Design of novel hexagonal s-band patches antenna array for RFID applications

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ABSTRACT

The design and study of the behavior of antennas adapted to radio-frequency identification RFID tags take on all their importance because they must respond to integration problems and therefore the need to design a structure with minimal dimensions, without however deteriorating their performance. The rise in frequency makes it possible to have short wavelengths so that it becomes possible to have a great integrationas as well as very fast bit rate. But, this induces a smaller range due to the propagation losses according to the model of Friis. In this article, a new patch antenna array for microwave frequency band in radio-frequency identification RFID applications will be presented. The antenna covers the band for the central frequency of 2.45 GHz with better loss characteristics. In addition, the antenna offers a high gain at this frequency. After the digital design of the antenna element, which was carried out using the commercial software CST MWS®, the antenna is printed on an FR4 substrate with a dielectric constant of 4.3 and a thickness of 1.6 mm. The comparison between the simulation results and the measurement results proves that the antenna achieves satisfactory impedance matching and radiation efficiency.

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1. INTRODUCTION

Marking and traceability technologies have undergone considerable development in recent years, made possible by the combination of the dematerialization of monitoring processes, the drop in the costs of media and information processing capacities, and reading without contact. Substitution of radio frequency identification (RFID) chips for bar codes has begun in the professional and consumer mass markets. It is in this context that the design and study of the behavior of antennas adapted to these systems take on all their importance because they must respond to integration problems and therefore the need to design a structure with minimal dimensions, without however deteriorating its performance [1], [2]. The two most discussed components of an RFID system are the tag and the reader [3], [4]. The reader antenna allows the activation of tags and the transmission of information to the reader. It is an essential identification element in RFID system and its design and miniaturization are of a great interest.

Four frequency ranges, part of industrial, scientific, and medical (ISM) radio bands, have been standardized for the RFID applications: low frequency (LF) at 125 and 134.2 kHz; high frequency (HF) at 13.56 MHz; ultra high frequency (UHF) at 433 MHz and in [860-960] MHz; and microwave frequency at

2.45 GHz and 5.8 GHz [5], [6]. According to RFID applications, the selection of the frequency depends essentially on two main factors: the material of the object being tagged (to cope with absorption) and the read range required. LF and HF bands ensure short reading ranges and low data rate, while UHF and Microwave bands ensure long read ranges and high data rate [7]. The literature contains many designs of RFID antennas in the different bands to meet the very large number of existing RFID applications in all areas of the public and industry [8]-[16]. However, the need to achieve high performance is still relevant today [17]-[21].

In this work, we designed a new patch antenna array operating in microwave band (precisely at 2.45 GHz) for RFID reader, to achieve higher operating range and high data transfer rate as well as cost and size effectiveness [22], [23]. This type of RFID system ensures good anti-collision and can be used in passive, active and semi-active modes. Some structures of RFID antennas have been reported recently in in the target band (2.45 GHz).

Research by Lu *et al*. [24], a pi-shaped shorted structure based planar antenna is proposed using IE3D software. The antenna has size of 27 mm × 10 mm, bandwidth of 135 MHz, return loss of -39.68 dB and gain of 0.766 dBi. A reader antenna with hexagonal geometry was designed with return loss of -20.64 dB. Realized gain is 12.65 dB and bandwidth is 40 MHz [25]. Xie *et al.* [26] presented a four planar dipole-array antenna. The bandwidth is 270 MHz, and return loss at resonant frequency is -35.3 dB with gain up to 7 dBi. Xing *et al*. [27] presented a dual-band RFID antenna for 0.92 GHz UHF near-field RFID antenna with far-field circularly polarized radiation at 2.45 GHz. The gain of the circularly polarized antenna is about 4.5 dBi and the bandwidth of 110 MHz. Yu *et al.* [28] presented a dual-band dipole antenna operating at 2.45 GHz and 5.8 GHz, composed of a bent and a rectangular microstrip patch. Return loss and bandwidth at 2.45 GHz are −18.77 dB and 80 MHz respectively. An other dual-band at 2.45 GHz and 5.8 GHz antenna for reader is proposed in [29]. The antenna is fabricated on Rogers RT/duroid 5880 substrate with dimensions 33x25 mm^2. A bandwidth of 310 MHz and a gain of about 2.30 dB are realized respectively in 2.45 GHz. Birwal *et al.* [30] proposed a circular polarization RFID reader antenna using bi-directional CPW feding. The antenna with square shape is printed on FR4 substrate of 60×60 mm^2. The results show a -3dB-bandwidth of of 28.3% (2.03-2.7) GHz and a maximum gain of 3.17 dBi. Accordy to Ali *et al.* [31], a flexible antenna using waveguide feding is presented for RFID applications, with an overall size of (43×30×1.67) mm^3. The impedance bandwidth is 2.1-2.98 GHz. The achieved gain is 2.47 dB and the return loss is less than -10 dB. Alami *et al.* [32] designed a 2x1 array antenna using RT/duroid-5880 substrate of total size (110.5×83) mm^2. The proposed array antenna has -25.36 dB for the reflection coefficient and 9.22 dB for the gain.

In this paper, we investigate new antenna structure (Hexagone) to address the state-of-the-art RFID antenna shortcomings and achieve performance improvement in terms of bandwidth, matching, and gain. The structure of this antenna allows having better performances compared to a rectangular or circular patch antenna [33]. We present in this study, the reflection coefficient and the radiation pattern of a single patch antenna and patch antenna array obtained by simulation by CST MWS® [34]. A discussion of the performances, improvement measures of this antenna concludes this work.

2. ANTENNA DESIGN

2.1. Regular hexagon structure

Maximum read range MaxRR can be determined, from Friis propagation model in the far-field propagation context [35], [36], by:

$$R_{Max} = \frac{\lambda}{4\pi}\sqrt{\frac{P_t G_t G_r}{P_{th}}\left(1-\left|\frac{Z_c-Z_a}{Z_c+Z_a}\right|^2\right)} \quad (1)$$

Where λ is the operating wavelength

P_t is the reader-transmitted power, and G_t is the gain of its antenna

G_r is the gain of receiving tag antenna, and P_{th} is the sensitivity of the RFID tag. Z_c and Z_a are the chip and antenna impedance, respectively.

It clearly appears that MaxRR depends on impedance matching and antenna gain. According to [33] the hexagonal geometry can improve the patch antenna performance such as gain and return loss. We will therefore design in the rest of this paper an hexagonal patch antenna operating at the resonant frequency of 2.45 GHz. To do so, we will use the results of a circular patch antenna [22], [37], considering same areas (invariance of the electrostatic energy) for the hexagonal and circular patches (Figure 1). In (2) gives the fundamental resonant frequency (TM11 mode) of a circular patch antenna:

$$f_{res} = \frac{1.84118c}{2\pi r_e\sqrt{\varepsilon_r}} \quad (2)$$

Where: f_{res}: resonant frequency

c: speed of light in free space

ε_r: relative permittivity of the substrate

r_e: effective radius of circular micro strip antenna, given by in (3).

$$r_e = r\left\{1 + \frac{2h}{\pi r\varepsilon_r}(1.7726 + ln\frac{\pi r}{2h}\right\}^{1/2} \quad (3)$$

With r is radius of the circular patch antenna and h is height of the substrate
The equivalence of the areas makes it possible to deduce the length (w) of one side of the regular hexagon, in (4):

$$\pi r^2 = \frac{3\sqrt{3}}{2}w^2 \quad (4)$$

By fixing the working frequency at 2.45 Ghz, we deduce w. In what follows, we will adopt a modified hexagonal structure, for which an analytical form of the resonance frequency does not exist; we therefore adjust the dimensions numerically.

2.2. Structure and geometry of the proposed patch antenna

The proposed structure of the patch antenna is inspired by the hexagonal antenna presented in [38], as shown in Figure 2. The dimensions are shown in Table 1. The antenna is implemented on FR4 substrate for which dielectric constant ε_r =4.3, tanδ=0.025, and thickness=1.6 mm. The size of the RFID antenna is 36×10 mm^2. We have adopted a power supply by a coplanar wave CPW thus allowing having a very large bandwidth. The microstrip line having a 50 Ohm power port.

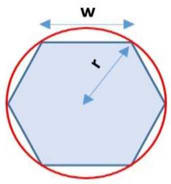

Figure 1. Regular hexagon structure

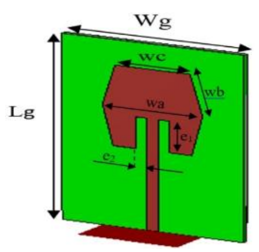

Figure 2. Geometry of antenna design

Table 1. Dimensions of the patch antenna

Parameter	Dimension (mm)
Substrate length (Lg)	69.41
Substrate width (Wg)	47.2
Patch width (wc)	9.75
Patch length (wb)	10.25
Notch (e_1)	11.75
Notch (e_2)	2.72

3. RESULTS AND DISCUSSION

3.1. Simulation and experiment results for one patch element

The proposed patch antenna was designed with CST MWS. Figure 3 shows the impedance matching result. From Figure 3, we notice the value of the return loss, less than -10 dB at 2.45 GHz, which means a minimum return power can be reflected at this frequency. The voltage standing wave ratio VSWR value is also less than 1.5 (Figure 4), which supports our new design results.

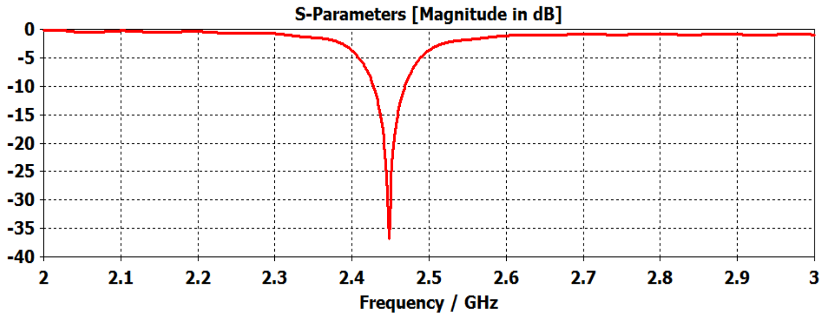

Figure 3. The reflection coefficient

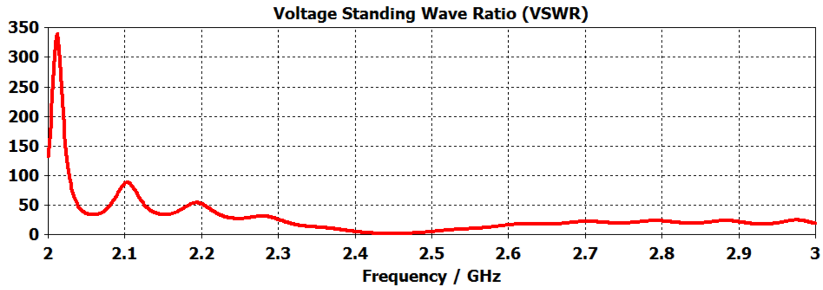

Figure 4. Standing wave rate as a function of frequency

Figure 5 presents 3D radiation pattern, where we can see the radiation lobe containing the maximum energy and maximum direction of radiation. At working frequency, the gain reachs a maximum value greater than 2.5 dBi as shown in Figure 6. For RFID systems, the reading range is a critical parameter [39]. From Figure 7, we noticed 2.43 meters for the main lobe magnitude, which represents the reading range of the proposed antenna.

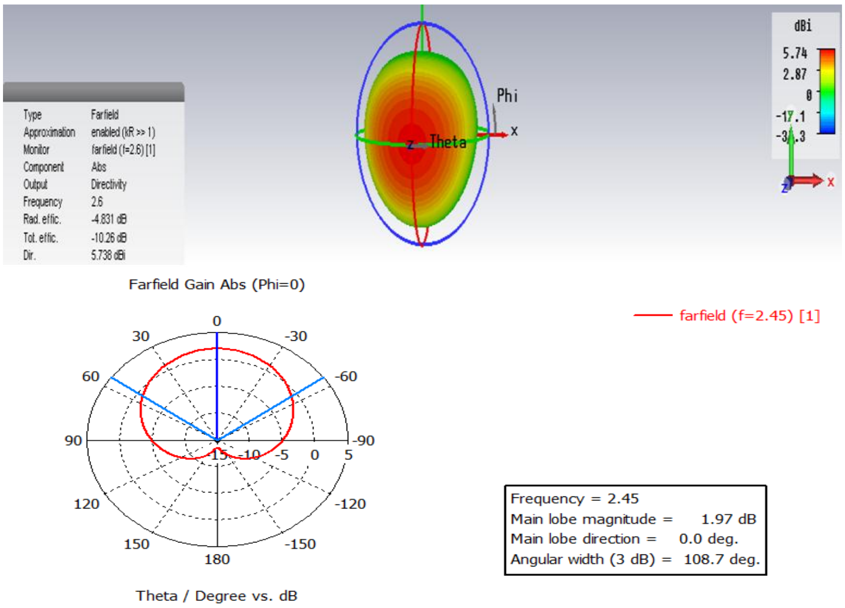

Figure 5. The new patch antenna 3D radiation pattern in directivity and polar

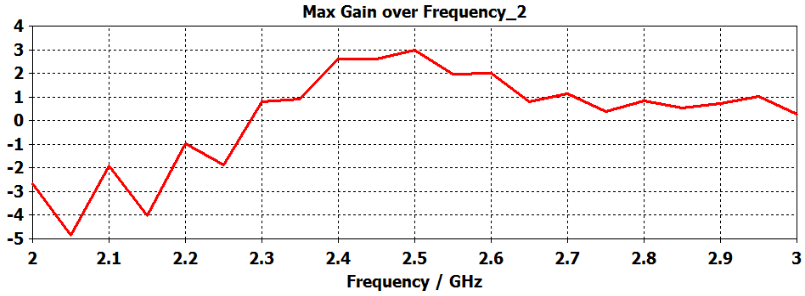

Figure 6. Gain variation as a function of frequency

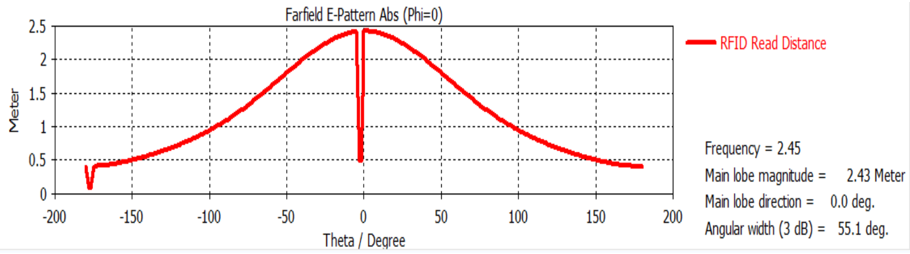

Figure 7. The RFID reading range

The structure of the proposed antenna was optimized to acheive compactness and interesting retun loss in operating band. Based on the obtained simulation results, we manufactured the antenna and measured the S11 parameter. Figure 8 shows a photograph of the antenna made with the dimensions shown in Table 1. The antenna reflection coefficient measurements were performed using the agilent technology PNA network analyzer n5222a (Figure 9). The comparison between the simulated and the measured results for the return loss and VSWR parameters of the proposed antennas are shown in Figure 10 and Figure 11.

Figure 8. Fabricated prototype of the proposed antenna

Figure 9. Antenna patch proposed test

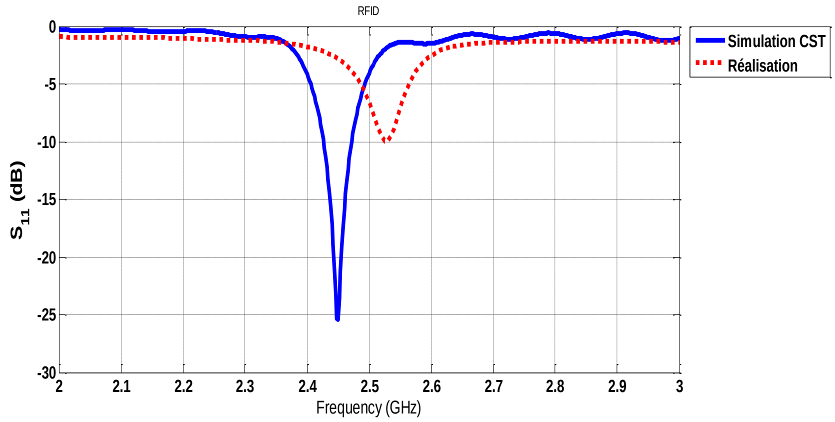

Figure 10. Comparison of simulated and measured reflection coefficient of the proposed antenna

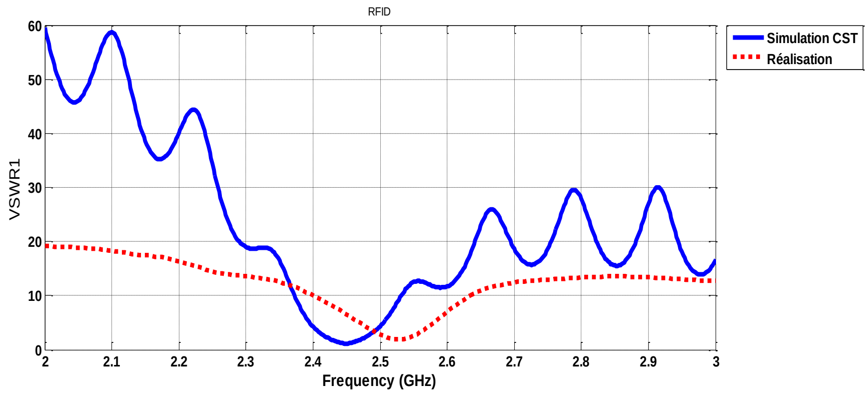

Figure 11. Comparison of simulated and measured VSWR of the proposed antenna

By making a comparison between the numerical and experimental approaches, it is quite clear that the results obtained are in harmony, although we marked some differences in the comparison graphs due to measurement and manufacturing errors; For S11 and VSWR where we have measured a value less than -10 dB, respectively a value less than 2.

3.2. Simulation of an array of two printed antennas

We present in this subsection simulation results of an antenna array of two patch elements, separated by a distance d=0.6 mm (Figure 12). We opt for the parallel feeding method through a feed network in the form of a T-junction (power divider), where the characteristic impedance of the two microstrip lines can be determined as follows [40]:

$$Z_{nc} = N_l Z_c \quad (5)$$

Where N_l is the number of the microstrip lines. The characteristic impedance (Z1) of the two microstrip lines is then 100 Ω. The Reflection coefficient and the voltage standing wave ratio of the linear array of two patches are respectively shown in Figure 13 and Figure 14. From Figure 14 we notice that the gain in a two parallel fed patches antenna array is improved compared to a single element antenna. The obtained values from our proposed antenna are:

a. gain: 5.14 dBi
b. directivity: 7.83 dBi
c. aperture antenna: 75.8 deg.

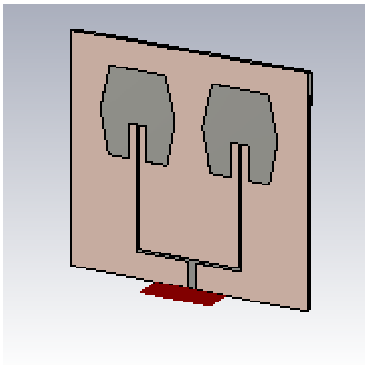

Figure 12. The patch antenna array

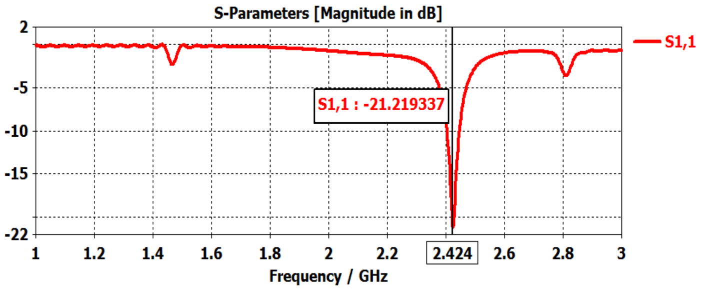

Figure 13. The reflection coefficient of a two elements array antenna

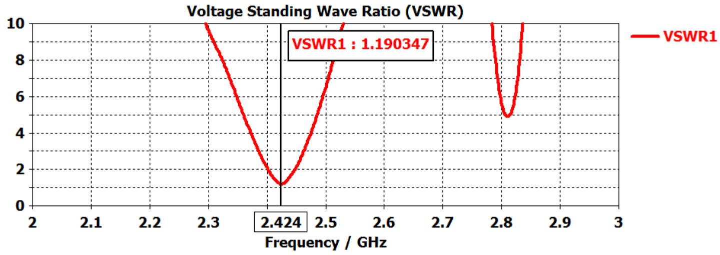

Figure 14. The VSWR coefficient of two elements array antenna

4. CONCLUSION

In this paper, an hexagonal microstrip patch antenna array operating at 2.45 GHz for RFID applications has been proposed. This antenna is made up of radiating transmission lines bent in a T, allowing better performance compared to a traditional UHF patch dipole antenna.The proposed antenna is fabricated on an FR-4 substrate and its S11 is measured showing good agreement with simulation. High gain and good matching were obtained. Performance improvements were also demonstrated in simulation with a lattice of two elements radiating in the same band. These results make the hexagonal S-band patch antenna with notches a suitable candidate for 2.45 GHz RFID applications, suggesting future optimization work.

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