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Study of the PIFA Antenna for RFID Applications

Loubna Berrich and Lahbib Zenkouar

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Abstract

In this chapter, we did an introduction to radio frequency identification (RFID) technology, to define the different components of this system, then the frequencies of utilization for this application, and finally the advantages and disadvantages of this technology. Then we presented the design and simulation of a planar inverted-F antenna (PIFA) with a T-shaped slot. We studied the effect of changing the type of feed supply, the type of substrate, and the position of the connecting line between the ground plane and the radiating element. We chose the frequency of resonance of the antenna for the RFID applications at 5.8 GHz. The results obtained by the HFSS software are very satisfactory with a very minimal return loss.

Keywords: PIFA, RFID, slot, return loss, HFSS

1. Introduction

Radio frequency identification (RFID) is a technology used mainly to identify tagged items or to track their locations. The identification technology by radio frequency (RFID) uses electromagnetic fields to automatically identify and track tags attached to objects. The tags contain electronically stored information; passive tags collect energy from a nearby RFID reader's interrogating radio waves. Active tags have a local power source (such as a battery) and may operate hundreds of meters from the RFID reader. The first secure system identifying the friend and the foe (IFF) was the first form of RFID's technology. In 1948, Stockman (Stockman, 1948) proposed the identification from distance. He defended that it is possible to vary the amount of reflected power (also called load modulation antenna) by the alternation of the load of the tag antenna and consequently it has a modulation. Identification by radio frequency, known as RFID, is a smart technology that is very performed, flexible, and more suitable to automatic operations. RFID is an automatic identification method using radio waves

to read the data contained in the devices called tag RFID. RFID technology is used to monitor, identify, and track objects, animals, and people away. The RFID system has two key features: RFID tag (label) and RFID reader. Today, this technology finds use in access controls, vehicle safety, animal tracking and patients in hospitals, and other applications [1].

The purpose of this chapter is the design and simulation of a PIFA with a T-shaped slot. We studied the effect of changing the type of feed supply, the type of substrate, and thus the position of the connecting line between the ground plane and the radiating element. The PIFA consist of a radiating element of length equal to the quarter wave and of a short circuit of several types: plane, tongue, or wire. This structure has advantages over a traditional patch antenna: cost and ease of manufacture, reduced size, thin profile, and bandwidth.

2. Principle of RFID

RFID is part of automatic identification technologies; this technology makes it possible to identify an object or a person, to follow the path and to know the characteristics at a distance thanks to label emitting radio waves, attached to or incorporated into the object or person. RFID technology allows reading of labels even without direct line of sight and can cross thin layers of materials [2, 3].

2.1. Components and operation of the RFID system

RFID includes labels, readers, encoders, and middleware which allow integrating the flow of data in the information system of the company.

2.1.1. The tag

One of the most used identification methods is to house a serial number or a sequence of data in a chip and connect it to a small antenna. This couple (chip + antenna) is then encapsulated in a support. These "tags" can then be incorporated in objects or be glued on products, **Figure 1**. The format of the data on the labels is standardized at the initiative of electronic product code (EPC) Global.
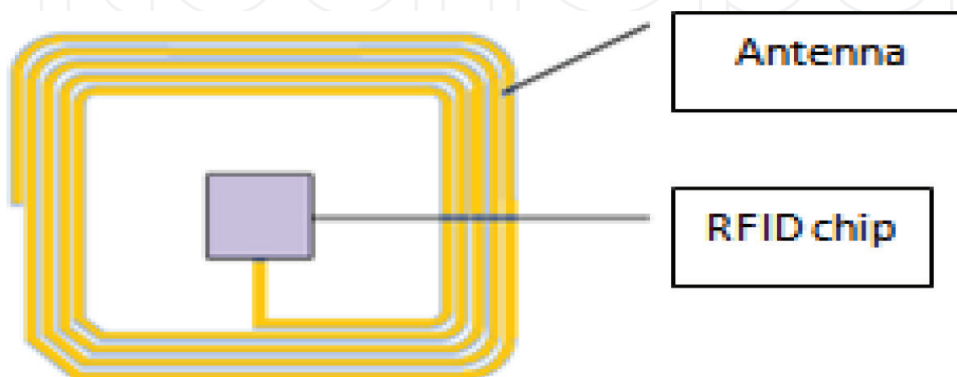
Figure 1. Tag antenna.

2.1.2. The reader

The reader/recorder is constituted of a circuit that emits electromagnetic energy through an antenna and an electronics that receives and decodes the information sent by the transponder and sends them to the data collection device. Not content to read RFID tags, he is able to write their content. The RFID reader is the element responsible for reading radiofrequency labels and transmitting the information they contain (EPC code or other, status information, crypto-graphic key, etc.) to the next level of the system (middleware). This communication between the reader and the label takes place in four stages:

1. The reader transmits by radio the energy necessary for the activation of the tag.

2. It launches a query querying the tags nearby.

3. It listens to answers and eliminates duplicates or collisions between answers.

4. Finally, it transmits the results obtained to the applications concerned.

2.2. The different types of tags and their technical specificities

2.2.1. Active tags and passive tags

To exploit the information contained in these labels, it is imperative to have the appropriate reader. This one emits radio waves toward the capsule which allows to supply it with energy (electromagnetic induction feed); in other words to activate it, these chips are not able to per-form dynamic treatments but only to return static data (**Figure 2**).

2.2.2. Passive tags (without battery)

Without any external power supply, they depend on the electromagnetic effect of receiving a signal emitted by the reader. It is this current that allows them to power their microcircuits. They are inexpensive to produce and are generally reserved for volume productions. They
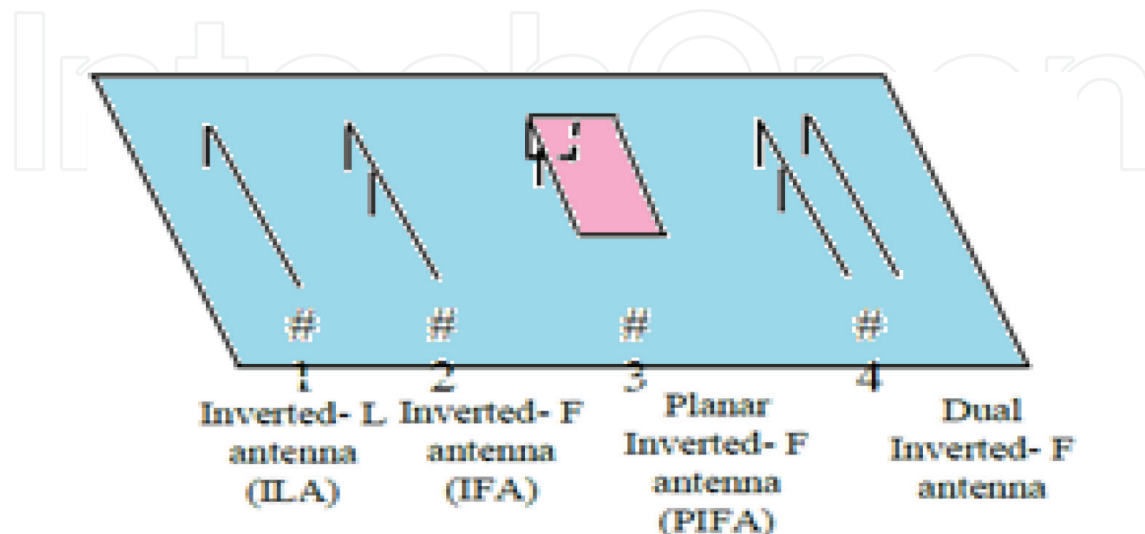
Figure 2. The different geometries of the inverted antennas.

are the ones we find especially in logistics and transport. They use different radio frequency bands according to their capacity to transmit remotely more or less important and through different substances (air, water, metal). The reading distance is less than 1 m. Low and high frequencies are standardized worldwide. These chips are stuck on the products for a follow-up. They are disposable or reusable depending on the case.

2.2.3. Semi-passive tags

These tags are similar to passive ID cards. They use similar technologies but with some important differences. They also have a small battery which works constantly, which frees the antenna for other tasks, in particular the reception of return signals. These tags are more robust and faster in reading and transmission than passive tags, but they are also more expensive.

2.2.4. Active tags

Active tags are the most expensive because they are more complex to produce and provide transmission functions, functions of capture or processing of the captured information, and either or both. Thereby, they need an onboard power supply you have to know that these labels prove particularly well adapted to certain functions, including the creation of authentication systems, security, anti-theft, etc.

Short, they are ideal for triggering an alert or alarm. They can emit several hundred meters.

2.3. Frequencies used in RFID

RFID systems generate and reflect electromagnetic waves. In particular, RFID systems must be careful not to disrupt the operation of other radio systems. We cannot, in principle, use only the frequency ranges specifically reserved for industrial, scientific, or medical applications. These frequency ranges are called industrial-scientific-medical (ISM). The main frequency ranges used by RFID systems are the low frequencies (125 and 134.5 kHz) and ISM frequencies: 6.78, 13.56, 27.125, 40.68, 433.92, 869.0, 915.0 MHz (not in Europe), 2.45, 5.8, and 24.125 GHz.

2.4. Advantages and constraints of radio frequency tags

The advantages of radio frequency labels over the barcode are

• The ability to update the content

Unlike bar code for which data are frozen once printed or marked, the content of the data stored in a radio frequency tag will be able to be modified, increased, or decreased by authorized stakeholders (read and write tags).

• Greater content capacity

Certainly bar codes that can store important content data appeared these last years, two-dimensional or matrix barcodes. However their use in industrial or logistic worlds remains problematic; they require conditions printing and reading. The commonly used barcodes are limited to data contents of less than fifty characters and in these extreme cases require an A4

or A5 size label. In a radio frequency tag, a capacity of 1000 characters is easily storable on 1 and 2 mm and can easily reach 10,000 characters in a logistics label affixed to a pallet.

• The marking speed

The barcode in a logistic context most often requires the printing of a paper medium. Handling and labeling are manual or mechanical operations. The radio frequency labels can be included in the handling support or in the packaging from the outset. Data concerning objects contained or transported are written in a split second at the time of the constitution of the logistics or transport unit, without further manipulation.

• Security of access to the content

Like any digital medium, the radio frequency tag can be protected by password in writing or reading.

The data can be encrypted. In the same label, a part of the information can be freely accessible and the other protected. This faculty makes the RF tag, a tool adapted to the fight against theft and counterfeiting.

• Longer life

In applications where the same object can be used multiple times, as the identification of handling supports, or the consignment of the container, a radio frequency tag can be reused 1,000,000 times.

• Greater positioning flexibility

To enable the automation of the reading of the logistic barcode labels, standardization bodies like EAN, have defined positioning rules on logistics units. With the radio frequency tag, it is possible to abstract constraints related to optical reading; she does not need to be seen. It is enough for him to enter the field of the reader so that his presence is detected.

• Better protection against environmental conditions

RFID tags do not need to be positioned outside the object to be identified. They can therefore be better protected from attacks related to storage, to the handling or transport. In addition, their operating principle does not make them susceptible to soiling or various spots that interfere with the use of the barcode.

2.5. Constraints of radio frequency labels

• Disturbance by the physical environment

The reading of radio frequency tags is disturbed by the presence, for example, of metals in their immediate environment. Solutions must be studied case by case to minimize these disturbances.

• Disturbances induced by the labels between them

In many applications, several radio frequency tags may occur at the same time in the reader's field voluntarily or involuntarily. This can be wanted in store, at the time of checkout or between anti-theft doors.

In this last case just detect a stolen object, a label not inhibited by the box. Technology allows it today. More complex is the need to identify and read the contents of several labels in a field without forgetting; to do this the readers use algorithms or anti-collision techniques, etc.

- Sensitivity to parasitic magnetic waves

In certain circumstances, RFID reading systems are sensitive to spurious electromagnetic waves issued by computer equipment (computer screens) or lighting systems more generally by electrical equipment. Their use must be tested taking into account the environment.

- The regulatory constraints related to the impact on health

This question has been debated for a few years, in particular concerning the anti-theft gates and cell phones. Passive tags themselves present no risk whatever their number is since they are active only when they are in the field of a reader. The studies therefore focus on readers and aim to define the regulatory criteria of their emission power to prevent them from creating disruptions.

2.6. Examples of applications

RFID tag applications are already very numerous; we give some examples of the possibilities offered by this technology:

- Tracking and sorting luggage

The airlines are currently studying the replacement of RFID tags.

- The automatic toll

Many management companies' toll motorways have already put in place systems subscription based on RFID tags and microwave, placed in vehicles. Subscribers benefit in special way of crossing toll gates. Payment is made without stopping the vehicle, by simply reading his identification.

- Access control

RFID tags are already used for access control of buildings or car parks.

- Animal tracking

More and more applications of animal traceability are growing, whether it's ear tags on farm animals or the subcutaneous labels for horses or pets. In all cases, it's about ensuring animal traceability for the purpose of sanitary control or the quality of herds.

- Cleaning clothes

For the cleaning of work clothes, companies are putting in place systems uniform identification based on RFID tag with a diameter of 20 mm and a thickness of 2.5 mm, the frequency 13.56 MHz read/write at 20 m.

These labels are attached to the garment; they resist washing operations. They allow a follow-up of the washing operations and easy identification of the wearer of the uniform.

- Waste collection

In Europe as well as in Japan and the United States, household or industrial waste collection companies are concerned with improving the load distribution of garbage collection and treatment. The principle is to equip each bin or container of an RFID tag and the collection trucks for readers and weighing system, so that each operation can automatically identify the "producer" and measure the weight of the collected material.

- Supply chain management

In logistics, four levels of applications can be distinguished:

- Delivery

- Home

- In transit

- Local

At the time of shipment, labels can facilitate the collection of products and the constitution of pallets, sorted by destination and loading control. The label may contain, in addition to the product identification, or the contents of a pallet, that of the manufacturing lot number, consignee identification, order number, handling details, etc. This information collected at the time of loading can be stored in the RFID tag container or means of transport to facilitate checks during transit, customs, access, or exit authorization. Similarly, upon receipt of the goods, the data can be collected to automatically perform audits and update the inventory and make reconciliations with commercial documents or EDI messages. In transit, the label is used to trace the product at each point of loading and unloading or simply passing. Thus, the sender can be informed at any time transport stream. Locally, labels allow product inventory but also media management handling and equipment (gas bottles, etc.).

3. The choice of the PIFA

There are several types of antennas for RFID applications; among these antennas we mention that antennas of the planar inverted-F antenna (PIFA) type are the most used in portable devices for GSM, Wi-Fi, RFID applications, etc. due to their low manufacturing cost and their compactness, as it has very small dimensions compared to a half-wave antenna. The PIFA is obtained by placing the short circuit (plane, wired, or tongue-like) between the half-wave resonator and the ground plane, at the precise point where the electric field vanishes for the fundamental mode. This makes it possible to overcome one half of the resonator and thus have an X/4 resonance. This type of antenna has the advantage of presenting a desired quasi-isotropic radiation in RFID applications, since the relative orientation of the tag relative to the reader is uncertain.

4. Study and design of a PIFA

4.1. Structure of a PIFA

The PIFA is the result of the transformation of the inverted-F antenna (IFA) from a horizontal wire element to a planar structure to compensate for his loss of maladjustment and improve its radiation characteristics. The planar inverted-F antenna (PIFA) is a quarter wave antenna integrated and miniaturized by comparing it with monopole antennas. Also, it has good advantages over a traditional patch antenna (cost and ease of manufacture, small size, and bandwidth). The inverted plane antenna F is a rectangular microstrip antenna powered by a coaxial probe. It is called an inverted-F antenna because the side view of this antenna resembles the letter F with its face down [4, 5–9].

The ILA consists of a short vertical monopole with the addition of a long horizontal arm at the top. Its input impedance is almost equivalent to that of the short monopole with the addition of the reactance caused by the horizontal wire above the ground plane. In general, it is difficult to match the impedance to a power supply line since its input impedance consists of low resistance and high reactance. Adding the additional inverted-L element adjusts the input impedance of the antenna. The impedance bandwidth of the IFA antenna is less than 2% on the center frequency. One way to increase the bandwidth of the IFA antenna is to replace the upper horizontal arm with a plate oriented parallel to the ground plane to form the inverted plane antenna F (PIFA). More generally called planar inverted-F antenna (PIFA) in the scientific literature, they have the advantage of being compact with a wide bandwidth. **Figure 3** shows the different elements of the PIFA [4].

Figure 4 shows the side view of the PIFA.
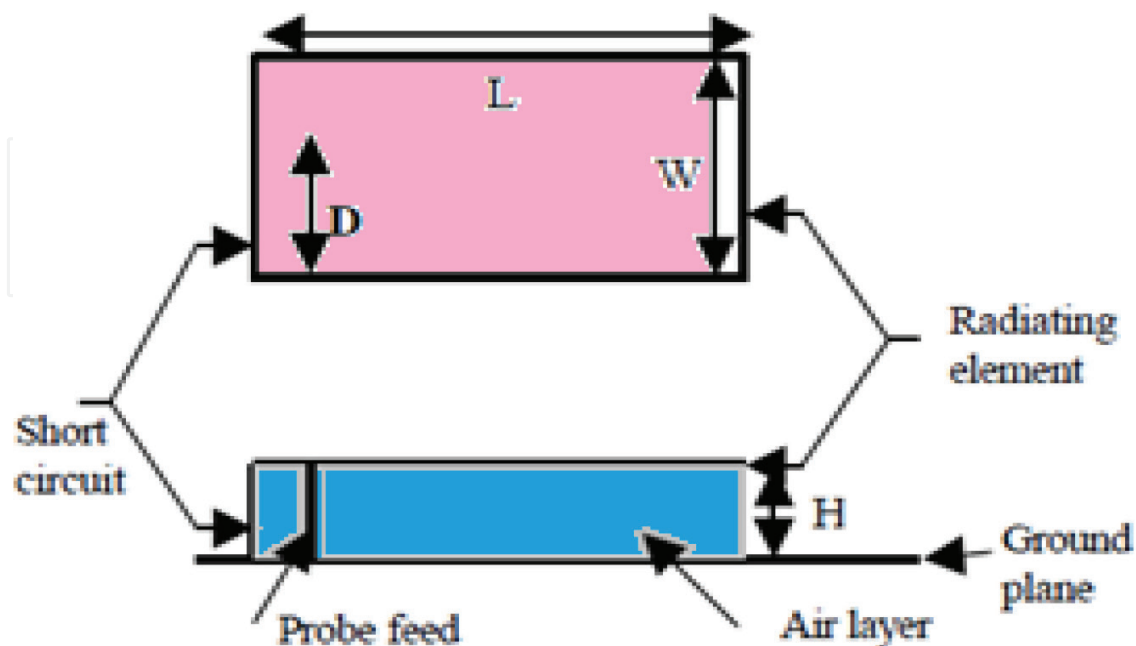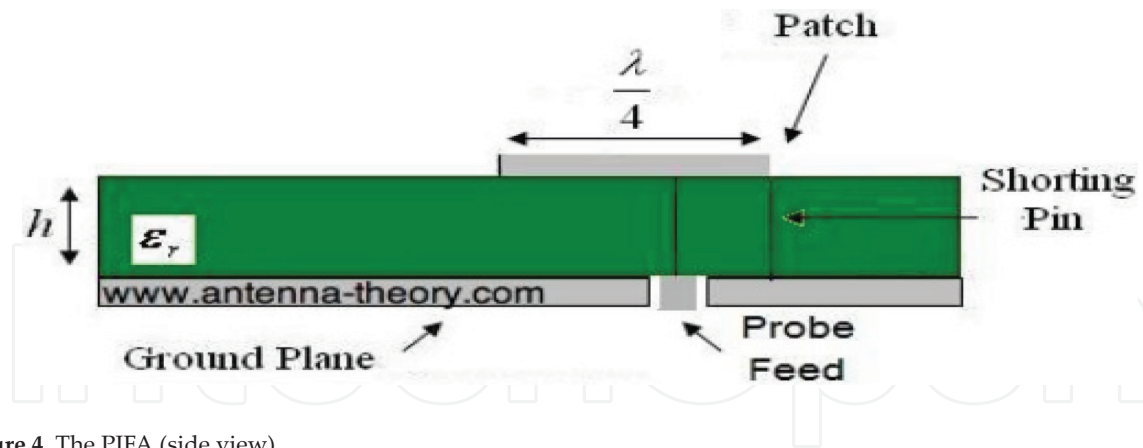

Figure 3. The PIFA.
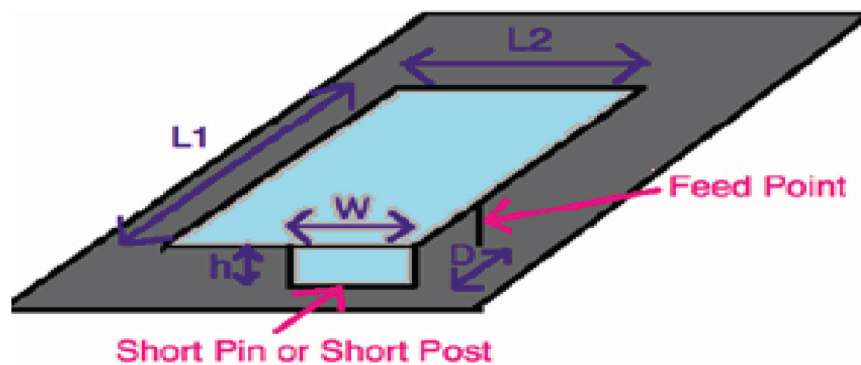
Figure 4. The PIFA (side view).

Figure 5. PIFA.

More generally called planar inverted-F antenna (PIFA) in the scientific literature, they have the advantage of being compact with a large bandwidth; it is mainly characterized by the presence of a plate that plays the role of a short circuit between the radiating patch and the ground plane as shown in **Figure 5** where h is the height of the short circuit, W its width, and D the distance between the short circuit and the feed point of the patch antenna.

The resonance frequency of a PIFA is approximated by equation (Eq. (1)).

$$L_1 + L_2 - W = \frac{\lambda}{4} \tag{1}$$

With L_1 and L_2 the dimensions of the radiating patch, λ is the calculated wavelength for the medium separating the patch and the ground plane [4, 5–9].

5. Results and discussion

The antenna proposed is an antenna consisting of a rectangular patch with a width W = 20 mm and a length L = 18 mm placed on a substrate with a width W = 30 mm and a length L = 30 mm using FR4_epoxy, characterized by a relative permittivity of 4.4, a relative permeability of 1,

tgδ of the dielectric losses = 0.02, and a thickness e = 0.7 mm. The antenna is connected to the ground plane through a rod with a height h = 10 mm and a width of 10 mm, **Figure 6**.

5.1. Effect of the slot

In contrary to a conventional PIFA, the short circuit is not realized over the entire width of the antenna but through a flat short circuit which is a metal tongue of width W. A T-slot with a width of 0.5 mm in the metal radiating element ensures a good match between the impedance of the chip and the input impedance of the PIFA. The geometry of this antenna is shown in **Figure 7**.

The Ansoft high frequency structure simulator (HFSS) logger is a very high-performance microwave simulator that models and simulates 3D global fields radiated by microwave structures (antennas, filters, guides, connectors, PCBs, etc.). Characteristics for antennas such as (Gain, SAR, VSWR, Sij, etc.). It is based on the finite element model which consists in solving the equations of the field in discrete points defined in an orderly way in the complete domain of the structure. It directly solves the Maxwell equations in their differential form by replacing the differential operators by difference operators, thus realizing a discretization approximation.

The results of the both PIFA antennas with and without slot at 5.8 GHz are:

Figure 8 shows the return loss of the PIFA, S11 = −21 dB with a bandwidth equal to 200 MHz.

Figure 9 shows the reflection coefficient of the PIFA, s_{11} = −33 dB with a passband equal to 150 MHz.

Figure 9 shows that our antenna is well adapted.

Another essential character for knowing the parameters of the antenna is the SWR of the antenna PIFA.

Figure 10 shows the SWR of the antenna PIFA SWR = 1.09 < 2.

The SWR parameter of the PIFA fitted with a T-slot is less than 2 (**Figures 11–13**).
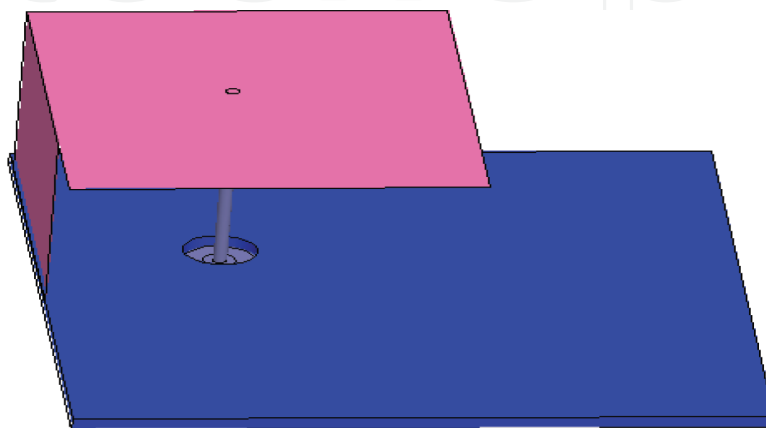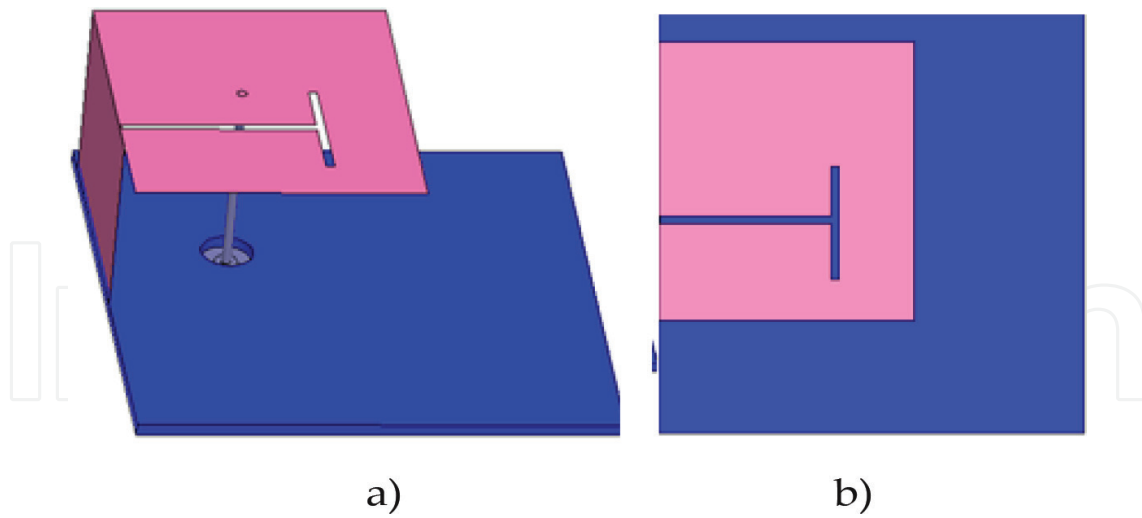

Figure 6. The structure of the PIFA on HFSS.

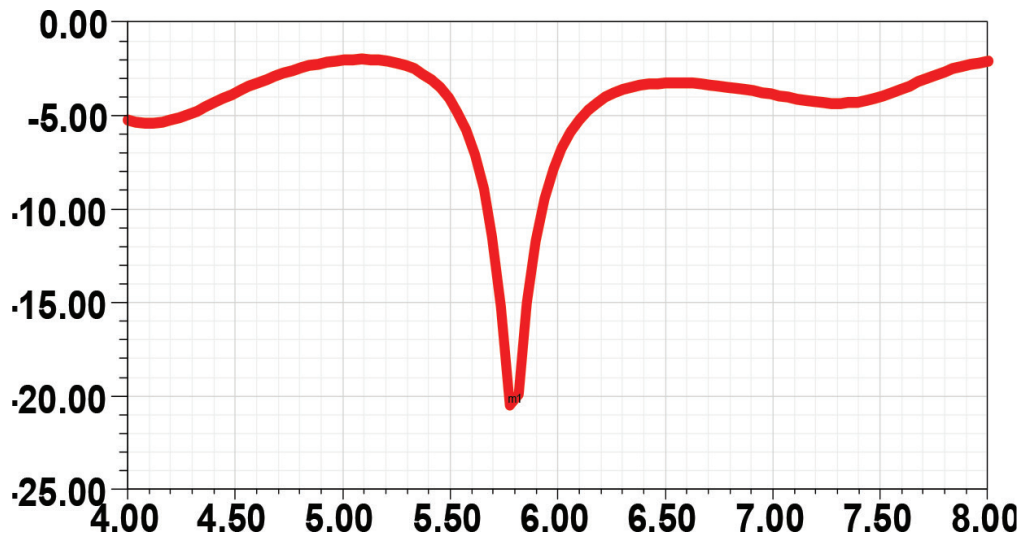**Figure 7.** The structure of the PIFA with T-slot on HFSS. (a) side view and (b) top view.
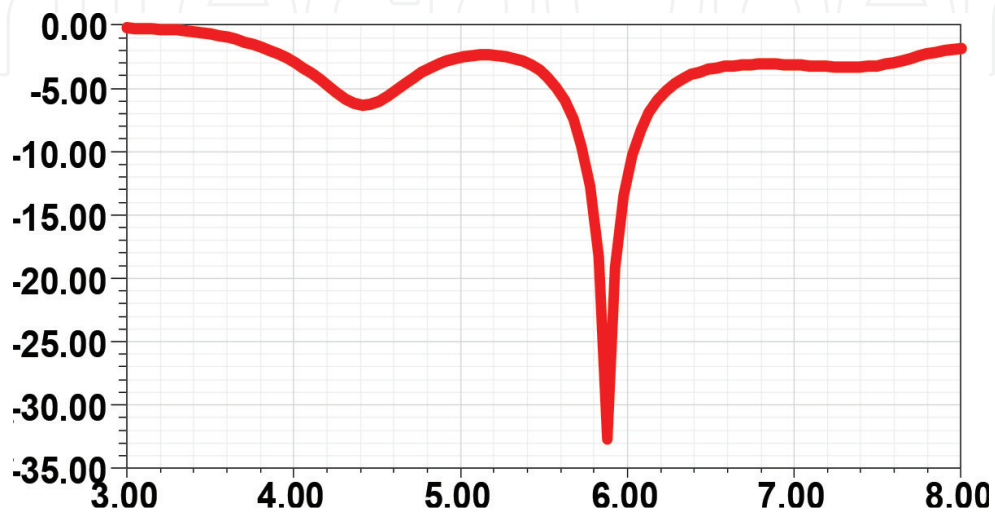

Figure 8. Return loss of the PIFA.

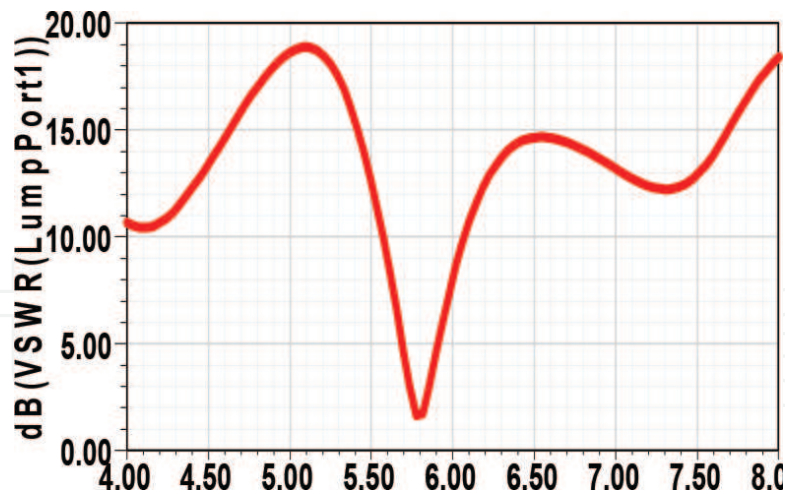**Figure 9.** Reflection coefficient of the PIFA.
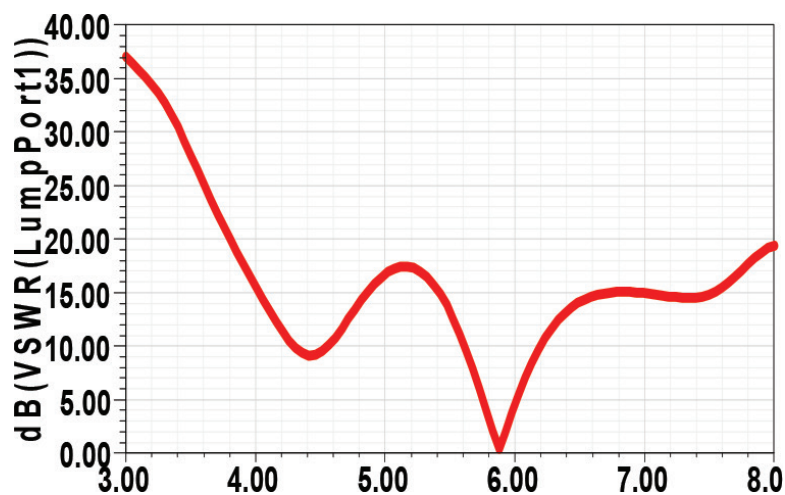
Figure 10. The SWR of the PIFA.

Figure 11. The SWR of the antenna with T-slot.

The appearance of **Figure 14** shows the gain of the PIFA without slot equal to 2.4 dB around the resonance frequency 5.8 GHz.

The appearance of **Figure 15** shows the gain of the PIFA is equal to 3.4 dB around the resonance frequency 5.8 GHz (**Table 1**).

From the results obtained, we notice that the T-slot has a positive effect on our PIFA: a decrease in return loss and an increase in gain.

5.2. The effect of changing the substrate type

Changing the substrate has a major effect on the antenna especially on the return loss and the resonance frequency. In this work we studied the effect of substrate change; we used three types of substrate: FR4 epoxy with a permittivity equal to 4.4, Rogers RT/Duroid 6006 with a permittivity equal to 6.15, and Rogers RT/Duroid 5880 with a permittivity equal to 2.2.
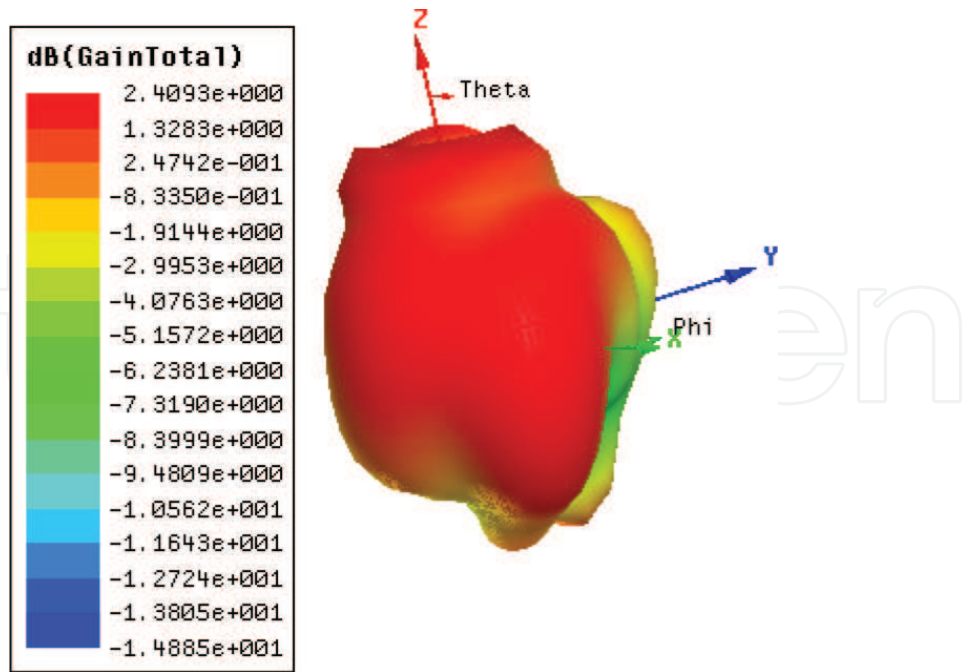
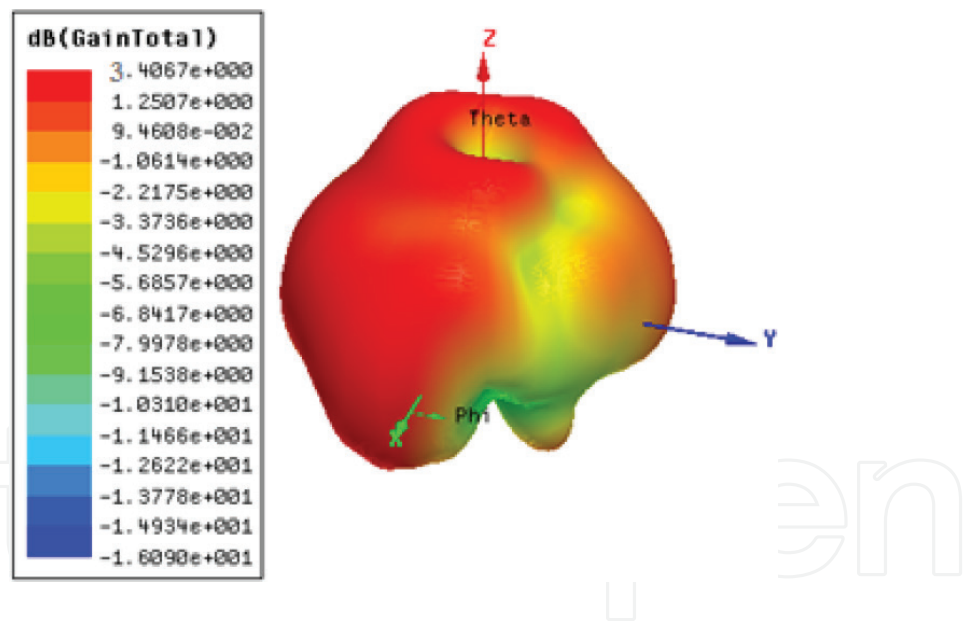**Figure 12.** The 3D radiation pattern of the PIFA.

Figure 13. The 3D radiation pattern of the PIFA with T-slot.

Figures 16–18 show the reflection coefficient of the PIFA for the three substrates used:

The change of substrate has a major effect on the antenna especially on the reflection coefficient and the resonant frequency used in this work. To achieve the resonance frequency 5.8 GHz, it is necessary to modify the dimensions of the radiating element, which automatically influences the reflection coefficient.

The following table summarizes the results of the three simulations:
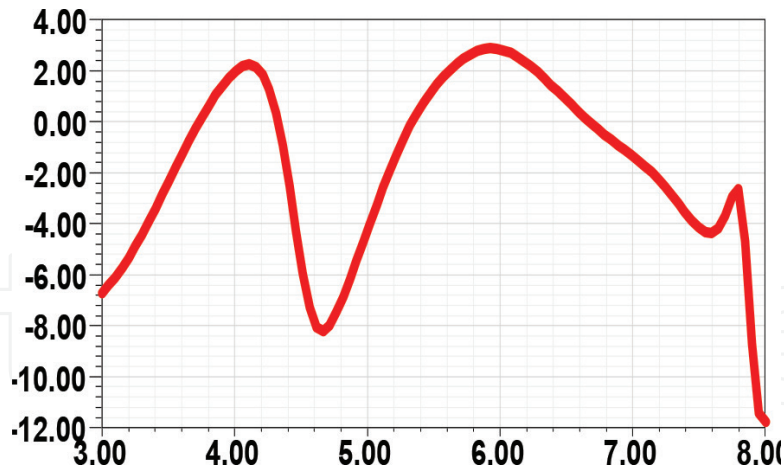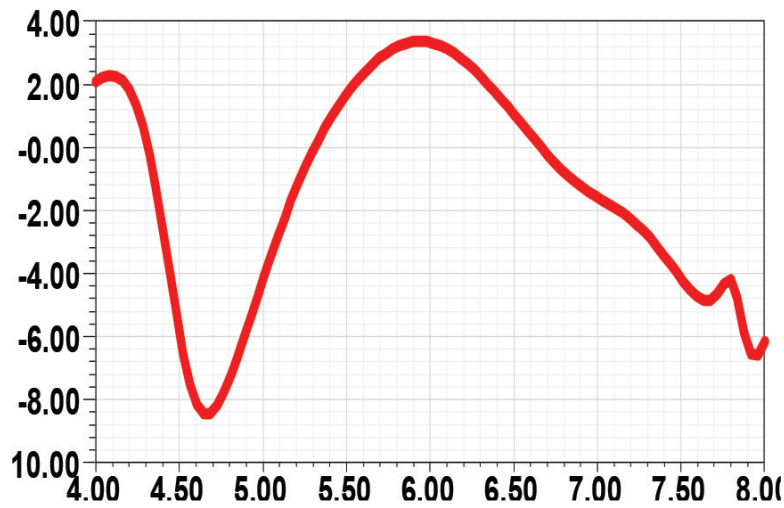
Figure 14. Gain of the PIFA.

Figure 15. Gain of PIFA with slot.

	PIFA without T-slot	PIFA with T-slot
S_{11}	–21 dB	–33 dB
Gain	2.4 dB	3.4 dB
SWR	1.09	1.01

Table 1. Recapitulation of the results.

From **Figures 16–18** and **Table 2**, we noted that for the substrate FR4 epoxy (εr = 4.4), the antenna resonates at (5.8 GHz) with a return loss is equal to −33 dB.

For RO6006 (ε_r = 6.15) the antenna resonates at (5.78 GHz), and the return loss is −26 dB, but for Ro5880 (ε_r= 2.2), the antenna has a resonant frequency (5.8 GHz) with a return loss of −17 dB.
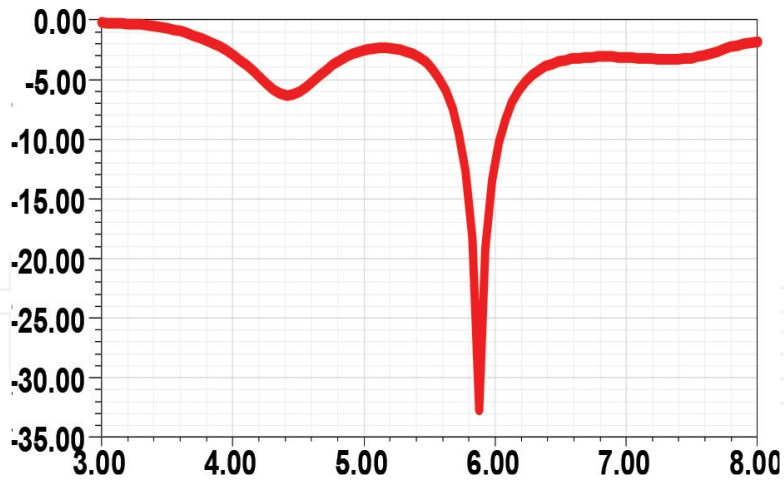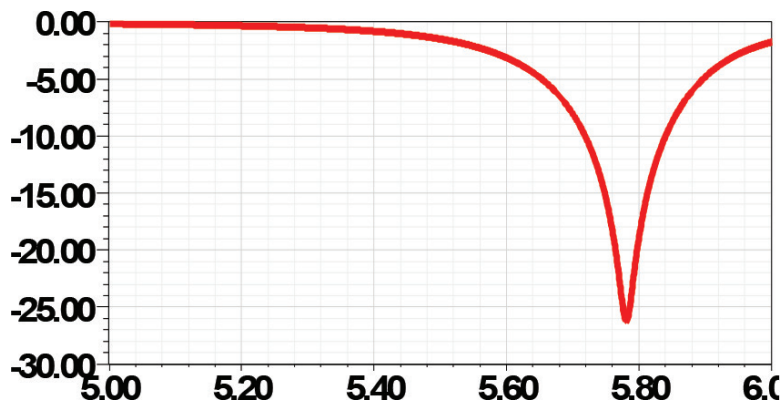
Figure 16. Return loss (epoxy FR4).

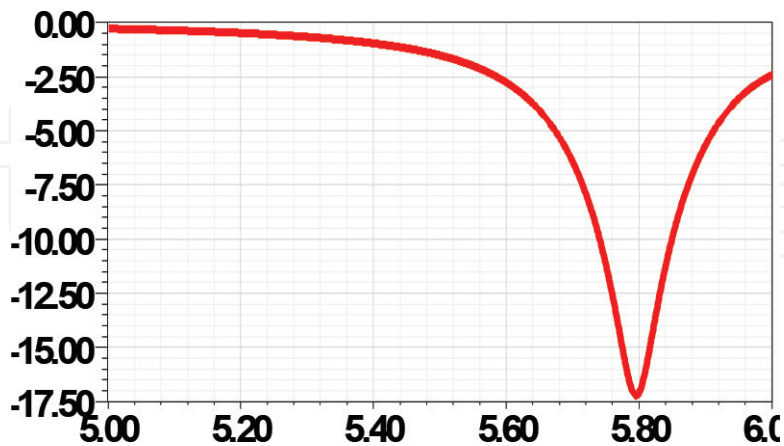**Figure 17.** Return loss (Rogers RT/Duroid 6006).

Figure 18. Return loss (Rogers RT/Duroid 5880).

5.3. Changing the position of the line

The connecting line between the substrate and the radiating element of the PIFA can take several positions, either at the end or at the center of the radiating element.

In this study we compared the results of simulations of the PIFA with three different positions of the connection line.

Figures 19–21 present the return loss of the antenna PIFA for the three positions.

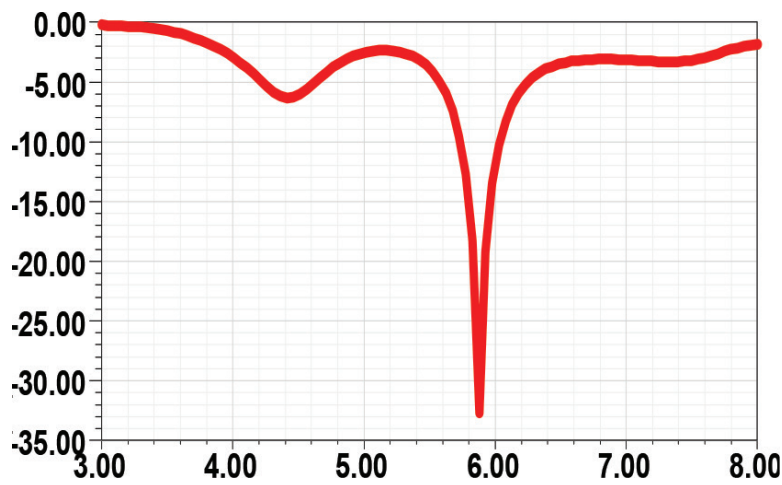|	RO5880	FR4 epoxy	RO6006
Width	32 mm	30 mm	29 mm
Length	26 mm	26 mm	26 mm
f_r	5.8 GHz	5.8 GHz	5.78 GHz
S_{11}	−17 dB	−33 dB	−27 dB

Table 2. Recapitulation of the results.

Figure 19. Return loss (Position 1).
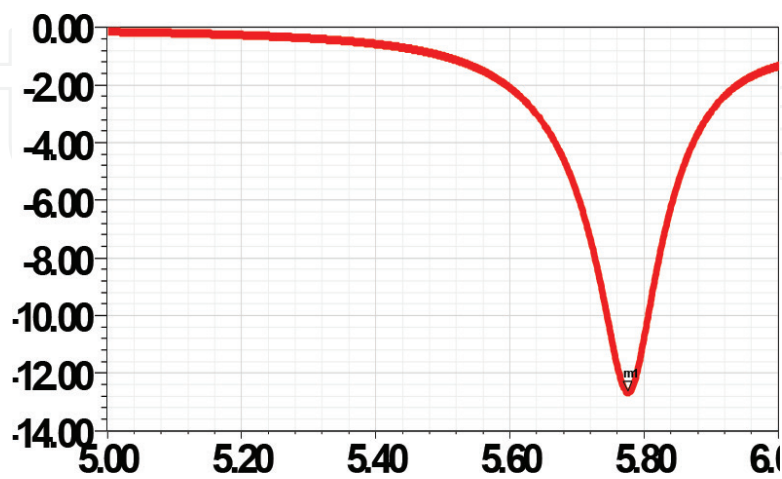
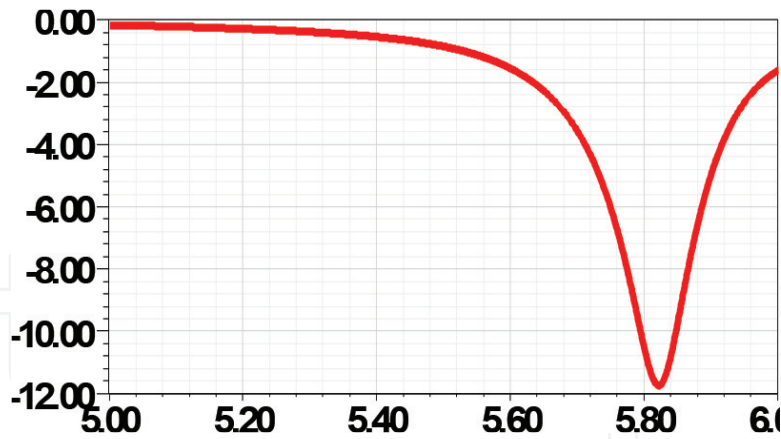**Figure 20.** Return loss (Position 2).

Figure 21. Return loss (Position 3).

Position	P_{x1}	P_{x2}	P_{x3}
S_{11}	−33 dB	−20 dB	−17 dB

Table 3. Recapitulation of the results.

From **Figures 19–21** and **Table 3**, we noted that for = 10 mm the antenna resonates at (5.8 GHz) with a return loss is equal to −33 dB. For P_{x2} = 15 mm the antenna resonates at (5.78GHz) and the return loss is –26 dB, but for P_{x3} = 20 mm, the antenna has a resonance frequency (5.8 GHz) with a return loss is of –17 dB.

Based on the results we deduced that as one moves away from the end of the radiating element the return loss becomes greater.

5.4. Change of power supply type

Microstrip feed line and the coaxial cable feed are easy to implement; nevertheless this type of power supply generates of parasitic radiation, which affects the radiation pattern. In this study we chose to feed our antenna via a coaxial cable and secondly via a microstrip line. We will compare the results obtained for these two feeding modes. To use these power modes, the microstrip line or the coaxial cable is adapted. For printed antennas this is parameter S_{11} which reflects the adaptation of the antenna.

In this work, we chose to feed our antenna via a microstrip line and secondly via a coaxial cable. We will compare the results obtained for these two modes of feeding. To use these power modes, it is necessary that the microstrip line or the coaxial cable is adapted. For printed antennas it is the parameter S11 that reflects the adaptation of the antenna. Otherwise, an antenna is considered suitable and isolated when the parameter S_{11} is less than −10 dB, which equates to at least 10% of losses. **Figures 22** and **23** show the reflection coefficient of the PIFA fed via a coaxial cable and a microstrip line.
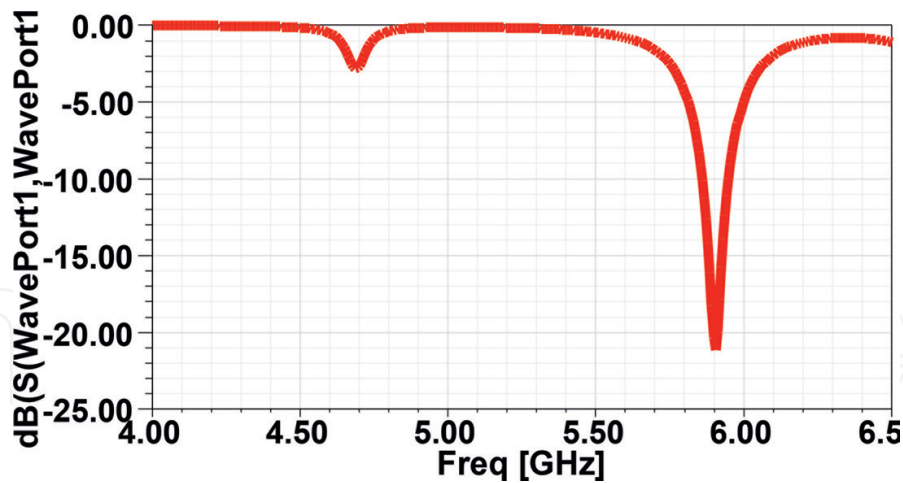
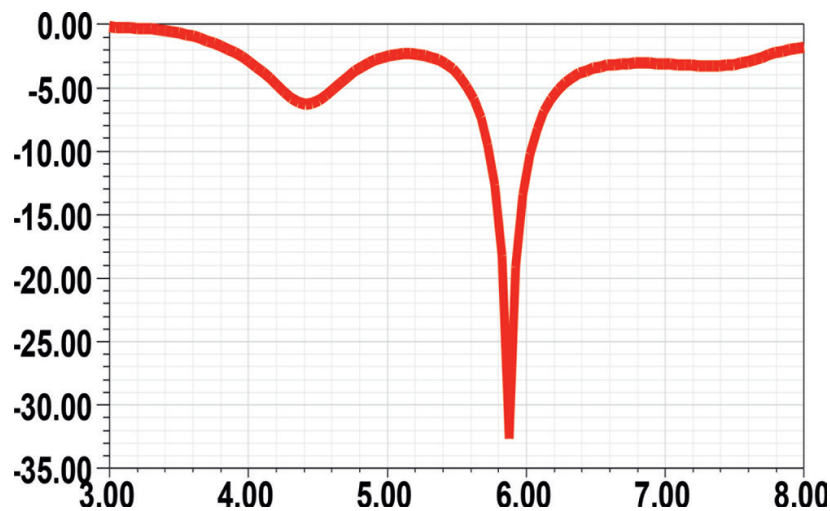**Figure 22.** Return loss of the antenna supplied via microstrip line.

Figure 23. Return loss of the antenna supplied via coaxial cable.

From **Figures 22** and **23**, we notice that the reflection coefficient PIFA powered by coaxial cable is equal to −33 and −22 dB for the antenna powered by a microstrip line. So feeding via a coaxial cable is the best technique to power a PIFA.

6. Conclusion

In this chapter, in the first part, we did an introduction to automatic identification technology, to define the different components of this system, then the frequencies of utilization for this application, and finally the advantages and disadvantages of this technology. In the second part, we presented the design and simulation of a PIFA adapted by a T-slot and powered by a coaxial cable. We studied the effect of changing the type of feed and the substrate type and thus the position of the connecting line between the ground plane and the radiating element.

We chose as the resonance frequency of the antenna for RFID applications the frequency 5.8 GHz. We compared the results of simulations obtained by the Ansoft HFSS software. The results obtained are in perfect harmony for RFID applications, either in terms of frequency or bandwidth. Similarly, the significant maxima have been obtained for parameters S11, Gain, SWR, and radiation pattern.

Author details

Loubna Berrich* and Lahbib Zenkouar

*Address all correspondence to: loubna.berrich@gmail.com

Department of Electrical Engineering, Mohammadia School of Engineers, Research Team in Smart Communications (ERSC), E3S Research Center, Rabat, Morocco

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