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Design of a Miniaturized Patch Antenna with Reverse U-Shaped Slots for 2.45/5.8 GHz RFID Applications

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***Abstract*— In this paper, a dual-band antenna for reader of Radio Frequency Identification (RFID) applications is proposed, which operates at 2.45 GHz and 5.8 GHz. This antenna is excited by a 50Ω microstrip feed line, fabricated on Rogers RT/duroid 5880 substrate with dimensions 33x25 mm^2, dielectric constant of 0.0009 and thickness of 1.6 mm. The main objective of the slots U-shape inverse included on the front side of antenna is to get a dual-band frequency (2.45-5.8 GHz) and improve radiation characteristics in term of gain, reflection coefficient.**

The structure design, optimization and simulation results analysis were performed under simulator electromagnetic HFSS (high-frequency structure simulator), and focused on the return loss, bandwidth, gain and directivity.

The proposed antenna has a simple design and a miniaturized size compared to the patch antenna. It exhibits broadband impedance matching, consistent omnidirectional radiation patterns and appropriate gain characteristics in the applications of RFID.

***Keywords*— Antenna; RFID (Radio Frequency Identification); slots; U-shape inverse; dual-band; HFSS**

I. INTRODUCTION

Radio frequency identification (RFID) is a technology that provides wireless identification and tracking capability and is more robust than a bar code. Now RFID system finds many applications in various areas such as electronic toll collection, asset identification inertial item management, access control, animal tracking, and vehicle security companies, logistics systems, service industries, government agencies, and public service organizations in the past few years [1-2].

A basic RFID system is composed of two components, an RFID transponder (tag) and an interrogator or reader. The RFID interrogator transmits a radio frequency interrogation signal through the reader antenna and receives the backscattered signal from the transponder in the field of the antennas which are in the majority of patch antennas [3]. The Functioning of an RFID system is shown in Figure 1.

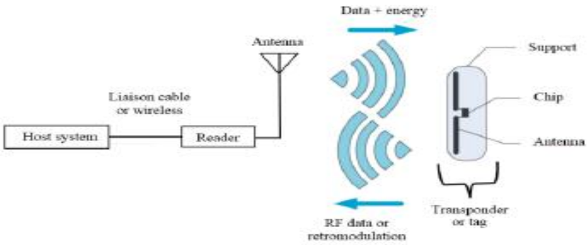

Fig.1: Functioning of an RFID system [4]

RFID systems can involve, according to the frequency band used, four types of applications: LF Applications (125 KHz), HF applications (13.56 MHz), UHF applications ([860-960] MHz) and microwave applications (2.45-5.8 GHz) [5].

At present, most of RFID systems operate in the megahertz frequency range. Higher frequencies that utilize free microwave ISM bands such as 2.45 GHz and 5.8 GHz are under active development [6]. In most of the presented microwave RFID system designs, antennas operate at their dominant mode, which is characterized by the lowest frequency of operation. The use of such modes of operation results in large size antennas, which are predominantly responsible for an increased size of an RFID tag. It becomes apparent that in order to miniaturize a microwave ID system, the main assignment is to miniaturize its antenna [7].

Indeed, the microstrip antennas have appeared in the fifties and have been developed in the seventies. However, several studies have been conducted to arrive at an optimal microstrip antenna that can meet the requirements of the telecommunications industry for aeronautical, aerospace and military applications. This type of antenna is easily adapted to planes surfaces and non-planes and present high strength and flexibility when mounted to rigid surfaces. The antennas are also very efficient in terms of resonance, input impedance and radiation pattern. The major disadvantages of antennas reside in their low polarization purity, low bandwidth and low gain [8].

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Among these antennas, this work focuses on the rectangular shaped patch antennas which are the subject of much research and development in recent years [9-10].

In this work, we suggest to design a new structure of rectangular-shaped patch antenna with slots on the radiating element. This antenna is excited by microstrip line having a power port adapted to 50 *Ω*. The slots inserted at the patch antenna have a direct impact on improving the radiation characteristics as well as the return loss, the bandwidth, the gain and the directivity. The proposed antenna is intended for RFID reader applications in the microwave band.

II. THEORETICAL STUDY OF PATCH ANTENNAS

In general, patch antennas have been the subject many studies and developments that today find themselves in the literature. There are several analytical models useful in sizing antenna geometries such as rectangular, circular or triangular [11], [12].

The rectangular patch antenna as shown in Fig.2, is calculated from the following equations (1-4).

The first part of the design of an antenna is the estimation its length (L) and it's the width (W) which are calculated using equations (1-4) [13].

$$W = \frac{c}{2fr} + \sqrt{\frac{2}{\varepsilon r + 1}} \qquad (1)$$

With fr is the resonant frequency of the patch antenna, ε_r the dielectric constant of the substrate and c the speed of light in free space. The effective dielectric constant (W/h >1) is given by:

$$\varepsilon eff = \frac{\varepsilon + 1}{2} + \frac{\varepsilon - 1}{2}\left[\frac{1}{\sqrt{1 + 12\frac{h}{W}}}\right] \qquad (2)$$

The extension of the length of microstrip patch antenna ΔL due to the fringe effect (edge effects) can be obtained by:

$$\Delta L = 0.412h\frac{(\varepsilon r + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon r - 0.258)(\frac{W}{h} + 0.8)} \qquad (3)$$

So, after taking account the edge effects, the final effective length of the patch antenna can be calculated by:

$$L = \frac{C}{2fr\sqrt{\varepsilon reff}} - 2\Delta L \qquad (4)$$

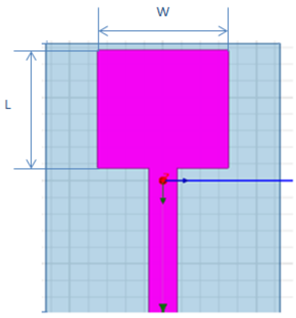

Fig.2. Rectangular microstrip patch antenna

III. STUDY AND DESIGN OF THE PROPOSED PATCH ANTENNA

- Antenna design

The structure of the proposed antenna has been designed on Rogers RT/duroid 5880 substrate (25x33) mm^2 (Ls x Ws), with a relative dielectric constant of 2.2, a thickness of H= 1.6mm, a loss tangent tan (δ) = 0.0009 and copper foil thickness of t=0.035 mm. This antenna is fed by a microstrip line with 50Ω characteristic impedance. The dimensions of the antenna are optimized and miniaturized by using Ansoft HFSS.

After many series of optimization, the final optimized antenna is validated with the following parameters: Wf = 3 mm, Lf = 17.8 mm, Lg = 1.5 mm and Wg = 25 mm. The total volume of the proposed antenna is (33x25x1.6) mm^3. The configuration of the proposed antenna is shown in Fig. 3.

Table 1 shows the dimensions of the antenna proposed. The overall dimensions of the radiating element, the feed line and the substrate have been reduced to miniaturize the final structure.

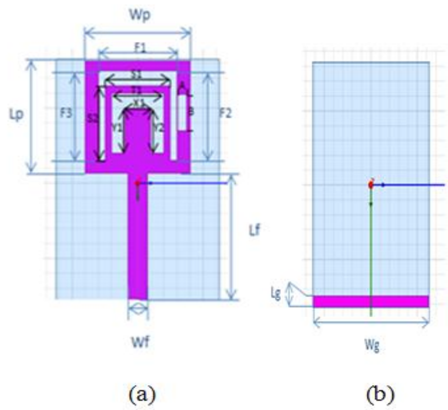

Fig.3. Geometry of the proposed antenna (a) top view ,(b) back view

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TABLE I. DIMENSIONS OF THE PROPOSED ANTENNA

Parameter	Value (mm)
L_s	33
W_s	25
L_g	1.5
W_g	25
L_p	15
W_p	16
Lf	17.8
Wf	3
F1=F2=F3	12
S1=S2=S3	10
T1=T2=T3	8
X1	4
Y1=Y2	6
A	1.4
B	4.8

- *Antenna design steps*

By correctly adjusting the dimensions of the antenna and feeding structure the impedance matching of the proposed antenna is improved that produces wider impedance bandwidth with satisfactory radiation pattern. The wide bandwidth and impedance matching with reduced size of the antenna is achieved by the different surface magnetic currents of the structure [14]-[15].

Firstly, we design the patch antenna without slots (as shown in Ant1 in Fig.4). Secondly, we modify the structure by inserting rectangular slots in inverse U-shape on the front side of the antenna to get an adaptation at both frequencies 2.45 and 5.8 GHz (Ant2). Finally, we made another modification by adding rectangular slot and a shaped slot U-inverse with small size, compared to previous slots, on the top layer of the antenna (Ant3), in order to improve the reflection coefficient and the bandwidth of our antenna.

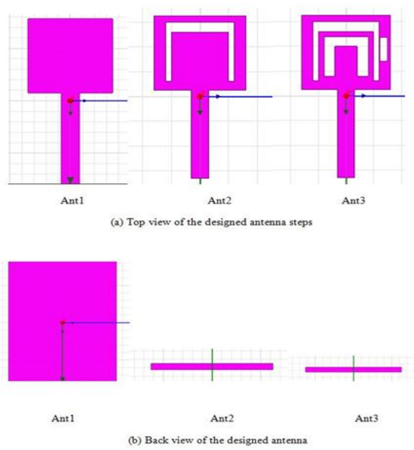


Fig.4. Evolution geometry of the proposed antenna

Fig.5. shows the different reflection coefficients corresponding to each antenna 1 to 3.

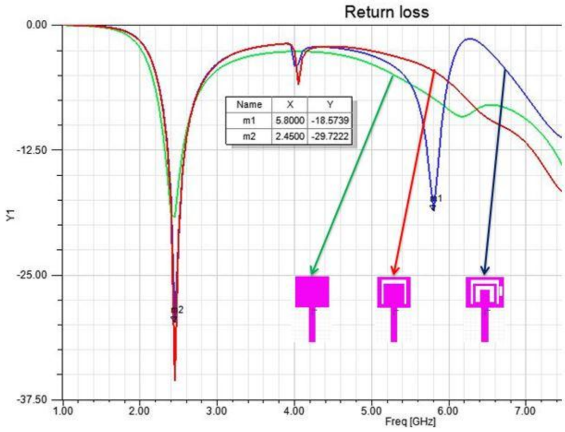


Fig.5. Different reflection coefficient obtained of each antenna

Figure 6 shows the effect of A, the width of the slot, on the return loss by fixing the other parameters. From this figure, it can be seen that the best result obtained is that equivalent to A = 1.4 mm. For other values, the coefficient of reflection increases at f1 = 2.45 GHz and decreases at f2 = 5.8 GHz with a left slight lag at f2.

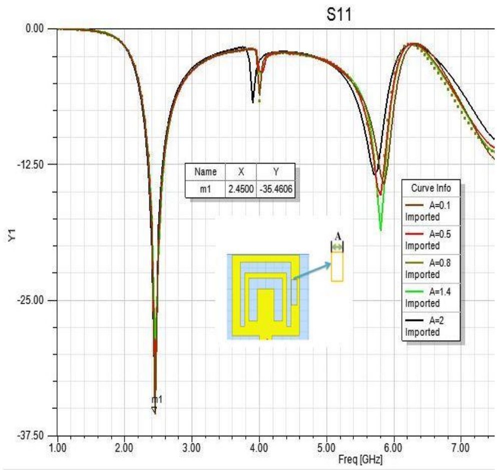


Fig.6. the effects on return loss for different width of the Slot (A)

IV. SIMULATION RESULTS AND DISCUSSION

The antenna performance was studied by using the high-frequency structural simulator HFSS software whose numerical analysis is based on the finite element method [16]. Fig. 7 illustrates the reflection coefficient obtained from simulation tool.

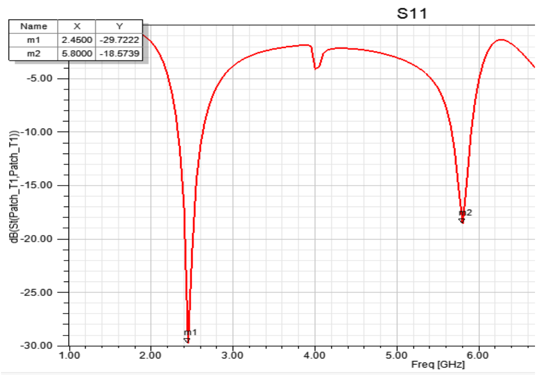
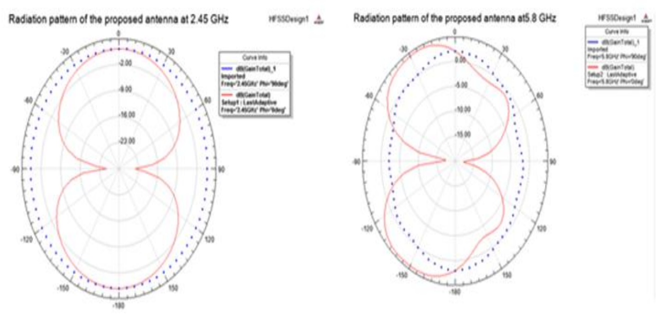


Fig.7. Simulated return loss for the proposed antenna

The simulated return loss of the proposed antenna is represented in Figure 7. The return loss curve shows that the proposed antenna is excited at 2.45 GHz with a –10 dB return loss bandwidth of 310 MHz (2.32–2.63 GHz) and at 5.8 GHz with an impedance bandwidth of 240MHz (5.66–5.90 GHz). The maximum return loss of -29.72 dB and -18.57 dB is obtained at the resonant frequencies of 2.45 GHz and 5.8 GHz respectively.

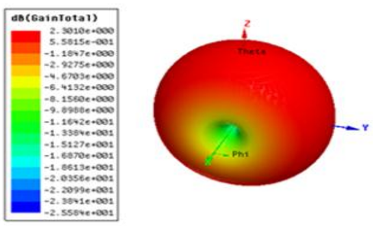
The far field radiation patterns of the proposed antenna in the E-plane (φ = 90°) and the H-plane (φ = 0°) for the resonant frequencies 2.45 GHz and 5.8 GHz respectively are represented in fig. 8.



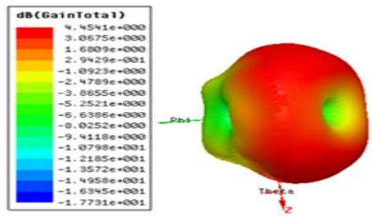
(a) (b)

Fig.8. Simulated radiation pattern of the proposed antenna in both E-plane and H-plane at (a) 2.45 GHz and (b) 5.8 GHz.

Fig. 9 presents the 3D radiation pattern at the resonant frequencies 2.45 GHz (a) and 5.8 GHz (b).



(a)



(b)

Fig. 9. 3D radiation pattern for the proposed antenna at resonant frequency 2.45 GHz (a) and 5.8 GHz (b)

The gain of the proposed antenna is about 2.30 dB and 4.45 dB at the resonant frequencies of 2.45GHz and 5.8GHz respectively. This result is satisfactory to ensure the proper functioning of this antenna for RFID applications.

V. CONCLUSION

Microstrip antenna has become a rapidly growing area of research. Their potential applications are limitless, because of their light weight, compact size and ease of manufacturing. In this paper, we design a miniaturized patch antenna in the microwave band. the return loss was below -10dB for both bands, with impedance bandwidth of 310 MHz and 240 MHz in 2.45 GHz and 5.8GHz respectively. The proposed antenna has been numerically analyzed and simulated using HFSS software. It has a simple design and a miniaturized size. The proposed antenna is intended for RFID reader applications in the microwave band.

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