5th International Conference on Control Engineering&Information Technology (CEIT-2017)
Proceeding of Engineering and Technology –PET
Vol.32 pp. 103-107

Miniaturization and Study of Substrate material of an Microstrip Patch Antenna for a Passive UHF RFIDTag

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***Abstract*— This paper present the miniaturization and study of the substrate material of a rectangular patch RFID antenna at at a resonance frequency of 915MHz. The chip used in this study is a chip Impinj Monza 4E, with an impedance of Zc = (11-j143) Ω in 915 MHz. We used a new method to miniaturize the patch antenna, the method is to change the material properties of substrate, we use a substrate with a high relative permittivity (ε_r), then we use a substrate with a high relative permeability (μ_r) and finally we use a magneto-dielectric substrate. The Simulation results obtained of this miniaturized antennas has an acceptable results in terms of adaptation, gain, efficiency, return loss (S_{11}), and VSWR.**

Keywords—Rectangular patch antenna ;RFID; Passive Tag;Magneto-dielectric ; Miniaturized atenna.

I. INTRODUCTION

The RFID is a technology that uses radio-frequency electromagnetic fields to transfer data by using an RFID tag and is becoming one of the most popular wireless communication techniques in the world, because it facilitates the daily life of the person on different areas, for example in distribution logistics and purchasing, industry, manufacturing companies, medicine, etc [1, 2].

An RFID system is composed of three main components, the reader, the tag and the host computer:

The tag consists of two parts, the chip and antenna, the chipset stores the unique data for the tag; the antenna allows the chip to receive power and transmit information [3, 4].

The reader is connected to the host computer which is used to program the reader and store information received from the tag [3,4].A simple scheme of the system is shown in Fig. 1.

The most used RFID Tag antennas operate in the UHF band (860-960 MHz) mainly because of the longer read range [5].

In this work, we present a miniaturized patch antenna for Passive UHF RFID tag; the method used consists to change the properties of the substrate material, we use the dielectric, magnetic and magneto-dielectric material for the design of the miniaturized patch antenna and finally we compare the obtained result.

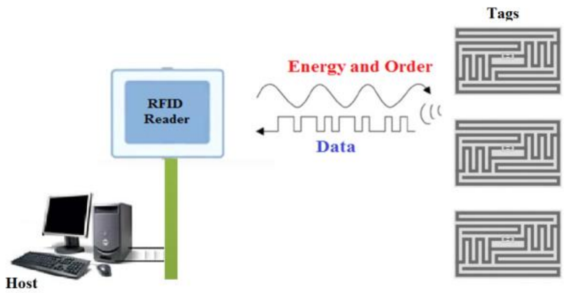

Fig. 1. scheme of an UHF RFID system.

II. THEORITICAL STUDY

Miniaturization of patch RFID antenna has been a topic of interest for a long time, among the methods used to miniaturize an antenna is to change the material properties of substrate by using a purely dielectric substrate with a high relative permittivity, patch antennas on high dielectric constant substrates have the benefit to reduce the element size because the length and the width of the patch are inversely proportional to the square root of ε_r(eq: (5) and eq:(7)), however it leads to narrow bandwidth also to decrease the radiation efficiency and the radiation pattern [6, 7].

According to the work of Hansen and Burke in [8], properly increasing the relative permeability leads to efficient size reduction for the microstrip antennas.

We using a magneto-dielectric (MD) substrate with relatively high permittivity and permeability, an RFID patch antenna printed on a magneto-dielectric material allows improvement of bandwidth and efficiency [9,10,11].

$$BP \approx \frac{96\sqrt{\frac{\mu_r}{\varepsilon_r}} \cdot \frac{h}{\lambda_0}}{\sqrt{2}(4+17\sqrt{\mu_r \varepsilon_r})} \quad (1)$$

Material characterization of magneto-dielectric substrate is to determine the frequency dependent permittivity, electric loss tangent ($tan\delta_e$) and the magnetic loss tangent ($tan\delta_m$), and

ISSN 2356-5608

also the substrate with permeability larger than the permittivity ($\mu_r > \varepsilon_r$) [10].

Using a dielectric or magneto-electric material allows the reduction of guided wavelength and thus causes the reduction of the physical length of the radiating element [12]. The electrical wavelength λ_g, is inversely proportional to the refractive index n of the substrate as:

$$n = \sqrt{\varepsilon_r \mu_r} \quad (2)$$

$$\lambda_g = \frac{c}{f_r\sqrt{\varepsilon_r \mu_r}} \quad (3)$$

$$L \cong \frac{\lambda_g}{2} \quad (4)$$

Where c is the speed of light and f_r is the resonant frequency of the antenna.

Wheeler defined an electrically small antenna as one whose maximum dimension is less than $\frac{\lambda_0}{2\pi}$ [13]. And λ_0 is the wavelength in air.

All the respective formulas and the calculated dimensions of the patch antenna are given below [14]:

$$W = \frac{c}{2fr\sqrt{\frac{(\varepsilon_r+1)}{2}}} \quad (5)$$

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}} \quad (6)$$

$$L_{eff} = \frac{c}{2fr\sqrt{\varepsilon_{reff}}} \quad (7)$$

$$\Delta L = 0.412h\frac{(\varepsilon_{rff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{rff}-0.258)\left(\frac{W}{h}+0.8\right)} \quad (8)$$

$$L = L_{eff} - 2\Delta L \quad (9)$$

Where W and L are the width and length respectively of the patch, ε_{reff} is the effective dielectric constant and L_{eff} is the effective length.

III. RFID Patch Antenna Design

The original antenna structure is introduced in [15], the proposed rectangular patch antenna has a resonant frequency of 915 MHZ; this antenna is composed of a rectangular radiating patch. It is achieved by using an FR4 substrate with:

- Dielectric constant $\varepsilon_r = 4.4$.
- Loss tangent $tan\delta = 0.02$.
- Height of dielectric substrate H = 1.59mm.

The chip used in this configuration is a Monza 4E chip, according to the data sheet of this chip, the impedance has a value of Zc= (11-j143) Ω at the frequency of 915 MHz [16]. In order to deliver the maximum power from the antenna to the chip, the input impedance of the antenna Za should be complex conjugate of the chip impedance Zc (Zc = Za*) [17]. Therefore, the antenna is designed for Za = (11 + j143) Ω. The initial rectangular patch antenna is represented in Fig 2.

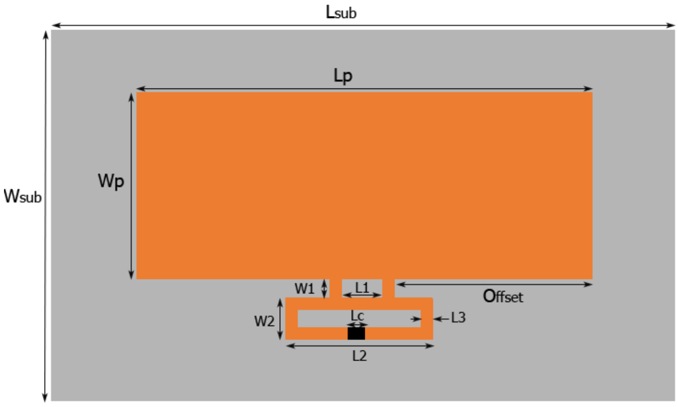

Fig. 2. The Geometries of the initial antenna.

The detailed dimensions of the initial antenna are listed in TABLE I.

TABLE I. DIMENSION OF THE INITIALPATCH ANTENNA .

Parameter	**Dimension(mm)**
W_{sub}	63
L_{sub}	126.8
W_P	37
L_P	99
L_1	7.7
L_2	25
L_3	1
L_c	3
W_1	1.5
W_2	6.5
Offset	44.65

IV. Results and Discussion

A. *Characterization of Substrate Material and Miniaturization*

1) Dielectric substrate

The Figures: Fig.3 and Fig.4 shows the effect of the relative permittivity of a dielectric substrate on the guide wavelength and the resonant frequency.

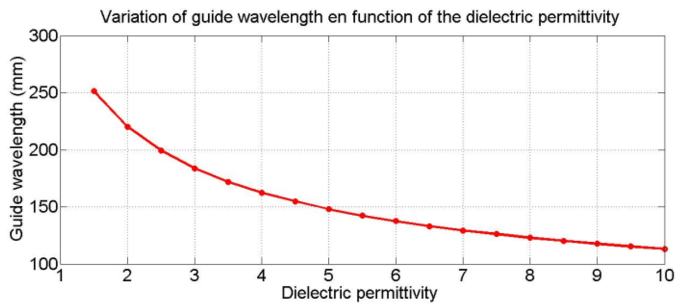

Fig. 3. Simulated $\lambda_g$guideed in the substrate on different value of ε_r.

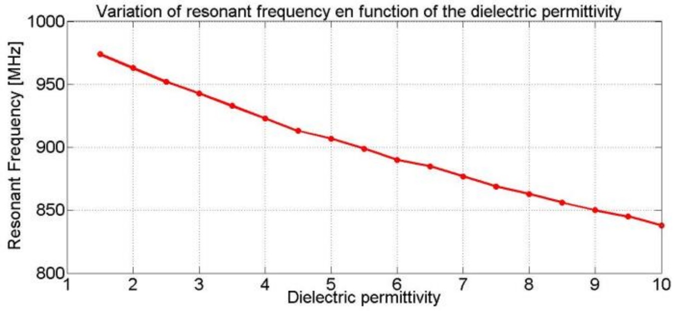

Fig. 4. The effect of ε_r on the resonant frequency.

2) *Magnetic substrate*

The Figures: Fig.5 and Fig.6 shows the relative permeability effect for a magnetic substrate on the guide wavelength and the resonant frequency.

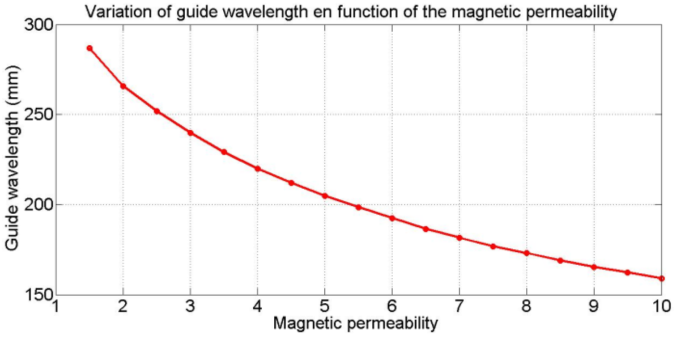

Fig. 5. Simulated λ_g guideed in the substrate on different value of the μ_r.

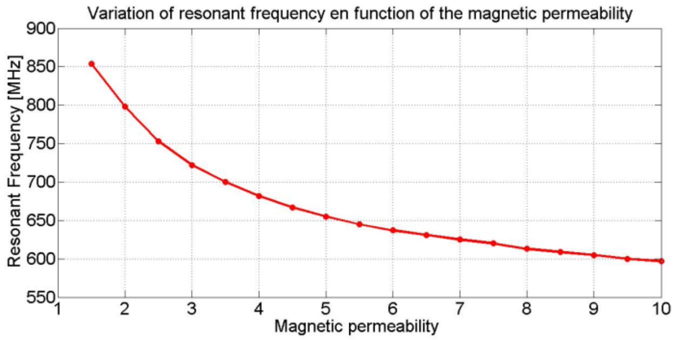

Fig. 6. The effect of the μ_r on the resonant frequency.

3) *Magneto-dielectric substate*

In this section we compare the main results of the studied patch for different materials knowing that the optical index $n = \sqrt{\varepsilon_r \mu_r} = 2.82$ remains constant.

The resonant frequency becomes inversely proportional to the refractive index of the material; the obtained results are summarized in the following table (Table II).

All the results shown in this table are for materials with loss tangent $tan\delta_e = tan\delta_m = 0.02$.

TABLE II. THE EFFECT OF THE SUBSTRATE ON THE RESONANT FREQUENCY.

Relative Permittivity (ε_r)	*Relative permeability (μ_r)*	*Resonant Frequency(MHz)*
8	1	852.9
7	1.14	840.9
6	1.33	813.9
5	1.6	784.9
4	2	754.9
3	2.66	717.9
2.66	3	702.9
2	4	669.9
1.6	5	649.9
1.33	6	633.9
1.14	7	622.9
1	8	612.9

B. *Return Loss*

The simulated return loss results of the different antennas proposed are shown in Fig. 7.

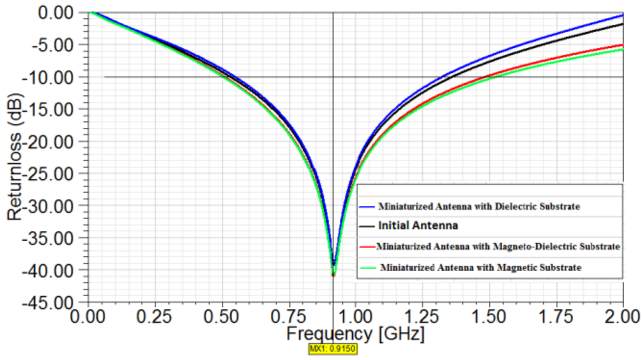

Fig. 7. Simulated return loss (S11).

C. *Input Impedance*

Fig. 8 and Fig. 9 shows the simulated input resistance and input reactance for the miniaturized antennas and the initial antenna.

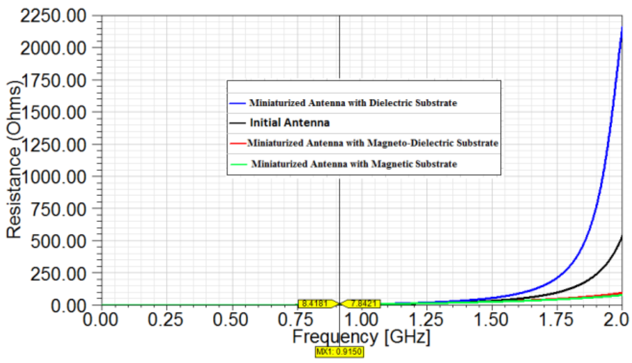

Fig. 8. Simulated input resistance.

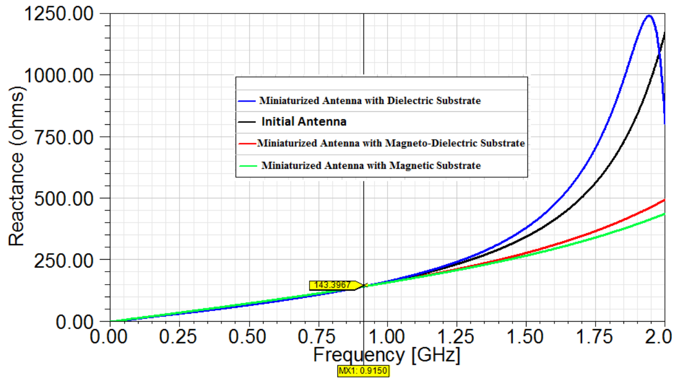

Fig. 9. Simulated input reactance.

D. *Radiation Patterns*

Fig .10 illustrate the simulated radiation patterns for the miniaturized antennas and the initial antenna at 914.9MHz in the H-plane and the E-plane, the radiation pattern is bidirectional in the H-plane and omnidirectional in the E-plane.

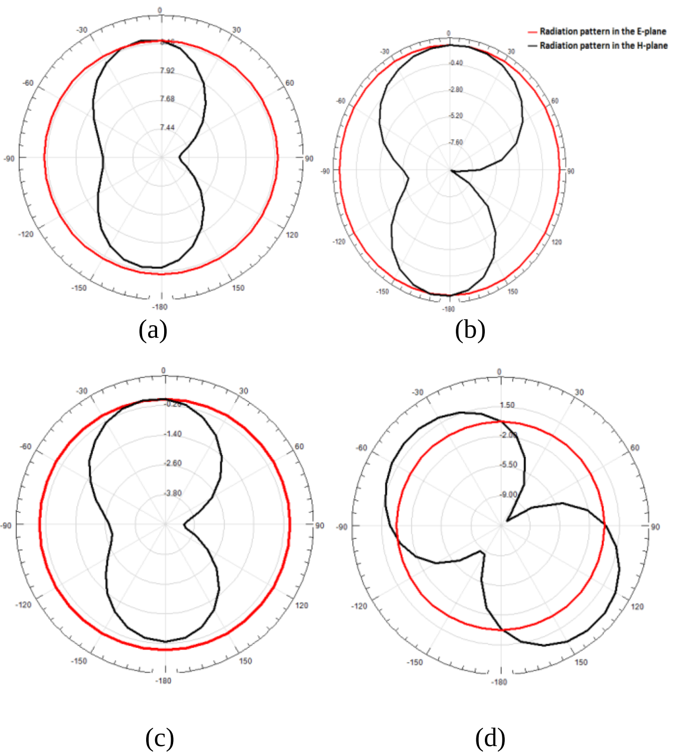

Fig. 10. Simulated radiation patterns at 914.9MHz for the initial antenna (a) the miniaturized antenna with dielectric substrate (b), antenna with magnetic substrate (c) and antenna with magneto-dielectric substrate (d).

The obtained results for the proposed antenna, are resumed in Table III and Table IV.

TABLE III. THE DIFFERENT ANTENNA PARAMETERS.

Parameters	**Miniaturized antenna with different substrate materials**		
	Dielectric	***Magnetic***	***Magneto-Dielectric***
ε_r	6.4	1	2
μ_r	1	5.5	4
W_{sub}[mm]	63	62.67	63.8
L_{sub}[mm]	79.9	80.8	79.8
W_p[mm]	37	37	37
L_p[mm]	53	53	52
L1[mm]	8	13	8
L2[mm]	24	25	20.6
L3[mm]	1	1.8	1.8
Lc[mm]	3	3	3
W1[mm]	1.5	1.5	1.5
W2[mm]	6.5	6.17	7.3
Offset[mm]	21.5	18.2	20.2

TABLE IV. COMPARISON BETWEEN THE CHARACTERISTICS OF THE ANTENNAS.

Antenna type	**The electrical characteristics of the antenna**			**The radiation characteristics of the antenna**	
	VSWR (dB)	***Return Loss (dB)***	***Input impedance (Ω)***	***Gain (dB)***	***Radiation Efficiency (%)***
Non-Miniaturized antenna	0.19	-38.78	7.71+j143.2	8.21	89.8
Miniaturized antenna with dielectric substrate	0.91	-39.17	7.86+j143.3	2.23	86.3
Miniaturized antenna with magnetic substrate	0.16	-40.63	8.35+j143.3	1.6	89.3
Miniaturized antenna with magneto-dielectric substrate	0.15	-40.82	8.41+j143.3	4.62	87.03

V. CONCLUSION

In this paper, we have presented the miniaturization of the RFID Tag antenna and studied the effect of the relative permittivity and the relative permeability of the substrate on the guide wavelength and the resonance frequency.

The initial rectangular patch antenna for an RFID tag is operating at 915.9 MHz, its miniaturization is achieved by the use of a purely dielectric substrate, magnetic substrate and magneto-dielectric substrate. We conclude that the miniaturized antenna with magneto-dielectric substrate has good results compared to the other substrates in terms of return loss (S11), gain (G = 4.62 dB) and input impedance. Then the miniaturization of the antenna can be obtained using magneto-dielectric materials with improved performance.

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