DESIGN

The proposed microstrip antenna has a circular shape that operates at 2.4GHz. It is etched on one side of a standard FR4 dielectric substrate. The substrate material has a compact dimension of $W_s \times L_s \times h$. A 50 Ω microstrip line with an inset of y0 is used to excite the radiating circular patch. The radius of the circular microstrip patch was calculated by (1) (Balanis, 2005):

$$a = \frac{F}{\sqrt{1 + \frac{2h}{\pi.\varepsilon_r.F}[\ln(\frac{\pi.F}{2h}) + 1.7726]}} \tag{1}$$

Where:

$$F = \frac{8.791 \times 10^9}{f_r.\sqrt{\varepsilon_r}}$$

ε_r: dielectric constant of the substrate.

f_r: the resonance frequency

By applying the previous equation and after optimization with CADFEKO, the radius of the circular patch antenna with a resonant frequency of 2.4GHz is a= 17.3mm.

Figure 1 presents the designed basic patch antenna structure and table.1 illustrates the dimensions of the patch antenna.

The simulation results obtained by CADFEKO solver for the designed circular microstrip patch antenna in terms of reflection coefficient S11, input impedance, far-fields E-plane, H-plane and 3D radiation patterns at 2.4GHz are shown respectively in Figures 2, 3,4and 5.

The simulation result found by CADFEKO of the designed patch antenna is shown in figure 2. it provides the resonant frequency at 2.4GHz with a reflection coefficient of −19.87dB. The simulated impedance bandwidth is about 30MHz (2.39–2.42 GHz).

Figure 3 illustrates the simulated input impedance of the designed patch antenna versus frequency. At 2.4GHz Z=51+j2Ω, this result confirmed that the designed antenna is well adapted. The simulated results E and H planes radiation patterns are presented in figure 4. It is shown from the figure that

Figure 1. geometry of the designed basic antenna

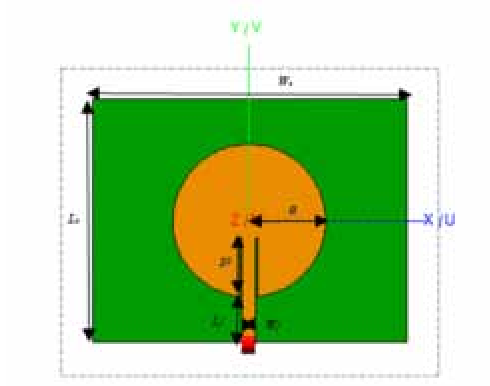


Table 1. Parameters of the designed basic antenna

Parameters	*Dimensions(mm)*
W_s	*71*
L_s	*55*
a	*17.3*
L_f	*10.15*
W_f	*3*
y_0	*13.5*

Figure 2. Simulated reflection coefficient S_{11} versus frequency

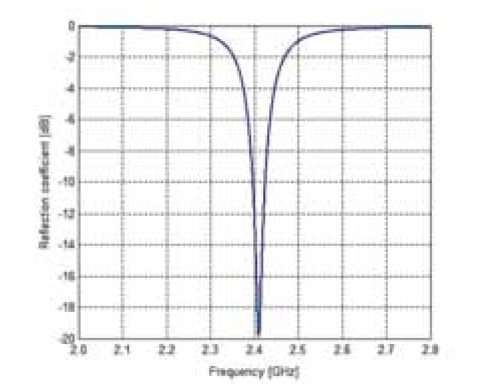


Figure 3. Simulated real and imaginary impedance versus frequency;

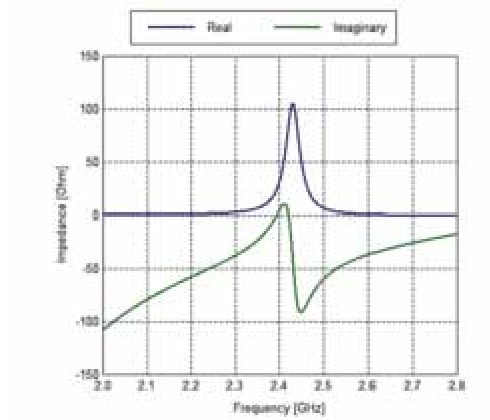


Figure 4. Simulated E and H planes of the designed patch antenna at 2.40 GHz

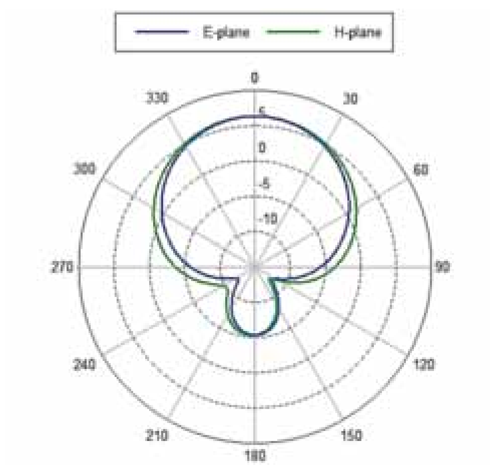
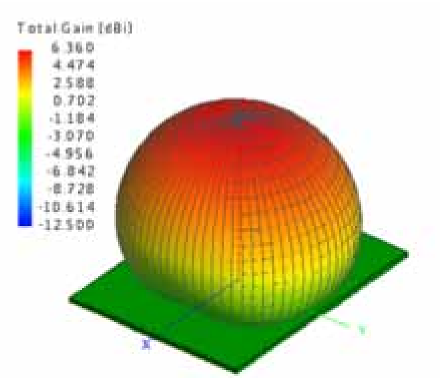


Figure 5. 3D radiation pattern of the designed patch antenna at 2.4 GHz



the E-plane and H-plane radiation patterns are directional at 2.4 GHz. The 3D radiation pattern is given in figure 5with a maximum gain of 6.36dB.

CIRCULAR MICROSTRIP PATCH ARRAY ANTENNA DESIGN

Design And Analysis Of A 2*1 Array

The proposed array antenna structure 2x1 is depicted in figure 6. Each circular radiating patch has the same radius as used above in order to increase the antenna performances.

Figure 6. geometry of the designed 2*1 array antenna

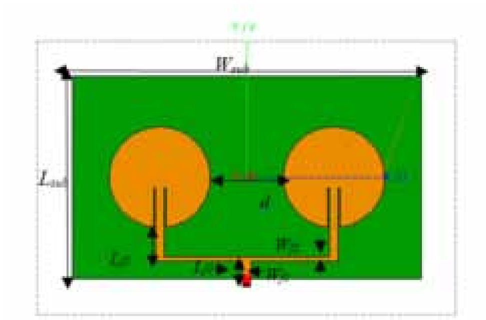


Table 2. Parameters of the designed 2*1 array antenna

Parameters	*Dimensions(mm)*
W_{sub}	*119.2*
L_{sub}	*55*
d	*25*
L_{f1}	*5.8*
W_{f1}	*3*
W_{f2}	*1.6*
Lf_2	*11.5*

The proposed array is printed in FR4 substrate with a thickness h. The distance separated the circular radiating patch is d. The dimensions of the proposed 2x1 array antenna are resented in table2.

Figure 7 shows the variation of the reflection coefficient S11. It is observed that the antenna resonance at frequency 2.4GHz with a reflection coefficient of −42.42dB. And the simulated impedance bandwidth is about 45MHz (2.375–2.42 GHz). Figure 8 shows the simulated f E-plane and H-plane at 2.4 GHz for the designed 2*1 circular array antenna. From the figure we observe that E-plane and H-plane are directional. Figure 9 shows the 3D radiation pattern. It has observed from the figure that the maximum gain is 8.1dB.

Figure 7. Simulated reflection coefficient S_{11} versus frequency of the designed 2*1 array antenna

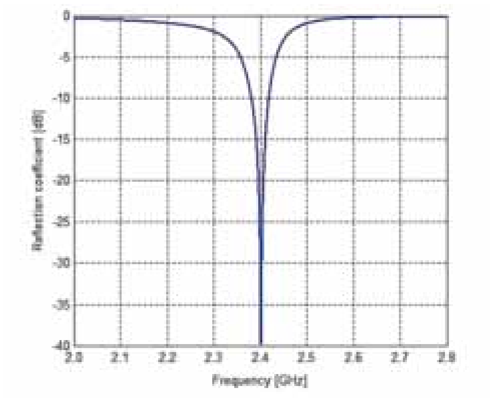


Figure 8. Simulated E and H planes of the designed 2*1 array antenna at 2.4 GHz

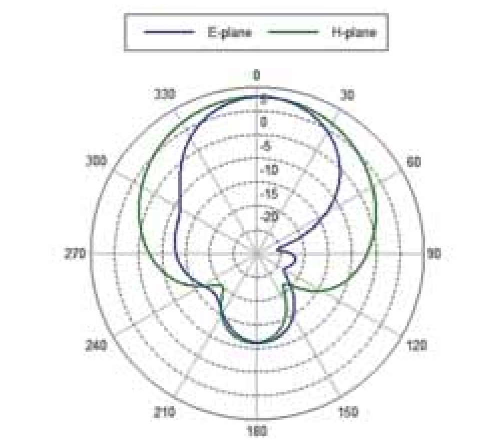
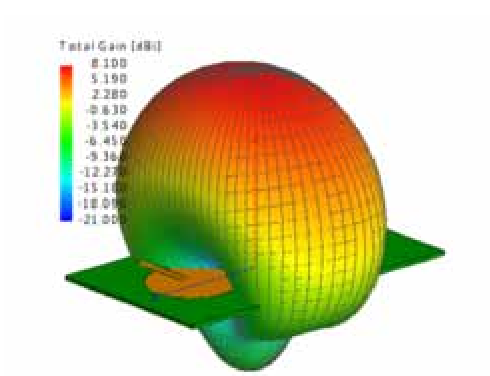


Figure 9. 3D radiation pattern of the designed 2*1 array antenna at 2.4 GHz



Design And Analysis Of A 4*1 Array

Here, in order to enhanced the radiation characteristics of an identical four circular radiating patches used in the first section of this work. Figure 10. presents the geometry of the designed 4*1 array antenna and the dimensions of the different parameters are shown in Table 3.

The simulation results acquired for the designed 4*1 array antenna in terms of reflection coefficient by using CADFEKO is depicted in Figure 10. It is also noted from the figure that the antenna can operate at 2.4GHz with reflection coefficient of −29.7dB. And a bandwidth of 51MHz. The E-plane and H-plane radiation patterns at 2.4GHz are presented in figure 11. it is noticed from

Figure 10. geometry of the designed 4*1 array antenna

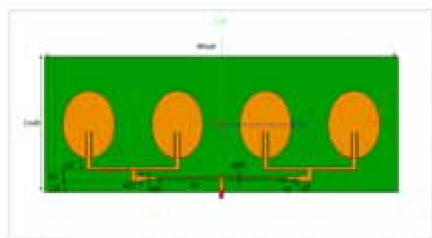
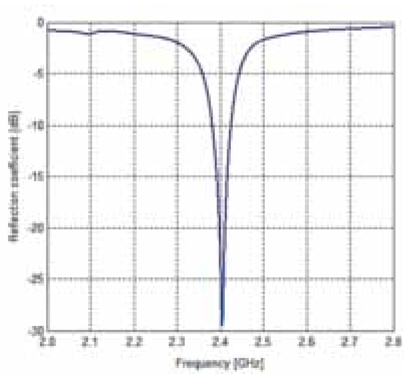


Table 3. Parameters of the designed 4*1 array antenna

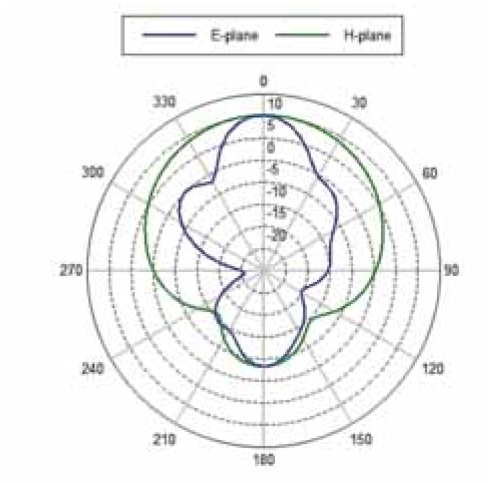
Parameters	*Dimensions(mm)*
W_{sub}	*238.4*
L_{sub}	*55*
d1	*25*
d2	*8.6*
d3	*8.6*
L_{f1}	*7.1*
W_{f1}	*3*
L_{f2}	*5.8*
Wf_2	*1.6*

Figure 11. Simulated reflection coefficient S_{11} versus frequency of the designed 4*1 array antenna



the figure that the directional behavior of the designed antenna at the resonant frequency 2.4GHz was preserved. The 3D radiation pattern is presented in Figure 12 and the maximum gain is 10.29dB.

Figure 12. Simulated E and H planes of the designed 4*1 array antenna at 2.4 GHz



SUMMARY OF SIMULATION RESULTS AND DISCUSSION

Table. 4 gives a performances comparison of the designed circular basic antenna with the 2*1 and 4*1 array antennas. The parameters that compared are the resonant frequency, the reflection coefficient, the gain and the bandwidth.

The designed 2*1 and 4*1 array antennas provide a good impedance matching at 2.4GHz.

The bandwidth enhanced into 45MHz for 2*1 array antenna, while for the 4*1 array antenna it was improved into 51MHz. Also, it is observed from the table that the 2*1 array, while for the 4*1 array antenna has a gain of 10.29dB. From that, it is noticed from the table that the use of four elements has increased the antenna gain and bandwidth more than the two elements.

Figure 13. 3D radiation pattern of the designed 4*1 array antenna at 2.4 GHz

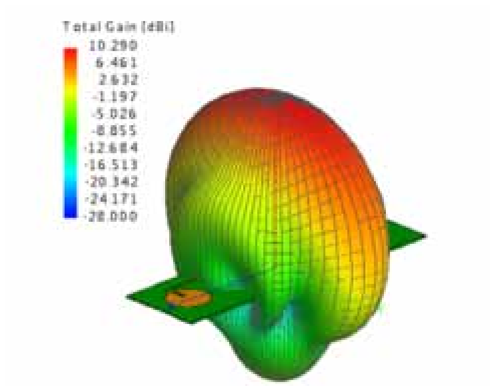


Table 4. Summary of simulation results

	Circular basic antenna	2*1 array antenna	4*1 array antenna
f_r	*2.4GHz*	*2.4GHz*	*2.4GHz*
S_{11}	*-19.87dB*	*-42.42dB*	*-29.7dB*
Bandwidth	*30MHz*	*45MHz*	*51MHz*
Gain	*6.36dB*	*8.1dB*	*10.29dB*

Conclusion

This paper presents the design 2*1 and 4*1 RFID reader array antenna operates at 2.4GHz, for Zigbee, Bluetooth, and WIFI correspond to IoT applications. The antenna was performed using CADFEKO. The 4*1 configuration presents a good performance in terms of gain and bandwidth compared with the designed single and 2*1 array antenna. The increase in the number of radiating elements improves the antenna performances especially the gain. This structure will be a good solution for IoT applications. As perspective of this work, fabrication and measurement should be done to confirm the simulated results.

REFERENCES

Alami, A. E., Bennani, S. D., Bekkali, M. E., & Benbassou, A. (2005). *Design, analysis and optimization of a new structure of microstrip patch antenna for RFID applications*. Academic Press.

Balanis, C. A. (2005). *Antenna theory: Analysis and design* (3rd ed.). John Wiley.

Chen, Z. N., & Qing, X. (2010). Antennas for RFID applications. *2010 International Workshop on Antenna Technology (IWAT)*, 1-4. doi:10.1109/IWAT.2010.5464865

Dong, Y., Choi, J., & Itoh, T. (2017). Folded Strip/Slot Antenna with Extended Bandwidth for WLAN Application. *IEEE Antennas and Wireless Propagation Letters*, *16*, 673–676. doi:10.1109/LAWP.2016.2598276

El Alami, A., Ghazaoui, Y., Das, S., Bennani, S. D., & Ghzaoui, M. E. (2019). Design and Simulation of RFID Array Antenna 2x1 for Detection System of Objects or Living Things in Motion. *Procedia Computer Science*, *151*, 1010–1015. doi:10.1016/j.procs.2019.04.142

Fahmy, A., Altaf, H., Al Nabulsi, A., Al-Ali, A., & Aburukba, R. (2019). Role of RFID Technology in Smart City Applications. *2019 International Conference on Communications, Signal Processing, and their Applications (ICCSPA)*, 1-6. doi:10.1109/ICCSPA.2019.8713622

Giay, Y., & Alam, B. R. (2018). Design and Analysis 2.4 GHz Microstrip Patch Antenna Array for IoT Applications using Feeding Method. *2018 International Symposium on Electronics and Smart Devices (ISESD)*, 1-3. doi:10.1109/ISESD.2018.8605455

Ikram, T., Najiba, E. A. E. I., Jorio, M., & Slimani, A. (2017). A high gain 1*2 array RFID reader MPA for indoor localization applications. *2017 International Conference on Wireless Technologies, Embedded and Intelligent Systems (WITS)*, 1-6. doi:10.1109/WITS.2017.7934639

Katoch, S., Jotwani, H., Pani, S., & Rajawat, A. (2015). A compact dual band antenna for IOT applications. *2015 International Conference on Green Computing and Internet of Things (ICGCIoT)*, 1594-1597. doi:10.1109/ICGCIoT.2015.7380721

Khardioui, M., Bamou, A., El Ouadghiri, M. D., & Aghoutane, B. (2020). Implementation and Evaluation of an Intrusion Detection System for IoT : Against Routing Attacks. In M. Ezziyyani (Ed.), *Advanced Intelligent Systems for Sustainable Development (AI2SD'2019)* (Vol. 92, pp. 155–166). Springer International Publishing. doi:10.1007/978-3-030-33103-0_16

Nate, K., & Tentzeris, M. M. (2015). A novel 3-D printed loop antenna using flexible NinjaFlex material for wearable and IoT applications. *2015 IEEE 24th Electrical Performance of Electronic Packaging and Systems (EPEPS)*, 171-174. 10.1109/EPEPS.2015.7347155

Nate, K. A., Hester, J., Isakov, M., Bahr, R., & Tentzeris, M. M. (2015). A fully printed multilayer aperture-coupled patch antenna using hybrid 3D / inkjet additive manufacturing technique. *2015 European Microwave Conference (EuMC)*, 610-613. doi:10.1109/EuMC.2015.7345837

Ouazzani, O., Bennani, S. D., & Jorio, M. (2017). Design and simulation of 2*1 and 4*1 array antenna for detection system of objects or living things in motion. *2017 International Conference on Wireless Technologies, Embedded and Intelligent Systems (WITS)*, 1-5. doi:10.1109/WITS.2017.7934640

Varum, T., Duarte, M., Matos, J. N., & Pinho, P. (2018). Microstrip Antenna for IoT/WLAN applications in Smart Homes at 17GHz. *12th European Conference on Antennas and Propagation (EuCAP 2018)*, 116. doi:10.1049/cp.2018.0475

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