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Monopole Antenna Design for UHF Circularly Polarized RFID Applications

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Abstract—Radio Frequency Identification (RFID) technology is one of the simplest forms of wireless communication systems. It is a unique concept that aims at connecting and identifying tagged assets or objects to RFID readers to collect information. This paper presents the design and implementation of a compact dual-band monopole antenna for RFID applications. The proposed design is a microstrip antenna structure composed of two coupled armed meander-lines having 90° between them to achieve circular polarization. The proposed design is mounted on a 1.6 mm thick FR4-epoxy substrate backed by a partial ground plane with the total area of ($58 \times 80\,\text{mm}^2$) to ensure compact size of the design. The designed antenna is fed through a 50-ohm transmission line of length 28.5 mm. The antenna is considered dual bands that resonate at 850 MHz and 1.5 GHz and radiates circularly polarized waves with an axial ratio of 1.4. The simulation results using HFSS software showed promising performance with a bandwidth of 141 MHz at centre frequency 850 MHz and 287 MHz at centre frequency 1.5 GHz, respectively. The S_{11} parameter shows return loss of −21 dB at 850 MHz band while at the higher frequency band the return loss is much better which was −39 dB. The design provides a perfectly omnidirectional radiation pattern and high radiation efficiency of 93%. Fabrication of the proposed design is done with practical results having a similar trend to the simulated ones to convey good performance of the designed antenna.

1. INTRODUCTION

Radio frequency identification (RFID) technology is a beneficial technology in many ways especially in the business world and industry. It has become popular in the recent years and has attracted the attention of many researchers. The base of this technology lies behind the complete automatic identification of objects, gathering data or credentials about them then directly introducing these data into computerized systems without any intervention from humans. RFID could be easily found integrated within systems that we deal with every day like automatic parking, inventory management, and preventing shoplifting. It is a unique concept that aims at connecting and identifying tagged assets or objects to RFID readers to collect information. It could be safely said that it resembles bar code, but it is much more complicated [1]. The idea behind RFID technology can be simply described as a radio frequency transmission process between two parties: a tag and a reader where they exchange data within a limited range. The essential use of this innovation lies in the automatic tracking of objects as well as for data acquisition. The fundamental frequencies used for item tagging are 13.56 MHz (HF) and 800–900 MHz (UHF).

Since tag antenna plays a vital part in data transmission, it has been investigated by many researchers. The design in [2] demonstrates an RFID tag antenna with dual bands working in UHF (915 MHz) and microwave band (2.45 GHz). The design aims at enhancing the antenna's bandwidth

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to ensure a better detection range, which is done through a profile consisting of a meander monopole slot wire and a stub. The results show that manipulating the dimensions of the stub highly affect the return loss as it shifts the resonance frequency. A compact multiband monopole antenna for ISM band applications presented in [3] operates at 2.4 GHz. The paper shows the antenna operating in four frequency bands: 2.4 GHz, Bluetooth, WiMAX, Wi-Fi, which makes it efficient, and moreover, it achieves good gain about 3.4 dBi. However, its size is not as compact as needed for RFID applications. The work done in [4] demonstrates a great effort in creating an RFID band for the human use, and it also demonstrates the complexity of dealing with the human skin under the substrate. For vehicle identification and tracking [5], a UHF RFID tag antenna is designed with a fed point meander line design on a laminated glass substrate to be mounted on a car window shield. However, the glass substrate used is not practical, could easily shatter, and not commercially available in wide ranges.

The greatest challenge while designing an RFID tag is to achieve a proper read performance through having high efficiency while keeping a compact size for the antenna. In adding to that, cost reduction comes as a great concern especially when active tags are used in large systems like retail management.

The main objective of this paper is to provide a novel, simple, and efficient design of a monopole antenna for RFID applications, working in UHF band having circularly polarized radiation. The specifications require the design:

- To be compact in size.
- To have an appropriate reading range.
- To achieve high efficiency at least 80% and good bandwidth more than 50 MHz in both bands.
- To achieve circularly polarized radiated field.

2. ANTENNA STRUCTURE

2.1. Proposed Design

The structure of the antenna for RFID applications is shown in Fig. 1. The proposed design uses an FR4-epoxy substrate with an overall dimension ($60 \times 80 \times 1.6\,\text{mm}^3$). The structure of the first design is shown in Fig. 1. As one can see from Fig. 1, the radiating line has two identical arms with each of them being a meandered line folded in a minimal possible area. The two arms are placed such that the angle at the split point from the feed line is 90°. A partial ground plane is placed on the other side of the substrate as depicted in Fig. 1. The structure proposed here is suggested to produce a circularly polarized radiated field. The meandered line width is 1.41 mm for both arms, and they met at the middle point of the substrate and joined to the microstrip transmission feedline. The partial ground approach allows omnidirectional radiation which would enhance the antenna's performance.

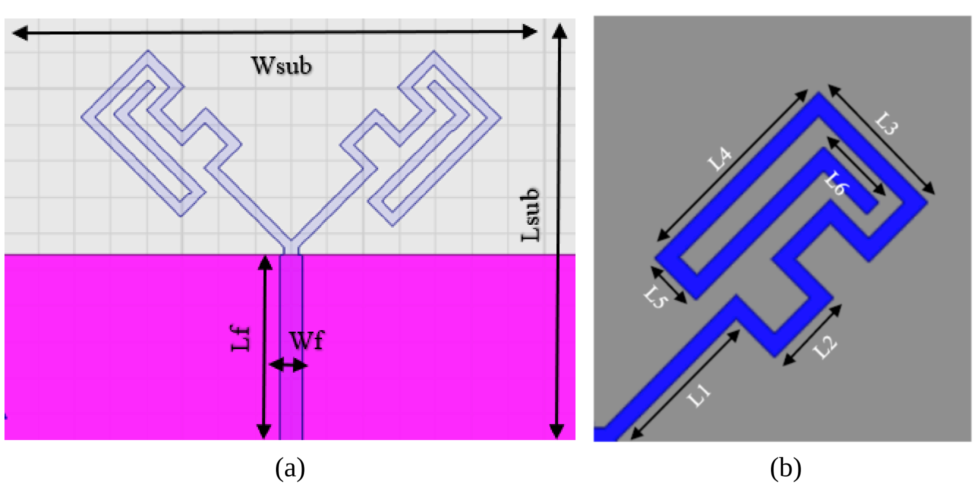

Figure 1. Geometry of the proposed first design.

Figure 1(b) illustrates the dimensions of the meander line, while Table 1 gives the values for all symbols used in Fig. 1.

Table 1. Proposed design dimensions.

Dimension	**Value (mm)**
L_{sub}	60.0
W_{sub}	80.0
L_f	28.5
W_f	3.0
L_1	14.3
L_2	7.0
L_3	13.0
L_4	19.5
L_5	5.0
L_6	6.7
Ground Plane Width	80.0
Ground Plane Length	27.0

A comparison between the proposed design and the design presented in [6] shown in Table 2 will prove that the area of the designed antenna achieved here is suitable for implementation and usage real life applications. Moreover, the proposed design has the advantage of small area.

Table 2. Comparison between proposed design and [6].

Paper	**Frequency**	**Dimensions**	**Area occupied**	**Height**
Reference [6]	0.885–0.962 GHz and 1.69–3.8 GHz	$110 \times 50\,\text{mm}^2$	$5500\,\text{mm}^2$	0.8 mm
Proposed Design	850 MHz and 1.5 GHz	$60 \times 80\,\text{mm}^2$	$4800\,\text{mm}^2$	1.6 mm

2.2. Design Optimization

After reaching this design, an optimization procedure is done which entails choosing acceptable cases and trials of the design to reach the most optimum design with its required specifications fulfilled. The design is transformed into its final form as illustrated in Fig. 2 with design physical dimensions explained in Table 3. Multiple small changes have been done to the design just to improve the antenna performance. For instance, in the previous design the return loss for the first resonance frequency (850 MHz) was about −11 dB which would be much better because reducing the reflection coefficient results in a better radiation of power. In addition to that, the bandwidth of the designed antenna is very narrow. The proposed solutions for these minor inconveniences are explained as follows:

- Flip over one of the meander line branches as shown in Fig. 2. Upon applying this technique, the gained results of the proposed design are absolutely promising and will be discussed later in "Results and Discussions" section.
- Slightly decrease the partial ground length.
- The design had a room for a possible decrease in the substrate length which would be in favour of miniaturization of the design, so the area of the final design is $46.4\,\text{cm}^2$; however, the area occupied by the radiating arms is only about $15\,\text{cm}^2$ ($28\,\text{mm} \times 54.1\,\text{mm}$). The complete dimensions of the new optimized design are explained in Table 3 and shown Fig. 3.

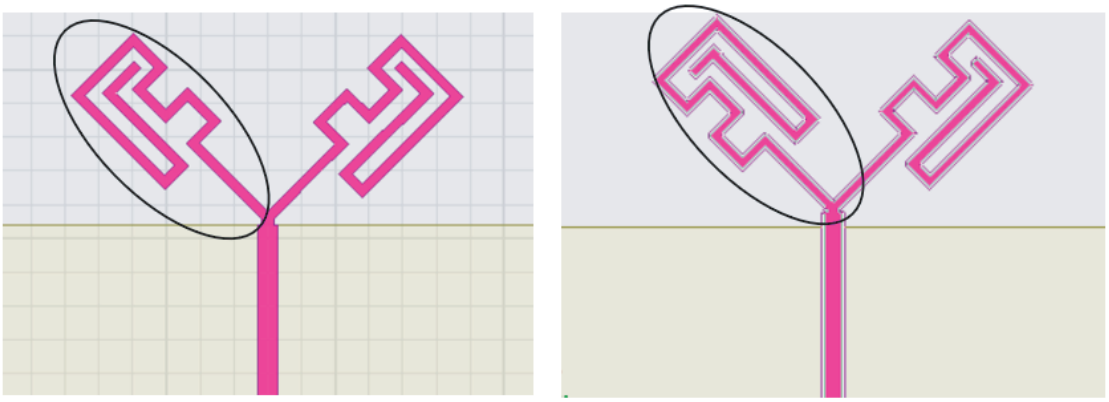

Figure 2. Antenna design after optimization.

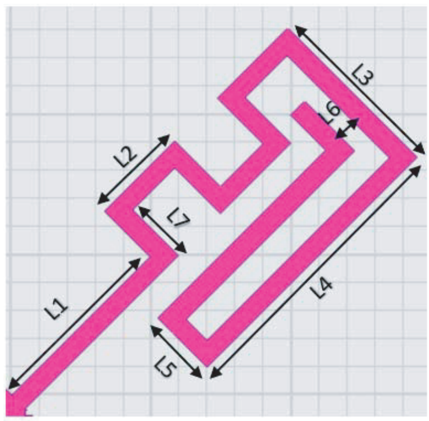

Figure 3. Meander line design.

Table 3. Final design dimensions.

Physical Dimension	Value (mm)
Substrate Length	58
Substrate Width	80
Substrate Height	1.6
Feedline Length	28.5
Feedline Width	3
Lines' Thickness	1.41
L_1	15.5
L_2	7
L_3	13
L_4	21
L_5	5
L_6	1.51
L_7	4.5
Ground Plane Width	80
Ground Plane Length	26.3

3. RESULTS AND DISCUSSIONS

3.1. Before Optimization

The return loss shows a result of −11.7 dB at 850.4 MHz and −14.3 dB at 1.54 GHz as shown in Fig. 4. The response gives maximum return loss at 2.42 GHz. The bandwidth of the first operating frequency (850.6 MHz) is 13 MHz which is very narrow. However, the bandwidth at the higher frequency (1.54 GHz) is 140 MHz ranging from 1.47 to 1.61 GHz. The radiation efficiency is 75%.

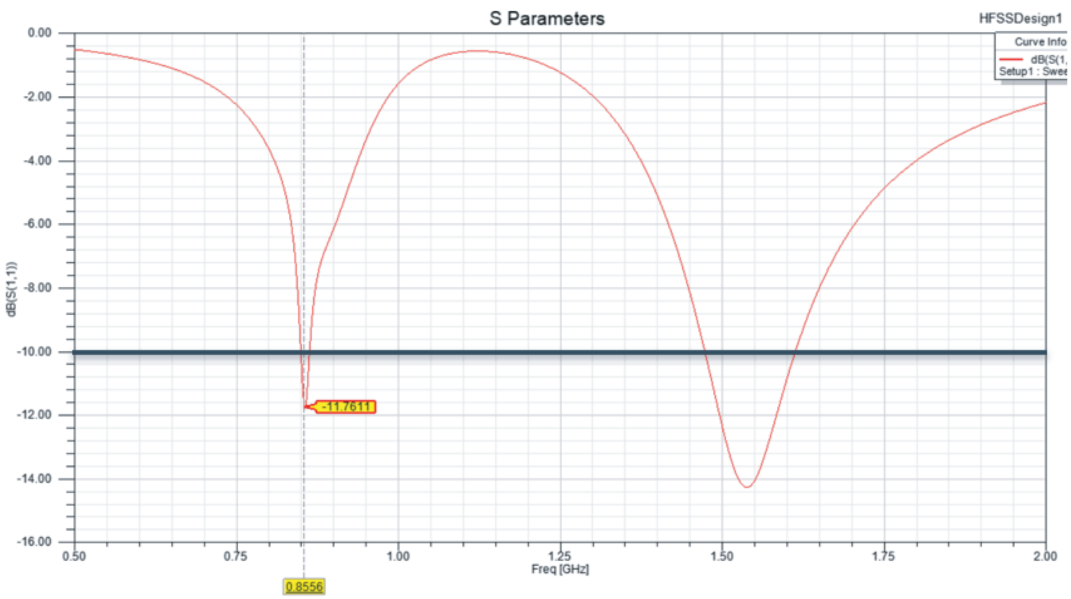

Figure 4. Return loss.

3.2. After Optimization

The return loss is found to be −21.5 dB at 850 MHz and for the second band of operation at 1.49 GHz, and there is much better return loss at −40 dB. The analysis of the return loss is very satisfactory before

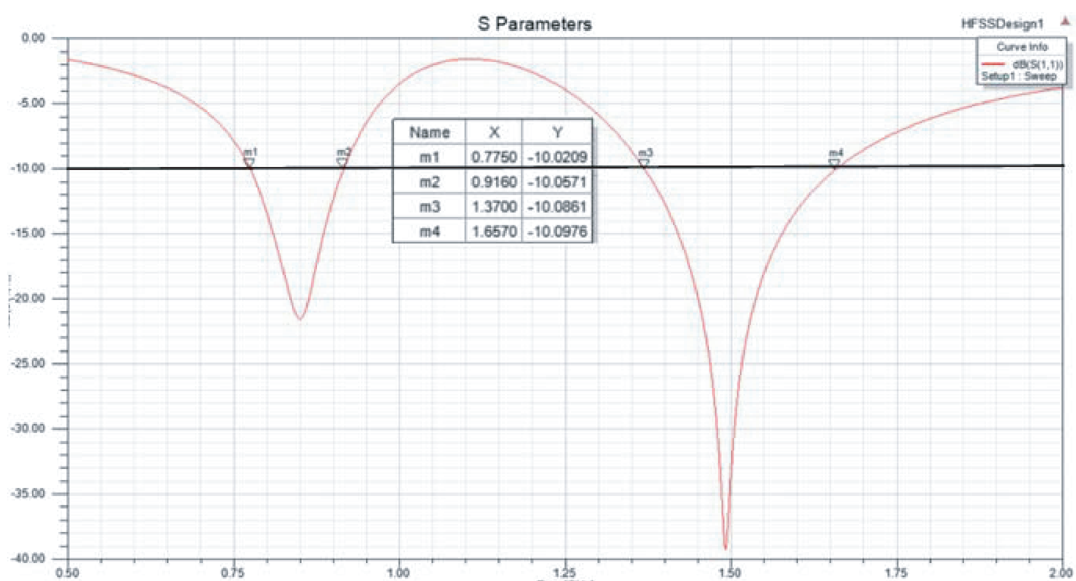

Figure 5. Return loss after optimization.

manufacturing the antenna as it gives a tolerance for fabricated design. The bandwidth if the design could be obtained by looking at the line of -10 dB of the S_{11} graph illustrated in Fig. 5. The bandwidth ranges from 775 MHz to 916 MHz with a total bandwidth of 141 MHz while at 1.5 GHz, it has a larger range than the first frequency. It operates from 1.37 GHz to 1.65 GHz, which gives a bandwidth of 287 MHz. This final design presents a great improvement specifically regarding the antenna's bandwidth in addition, and the radiation efficiency of the design is 93% as shown in Fig. 8 which proves that the proposed design improves the antenna performance. In general, the radiation efficiency is affected by the change in the design to a lossy material like FR4-epoxy. One of the fundamental goals set for this design is to have an omnidirectional radiation pattern. The 3D polar plot of the radiation pattern is graphically represented in Figs. 6 and 7 indicating that the proposed design has achieved omnidirectional radiation patterns at both frequencies 850 MHz and 1.5 GHz. The antenna radiation pattern at 1.5 GHz has wide beamwidth and perfect omnidirectional pattern in all directions which means that the antenna power is distributed equally in all directions. This final design presents a great improvement specifically regarding the antenna's bandwidth, and in addition, the radiation efficiency of the design is 93% as shown in Fig. 8 which proves that the proposed design improves the antenna performance. Later on to better enhance the gain, the work achieved in [7] could be of significant help.

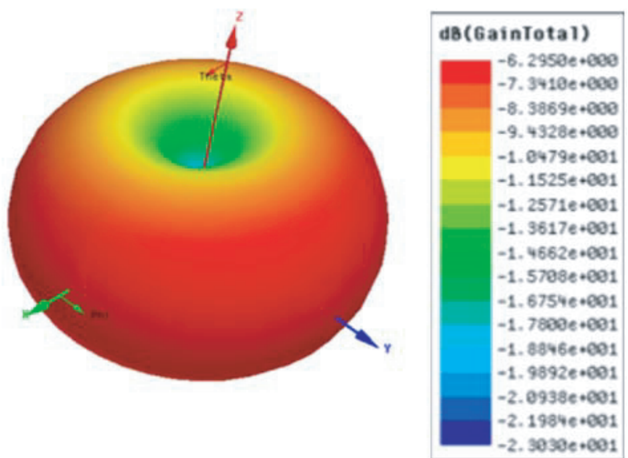

Figure 6. Radiation pattern at 850 MHz.

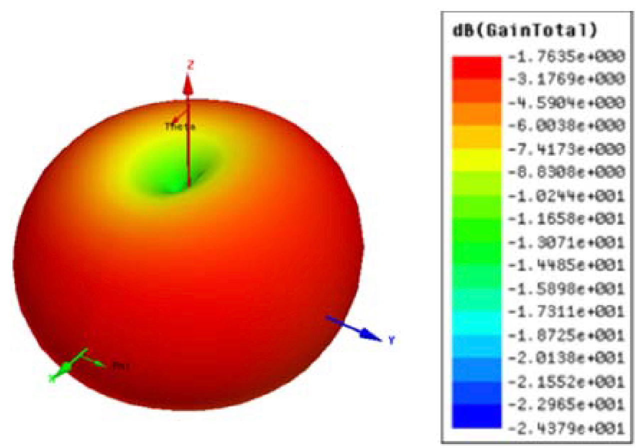

Figure 7. Radiation pattern at 1.5 GHz.

Antenna Parameters:

Quantity	Freq	Value
Max U	0.85GHz	0.018545 W/sr
Peak Directivity		0.25031
Peak Gain		0.23469
Peak Realized Gain		0.23305
Radiated Power		0.93105 W
Accepted Power		0.993 W
Incident Power		1 W
Radiation Efficiency		0.93761
Front to Back Ratio		-N/A-
Decay Factor		0

Figure 8. Radiation efficiency.

The axial ratio for the proposed design is found to have magnitude 1.4 at the operating frequency 0.8563 MHz as shown in Fig. 9, which represents reasonable circularly polarized radiation.

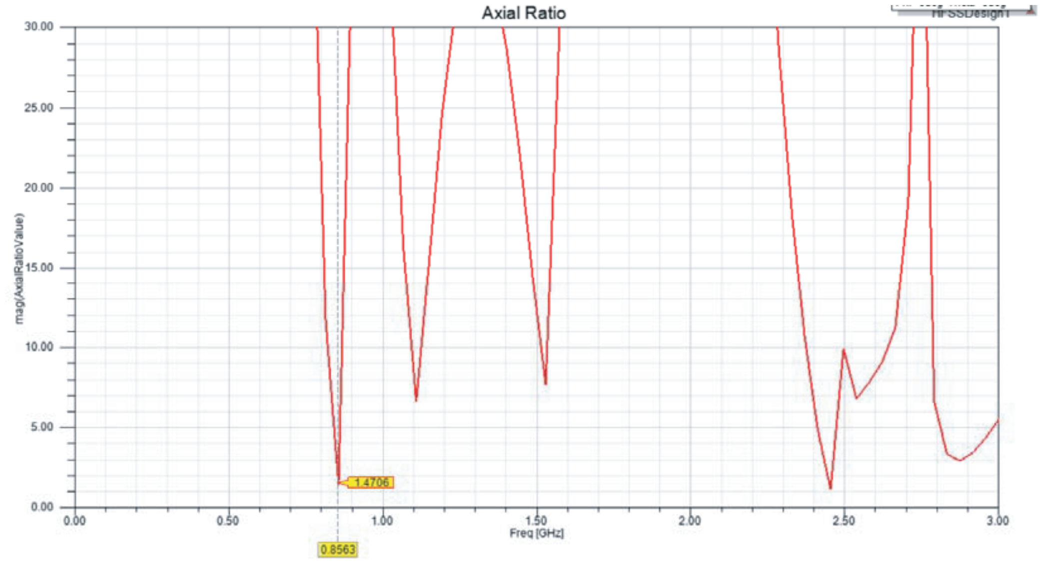

Figure 9. Axial ratio.

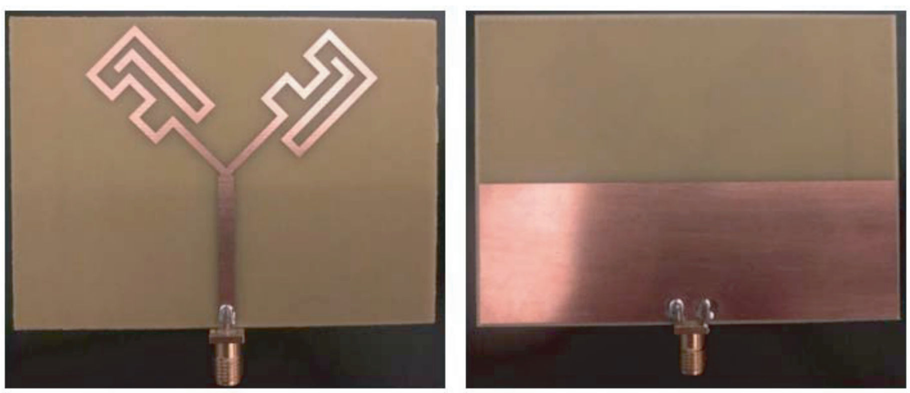

Figure 10. Fabricated design.

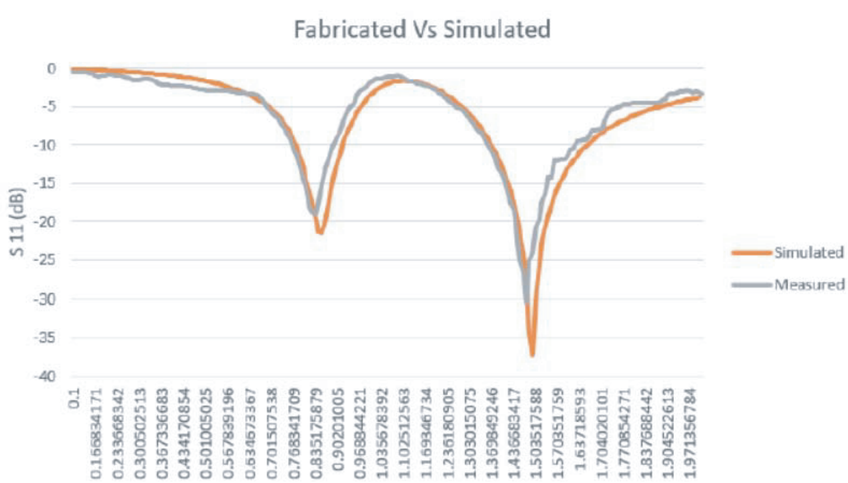

Figure 11. Return loss of fabricated design vs simulated design.

4. FABRICATION

The next stage was to implement and measure the proposed design in order to obtain the practical results. The antenna was fabricated at the NIT laboratory and shown in Fig. 10. The measured S_{11} results have a typical trend as the simulated one for the two resonance frequencies as depicted in Fig. 11. The first is 850 MHz with return loss about -18 dB while at the second frequency of 1.5 GHz it is -30 dB as shown. Comparing the experimental and simulated results, it is obvious that the proposed antenna has achieved the design requirements. This proves the good performance of the proposed design and verifies its operability, making it suitable for various RFID applications.

5. CONCLUSION

In this paper, a new design in the field of RFID applications is approached. The use of a meander line technique is employed to create two identical radiating arms with 90° between them and fed through a transmission line using an FR4-epoxy substrate material. The proposed antenna has achieved the following design requirements:

- The design is compact as the overall dimensions are ($58 \times 80 \times 1.6$ mm).
- Dual bands are achieved with a return loss of -18 dB at 850 MHz and -30 dB at 1.54 GHz, respectively.
- The design shows good performance regarding the read range as the bandwidth is high specifically after optimization the design to be 287 MHz at 1.5 GHz band.
- The radiation efficiency is found to be 93%.
- The radiation pattern is omnidirectional.
- Practical and theoretical results are in an excellent agreement which makes the antenna suitable for RFID applications.

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