Dipole antenna with biconical and pyramidal horn design in radio frequency identification simulations

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Article Info

ABSTRACT

Radio frequency identification (RFID) systems are used in several applications. It is widely used in retail, corporations, and schools for several purposes such as inventory, identification, and cashless payments. The components of an RFID system include a tag and a reader. The RFID reader includes an RF module that transmits and receives signals. While the RFID tag transmits embedded signals, which is typically some form of identification. The tag is a passive component powered by the reader. The two components make use of antennas to communicate the signals with each other. The design of the antenna is an important factor to consider in the production of the RFID. The size of the antenna must be small enough to provide convenience and the gain must be strong enough to effectively transmit and receive signals between the two components. In this paper, an antenna for an RFID tag is designed using MATLAB software. The antenna to be designed must be cost-efficient and be able to radiate an acceptable gain. This research creates a dipole antenna with biconical and pyramidal horn design in RFID simulations.

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1. INTRODUCTION

The radio frequency identification (RFID) system is prominently used in various applications in the modern world. RFID stands for radio frequency (RF) identification and this technology works in a way where a reader captures digital data that has been encoded in RFID tags using radio waves. An RFID system usually includes three things which are the RFID tag, the RFID reader, and the antenna. The tag consists of an integrated circuit and an antenna and the tag's function is to be able to send information to the reader. Subsequently, the reader is used to receive radio waves and convert them into a data form that is more usable [1].

The RFID system has many applications and is widely used in various industries such as inventory management, personal identification, and cashless payments. The use of the RFID system as an alternative to barcodes has increased with time. The advantage of using the RFID system rather than the barcode system stems from an RFID not needing a line of sight to identify items and can simultaneously scan multiple items. There is also the added advantage that the read time significantly improves. The RFID system still has its drawbacks of the reader and tag collision where reader collision is when a reader can experience interference from a second reader and tag collision is when there are too many tags present which causes the reader to be confused when data is being transmitted at the same time [2].

RFID tags can be classified as either passive or active whereas the passive one does not have its power source, where its power usually comes from the reading antenna. While the other has its power source, where batteries are usually used. RFID systems have three main types which are high frequency, low frequency, and ultra-high frequency. The frequency of an RFID system will depend on the application of the said system [3].

2. BACKGROUND OF THE STUDY

The use of RFID technology has risen in recent years as the technology is considered to be simple and intangible to the object according to Azhaguramyaa and Srinivasan [4]. In Bouhassoune *et al.* [5] an overview of RFID technology is discussed and analyzed including an example of how the RFID system can be used for the connection of objects that track and process. As RFID technology is rapidly being used as an alternative to existing systems such as barcodes and near-field communication, the study to improve the design process of RFID systems needs to be focused upon by researchers.

The meander technique is used the reduction the length of an antenna. A meander is defined as a square in its most basic meaning. For the meander technique to be applied to a dipole antenna the number of meanders on each side must be considered. The more meanders there are present on the dipole antenna will result in the antenna becoming more stable. The characteristics of a dipole antenna change when the meander technique is applied. The far-field radiation pattern does not change. Upon observation, the impedance of a meander dipole drops which means a lower standing-wave ratio (SWR) can be obtained. The side-to-end ratio also increases upon using the meander technique. Other changes in characteristics that can be observed upon utilization of the meander technique are its reduction of radiation efficiency, reduction of gain, and the increase in work to build and deploy [6]. The use of straight dipoles in an RFID system can be observed in a paper conducted by Zheng *et al.* [7]. The use of meander dipoles in an RFID system can be observed in a paper conducted by Kruesi *et al.* [8].

3. STATEMENT OF THE PROBLEM

With the abundant use of RFID technology in applications and its steadily increasing presence, the design for an antenna to be used with the RFID must be carefully produced with the corresponding parameters required for it to work properly. Finding the most suitable antenna to be paired with the RFID tag is essential for an effective system to be produced. The cost-efficiency of building an RFID system must also be considered to get the best value and results that can be produced. To ease the process required in the designing of antennas for an RFID system, software using the program MATLAB is proposed to design a dipole antenna that will be cost-efficient and also be able to produce the required gain. The program will be used to produce three types of dipole antennas which will be a straight dipole antenna, a meander dipole antenna, and a hollow dipole antenna.

4. SIGNIFICANCE OF THE STUDY

The antenna is a component in the RFID system that is used by the tag to transmit data to the reader. The antenna enables the RFID system to communicate and be able to locate the object that is being observed. The design of an antenna can be regarded as an essential part of the process as the parameters of the RFID system will be dictated as well by the antenna. With the creation of a dipole antenna design for RFID applications in MATLAB, the ease of seeing the results of a theoretical design can ultimately advance the time needed in testing simulations. As the dipole antenna is considered an antenna that is simple to use and relatively cheap, the software can guide users to determine what the most suitable dipole antenna should be used in the RFID system that they would want to be implemented. The usage of this program will also enable its users to easily utilize the meander technique to shorten the length of an antenna and see its corresponding effects on the parameters. The application will help researchers to further compare and decide which antenna design would likely be best suited. The researchers will also be able to use software that is relatively easy to access as it is in MATLAB.

5. DESCRIPTION OF THE SYSTEM
5.1. Straight dipole antenna

The straight dipole antenna has the dimensions 156 mm×5 mm (length × width). The width of the arms is 2 mm. The feed is located on the middle top part of the antenna, indicated by a red dot. Figure 1 shows the design of a straight dipole antenna.
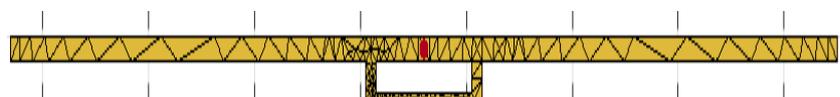

Figure 1. Design of the straight dipole antenna

5.2. Meander antenna

The antenna with a meander line design was based on the design of the previously defined dipole. The dimensions of the antenna are 130 mm×5.4 mm. The width of the stip is 2 mm. The feed is situated on the middle top part of the antenna. Figure 2 shows the design of the meander dipole antenna.
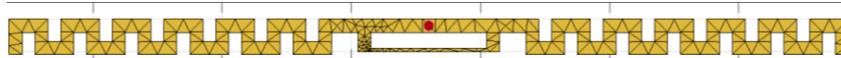
Figure 2. Design of the meander dipole antenna

5.3. Hollow meander antenna

The hollow meander antenna follows the design of the meander line. The dimensions of the hollow meander antenna are 130 mm×5.4 mm, with the outer width of the arms is 2 mm and the inner width of the strip is 1.2 mm. The feed is located on the middle top part of the antenna. Figure 3 shows the design of the hollow meander dipole antenna. The directivity and current distribution were described over the operating frequency of 918 MHz to fit the boundaries defined by the Department of Transportation and Communications. The impedance was described over the frequency range of 800 MHz to 1 GHz.

Figure 3. Design of the hollow meander dipole antenna

6.   METHOD (WITH FLOWCHART)

The designs of the antennas were first fabricated using the partial differential equation (PDE) toolbox. The geometrical layout was drawn and the boolean operation was set into the set formula tab to finalize the drawing. The mesh was then initialized and exported to the workspace of MATLAB. Using the variables exported, a custom mesh antenna that follows the geometric design created in the PDE modeler can be simulated in MATLAB software. A feed is then placed in the custom antenna. The radiation pattern and current density are then plotted with an operating frequency of 918 MHz. The impedance is graphed along with frequencies of 800 MHz to 1GHz. Figure 4 shows the flowchart of the methodology.
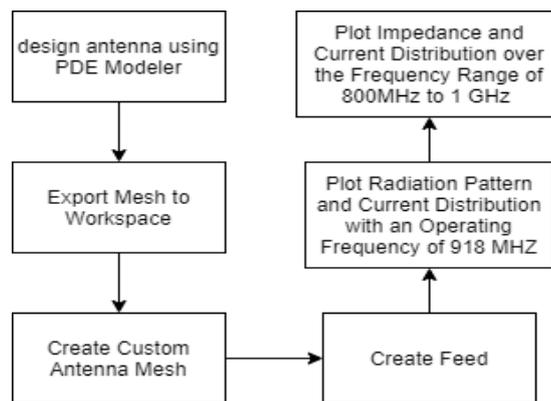
Figure 4. Flowchart of the methodology

7.   REVIEW OF THE RELATED LITERATURE

There have been several studies that have investigated the design of antennas for RFID systems. One such study is discussed in the article "Design and modeling of a compact circularly polarized antenna for RFID applications" done by Das *et al.* [9]. In this experiment, the researchers were designing an antenna using Koch fractal geometry. Two antennas were designed at operating frequencies of 2.435 GHz and 5.78 GHz and both had an axial ratio bandwidth of 3 dB. The proposed design was made to minimize the dimensions of the antennas to be more suited to portable devices and their demands.

A study was conducted on the design of a miniaturized antenna for RFID application and was thoroughly explored in the article "Iterative technique for analysis and design of circular leaky-wave antenna for the 2.45-GHz radio-frequency identification applications" done by Sghaier and Latrach [10] in 2020. The proposed antenna design improved the bandwidth by implementing a multilayer dielectric configuration. The study was proposed to demonstrate the results of implementing angular rings in radiating structure loaded for patch size reduction and to showcase the benefits of the proposed structure in the development of circular polarization in the maximal radiation pattern. An experimental test was conducted and showed that in the 2.45 GHz band, the new antenna design was shown to be suitable for RFID applications [10].

A paper that discusses the design for a miniaturized and low-profile UHF RFID antenna was stated in the article "Design of miniaturized and low-profile UHF RFID metal-mountable tag antenna" done by Tang *et al.* [11]. In the experiment that the researchers conducted, the designing process was carried out in the software CST microwave studio (CT MWS). This program is where the modeling and simulation took place. Analysis of the effects of various sizes of the inset-feed structure and the size of the rectangular slot on the input impedance on the antenna were done and with the results, the parameters could be adjusted to suit the conjugate impedance required linking the antenna and microchip [11].

A meandered microstrip antenna design that could be used in RFID applications was tackled in the article "Design of a meandered line microstrip antenna with a slotted ground plane for RFID applications" done by Das *et al.* [12]. The contents of the paper discussed the analysis and construction of the meandered microstrip antenna design that had a defected ground structure. The antenna that was designed was found to operate over the range of frequencies 5.74 GHz-6 GHz and had 5.82 GHz as its resonant frequency. An omnidirectional radiation pattern was observed with the proposed design. At an operating frequency of 5.82 GHz, RFID applications were possible [12].

A polarized microstrip patch antenna design that had a low axial ratio in UHF that was to be used in RFID applications was considered in the article "A low cost circularly polarized microstrip patch antenna with the low axial ratio for UHF RFID applications" done by Naidoo *et al.* [13]. Simulations of the said design were executed with the CST studio suite software. Parameters of the antenna were presented and discussed as well in the paper [13].

Designs for a UHF tag antenna were reflected upon in the conference paper "Design of UHF tag antenna based on internet of things" done by Huajuan [14]. In the paper, a comprehensive analysis of the RFID system operating on UFH applied to the tag antenna design including methods to quantize performance according to the knowledge of electromagnetic theory in antenna design can be found. Simulations were also done to prove that the proposed antenna design was working optimally. The paper discusses a compact UHF antenna with a frequency that covers a range of 840 MHz-965 Mhz [14].

In a study for monitoring parameters of photovoltaic panels, antenna designs for RFID sensors were discussed in the article "Designing antennas for RFID sensors in monitoring parameters of photovoltaic panels" done by Weglarski *et al.* [15]. In the experiment conducted, RFID sensors were used to supply an improvement in performance for module supervision that was important in the observation of parameters of green energy plants. An antenna design was proposed to solve a problem that involved RFID transponders detuning in the presence of glass or metal surfaces. An antenna model was designed in the Hyper Lynx 3D EM software [15].

8. THEORETICAL CONSIDERATION

The physical characteristics of the antenna affect the performance of the system. The parameters that were assessed in the simulation were the design techniques and size. The objective of the design was to increase the efficiency of the RFID system without compromising the cost. The meander line antenna is used to substitute a straight dipole antenna in the system for size reduction of the antenna [16]. The short dipole antenna and the meander line design have an inductive shortening loop for the matching section. at the middle attached to two equal radiating arms. The design would result in an omnidirectional radiation pattern [17]. The matching section is equivalent to the circuit below. The impedance of the antenna design would be inductive to conjugate the capacitive impedance of the chip [18]. Figure 5 shows the circuit of the matching section.
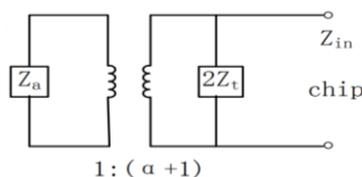

Figure 5. Equivalent circuit of the matching section

The meander line antenna extends the radiating arms of the antenna without lengthening the size of the antenna. However, the ink consumption in the production of the meander line antenna would be greater than that of the straight dipole antenna. To address the situation, a hollow meander line antenna is constructed to minimize the cost of the manufacture of the antenna. The proposed design of the hollow meander antenna would have a ratio of 0.6. The hollow design must not have a significant deterioration effect on antenna performance [19].

9.   DATA AND RESULTS
9.1. Straight dipole antenna

Figures 6-9 shows the radiation pattern, impedance over 800 MHz to 1 GHz, S-Parameter over 800 MHz to 1 GHz and current distribution of a straight dipole antenna. This test is important as we will be able to know the effectivity of the antenna system. In Figure 6(a) the radiation pattern of a 3D straight dipole antenna was shown while on Figure 6(b) the 2D azimuth plane of a straight dipole antenna was shown. These are the radiation pattern of the antenna shown in different perspectives.
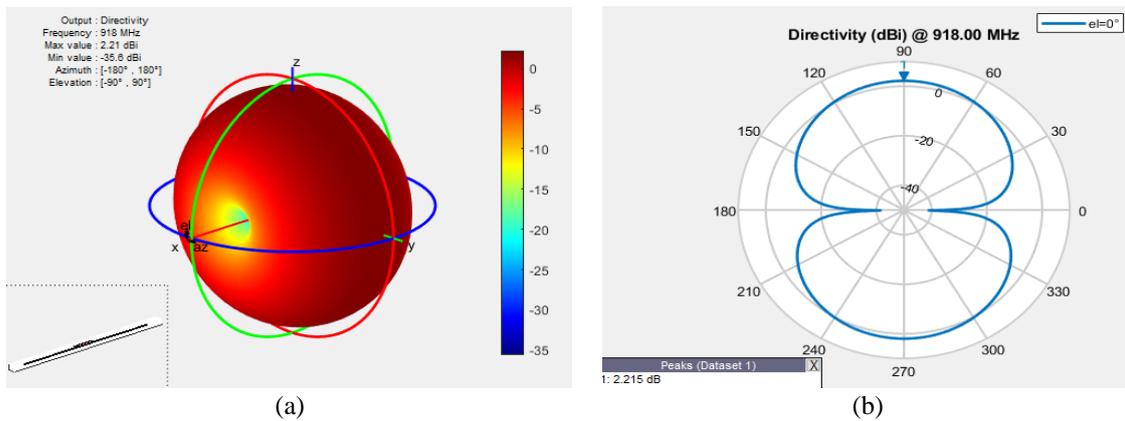

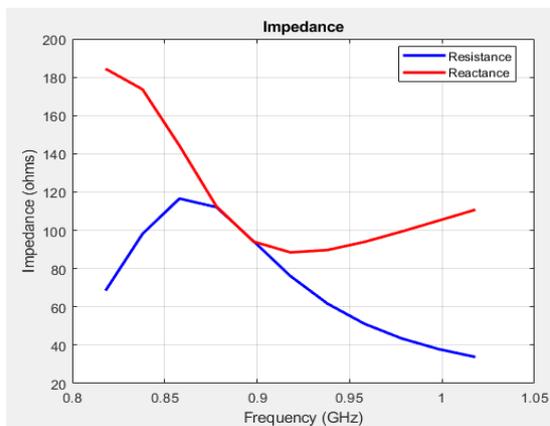Figure 6. Radiation pattern in (a) 3D and in (b) 2D azimuth plane
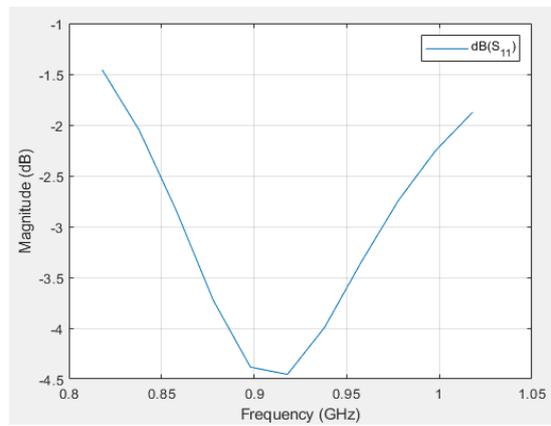

Figure 7. Impedance over 800 MHz to 1 GHz   Figure 8. S-Parameter over 800 MHz to 1 GHz
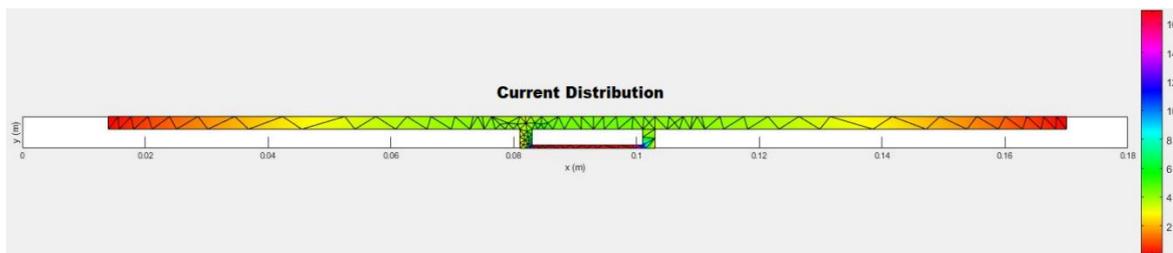

Figure 9. Current distribution

9.2. Meander dipole antenna

Figures 10-13 shows the radiation pattern, impeadance over 800 MHz to 1 GHz, S-Parameter over 800 MHz to 1 GHz and current distribution of meander dipole antenna. These testing parameters are important so we can know the effectivity of the antenna. In Figure 10(a) the radiation pattern of a 3D meander dipole antenna was shown while on Figure 10(b) the 2D azimuth plane of a meander dipole antenna was shown. These are the radiation pattern of the antenna presented in different perspectives.

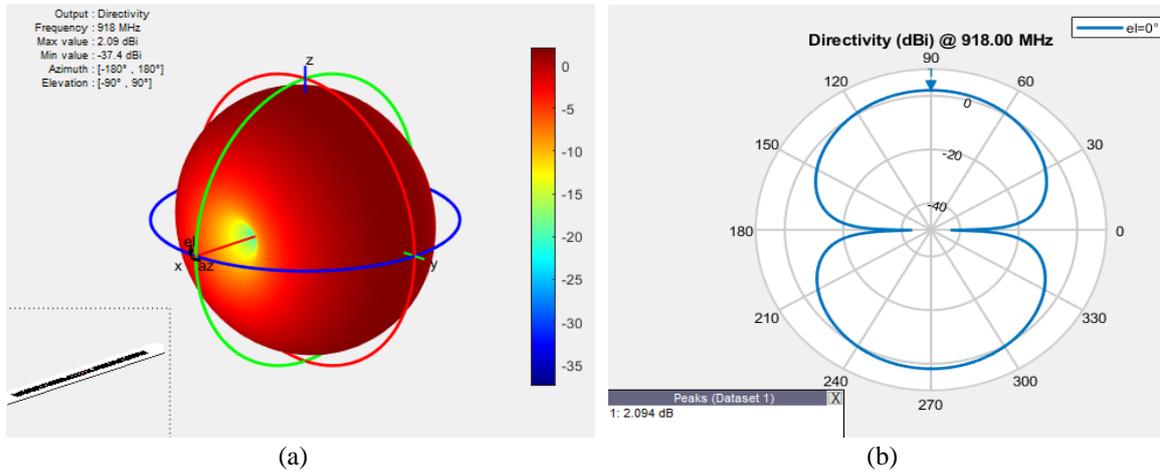(a)   (b)

Figure 10. Radiation pattern in (a) 3D and in (b) 2D azimuth plane
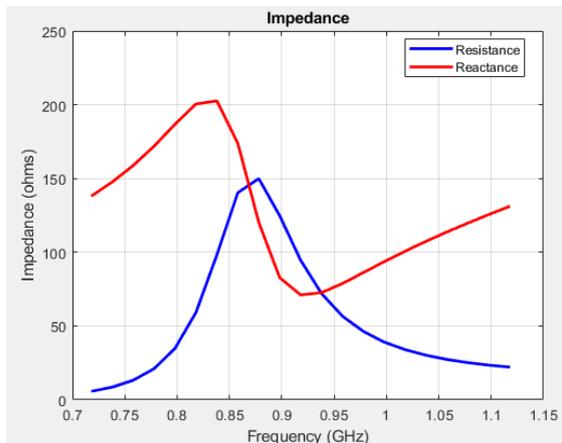

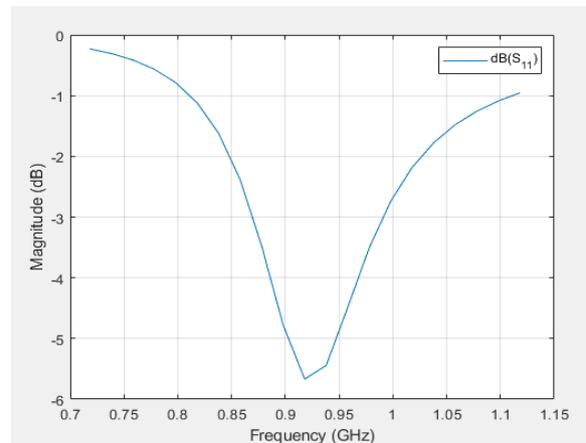Figure 11. Impedance over 800 MHz to 1 GHz   Figure 12. S-Parameter over 800 MHz to 1 GHz

Figure 13. Current distribution

9.3. Hollow meander pyramidial antenna

Figures 14-16 shows the radiation pattern, impedance over 800 MHz to 1 GHz and S-Parameter over 800 MHz to 1 GHz of a hollow meander pyramidial antenna. These testing parameters are important so the effectivity of the antenna can be determined. In Figure 14(a) the radiation pattern of a 3D hollow meander pyramidial antenna was shown while on Figure 14(b) the 2D azimuth plane of a hollow meander pyramidial antenna. These are the radiation pattern of the antenna presented using different assestments.

(a)   (b)

Figure 14. Radiation pattern in (a) 3D and in (b) 2D azimuth plane

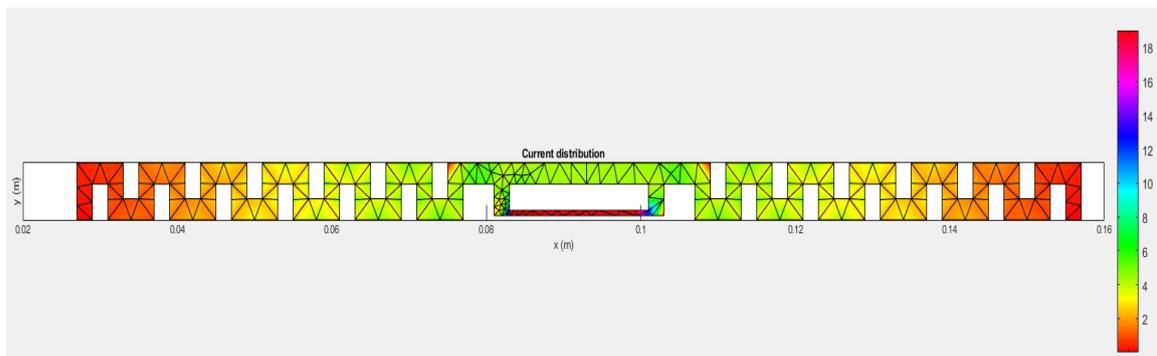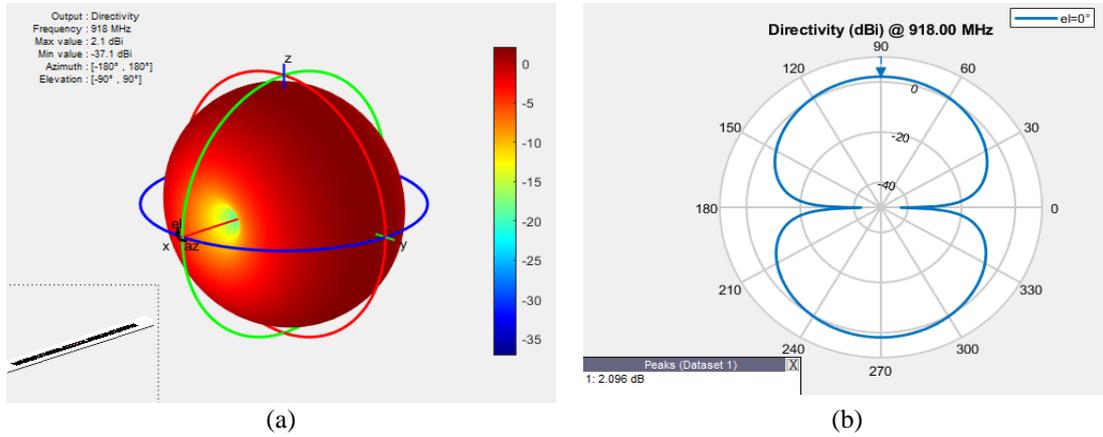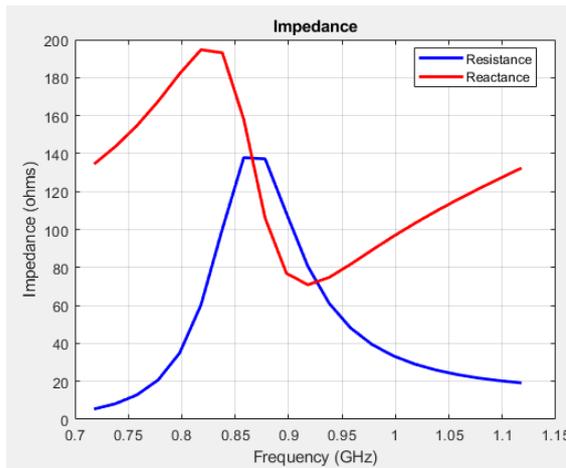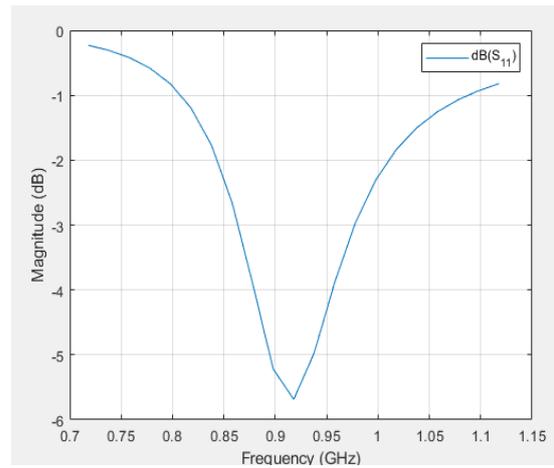Figure 15. Impedance over 800 MHz to 1 GHz   Figure 16. S-Parameter over 800 MHz to 1 GHz

10. ANALYSIS OF DATA

In the simulation done, the straight dipole antenna was used as a reference to examine the effectiveness of using the Meander Line Antenna in an RFID application [20]. The objective of the experiment was to design an antenna that is cost-efficient yet can function better than the simple straight dipole antenna. The designed antenna must be able to improve the RFID system [21], [22].

An important factor to consider in the antenna design is the size. A compact antenna design is desired. Hence, the meander line antenna was designed to have smaller dimensions than the reference dipole antenna [23], [24]. The meander line antenna design was 0.2 mm longer along the y-axis and 26 mm shorter along the x-axis [25]. The placement and the size of the feed for the meander line antenna were kept the same as the straight dipole antenna [26].

The S-Parameters in the first two designs of the antenna showed that the meander line antenna radiates better than the straight dipole antenna at the operating frequency of 918 MHz. At 918 MHz, the S11 parameter, indicates the return loss, of the straight dipole antenna -4.454 dB. While the S11 parameter of the meander line antenna is -5.668 dB [27], [28]. The data showed that the meader line antenna radiates more power in comparison with the straight dipole antenna. The simulation showed that the use of the meander line antenna resulted in improved performance of the RFID system as contrasted to when a straight dipole antenna is used.

To address the cost efficiency of the design, the meander line antenna was made hollow to lessen the consumption of the ink when it is printed. The width of the hollow meander line antenna is 60% of the meander line width, 1.2 mm. With the removal of the portion of the width, the antenna was still able to perform well [29], [30]. The results of the simulation of the hollow design were similar to the results of the first designed meander line antenna.

11. CONCLUSION

The design of the antenna in an RFID system is an essential factor to consider. Different designs can affect the overall performance of the system and can also affect the cost of production. Since RFID tags are usually produced in bulk, the design mustn't consume excessive ink, and unnecessarily adds to the cost. The convenience of carrying the RFID tag is also crucial for the buyers. Hence, the design of the antenna of the RFID tag must also be compact. The proposed design aims to cater to the desires of the consumers. To test the effectiveness of the proposed design, a simulation of the straight antenna, the meander line, and the hollow meander line antenna was done using MATLAB software. The performance of the three antenna designs over the same environment was observed and compared. The antenna geometry of the three antennas was constructed using the PDE modeler of the PDE toolbox. The designs were simple enough to be mass-produced commercially.

12. RECOMMENDATIONS

The simulation of the straight antenna, meander line antenna, and hollow meander line antenna in the experiment was done in an environment where noise is not taken into account. In a physical implementation, several other factors would affect the results of the simulation of the three antennas. Although in theory, the assumptions made were tested and confirmed in the MATLAB simulation, the practical results would have deviations from the theoretical results. Additionally, in an actual setting, consumers prefer having a physical confirmation of the claim rather than mere software simulations. The designs of the antenna can be printed and physically implemented to further improve the accuracy of the results of the performance of the antennas and to test the cost-effectiveness of the proposed design. RFID systems can have different frequency ranges of operation.

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