Design of a miniaturized wideband disc monopole antenna used in RFID systems

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ABSTRACT

Radio-frequency identification (RFID) is an important wireless technology which utilizes radio frequencies (RFs) for exchanging data between two or more points (tags and readers), that represent an automatic identification (Auto-ID) system. This paper introduces an omnidirectional microstrip antenna operates at 2.45 GHz used for a radio-frequency identification (RFID) technology. The length of the proposed antenna is 36.5 mm and the width is 27 mm. The substrate material which has been used as a base of antenna is FR4 that has dielectric constant value of 4.3 and dielectric thickness value of 1.6 mm. Regarding the resonance frequency, return loss of the proposed antenna design is -34.8 dB. A promising directivity outcome of 2.8 dB has been achieved with omnidirectional radiation pattern as well as an acceptable efficiency of 66%. The proposed antenna design accomplishes a wideband frequency of 1.21 GHz in the frequency range of (2.14 - 3.35) GHz. The computer simulation technology (CST) microwave studio software has been used for implementing the proposed antenna design. The antenna design fabricatation and its characteristics have been measured using vector network analyzer (type MS4642A). The obtained results of the experimental design achieve a little bit differences as compared with the simulation results.

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1. INTRODUCTION

Radio frequency identification (RFID) is an auto-ID technology that employs electromagnetic (EM) waves to exchange information between readers and tags for tracking and identification [1]. Radio frequency identification in the ultra-high frequencies (RFID UHF) is considered among the emerging technologies in the field of identification, used widely in different areas due to benefits that present as the long read range and miniaturized size [2]. This technology uses radio waves propagation for the communication between the reader and the tags [3]. The RFID technology is applied in several applications such supply chain management, security, access control, tracking and logistics.

A standard RFID system contains tag, reader and its antennas. The reader's antenna transmits a radio frequency (RF) signal to the tag and receives an information signal from it [4]. The RFID system in ultra-high frequency (UHF) band is much important due to its features of fast reading speed, high data transfer rate and long detection in range. Ideally, the frequency band of UHF-RFID system is start from 860 to 960 MHz. Several frequency ranges of UHF-RFID bands have been assigned depends on the country, location and zone [5]. Thus, design a wideband antenna of reader with desirable performance during the entire band of (860–960) MHz is useful for the RFID system arrangement and enforcement, furthermore cost reduction [6].

There are three typical categories of RFID tags; active, passive and semi-(active / passive) / battery support passive [7, 8]. Every one of these categories has privte features from its inner elements and operation range. The parts of ctive tag are battery and sender that help to transmit the signal that produces an extended and more credible send range. Further, there is no battery and sender in passive tag but it powered by the received signal from the reader by using a backscatter. The semi-active tag reflects the reader signal with backscattering but signal is confirming by exploiting an inner power source batteries [9]. RFID is fastly mounting technology and presents many advantages than conventional identification system such as barcode. The condition of barcode reading is needed to be in line of sight (LOS) between scanner and label where the movement of objects manually or scanner is required [10]. The processes of reading data in RFID technology from tag can do without LOS and also there is no alignment needed. Singh et al. [11] presented a summarized overview of the RFID technology.

In this work, a microstrip antenna has been proposed in order to be resonateed at 2.45 GHz for RFID application. The proposed antenna design is differ from conventional microstip antenna designs where the offered design merges the partial ground technique with omnidirectional radiation. The presented antenna size is (36.5 × 27 × 1.67) mm^3 which achieves good impedance matching, suitable gain, wide bandwidth, good efficiency, small size and radiation patterns over the complete operating band.

2. BACKGROUND

The ideal RFID system contains two RFID subsystems these are tag and reader as shown in Figure 1 [9]. The antenna is one of the important devices in RFID system. RFID is noncontact (wireless) system use radio frequency (RF) through electromagnetic fields (EMFs) as a transmitting channel to carry data from point to other for automatically identifying purposes [12]. The antenna of reader transmits an RF signal to the antenna of tag and receives data from it [9]. The tag contains a chip as an electronic element and antenna where the chip includes the necessary information to identify an object. The reader sends and receives RF energy of the other side (tag) of RFID [7].

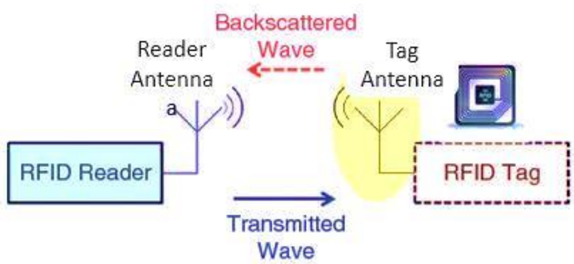


Figure 1. Simple scheme of RFID system

One of the main components in RFID system is antenna that permits to communicate data between tag and reader. RFID system operates on various bands of frequency varies between 30 Hz and 5.8 GHz with respect to its applications [13, 14]. Internationally, RFID communication is mainly divided into four frequency bands as low frequency (125 – 134) KHz, high frequency of 13.56 MHz, ultra-high frequency (860 ~ 960) MHz and microwave (MW) frequency of (2.45 or 5.8) GHz [15]. However, the microwave (MW) RFID is highly interesting, because the reading range is long, typically (2 – 15) m [16]. Recently, RFID technology is wider in applications such in wireless communication (Wi-Fi) [17, 18]. The RFID system consists of two different layers which are physical layer and information technology (IT) layer [16].
Physical layer consists of the followings:

a) One or more radio-frequency (RF) tags
b) One or more interrogators (readers)
c) One or more reader antennas
d) Deployment environment

Information technology (IT) consists of the followings:

a) Hardware such as computers

b) Networks
c) Software (device drivers, filters, middleware, and user applications)

2.1. RFID operating principles

RFID system shown in Figure 2 consists of three components in two combinations: a transceiver (transmitter/receiver) and antenna which usually combined as an RFID reader. A transponder (transmitter/responder) and antenna are combined to make an RFID tag. RFID tag is read when the reader emits a radio signal that activates the transponder, which sends data back to the transceiver. Basic RFID system consists of an antenna or coil, transceiver (with decoder) and a transponder (RF tag) electronically programmed with unique information [19].

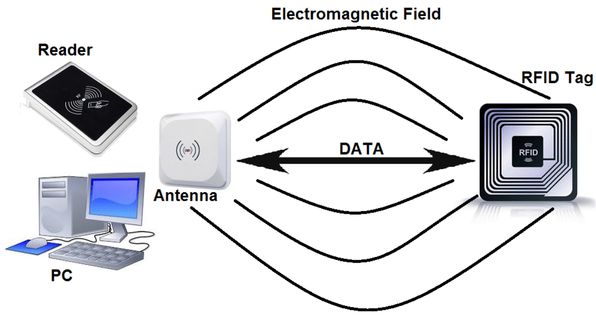


Figure 2. RFID system

The purpose of an RFID system is to enable data to be transmitted by a portable device, called a tag, which is read by an RFID reader and processed according to the needs of a particular application. The data transmitted by the tag may provide identification or location information, or specifics about the product tagged, such as price, color, date of purchase, and so on. A typical RFID tag consists of a microchip attached to a radio antenna mounted on a substrate. The chip can store as much as 2 kilobytes of data [19].

2.2. Operating frequency

With the development of Internet of Things (IOT) technology, RFID communication has been widely applied to daily life [20]. Each RF has its private read distance, performance and power requirements. By depending on the application the frequency is choice [2]. RFID systems are operated at widely differing frequencies, ranging from 135 KHz long wave to 5.8 GHz in the microwave range [16]. Internationally, RFID communication is mainly divided into such four frequency bands as low frequency (125 – 134) KHz, high frequency 13.56 MHz, ultrahigh frequency (860 – 960) MHz and microwave (2.45 GHz and above) [15].

2.3. RFID antennas

RFID antennas are used to transfer information between tag and reader antennas. RFID antenna kinds are patch antenna, linear polarized antenna, gate antenna and stick antenna. RFID antenna types are shown in Figure 3 [21]. According to the researchers, an RFID antenna should satisfy following requirement [21]: (i) should be small size, (ii) should have omnidirectional coverage or hemispherical coverage, (iii) provides maximum transfer signal, (iv) cheap, (v) robust and (vi) compact.

Microstrip antenna are increasing for use in REID applications especially in UHF band due to their low profile structure and conformal structure [13]. Microstrip patch antenna is printed on substrate material such as FR4 that has three layers; upper side, dilectric and ground plane, where the upper and ground planes are conductors such as copper or gold. A radiating patch can take any credible shape such as triangle, circle, fractal, etc. and is printed in the upper side, while lower side is represented ground plane as shown in Figure 4. The dielectric constant of the substrate (ε_r) is typically in the range $2.2 < \varepsilon_r < 12$ [22]. For reasonable performance of an antenna, a low dielectric constant or relative permittivity with thick dielectric is suitable to provide best radiation, acceptable efficiency and wide bandwidth [23].

Figure 3. RFID antenna types

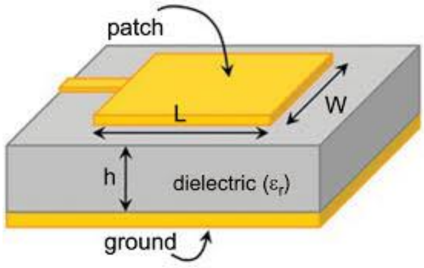


Figure 4. Microstrip patch antenna

3. RELATED WORK

The major demerits of the microstrip patch antennas are very narrow bandwidth, low efficiency, high feed network losses and low power handling capacity, which effect on performance of this antenna [22-24]. But, on the other side, the microstrip antenna has many merits such small size, low profile, low fabrication cost conformable and easy to build [24]. Many researchers are presently studied several shapes of antenna design used in RFID system by taking a different approach of patch and ground geometry. Generally, the smaller size, best efficiency good directivity and wider bandwidth of RFID antenna system are consider as an important problems of most research. In [25] a type of compact antenna with size of (30 × 30 × 1.6) mm^3 and narrow bandwidth with acceptable gain has been presented. The return loss bandwidth is 80 MHz in the frequency range of (2.42 − 2.5) GHz. In [26] designed an antenna to cover dual band 2.4, 5.8 GHz RFID operation frequency bands. The antenna structure likes an F-shaped radiator which has total size of (38 × 45 × 1.6) mm^3 and achieved good realized gain. In [27] a dual band printed omnidirectional antenna operates at 2.45 GHz is presented. The substrate has been used is FR4 and the size of the proposed antenna is (l5 × 85.75) mm^2 and dielectric thickness of 1.6 mm. The return loss of this antenna at 2.45 GHz is -10.61 dB and the bandwidth is 122 MHz. The gain that has been realized of this antenna is 3.798 dB. In [28] a compact microstrip stacked patch antenna operates at resonance frequency of 2.45 GHz is proposed for a mobile passive RFID reader. The antenna has dimensions of (58 × 58) mm^2 with large thickness of 11 mm. The narrow bandwidth with frequency range from 2.31 to 2.56 GHz and the peak gain achieved of 6.32 dB in the resonance frequency 2.45 GHz was presented. In [29] a single layer passive RFID tag antenna containing a pair of T and U slots cut on a square microstrip patch with an operating frequency of 2.45 / 2.41 GHz was proposed. Dimensions of this antenna are (35 × 35) mm^2 in which the proposed antenna has bandwidth of 250 MHz and the gain of approximate to 2.1 dB. In [30] an antenna operated at 2.45 GHz with the overall size of (35 × 26 × 1.67) produced gain of 2.5 dB at 2.415 GHz was presented. In [31] a new miniature microstrip antenna with size of (21.22 × 32.05) mm^2 and directivity of 1.91 dB. The bandwidth is equal to 327 MHz.

The solution of the main problems for the design of the proposed microstrip antenna are to achieve small size with wide bandwidth and suitable value of gain in addition to achieve best return loss value and VSWR that lead to get best performance for microstrip antenna. Many techniques are used to design a miniature antenna, as the slot technique [32-35], the fractal structure, the Defected Ground Structure (DGS) [36], or the use of metamaterial structure [37].

4. ANTENNA DESIGN AND GEOMETRY

The configuration of the proposed antenna is illustrated in Figure 3. The RFID antenna consists of a patch antenna as switch shape with balanced feed and partial ground antenna to achieve omnidirectional radiation pattern. It is printed on a suitable cost FR4 substrate material, whose relative permittivity, loss tangent, and thickness are 4.3, 0.025 and 1.6 mm, respectively. The slots size at the back sides and back middle of the antenna consist the dimensions of (1.5 × 14) mm and (23 × 0.25) mm, respectively. The comprehensive size of the general microstrip patch antenna has been determined as in ref. [22]. The width of the antenna structure depends on the speed of light in free space (v_o), relative permittivity (ε_r) and the resonate frequency (f_r) and it is calculated as (1).

$$W = \frac{1}{2f_r\sqrt{\mu_o\varepsilon_o}}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{v_o}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \quad (1)$$

Where $v_o = 3 \times 10^8\ m/s$,

$\mu_o = 4\pi \times 10^{-7}\, H/m$
and $\varepsilon_o = 8.85 \times 10^{-12}\, F/m$

The effective dielectric constant in the line (ε_{eff}) in this case is calculated as (2):

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+\frac{12h}{W}\right]^{-1/2} \tag{2}$$

The length of antenna increases due to fringing effect as (3):

$$\frac{\Delta L}{h} = 0.412h\frac{(\varepsilon_{eff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{W}{h}+0.8\right)} \tag{3}$$

ΔL is the extended patch length in each end due to fringing
The effective length is calculated by (4):

$$L_{eff} = \frac{1}{2f_r\sqrt{\varepsilon_{reff}}\sqrt{\mu_o\varepsilon_o}} = \frac{v_o}{2f_r\sqrt{\varepsilon_{reff}}} \tag{4}$$

The patche's actual length ($L_{act.}$) is obtained by (5).

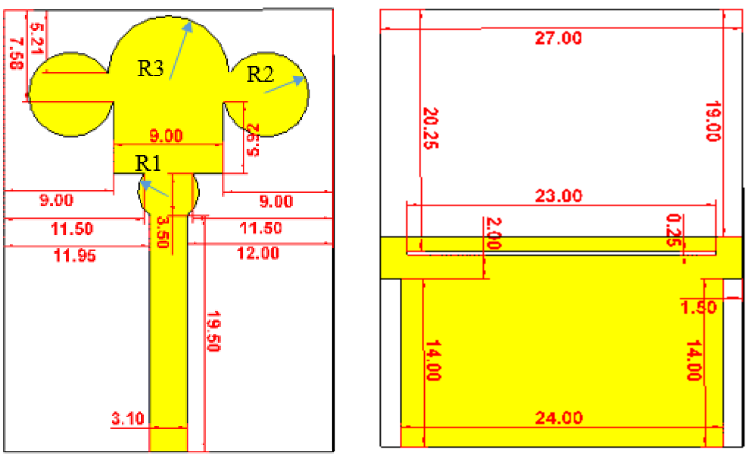
$$L_{act.} = L_{eff} - 2\Delta L \tag{5}$$

The dimensions of the base of substrate material that represented as ground plane, width (W_g) and length (L_g) are obtained as (6) and (7).

$$W_{substrate} = W + 6h \tag{6}$$

$$L_{substrate} = L + 6h \tag{7}$$

By using the above equations the dimensions of antenna is achieved as shown in Figure 5. The design parameters are listed in Table 1.



(a) (b)

Figure 5. Antenna design (a) patch, (b) ground plane

Table 1. Dimensions of the proposed antenna

Parameter	Dimension (mm)
Substrate width	27
Substrate length	36.5
R_1, R_2, R_3	*2.5, 3.5, 5*
Feed width	3.1
Feed length	19.5
Conductor thickness	0.035
Ground width	27
Ground length	17.5
Dielectric height	1.6

5. SIMULATION RESULTS AND DISCUSSION

Initially, the return loss (S_{11}-dB) can be obtained with respect to frequency as in Figure 6. the minimum dip in response is -34.8 dB accured at 2.45 GHz.

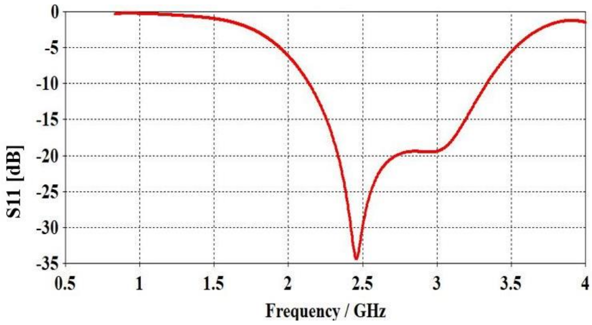


Figure 6. Return loss response

Calculation of Bandwidth (BW)
Lower frequency (f_L) = 2.14 GHz
Higher frequency (f_H) = 3.35 GHz
Center frequency (f_r) = 2.45 GHz

$$BW\% = \frac{f_H - f_L}{f_r} \quad (8)$$
$$BW\% = 49.38\ \% \quad (8)$$

As can be observed from Figure 4, the minimum return loss value of the disc monopole antenna is about -34.8 dB at the resonance frequency (2.45 GHz). The bandwidth of proposed antenna is 1.21 GHz in the frequency range of (2.14 − 3.35) GHz. In this work, it obvious that the presented antenna is appropriate for RFID applications in a wide band range of frequencies. The other decisive parameter beside the return loss (RL), that is concerning the bandwidth (BW) and effects on the antenna performance, is voltage standing wave ratio (VSWR). In fact it is limited in range, $1 \leq VSWR \leq 2$. Thus, the antenna can be capable to operate at frequencies where the value of VSWR is below than 2 [38]. The VSWR curve of the designed antenna is shown in Figure 7.

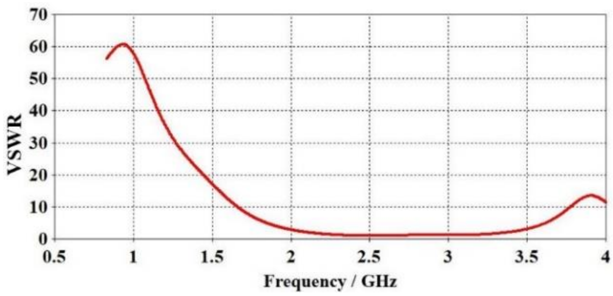


Figure 7. VSWR verses frequency

From Figure 7, it can be seen that the VSWR value of the proposed antenna at 2.45 GHz is about 1.08. As clarified from the frequency response in Figure 8 of the designed antenna, an appreciable gain value of 1.85 dB is obtained. The other considerable parameter related to gain, that interested in antenna performance is the directivity (D). Figure 9 offers the radiation pattern and directivity of the presented antenna. Theoretically, the relation between the gain (G) and directivity (D) is associated to antenna efficiency factor (η) as in (9).

$$G = \eta D \ (9) \quad (9)$$

The antenna efficiency factor (η) value is enclosed by ($0 \leq \eta \leq 1$). If the efficiency factor equals 1, then the antenna is lossless and practically, the gain (G) is less than the directivity (D). As spotted in Figure 9, the incident power in generally is radiated with less back lobe while the maximum directivity (D_{max}) observed from Figure 9 is 2.8 dB. The simulation results of the proposed antenna are extracted and collected in Table 2.

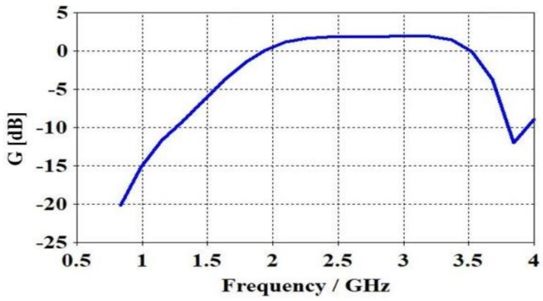


Figure 8. Realized gain

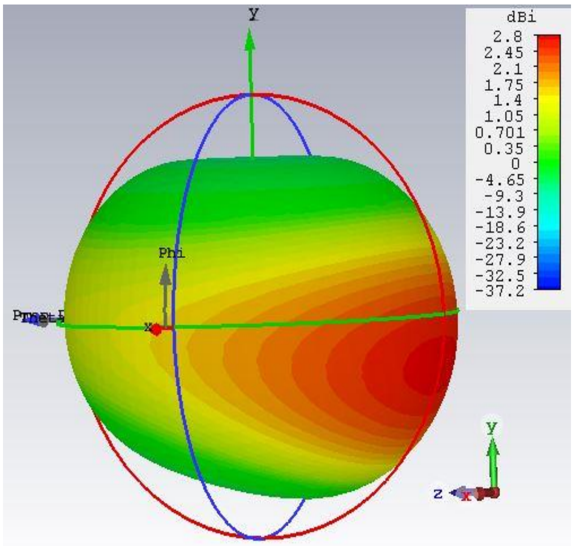


Figure 9. Radiation pattern with directivity

Table 2. Extracted simulation results of the proposed antenna

Parameters	Value
Frequency band (GHz)	2.14 – 3.35
Resonant frequency (GHz)	2.45
Bandwidth (GHz)	1.21
Return loss (dB)	-34.8
VSWR in minimum case	1.08
Gain (dB)	1.85
Directivity (dB)	2.8

To support this work the many useful parameters has been clarified such as surface current, radiation pattern and antenna input impedance as in the following subsections.

5.1. Surface current

In order to clarify the essence of the frequency band characteristic, the surface current distribution at the resonance frequency on the upper side represented as a patch and the ground plane is simulated, Figure 10 illustrate this behavior. From Figure 10, the current distribution is concentrated around the feedline and on the starting patch in addition in the middle ground slot, after that the surface current begin to spread gradually in patch and ground plane.

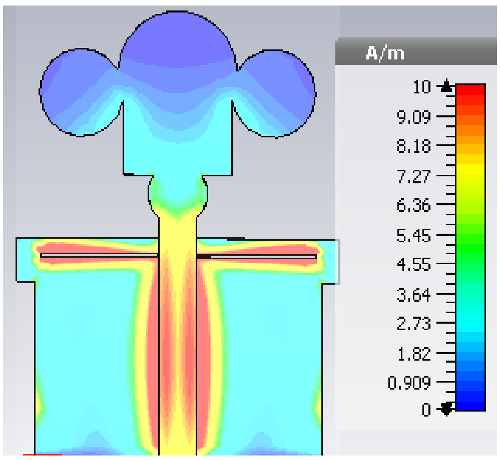
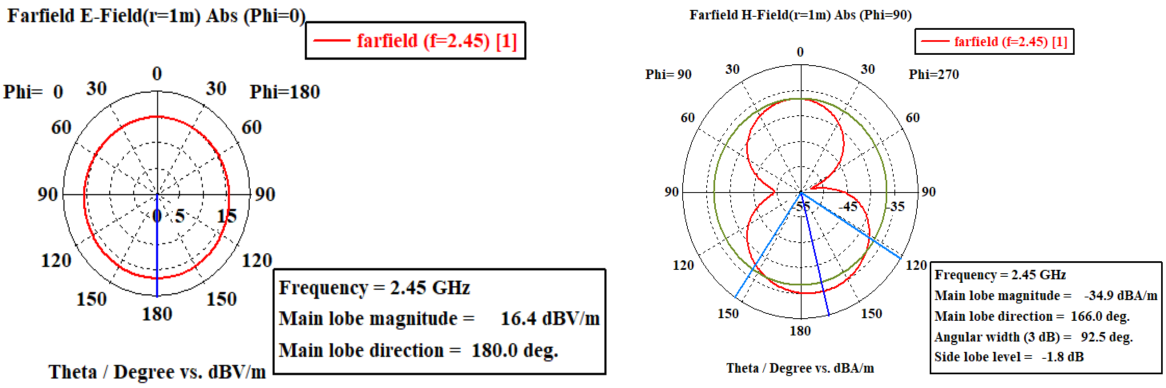


Figure 10. Surface current distribution

5.2. Radiation pattern

Figure 11 shows the simulated radiation patterns when phi = 0° and theta is varied from 0° to 180° at 2.45GHz. The proposed antenna provides an omnidirectional radiation pattern in the E-plane with main lobe direction at 180°, while provides directional pattern in H-plane at main directional pattern of 180°.

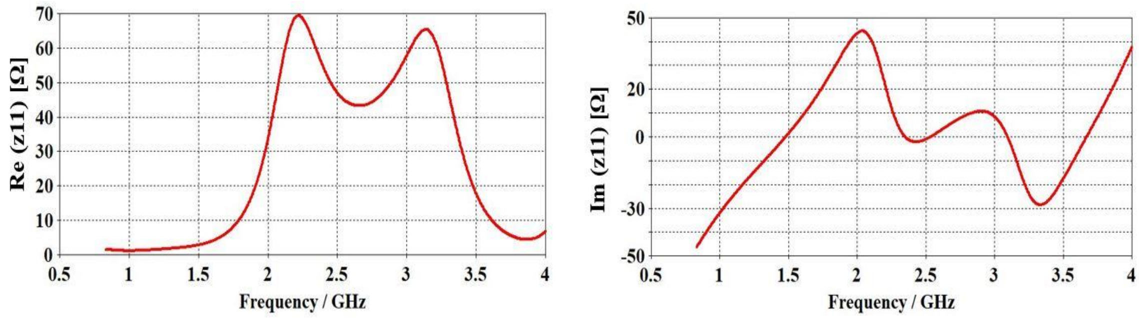


(a) (b)

Figure 11. Field patterns (a) E-Field at phi=0^{o}, and (b) H-Field at phi=90^{o}

5.3. Antenna impedance

The behavior of the proposed antenna for real and imaginary parts impedance of is shown in Figure 12. In the resonant frequency (2.45 GHz) the input impedance of the proposed antenna is (49.8+j1.2) Ω, that gives a good impedance matching between transmission line and antenna.



(a) Real impedance (b) Imaginary impedance

Figure 12. Simulation input resistance (a) real part, (b) imaginary part

6. MANUFACTURED ANTENNA AND RESULTS

Figure 13 shows the fabrication of the proposed antenna and its test and measured operation using vector network analyzer (VNA) type MS4642A. The simulated and measured results of return loss characteristics of the proposed antenna are illustrated in Figure 14. As can be observed from the experimental and simulation cases, a good and agreement return loss has been obtained. The measured and simulated VSWR are illustrated in Figure 15. The measured VSWR agrees well with the simulated one and equal to 1.08 at 2.45 GHz. Figures 16 and 17 show the measured and simulated of real impedance and imaginary impedance, respectively. It is observed from these figures that the results in case of simulation and measurement are relatively good agreement with each other.

As compared the proposed antenna design with the state of art relevant works, the proposed design achieves smaller size with wide bandwidth and best return loss as well as an omnidirectional radiation pattern. All these characteristics results show that proposed design outperforms the other relevant works designs. Table 3 summarizes the the proposed antenna design outcomes as compared with the other state of art works design.

(a) (b) (c)

Figure 13. Fabricated of the proposed antenna (a) patch plane, (b) ground antenna, (c) measured operation using VNA (type MS4642A) and test

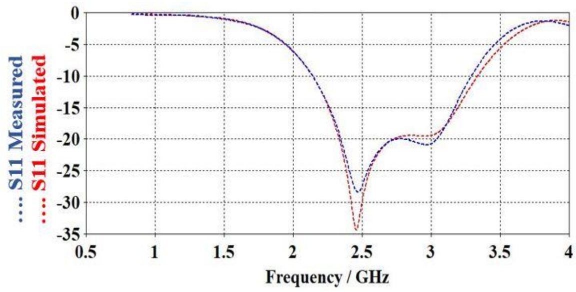


Figure 14. Simulated and measured results of antenna return losses

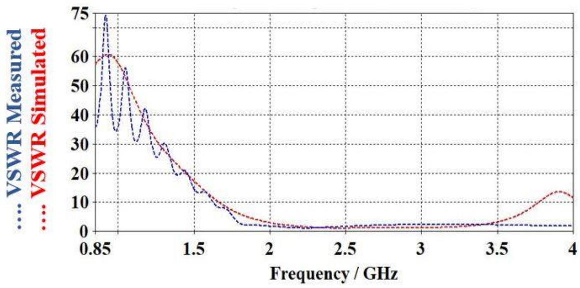


Figure 15. Simulated and measured results of antenna VSWR

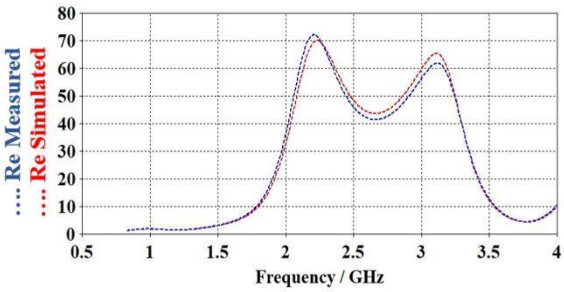


Figure 16. Simulated and measured results of antenna real impedance

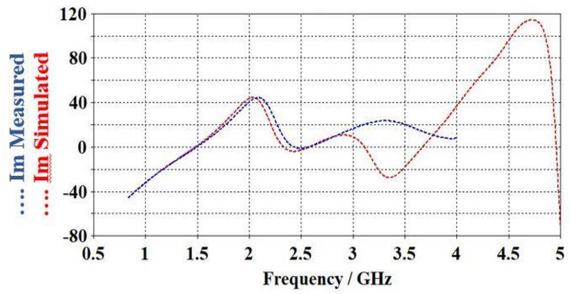


Figure 17. Simulated and measured results of antenna imaginary impedance

Table 3. Comparsion of this design with the other designs

Methods	Dimensions (mm^2)	Bandwidth (MHz)	Return Loss (dB)
[27]	30 × 30	80	17
[28]	38 × 45	Narrow bandwidth	20
[29]	15 × 85.75	122	10.61
[30]	58 × 58	250	55
[31]	35 × 35	250	50
Proposed antenna	27 × 36.5	1210	34.8

7. CONCLUSION

In this paper, a partial ground with slot in the ground plane of antenna is presented to operate at 2.45 GHz for universal ultra-wideband RFID applications. By using a partial ground theory with rectangular slot and switch shaped radiator in antenna design, a desired performance of gain, reflection coefficient, efficiency and wide bandwidth over the frequency range from 2.14 to 3.35 GHz is improved compared with conventional one. The radiation of the proposed antenna is omnidirectional radiation pattern. The results of the proposed antenna at less than 10dB return loss are bandwidth of 1.21 GHz, VSWR of 1.08 and maximum measured gain of 1.85 dB. The measurement results agree well with the corresponding simulated ones. The structure of the proposed antenna is attractive in addition to easy to design and fabrication. The proposed antenna has several advantages such as a very wide impedance bandwidth, omnidirectional radiation, and small size.

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