



Frequency Reconfigurable UHF RFID Dipole Tag Antenna Using a PIN Diode

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Abstract. This paper presents a design approach for a RFID reconfigurable dipole antenna for the UHF band. The frequency reconfiguration of this antenna, with a PIN diode, makes it possible to cover two frequency bands namely the European band (865.5–869 MHz) and the American band (902–928 MHz). The designed antenna is a copper dipole ($e = 0.035$ mm) printed on a FR4 epoxy substrate $\epsilon_r = 4.4$ with a volume of $90 \times 25 \times 1.6$ mm³. The reconfiguration was done by connecting a PIN diode to the ends of the two lines drawn at the top. The antenna has a 390 MHz (810–1200 MHz) bandwidth and covers the entire UHF RFID band. With reference to a 4w EIRP, the antenna can be read from 17 m. The simulations were done with HFSS which allowed us to find the antenna parameters, depending on the ON and OFF states of the PIN diode.

Keywords: RFID · PIN diode · UHF band · Tag antenna · Frequency reconfiguration

1 Introduction

With the development of RFID technology, UHF RFID (Ultra High Frequency 860–960 MHz) [1] is growing rapidly, notably thanks to the development of low cost liabilities Tags. The passive UHF tag technology with an emitted power of the order of 2 W makes it possible to reach a reading distance of about ten meters [2]. RFID systems are closely related to smart cards for storing data. These data are stored in an electronic device: the tag.

RFID antennas often encounter certain constraints such as capacity limitation, manufacturing cost, functionality in certain frequency bands. As a result, studies have been directed towards multiband functionality, significant miniaturization, the use of new dielectric materials and the strengthening of multifunctional capacities. In order to meet these needs, innovative methodologies are necessary for antennas design.

Data transfer takes place via electromagnetic waves. Their applications make it possible to choose the frequencies of use, but our study will be limited to the UHF band (860–960 MHz). It is made up of two physical entities which are the tag and the RFID reader. In the UHF band, communication takes place by scattering electromagnetic waves through antennas on either side as shown in Fig. 1.

The RFID reader or interrogator consists of an RF module or base station (transmitter and receiver) which emits electromagnetic waves and receives the information sent by the tag through antennas in order to transmit them to the control device or host system. While the tag or receiver is composed of a chip which is adapted to an antenna which has the role of radiating an electromagnetic wave during the transmission of the data stored in the chip. This technique involves in contactless reading and writing of data in the non-volatile memory of the RFID tag through backscattered RF signals. The voltage that develops across the antenna terminal powers the chip and returns information to the reader by varying the input impedance and modulating the backscattered signals [8]. A very important factor in the design is the impedance matching which allows the tag to recover the maximum energy received by its antenna and transmit it to the chip.

In the literature, many RFID tag antennas are designed using different substrates and metallic track materials [7–13]. Different tag antennas are designed based on different chips available on the market to operate in the UHF frequency band [9–11]. Most of them can only reason on one frequency band. Some non-reconfigurable dual-band antennas were designed to cover the European and American RFID UHF bands as in [12]. However, the goal was to design a UHF RFID tag antenna that could operate in two frequency bands such as the European and American frequency bands by frequency reconfiguration using a PIN diode.

In this paper, we present a frequency reconfigurable miniature UHF RFID dipole antenna by insertion of a PIN diode. This antennas can operate in two UHF bands: European band (865–869 MHz) and American band (902–928 MHz). This antenna is made of a copper printed on an epoxy FR4 substrate ($h = 1.6$ mm and $\epsilon_r = 4.4$) and is suitable for the Monza R6 chip. Simulations are done with the Ansys's electromagnetic simulation software named HFSS.

The remainder of the article is divided into a three sections: the second presents the design process of the sample (non reconfigurable) antenna and also the simulation results of the antenna. The Sect. 3 presents the simulation results of the reconfigurable antenna. The Sect. 4 concludes article.

2 Antenna Design Parameters

The design of the UHF tag antenna should have properties such as omnidirectional radiation, wide bandwidth and impedance matching with the chip to ensure maximum power transfer as shown in 1 [5].

$$Z_{ant} = Z_{chip}^* \quad (1)$$

Z_{ant} indicates the impedance of the UHF RFID tag antenna while, Z_{chip}^* is a complex conjugate of the input impedance of the chip [6]. Since RFID chips are often capacitive, the tag antenna must have an inductive impedance to achieve complex impedance

matching. If the antenna parameters (gain, power transfer efficiency and wavelength) are Known, it is possible to calculate the reading range of the RFID tag antenna from 2 [6].

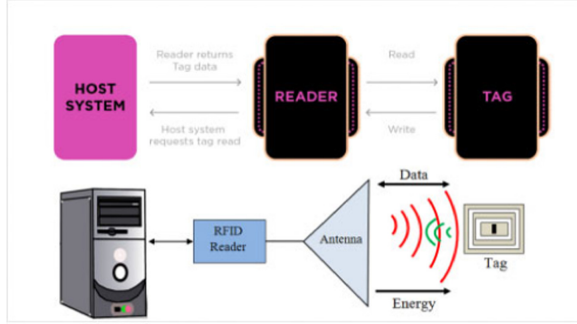


Fig. 1. RFID system bloc diagram

$$r_{\max} = \frac{\lambda}{4\pi} \sqrt{\frac{P_{EIRP} G_R}{P_{th}}} \tau \tag{2}$$

Here, λ is the wavelength, P_{EIRP} is the effective isotropic radiated power transmitted by the reader equivalent to $P_t G_t$ where P_t is the transmitted power and G_t the gain of the transmitting antenna, G_R is the gain of the reception antenna tag, P_{th} is the minimum power threshold to activate the RFID tag chip. While τ is defined as the power transmission coefficient indicated by [5]:

$$\tau = \frac{4R_c R_a}{|Z_a + Z_c|^2} \quad 0 < \tau < 1 \tag{3}$$

where $Z_c = R_c + jX_c$ is the tag IC impedance and $Z_a = R_a + jX_a$ is the tag antenna impedance.

2.1 UHF RFID Dipole Antenna

The antenna chosen is a dipole antenna, with meandering folds for miniaturization, which is printed on a $25 \times 90 \text{ mm}^2$ epoxy FR4 substrate with $\epsilon_r = 4.4$ and thickness of $h = 1.6 \text{ mm}$. The radiating plane is a copper dipole whose thickness is $e = 0.035 \text{ mm}$ and the line width is $W = 1 \text{ mm}$. After doing a parametric study on the length of all the horizontal bars L and the gap between two horizontal random breaks $W1$, while fixing the other parameters, we found $L = 14.5 \text{ mm}$ and $W1 = 2.5 \text{ mm}$. In the same way we found the other parameters such as $L1 = 32 \text{ mm}$, $L2 = 4 \text{ mm}$, $L3 = 24 \text{ mm}$, $L4 = 3 \text{ mm}$, $W1 = 2.5 \text{ mm}$ and $Wc = 2 \text{ mm}$. The antenna is designed to resonate first in the American frequency band then the insertion of a PIN diode allowed us to cover two bands of frequencies such as the European and American bands by adjusting the

state of the diode (ON and OFF) respectively. The technique adopted for the frequency reconfiguration of this antenna is based on the inserting of PIN diode by connecting two stubs at the top of the design Fig. 2. This antenna is suitable for the Monza R6 chip fromimpinj, which has the following characteristics: (13.5-j126.56) Ohms at 866 MHz and (11.9-j118.4) Ohms at 915 MHz [3].

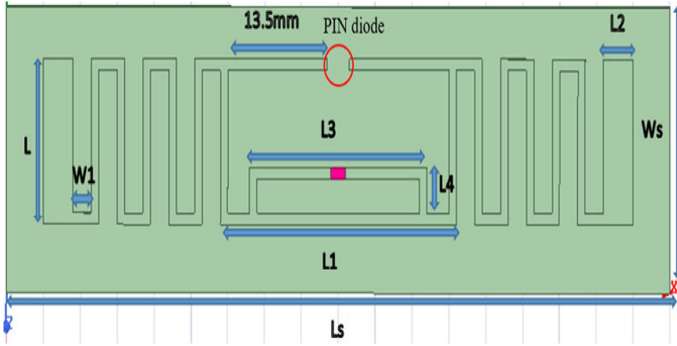


Fig. 2. Reconfigurable UHF RFID dipole antenna

2.2 Antenna Simulations Results Without PIN Diode

With these parameters, the antenna resonates at 916.7 MHz (Fig. 3) with a reflection coefficient of -45.86 dB and an input impedance of $13.02 + j118.88$ Ohms which is very close to the conjugate of that of the chip. This means a very good match between the antenna and the chip that will allow the RFID tag to recover the maximum energy that will be sent to it by the reader.

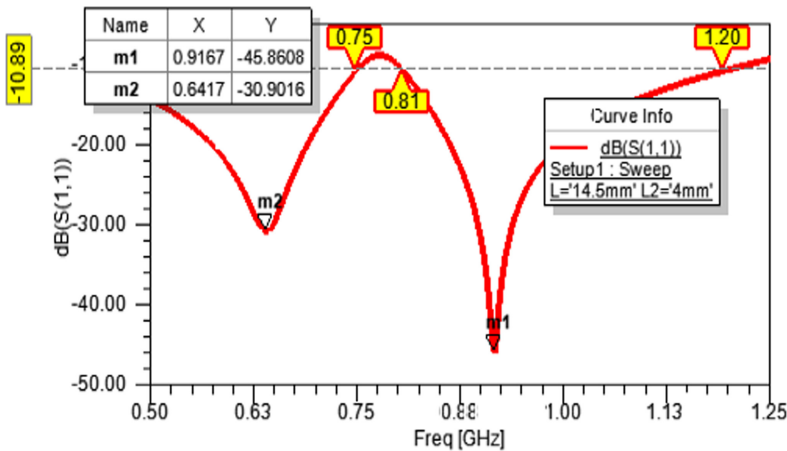


Fig. 3. Power reflection coefficient

Thus, we obtained a gain of 1.9 dB (Fig. 4) and a directivity of 2.1 dB which gives us a radiation efficiency of 90.47%. The antenna covers a wide bandwidth of 390 MHz (810–1200 MHz) for any Power reflection coefficient $S_{11} \leq -10$ dB.

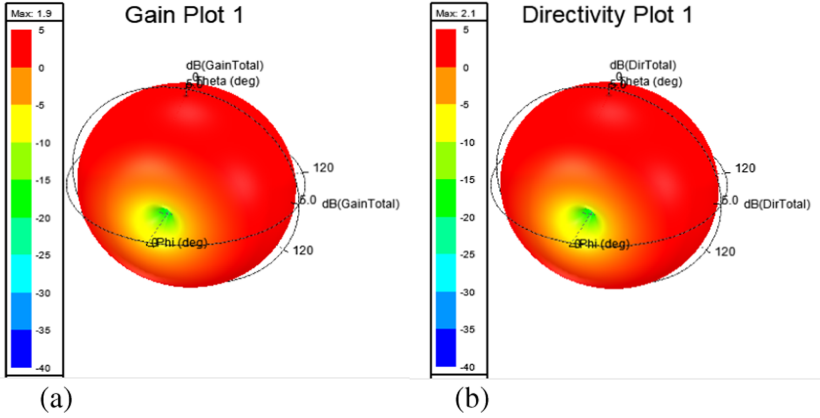


Fig. 4. 3D antenna gain (a) and directivity (b)

3 UHF RFID Antenna Reconfiguration

A reconfigurable antenna is an antenna of which at least one of the characteristics is modifiable after its completion, by application of an electronic component [4]. There are several antenna reconfiguration techniques such as using PIN diode, Varicap diode, MEMS (Micro ElectroMechanical Systems) and optical switches etc.

Our choice on the PIN diode is based on the two frequency bands to be covered, namely the American frequency band and the European one, by playing on the ON and OFF states of the PIN diode.

The diode used is the BAR64-02V whose datasheet is as follows (Fig. 5 and Table 1):

We keep the same antenna parameters by inserting the PIN diode at the level of the two stubs Fig. 2. However, the antenna resonates towards the lowest frequencies (866.7 MHz) in the ON state then in the OFF state towards high frequencies 913.3 MHz around the starting frequency (antenna without diode).

3.1 Results of Simulations of the Reconfigured Antenna

In the ON state, the inductive effect of the diode, which has the role of increasing the electric length of the lines of the folded dipole, allowed us to vary the resonant frequency from 916.7 MHz to 866.7 MHz located in the European band while covering a 380 MHz band at -10 dB with a reflection coefficient of -37.8915 dB Fig. 6. The increase in the reflection coefficient can be explained by losses due to the insertion of an active

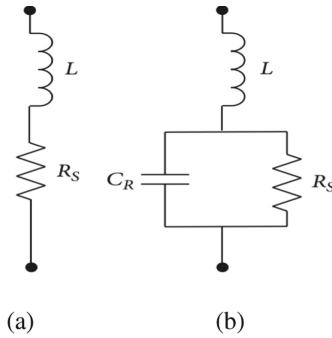


Fig. 5. PIN diode equivalent circuit (a) ON state (b) OFF state.

Table 1. Datasheet of the PIN diode BAR64-02V

PIN diode	Resistance (R)	Inductance (L)	Capacitance (C)
ON	2.8 Ω	0.6 pH	-
OFF	3 K Ω	0.6 pH	0.17 pF

component. The insertion of the diode causes a slight variation in the input impedance, which is $14.62 + j119.67 \Omega$, which is a little close to the calculated impedance $13.5 + j126.56 \Omega$ Fig. 7.

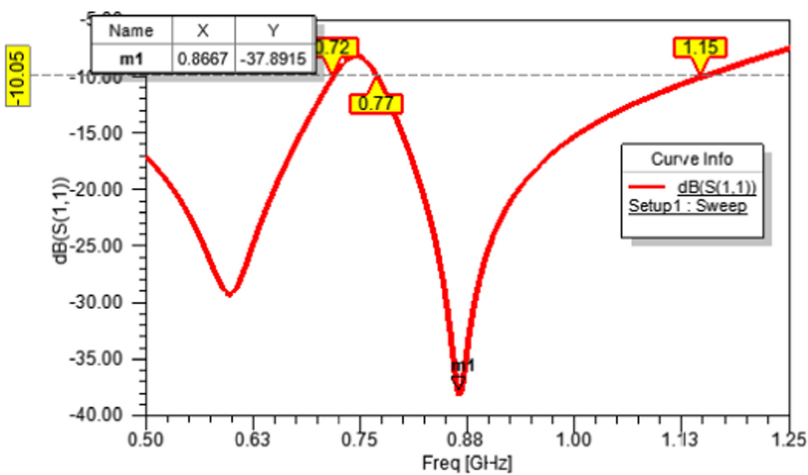


Fig. 6. Reflection coefficient in the ON state

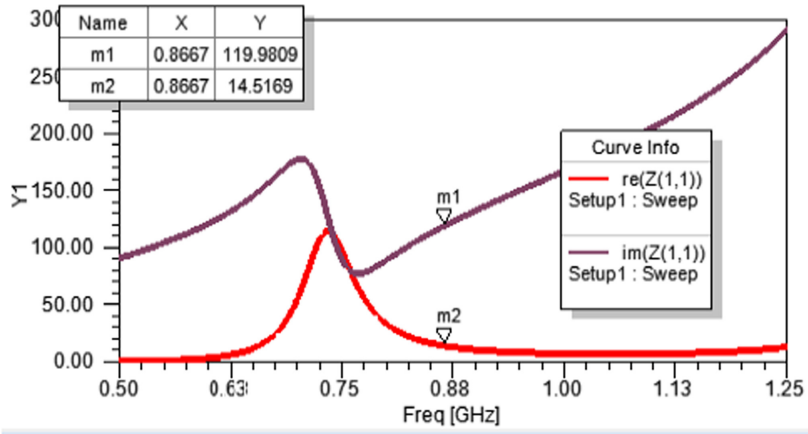


Fig. 7. Antenna impedance in the ON state

It provides a gain of 1.7 dB and a directivity of 2.1 dB which is anonymous with radiation efficiency of 80.95%. Due to the losses caused by the insertion of the diode on the antenna circuit, the antenna loses power which is the cause of the decrease in gain.

Due to the high resistivity of the diode and the capacitive effect which compensates the effect inductive of the diode in the OFF state, the antenna manages to resonate in the American band at 913.3 MHz with a reflection coefficient of -40.53 dB and a band of 400 MHz Fig. 8 as well as a good match of $13.91 + j119.28 \Omega$ Fig. 9.

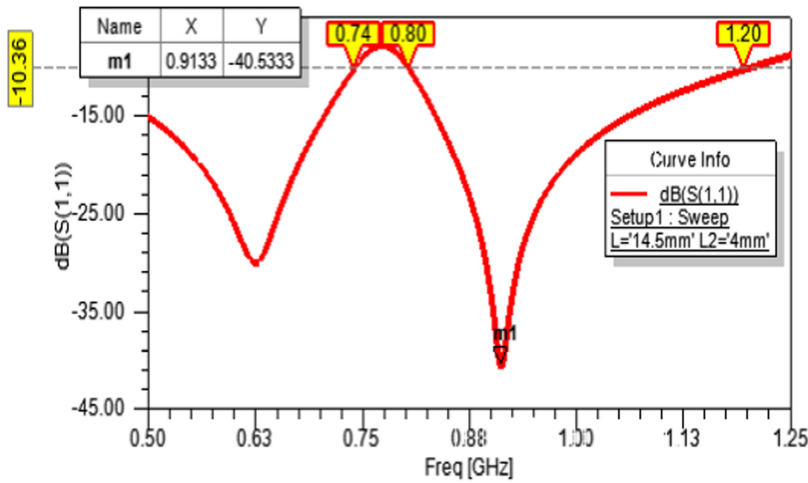


Fig. 8. Reflection coefficient in the OFF state

This antenna in the off state has a gain of 1.8 dB with a directivity of 2.1 dB which means that it is 85.57% efficient. Since the adaptation of the antenna to the state OFF

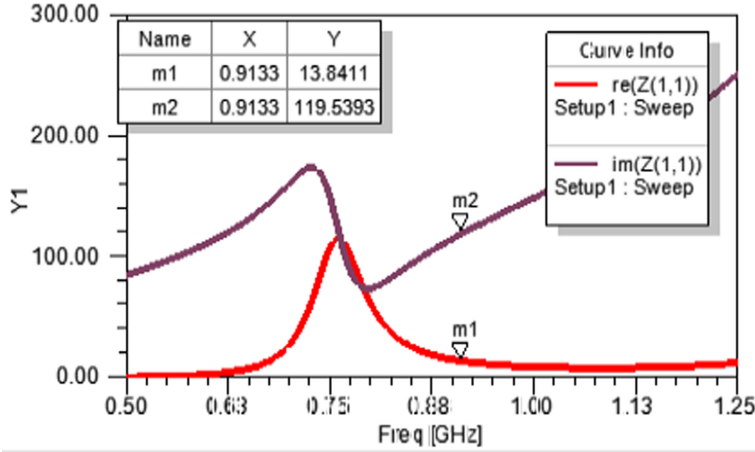


Fig. 9. Antenna impedance in the OFF state

being a little better than that in the ON state with the chip, the antenna gains more power which is the origin of a insignificant increase for the gain increase from 1.7 dB to 1.8 dB.

3.2 Comparison of the Results of the Proposed Antenna with the Results of Some Previous Dual-Band Antennas

The maximum reading range of an RFID tag is determined from the Eq. (2). According to the latest regulatory status of RFID in the EPC Gen2 band (860–960 MHz), the RFID transmission frequency ranges in some countries is shown in Table 2 [7].

Table 2. UHF band frequency and power allocation

Country/Region	Frequency range (MHz)	Power (W ERP)
Europe	865.6–867.6 915–921	4
USA	902–928	4
China	920.5–924.5	2
Japan	916.7–920.9	4

In Europe, the European Telecommunications Standards Institute (ETSI) is responsible for propose regulations in the field of telecommunications. The allowed value for the EIRP in Europe is 3.3 W while in America the EIRP is 4 W. Based on these ETSI standards, we calculated the RFID tag read range at each state. The sensitivity of the chip is -20 dBm [3]. The results are recorded in Table 3.

The comparison between the performance of our work and certain work has been made. The results are reported in the following table.

Table 3. Comparison table of the results of the proposed antenna with the results of some previous dual-band antennas

S. nos.	Substrate	Reconfiguration	Tag volume (mm ³)	Gain (dB/dBi) (865–869 MHz)	Gain (dB/dBi) (902–928 MHz)	Read Range (m) (865–869 MHz)	Read Range (m) (902–928 MHz)
[12]	FR4 epoxy	NO	60 × 20 × 1.6	−0 dB	−0.17 dB	5.5	5.8
[13]	FR4 epoxy	NO	139 × 32 × 1.6	0.94 dB	0.94 dB	17.4	16.8
This work	FR4 epoxy	YES	90 × 25 × 1.6	1.7 dB	1.8 dB	17.7	20.03

These results show that the proposed antenna, with a long read range and its ability to cover two frequency bands, is a good candidate for UHF RFID applications.

4 Conclusion

In this paper, we have proposed a frequency reconfigurable UHF RFID tag antenna capable of operating in two band regions i.e. European band and American band. This antenna printed on an epoxy FR4 substrate is small in size and is a broadband antenna. It can be used in many areas of RFID applications with long range. After simulations, we obtained a gain of 1.9 dB, a directivity of 2 dB, a radiation efficiency of 90.47% as well as a maximum reading range of 20.43 m. The insertion of the PIN diode in the antenna design resulted in low losses on the impedance adaptation as well as for the radiation. Due to a time constraint, the realization of this antenna was not made. In our next publications, we plan to carry out the construction and measurements of the proposed antenna. The reduction in size as well as the use of a ground plane as a reflector would be a major advantage, which will allow us to take measurements in more complex environments.

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