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Design of RFID Reader Antenna for Healthcare Applications

Abhinav Kumar Singh,[1] Tanmaya Kumar Das[2] and Santanu Kumar Behera[3]
Dept. of Electronics and Commn. Engg., National Institute of Technology, Rourkela, India
Email: [1]abhinavkrsingh7@rediffmail.com [2]tanmaykumar.das@gmail.com [3]s.k.behera@ieee.org

***Abstract*—An array based Reader antenna for RFID system having high gain with circular polarization (CP) is presented in this paper. Such antenna consists of two main radiation patches connected in parallel. The antenna is compact in size and is designed on a FR4 epoxy substrate with dielectric constant (ϵ_r) of 4.4 and loss tangent of 0.02. The antenna is excited with an inset feed line and it operates in ISM band with resonant frequency of 2.4 GHz. It is capable of reading multiple RFID tags within its operating frequency range. The dimension of the antenna is $0.96\lambda \times 0.585\lambda \times 0.012\lambda$, where λ represent the wavelength of the resonant frequency. The gain of the above antenna is 6.1 dB with a reflection coefficient (S_{11}) of -17.4 dB. To investigate the performance of the proposed antenna, different optimization techniques are applied with experimental demonstration. The axial ratio value of the proposed antenna array is 0.3 dB which makes this antenna suitable candidate for healthcare applications.**

***Index Terms*—Microstrip patch antenna (MPA), RFID, circular polarization, ISM band, inset feed.**

I. Introduction

The recent growth in wireless technology for healthcare applications has greatly involved many of the industrial researchers and academician. As the requirement for the sophisticated wearable medical devices is increasing day by day, the healthcare expenses and the demand for the resources of the hospital is growing [1]. Radio Frequency Identification (RFID) is one of the fastest rising areas in healthcare industry for automated identification and collection of data. They have widespread use in keeping eye on patients, tracking and locating surgical instruments, observation of supply chain, patient's drug usage monitoring, identification of newborn etc. Apart from the above it is also helpful in verification of hospital personnel, blood bag tracking, pharmaceutical counterfeit detection, access control to avoid medical equipment theft, maintaining the appropriate diet to patients by tagging of meal plateaux, and accessing medication status in biomedical applications [2]. For this technology several frequency bands have been allocated such as Lower frequency band (LF-band 125 kHz to 134 kHz), higher frequency band (HF-band,13.553 MHz to 13.567 MHz), Ultra High frequency band (UHF-band, 858 MHz to 930 MHz) and Microwave frequency band (2.4 GHz to 2.48 GHz and 5.7 GHz to 5.8 GHz) [3].

RFID system is essential for wireless data transfer that mainly consists of a tag and a reader antenna. The tag is basically used for encoding the data whereas the reader has an antenna along with the digital and RF section for extraction of tag encoded data. So an antenna plays a very crucial role in design of any RFID system. Practically the RFID Tag antennas are omnidirectional antenna and the Reader antenna are linearly or circularly polarized (CP) because of the random placement of the tags in the area. The circularly polarized antenna has low loss caused due to multipath effects between the tag and the reader [4], [5].

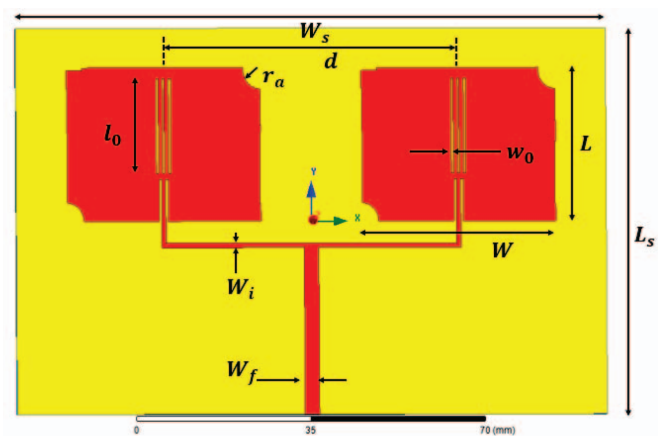


Fig. 1. Antenna geometry (top view).

In this paper a compact inset fed circularly polarized patch antenna operating in ISM band is proposed. The antenna consists of an array of two rectangular microstrip patch antennas to enhance the gain. The proposed design shows high gain, reasonable reflection coefficient value (S_{11}), low profile design, and a good axial ratio of 0.3 dB. The reader antenna can be used in healthcare applications in indoor environment for monitoring the status of the patient. This paper is structured as follows. Antenna geometry and design of the proposed structure are presented in Section II. Simulated results are shown in Section III followed by the conclusion in Section IV.

II. Antenna Design

The antenna is designed on a rectangular FR4 ($\varepsilon_r = 4.4$) epoxy substrate of length (L_s), width (W_s), height (h) of 1.5 mm using ANSYS HFSS v.15 software. The diagram with dimension of the antenna is shown in Fig. 1. The height of the substrate (h) is preferred in the range of $0.003\,\lambda_0 \leq h \leq 0.05\,\lambda_0$, where λ_0 is the free space wavelength. The length (L) of rectangular microstrip patch antenna (MPA) is in the range of $\lambda_0/3 < L < \lambda_0/2$ [6].

The dense substrate (substrate having less dielectric constant) is most desired for decent antenna performance because

TABLE I
DETAILS OF STRUCTURAL GEOMETRY .

Parameter	Dimensions (in mm)
Length of the substrate (L_s)	73
Width of the substrate (W_s)	120
Height of substrate (h)	1.5
Patch length (L)	29
Patch width (W)	39.2
Slot length (l_o)	18
Slot width (w_o)	0.5
Radius of the cut at corner (r_a)	3.5
Separation between two patch (d)	60
Width of 100 Ω feed-line (W_i)	0.8
Width of 50 Ω feed-line (W_f)	2.9

they offer good efficiency, good bandwidth and loosely bound fields for the free space radiation [7–9]. Circular Polarization and linear polarization can be achieved through either single element or arrays of similar microstrip patch antennas [10–15]. In this proposed work an array is used to obtain better gain value.

In this array antenna two similar patches are connected using 100 Ω power divider line with a thickness of (W_i) using inset feed which is then connected in series to the 50 Ω transmission feed line with thickness of (W_f). The minimum separation (d) between both the patches is maintained at 60 mm. The slotted section with dimension ($l_0 \times w_o$) has been incorporated within the patch using parametric analysis for proper impedance matching. The cut at the corners with radius r_a is made for achieving circular polarization.

As $W/h >> 1$ and $\epsilon_r \gg 1$, maximum number of the field lines exist inside the substrate and very few of the lines are in the space. As large amount of the E-field lines concentrates inside the substrate, thus the microstrip line look little wider than the actual physical dimension. This is due to the fringing [8], and therefore an effective dielectric constant ϵ_{reff} is introduced. The effective relative permittivity lies between the range $1 < \epsilon_{reff} < \epsilon_r$. As ϵ_{reff} is a function of frequency, with increase in operating frequency concentration of the field lines inside the substrate rises; the microstrip lines behave as a single homogeneous line made of only one dielectric [8].

A. Effective Dielectric Constant (ϵ_{reff})

Effective dielectric constant is basically fixed for low frequencies, but its value starts to increase continuously and ultimately comes to the value of substrate dielectric constant (ϵ_r) at intermediate frequencies [9].

For $\frac{W}{h} > 1$,

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left(1 + 12\frac{h}{W}\right)^{-1/2}. \qquad (1)$$

B. Effective Width, Effective Length, Resonant Frequency

After accounting the fringing effect, the elongation along the patch length can be calculated by the following expression [10].

$$\Delta L = 0.412 \times h \times \frac{(\epsilon_{reff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\epsilon_{reff} - 0.258)\left(\frac{W}{h} + 0.8\right)} \qquad (2)$$

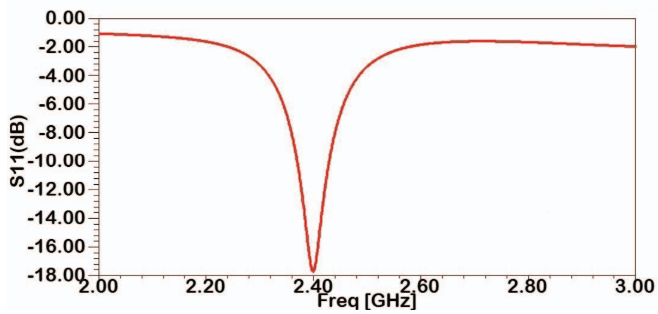


Fig. 2. S_{11} vs. frequency plot of the antenna in dB.

where ΔL is the extension in length on both sides due to fringing effect, W/h is the patch width to substrate height ratio. As the patch length is elongated by ΔL on both sides, the operational patch length now is ($L = 0.5 \times \lambda$ for dominant mode TM_{010} without fringing)

$$L_{eff} = 2\Delta L + L. \qquad (3)$$

The resonant frequency is given by

$$f_r = \frac{1}{2L\sqrt{\epsilon_r}\sqrt{\mu_0\epsilon_0}} = \frac{c}{2L\sqrt{\epsilon_r}} \qquad (4)$$

where c is the wave velocity in free space (3×10^8 m/s).

C. Design Width and Length

In an effective radiator, the practical width can be calculated by

$$W = \frac{1}{(\sqrt{2}f_r)\sqrt{\mu_0\epsilon_0}}\sqrt{\frac{1}{\epsilon_r + 1}} = \frac{c}{\sqrt{2}f_r}\sqrt{\frac{1}{\epsilon_r + 1}} \qquad (5)$$

$$L_{eff} = \frac{c}{2f\sqrt{\epsilon_{reff}}} \qquad (6)$$

$$L = \frac{c}{2f\sqrt{\epsilon_{reff}}} - 2\Delta L. \qquad (7)$$

In the proposed design $f = 2.4$ GHz and $\epsilon_r = 4.4$ for FR4 epoxy substrate of height 1.5 mm are choosen. By applying the above equation, the effective dielectric constant, $\epsilon_{reff} = 3.99$, width for single patch, $W = 38.22$ mm, effective length of single patch, $L_{eff} = 30.2$ mm are obtained.

However, optimization of the parameters is needed in order to get the best output, which can be done through the parametric analysis of the antenna. Thus the design parameters obtained are shown in Table I.

III. RESULTS AND DISCUSSION

Proposed compact antenna has been simulated using ANSYS HFSS version 15 simulation tool. This design is relatively small as compared to any other antenna of similar array structure. It provides a fairly good S_{11} value of about -17.4 dB as shown in the Fig. 2 at the designed frequency of 2.4 GHz.

Fig. 3 demonstrates the VSWR variation of the structure. The voltage standing ratio of the antenna is 1.3 at frequency 2.4 GHz.

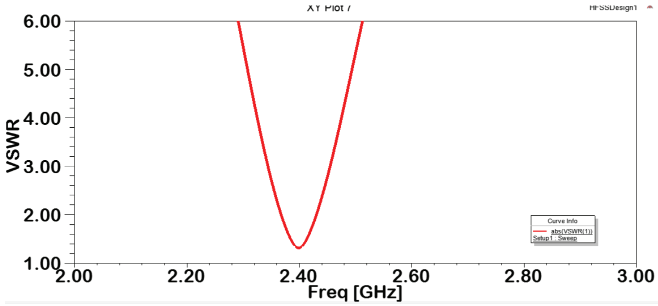


Fig. 3. VSWR variation with frequency.

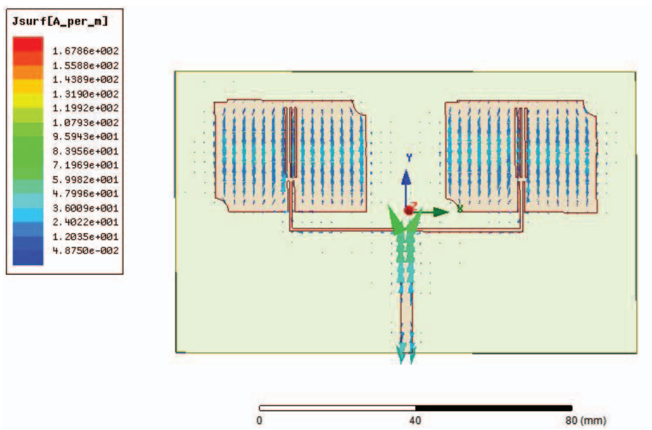


Fig. 4. 3D gain plot of the antenna array.

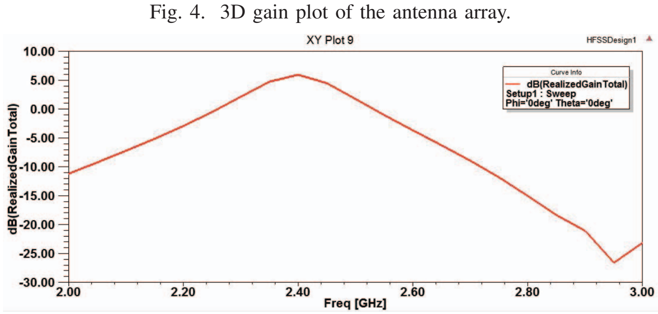


Fig. 5. Axial ratio plot of antenna array.

The antenna is circularly polarized having a gain of about 6.1 dB. The 3D polar plot is presented in Fig. 4.

The axial ratio of the circularly polarized antenna is found to be 0.3 dB, which is better for the RFID requirements in indoor environment for a narrowband antenna. Fig. 5 shows the axial ratio of the antenna array.

The variation of gain is shown in Fig. 6. It shows a maximum value of 6.1 dB at resonant frequency.

The surface current distribution of the proposed design is demonstrated in Fig. 7. It clearly indicates the presence of circular polarization in the antenna array.

The radiation patterns for XZ and YZ plane showing the co-polarization and cross-polarization levels are shown in Fig. 8. The simulation results show that cross polarization levels are -40 dB low at 2.4 GHz in XZ-plane and YZ-plane respectively.

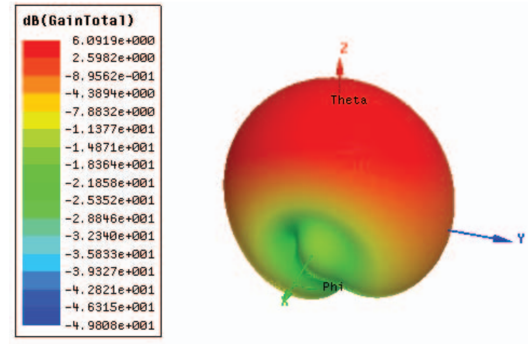


Fig. 6. Variation of gain of the antenna array with frequency.

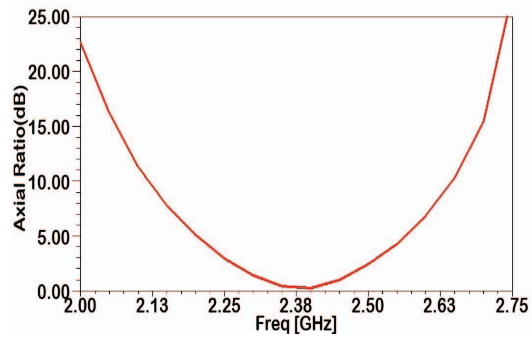
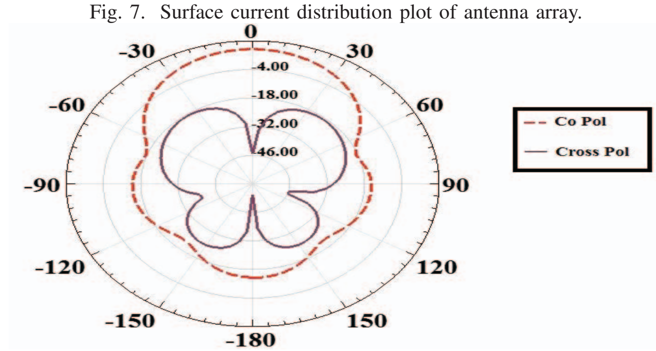
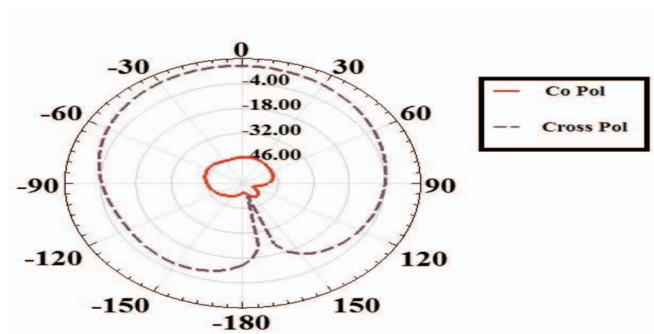


Fig. 7. Surface current distribution plot of antenna array.



(a)



(b)

Fig. 8. Polar plot of the antenna array at (a) XZ plane (b) YZ plane.

IV. Conclusion

In this paper an array based RFID reader antenna has been proposed. The design is made on FR4 epoxy substrate using ANSYS HFSS v.15 software at a frequency of 2.4 GHz. The compact antenna with dimension $0.96\lambda \times 0.585\lambda \times 0.012\lambda$

shows the reflection coefficient of -17.4 dB. The proposed gain of the antenna is 6.1 dB with a voltage standing wave ratio (VSWR) of 1.37 and axial ratio of 0.3 dB at resonant frequency. The simulation results indicate that the antenna fulfills all the requirements of RFID reader antenna for healthcare applications as well as in wireless communication.

REFERENCES

[1] Y. Hao and R. Foster, "Wireless body sensor networks for health-monitoring applications", *Physiol. Meas*., vol. 29, pp. R27–R56, Nov. 2008.

[2] G. Morrocco, "The art of UHF RFID antenna design: Impedance matching and size-reduction techniques", *IEEE Ant. and Propag. Magazine*, vol. 50, issue 1, Feb. 2008.

[3] K. Finkenzeller, *RFID Handbook: Fundamentals and applications in contactless Smart Cards and Identifications*, 1st edition, UK, J. Wiley and sons, 2010.

[4] Bo-Shau Chen, and Chow-Yen-Desmond Sim, "Broadband circularly polarized stacked patch antenna for universal UHF RFID applications", *International Sympos. on Antennas and Propag. Conf.* Procd., pp. 99–100, 2014.

[5] H.W. Kwa, X. Qing, and Z.N. Chen, "Broadband single-fed single-patch circularly polarized antenna for UHF RFID applications", in *IEEE AP-S Int. Antennas Propag. Symp.*, San Diego, CA pp. 1072–1075, Jul. 5–11, 2008.

[6] J.R. James, and P.S. Hall, *Handbook of Microstrip Antennas*, vols. 1 and 2, London, UK, Peter Peregrinus, 1989.

[7] D.M. Pozar, "Microstrip Antennas", *Proc. IEEE*, vol. 80, no. 1, pp. 79–81, Jan. 1992.

[8] C.A. Balanis, *Antenna Theory and Design*, 2nd edition, New York, John Wiley and sons, 2001.

[9] E.O. Hammerstad, "Equation of microstrip circuit design", *Proc. Fifth European Microwave Conf.*, pp. 268–272, Sept. 1975.

[10] Md. Aminul Islam, and Nemai Chandra Karmakar, "A 4×4 Dual Polarized mm-Wave ACMPA Array for a Universal mm-Wave Chipless RFID Tag Reader", *IEEE trans. on Antennas and propag.*, vol. 63, no. 4, pp. 1633–1640, Apr. 2015.

[11] Emran M. Amin, and Nemai C. Karmakar, "A Passive RF Sensor for Detecting Simultaneous Partial Discharge Signals Using Time–Frequency Analysis", *IEEE Sensors Journal*, vol. 16, no. 8, pp. 2339–2348, Apr. 2016.

[12] M. Aminul Islam, M. Shakil Bhuiyan and N. Karmakar, "A novel compact chipless RFID tag and near-field reader", *Asia-Pacific Microwav. Conf. 2011*, Melbourne, VIC, pp. 1518–1521, 2011.

[13] M. A. Islam and N. C. Karmakar, "A Novel Compact Printable Dual-Polarized Chipless RFID System", *IEEE Trans. Microwav. Theory and Tech.*, vol. 60, no. 7, pp. 2142–2151, July 2012.

[14] J. Shi, X. Qing, and Z. N. Chen, "Electrically large zero-phase-shift linegrid-array UHF near-field RFID reader antenna", *IEEE Trans. Antennas Propag.*, vol. 62, no. 4, pp. 2201–2208, Apr. 2014.

[15] J. Choo and J. Ryoo, "UHF RFID tag applicable to various objects", *IEEE Trans. Antennas Propag.* vol. 62, no. 2, pp. 922–925, Feb. 2015.