



# A Miniaturized Frequency Reconfigurable Patch Antenna for IoT Applications

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## Abstract

This work presents a novel frequency reconfigurable patch antenna design for Internet of Things (IoT) applications. The proposed antenna structure has hexagonal patch element. Frequency reconfiguration is realized by employing a varactor diode in the microstrip feedline. The miniaturization in the proposed antenna design is obtained by incorporating defected ground structure (DGS) in the ground plane along with reactive loading employing varactor diode. These miniaturization techniques result in size reduction with an overall antenna size of  $40 \times 40 \text{ mm}^2$ . The results achieved show that the presented antenna produces frequency reconfigurable feature with continuous tunability from 1.4 to 2.9 GHz, thus covering several wireless communication technologies like WiFi, Bluetooth, ZigBee, GPS, and other 2G/3G/4G cellular standards. The proposed antenna has stable gain patterns with maximum measured gain of 2.4 dBi. To prove the concept, proposed antenna is fabricated and measured. The simulations and measurements exhibit good agreement. The antenna design is compact, simple, planar and low-profile making it suitable for wireless handheld applications including IoT.

**Keywords** Frequency reconfigurable antenna · Internet of Things (IoT) · Low profile · Planar antenna · Varactor diode

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## 1 Introduction

The arrival of Internet of Things (IoT) has completely changed the telecommunication field as it provides exceptional applications in various fields [1, 2]. Modern IoT devices are mostly wireless enabled. WiFi, Bluetooth, global positioning system (GPS), radio frequency identification (RFID), 2G/3G/4G cellular, ZigBee, and the narrow band IoT (NB-IoT) are some well-known wireless standards for IoT. Therefore, IoT is very important for economics, industry, and for our everyday life. The IoT applications requires antennas to be small size, low cost, light weight, and conformal. Recently some antenna designs for IoT applications have appeared in literature [3, 4].

Reconfigurable antenna can switch between different bands according to the requirement and thus has the capability to operate as a multimode functional antenna. An antenna can be reconfigured by purposely changing its frequency, radiation or polarization characteristics. Different techniques can be used to realize reconfigurability in antennas such as integrating mechanical translations, electrical switches, or liquid metals. However, the most popular and widely used method is to employ switching components like radio frequency microelectromechanical system (RF-MEMS), varactors or PIN diodes to obtain reconfigurability in the antenna [5]. The biggest advantage of employing varactor diode is that they can produce continuous frequency tuning that is very desirable for IoT applications. However, unlike varactor diodes that can give continuous frequency tuning range, PIN diodes provide distinct operating bands. RF-MEMS switches-based antennas suffer from slow switching response as compared to varactors and PIN diodes [5].

To deal with multifunction and multistandard IoT devices, there is a need to propose a compact reconfigurable antenna that can allow the IoT device antenna communication over multiple bands, so that it can operate for various applications and standards. For this reason, reconfigurable antennas have gained significant attention for IoT applications recently [6–10]. In [6], a reconfigurable circular patch antenna with digital tuning capability was proposed for IoT devices. A slot, vias and digitally tunable capacitor (DTC) was used to tune the antenna for 868 MHz, 1.58 GHz, and 2.4 GHz band. The diameter of circular patch used in the design was 58.8 mm. In [7], a reconfigurable loop patch antenna was proposed for 760 MHz and 575 MHz bands. The antenna employed RF-MEMS switch for reconfiguration and total antenna dimensions were  $40 \times 40$  mm<sup>2</sup>. An inkjet printed based reconfigurable antenna for IoT applications was presented in [8]. Two PIN diodes were employed to achieve different reconfigurable bands between 1.5 and 4 GHz. The total size of antenna was  $40 \times 30$  mm<sup>2</sup>. In [9], a DTC based inverted-F reconfigurable antenna was presented for IoT applications. The operating band of the antenna was from 600 to 960 MHz with overall size of  $60 \times 13$  mm<sup>2</sup>. In [10], a polarization reconfigurable patch antenna design was presented for 2.4 GHz band IoT applications. Four PIN diodes were used to produce reconfigurability in the design. The total size of antenna was  $70 \times 70$  mm<sup>2</sup>. Most of the reported reconfigurable antennas for IoT applications have large size, narrow bandwidth and limited tunability.

Microstrip patch antennas are small, lightweight, compact, and easily integrated antennas with low fabrication cost as well, hence they are most suitable candidate for IoT applications. Different reconfigurable patch antennas have appeared in literature [11–17]. In these designs, reconfiguration was realized by employing PIN diode [11–13], varactor diode [14–16] and RF-MEMS switches [17]. In [11], a patch antenna having pattern and frequency reconfiguration capability was presented for 2.43 and 3.3 GHz. In [12] and [13], patch antenna covered several bands between 1.7–3.5 GHz. The designs using PIN diodes

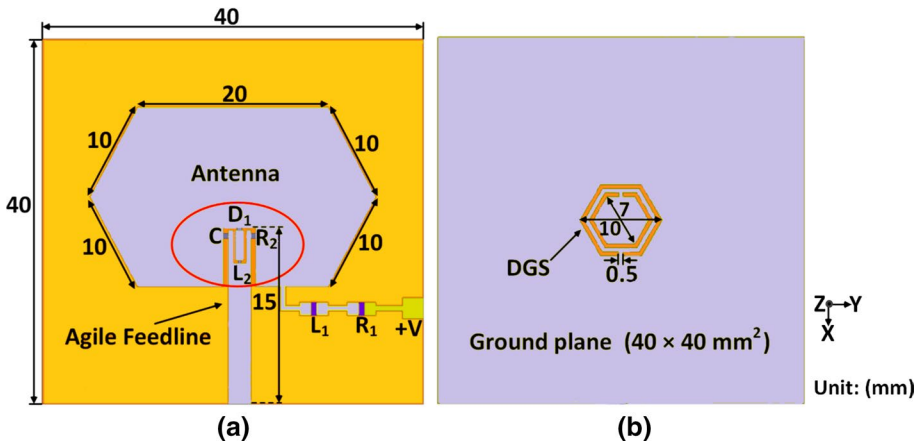
for reconfiguration had distinct working band. In [14], a dual band patch antenna with size of  $38 \times 38 \text{ mm}^2$  was reported for 2.22–2.28 GHz and 3.2–4.3 GHz bands. In [15], a stacked antenna system consisting of two square patch elements was designed covering two bands (i.e. from 1.7 to 1.9 GHz and from 2.1 to 2.5 GHz). Patch element size used in the design was  $82 \times 82 \text{ mm}^2$ . A square patch antenna was proposed in [16] having patch element size of  $48 \times 48 \text{ mm}^2$ . An E-shaped patch antenna using RF-MEMS for reconfiguration was presented in [17]. The antenna could be tuned between 2–3.2 GHz band and had patch of size  $44.1 \times 92.5 \text{ mm}^2$ . No reported frequency reconfigurable patch antenna used reconfigurable feed. By utilizing reconfigurable feed, we can reduce cost, minimize losses and remove unwanted mounted antenna's interference. Moreover, no active element is required on antennas' radiating surface to realize reconfigurability [18]. Therefore, the aim of this article is to design a compact frequency reconfigurable patch antenna realizing wide range frequency tuning employing varactor diode placed in feedline. Moreover, most of the reported reconfigurable antenna designs employ several diodes/switches to obtain reconfigurability, which results in high cost and complexity of the design. Our objective was to achieve wide continuous tuning range by using just one varactor diode in the antenna design.

This article presents a miniaturized frequency reconfigurable antenna based on reconfigurable microstrip feed. The proposed design contains hexagonal patch element antenna. A miniaturizing technique of reactive loading is implemented to make antenna structure compact. Further compactness is achieved by including hexagonal defected ground structure (DGS) in antenna's ground plane. This antenna is realized on FR-4 substrate with overall board dimensions of  $40 \times 40 \text{ mm}^2$ . Varactor diode was situated in microstrip feed to obtain frequency tunability. The proposed design displays wide frequency tunability range between 1.4 to 2.9 GHz with  $-10 \text{ dB}$  bandwidth of 183 MHz, covering various well-known 3G and 4G wireless standards like ZigBee, GSM, LTE, UMTS, PCS, Bluetooth, WiMAX and GPS. To the best of our knowledge, this is the only reconfigurable feedline based patch design having such compact overall design size and producing wide tuning range (i.e. 1.4–2.9 GHz) using single varactor diode, making it appropriate for modern IoT devices and wireless handheld devices.

In the following sections, antenna design details are given in Sect. 2, the simulations and measurements are illustrated in Sect. 3 and conclusions are stated in Sect. 4.

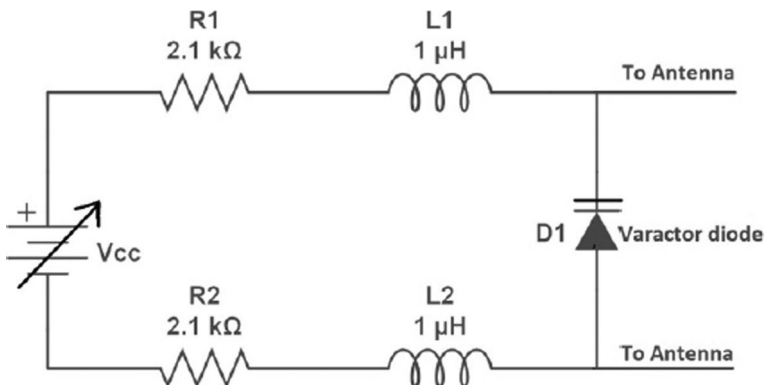
## 2 Proposed Antenna Design

The structure of proposed antenna and dimensions is presented in Fig. 1. Figure 1 shows the top layer and bottom layer of the proposed hexagonal-shaped patch antenna. The proposed antenna is realized on FR-4 material substrate ( $\tan \delta = 0.02$ , thickness = 1.5 mm and  $\epsilon_r = 4.4$ ). The complete antenna system is designed on substrate size of  $40 \times 40 \times 1.5 \text{ mm}^3$  making it appropriate for IoT devices and wireless handheld devices. The top layer of antenna consists of feedline and biasing circuit. A DGS is known to be utilized in antenna's ground to reduce antenna size and enhance bandwidth. [19]. The bottom layer (ground plane) of antenna has DGS slots in it. The ground plane dimensions are  $40 \times 40 \text{ mm}^2$ . The antenna parameters and feeding point locations were optimized using HFSS. Our objective was to bring the resonance frequency band down without changing size, for this purpose a hexagonal DGS was employed in the GND plane and reactive loading was also performed. By reactive loading and adding DGS, the resonance band came down from 3.38 GHz to 2.3 GHz. The DGS location was enhanced for the width of outer



**Fig. 1** Layout of the proposed frequency reconfigurable patch antenna for IoT. **a** Top view. **b** Bottom view

and inner slot and also for the distance among the two rings. This technique helped us in miniaturizing the antenna size and brought the resonate band to lower band. A  $50\text{-}\Omega$  ( $\Omega$ ) microstrip line feed with capacitor, a varactor diode ( $D_1$ ) and an inductor ( $L_2$ ) was used to obtain reconfigurability by altering reverse bias voltage of varactor diode. A frequency tunable band with continuous wide range tuning between 1.4 and 2.9 GHz was realized. Figure 2 shows the bias circuit used for varactor diode, which comprises of resistors ( $R_1$  and  $R_2$ ) and inductors ( $L_1$  and  $L_2$ ) in series joined with two terminals of varactor diode. The varactor diode (by way of resistor and inductor) was joined to variable voltage supply. Coaxial cable provides the DC ground and shared the same GND using SMA connector. Any coaxial cable DC is prevented by inductor  $L_2$ . The lumped elements values were  $C = 1\text{ nF}$ ,  $L_1 = L_2 = 1\text{ }\mu\text{H}$ , and  $R_1 = R_2 = 2.1\text{ k}\Omega$ .



**Fig. 2** Biasing circuit for varactor diode

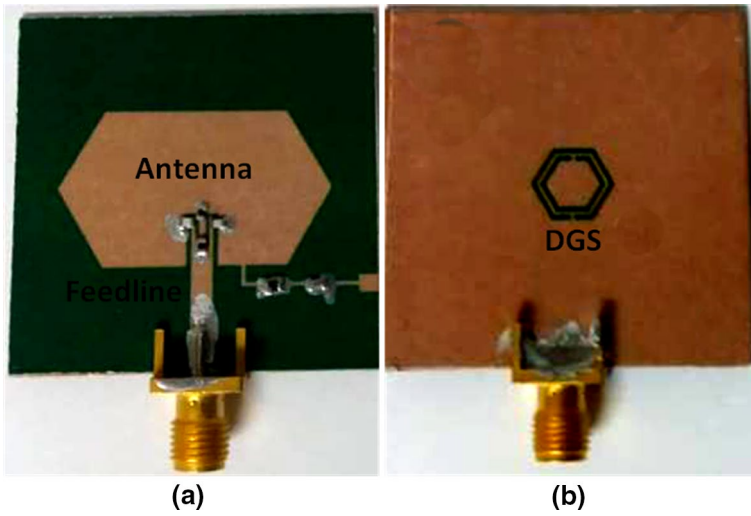


Fig. 3 Prototype of antenna. a Top plane. b Bottom plane

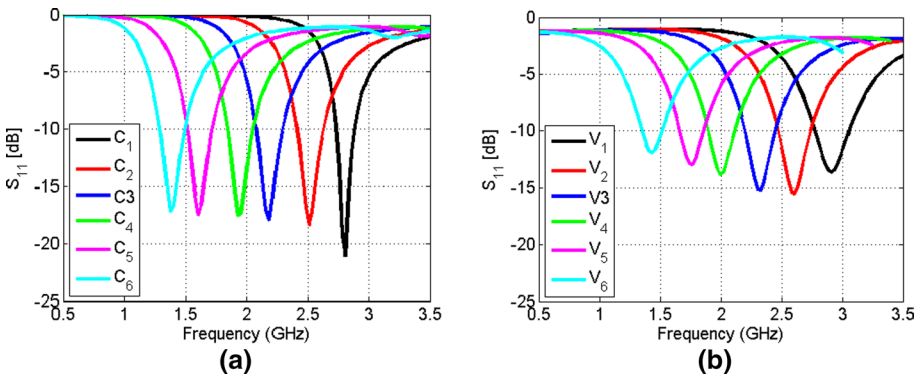


Fig. 4 S-parameters. a Simulated  $S_{11}$  b Measured  $S_{11}$

### 3 Simulation and Measurement Results

To analyze the performance of patch antenna, simulations were carried out using full-wave electromagnetic HFSS. The proposed design was fabricated and verified by measurements. Figure 3 shows the prototype of proposed frequency-reconfigurable antenna design fed by a 50-Ω microstrip feed. Varactor diode was employed in the microstrip feedline for reconfiguration. An SMA connector was utilized to feed the antenna.

#### 3.1 S-Parameters

The simulated and measured  $S_{11}$  reflection coefficients results are shown in Fig. 4. Parametric analysis were also performed on HFSS to understand the variation of  $S_{11}$

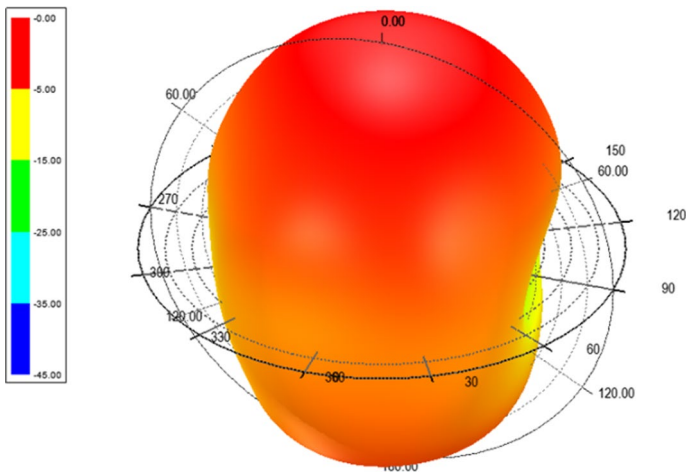
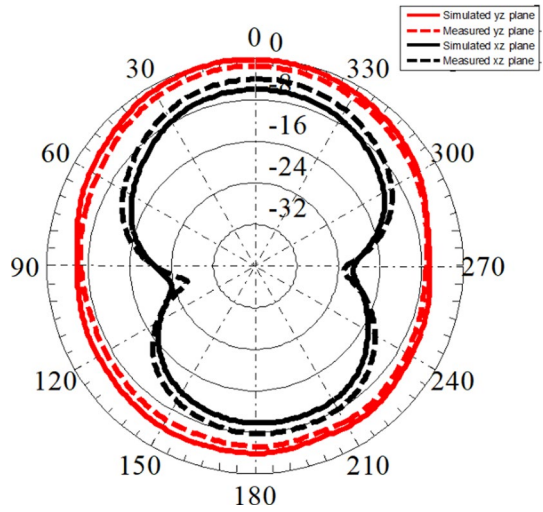
according to dimensions.  $S_{11}$  were measured using vector network analyzer. Figure 4a and b presents the simulated and measured  $S_{11}$  results for the proposed antenna respectively. The varactor diode we used for this design was BBY65-02 V having the operating capacitance range between 35 and 2.5 pF corresponding to voltage range of 0 V to 5 V. Continuous frequency agility was obtained by changing the reverse biased voltage of varactor. The simulated  $S_{11}$  in Fig. 4a shows that resonance frequency constantly changes from 1.3 to 2.8 GHz when the varactor diode capacitance is changed between 35 and 2.5 pF. The values of capacitance used for simulations are  $C_1=35$  pF.,  $C_2=20$  pF.,  $C_3=11$  pF.,  $C_4=4.5$  pF.,  $C_5=3.5$  pF. and  $C_6=2.5$  pF. The measured  $S_{11}$  result in Fig. 4b demonstrates that a wide continuous frequency tunability was achieved from 1.4 to 2.9 GHz by altering the reverse bias varactor voltage between 0 to 5 V. The measurements shown are for voltages  $V_1=0$  V,  $V_2=1$  V,  $V_3=2$  V,  $V_4=4$  V,  $V_5=4.5$  V and  $V_6=5$  V. Thus, the proposed antenna design realizes wide frequency reconfigurability from 1.4 to 2.9 GHz using just one varactor in microstrip feed. Thus, the presented antenna can cover GSM 1800, GSM 1900, LTE 2300/2500, NB-IoT 1700, WiFi (2.4 GHz), ZigBee (2.4 GHz), Bluetooth (2.48 GHz), UMTS (1.8–2.2 GHz), PCS 1900, GPS (1.58 GHz), WiMAX (2.5 GHz), etc. The  $-10$  dB simulated bandwidth was 175 MHz while  $-10$  dB measured bandwidth was 183 MHz. A little mismatch between simulated and measured curves is caused by connector losses, poor soldering, bias circuit impact, diode effects, difference in substrate properties, poor soldering and other fabrication errors.

### 3.2 Gain Patterns and Efficiency

The proposed antenna gain measurements were carried out in SATIMO Starlab anechoic chamber. The chamber walls are enclosed by RF absorbers to remove undesirable interference with measurements. Firstly, a RF signal of corresponding frequency was selected from Starlab chamber “source antennas” and then antenna was illuminated with this RF signal. The measurements include setting up known reference calibrated antenna in chamber over radiated path, then normalizing (or zeroing) the path loss. Horn antenna is chosen as a reference antenna because it offers wide frequency choice (from 0.3 to 30 GHz) and allows us to measure gain for this complete tuning range. The proposed antenna was swapped by reference horn antenna and gain/path loss measurements were conducted with respect to reference normalized path. We determined the antenna gain in dBi by adding the reference calibrated antenna gain to these measurements.

The simulated and measured normalized radiation patterns for  $y-z$  plane and  $x-z$  plane for 2.4 GHz are shown in Fig. 5. The proposed antenna has broadside radiation pattern in  $x-z$  plane and end-fire pattern in  $y-z$  plane. Such patterns are required for Bluetooth, GPS and other IoT applications. Thus, the proposed antenna has desirable patterns for IOT applications. The small variations between simulations and measurements are caused by scattering effects of measuring cables and connectors. Simulated 3-D radiation plot at 2.4 GHz from HFSS is shown in Fig. 6. The total efficiency and peak gain for the proposed antenna are given in Table 1. The measured gain ranges from  $-0.2$  dBi to 2.41 dBi and measured efficiency ranges from 59 to 79%. So good antenna efficiency and gain values were noticed for the entire operating range. The simulations and measurements are in fair agreement given that there is always some measurement error in an anechoic chamber. Figure 7 shows the radiation measurement setup.

**Fig. 5** Simulation and measurement radiation patterns of antenna at 2.4 GHz

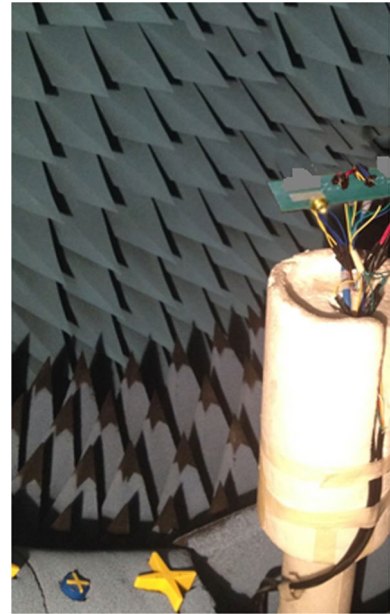


**Fig. 6** Simulated 3-D gain plot of antenna at 2.4 GHz

**Table 1** Peak gain and efficiency values of proposed antenna system

Frequency (GHz)	Peak gain, dBi		Efficiency, %	
	Simulated	Measured	Simulated	Measured
$f_s = 1.48, f_m = 1.53$	-0.19	-0.2	56	59
$f_s = 1.67, f_m = 1.72$	0.28	0.3	61	62
$f_s = 1.90, f_m = 1.90$	0.75	0.80	64	66
$f_s = 2.02, f_m = 2.01$	1.15	1.1	69	70
$f_s = 2.11, f_m = 2.14$	1.45	1.6	71	74
$f_s = 2.4, f_m = 2.46$	2.12	2.2	74	76
$f_s = 2.8, f_m = 2.82$	2.32	2.41	77	79

**Fig. 7** Radiation pattern measurement setup



### 3.3 State-of-the-Art-Comparison

Table 2 compares the performance and size of proposed antenna design with various types of patch designs reported in literature. The parameters compared in Table 2 were antenna type, total size, achieved frequency bands and number of diodes/switches used in the antenna to obtain reconfigurability. As seen, the proposed antenna ensures a better performance and has the smallest size to provide frequency reconfigurability. Majority of the design available in literature use several PIN diodes to obtain frequency reconfigurability and had distinct operating bands over 2 GHz. Moreover, most of the patch antennas cited in literature suffered from big size, limited tunability, and needed several switches/diodes to obtain reconfigurability. This table also illustrates that only few designs provide continuous tuning range for this frequency range and compared to them, the proposed patch antenna displays a wide range continuous frequency tunability (1.4 to 2.9 GHz) using only

**Table 2** Comparison of proposed antenna with existing designs

Ref.	Patch Type	Dimensions (mm)	Bands achieved (GHz)	No of diodes/switches
[11]	Rectangular	41 × 30	2.43, 3.3	2 PIN diodes
[12]	Rectangular	50 × 18.3	2.12, 2.18, 2.26, 2.37, 2.49, 3.10, 3.25, 3.36, 3.49	5 PIN diodes
[13]	Rectangular	31.3 × 29	2.19, 2.35, 2.55, 3.1, 3.25, 3.5	3 PIN diodes
[14]	Square	38 × 38	2.22–2.26, 3.24–4.35	1 Varactor diode
[15]	Square	82 × 82	1.68–1.93, 2.11–2.51	4 Varactor diodes
[16]	Square	48 × 48	1.83, 2, 2.18, 2.25, 2.38, 2.46, 2.55, 2.65	16 PIN diodes
[17]	E-Shaped	92.5 × 44.1	2–2.7, 2.7–3.2	2 RF MEMS
Prop	Hexagonal	W = 29	Continuous tuning (1.4 to 2.9)	1 Varactor diode



one varactor diode. It is apparent from the table that the proposed design has small size, displays a continuous wide range tuning for this frequency range and employs only one varactor diode to achieve frequency reconfigurability. Hence, this proposed antenna is a promising candidate for future wireless communications.

## 4 Conclusion

A novel frequency reconfigurable microstrip feedline based hexagonal patch antenna having wide frequency tunability range (i.e. from 1.4 to 2.9 GHz) has been presented in this paper. The proposed design employed ground plane DGS and reactive loading technique for miniaturization. These miniaturization techniques resulted in keeping the total size of antenna to only  $40 \times 40 \text{ mm}^2$ . The proposed design was made to work as a frequency tunable antenna by utilizing varactor diode in microstrip line feed. The measurement results showed that proposed design exhibits good gain and efficiency performance. The proposed antenna configuration includes various benefits such as low cost, low profile, planar structure, no radiation biasing interference, wide range tunability using just one varactor diode and simple fabrication. To our knowledge, this kind of novel compact frequency reconfigurable antenna design has not been published in literature so far for IoT applications with this wide frequency tuning range.

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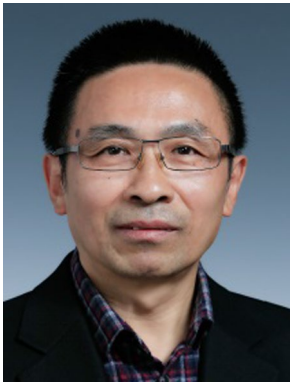
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