Chapter 10
Reconfigurable Antennas for Internet of Things (IoT) Devices

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Abstract The Internet of Things (IoT) is a network that provides interoperability between wireless and a variety of low-power wireless devices linked via the Internet. It is a platform that requires the transmission of a large volume of data and a higher number of communication links, which leads to packet collision, reduced network efficiency, and increased power consumption for retransmission of lost packets. Today, advancements in technology are moving ahead towards higher and higher frequency bands to facilitate higher data rates. To better establish communication links between wireless devices, the selection and reconfigurability of the antennas for the IoT devices play a key role. Some characteristics of antennas such as operating frequency, radiation pattern, and polarization are electronically reconfigured by changing the surface currents on the antenna by using techniques such as biasing of diodes, digitally tuned capacitors, shorting pins, and so on. Frequency reconfigurable antennas meet the requirement of operating in more than one operating frequency which is vital in technologies such as the IoT, where multiple communication links among devices are needed. This article presents a review of various reconfigurable antennas for IoT, and a reconfigurable microstrip slot antenna is proposed for emerging 5G and IoT applications. An optimal-sized antenna at 28/60 GHz with multiple slots on the rectangular patch and defected ground structure is designed and simulated. The simulated antenna exhibits good antenna performance characteristics, such as a realized gain of 6.54 dB at 28 GHz and 2.27 dB at 60 GHz. A bandwidth of 8.8% and 11.25% at 28 GHz, 60 GHz, respectively, is achieved. The radiation efficiency of 81% at 28 GHz and 83% at 60 GHz are obtained. An antenna is constructed using an FR4 epoxy as dielectric material, with a size of 7×7 mm^2 and with thickness of 0.8 mm. An inset feed with a quarter-wave transformer is used for good impedance matching.

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Introduction

The massive rise of the Internet of Things (IoT) and smart industrial use cases has created many technical and scientific obstacles, requiring creative research from academia and industry to produce cost-effective, scalable, efficient, and reliable antenna systems for IoT. An IoT device collects or detects data from an object or environment and sends it through a wireless channel to another device or the cloud. The devices can be controlled remotely over the wireless channel. Thus, it is evident that antenna plays a vital role in IoT Technology. Traditional antennas can only operate in a particular frequency band and have a predetermined emission pattern and polarization (Mathur et al. 2021). An IoT device, on the other hand, needs great capacity, simultaneous use of many frequency bands, and high-speed data transfer. The gadgets utilize many wireless services; hence additional transmission capacity is actually required. Using carrier aggregation, a single user can access many channels. Consequently, carrier aggregation aids in boosting IoT capacity and throughput. Each frequency band must be independently tuned without influencing other functioning bands in order to do this (Subbaraj et al. 2019). As a result, reconfigurable antennas (RAs) are envisioned as a suitable system that can modify basic properties such as operating frequency, polarization, and E and H plane radiation patterns to meet the demands of various communication systems such as IoT sensors and mobile stations. Microstrip patch antennas are ideal candidates for IoT applications because they are small, lightweight, compact, and easy to incorporate antennas with low fabrication costs (Mahlaoui et al. 2017; Merlin Teresa and Umamaheswari 2020; Riaz et al. 2022). Various reconfigurable patch antennas for IoT, Wireless, and Cognitive radio applications have been described in the literature (Karthika and Kavitha 2021; Madhav and Anilkumar 2019; Vamsee Krishna et al. 2019; Boufrioua 2020; Tu and Sang 2021; Allam et al. 2019; AL-Muttairy and Farhan 2020; Balanis 2003; Singh et al. 2020; Ullah et al. 2021; Wang et al. 2020; Akinola et al. 2021; AL-Fadhali et al. 2021; Asadallah et al. 2017; Ojaroudi Parchin et al. 2020; Trinh et al. 2017; Haydhah et al. 2021; Santamaria et al. 2021; Palsokar and Lahudkar 2020; Rajagopalan et al. 2013; Shankar 2021; Lee and Choi 2017; Chen et al. 2019; Al-Yasir et al. 2018; Ingle et al. 2021; Rao and Govardhani 2021; Barakali 2019; Balcells et al. 2010; Schaffner et al. 2000; Kamran Shereen et al. 2019; Ahmad et al. 2021; Shereen et al. 2020).

Reconfigurable Antennas (RAs)

The primary idea of a RA is to adjust the typical parameters by changing the physical features of the antenna by joining or separating different sections of it. Reconfigurability in terms of frequency, polarization, and radiation pattern can be achieved in various ways (Karthika and Kavitha 2021).

Reconfigurable Antenna (RA)-Types

Based on the antenna parameters that are dynamically modified, often the operating frequency, radiation pattern, or polarization, RAs can be of several types. The classification of reconfigurable antennas is illustrated in Fig. 10.1. The primary types of RAs include frequency RA, polarization RA, pattern RA, and hybrid or compound RA. Combination of two or more reconfigurability in one antenna is known as hybrid or compound RA. Further this is sub-classified into frequency and pattern RA, frequency and polarization RA, pattern and polarization RA, and frequency, pattern and polarization RA as shown in Fig. 10.1.

Frequency Reconfigurable Antenna

Multiple antennae are used in a modern wireless communication technology to execute a variety of application-oriented activities. The result is the system gets increasingly complicated and bulky. To achieve portability in wireless devices, multiple antennas residing in the device are replaced with a one radiating element to
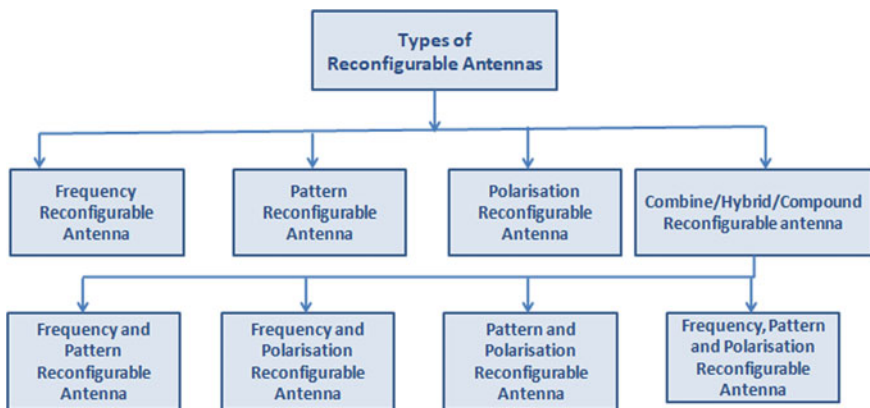

Fig. 10.1 Types of reconfigurable antennas based on change in parameters (Karthika and Kavitha 2021)

function at different frequencies, i.e., multi-band antennas were developed. Nevertheless, these antennas have a deterministic performance and unchangeable according to the user's needs. The concept of frequency reconfiguration is a great option in such situations. As a result, the radiating structure can change its operating frequency in response to demand. These antennas are crucial in technologies like 5G and IoT (Karthika and Kavitha 2021). (Mathur et al. 2021; Riaz et al. 2022; Madhav and Anilkumar 2019; Vamsee Krishna et al. 2019; Tu and Sang 2021; Allam et al. 2019; AL-Muttairy and Farhan 2020; Singh et al. 2020) presents various frequency-reconfigurable antennas for IoT devices (Subbaraj et al. 2019; Karthika and Kavitha 2021; Vamsee Krishna et al. 2019; Boufrioua 2020; Ullah et al. 2021; Rajagopalan et al. 2013) for Wireless communications and (Rajagopalan et al. 2013) for Cognitive Radio Applications. Table 10.1 illustrates the comparison between the suggested antenna and several frequency RAs mentioned in the literature.

Pattern Reconfigurable Antenna

A one only radiating element can substitute multiple single-purpose antennae by including reconfigurability in diverse parameters. Adaptive and non-adaptive radiation patterns are the two types of antenna radiation patterns. Compared to non-adaptive, adaptive radiation patterns gives greater network capacity (Lee and Choi 2017). Literature (Trinh et al. 2017; Haydhah et al. 2021; Santamaria et al. 2021; Palsokar and Lahudkar 2020) presented various pattern reconfigurable antennas for IoT Applications. In (Trinh et al. 2017), a cylindrical metal antenna with a maximum size of 0.58λ, 4 dBi Gain at 2.4 GHz frequency with 80% efficiency for IoT networking Applications is presented. The antenna is switched between three directional patterns and an omnidirectional pattern using PIN diodes as a switch (Haydhah et al. 2021). A novel antenna with four patterns of reconfigurability which include electric, magnetic omnidirectional, and two-directional patterns in two modes at 868 MHz is obtained by employing PIN diodes with 80×55 mm^2 sizes for IoT applications. An electronically pattern (EP) RA consisting of four-wire patches is reported in Santamaria et al. (2021). The patch is switched between four end-fire radiation states from 2.25 to 2.54 GHz and a SP4T switch is used to enable the radiation pattern steering. This method limits the use of electronic components in the reconfiguration process.
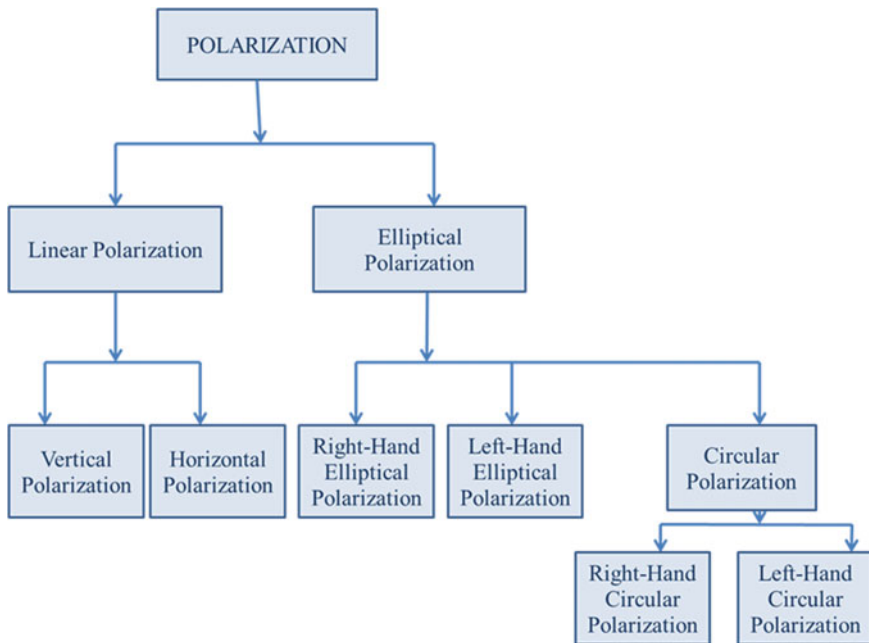
Polarization Reconfigurable Antenna

Polarization establishes the direction of the electric field of the transmitting or receiving RF transmission. Based on the type of orientation, it is categorized as Linear, Elliptical, or Circular Polarization. Vertical, Horizontal Polarizations are two types of linear polarization. Elliptical polarization is classified as Right-Hand (RH) and Left-Hand Elliptical Polarization (LHEP). Similarly, based on the direction of rotation (DoR) of RF signal, Circular Polarization is also classified as Right-Hand

Table 10.1 The comparison of constructed antenna with various frequency-reconfigurable antennae is reported in the literature

Ref	Antenna size (mm^2)	No. of bands	Operating bands (GHz)	Reconfiguration Techniques	Applications
Mathur et al. (2021)	59 × 61	2	2.398–2.955 and 2.234–2.944	Mechanical	IoT
Subbaraj et al. (2019)	25 × 10	4	0.9, 2.4, 3.5, and 5.5	Varactor diodes	Handheld Wireless devices
Riaz et al. (2022)	40 × 40	Continuous Tenability	1.4 to 2.9	Varactor diodes	IoT
Madhav and Anilkumar (2019)	40 × 30	4	2.2, 2.45, 4.26, and 7.34	PIN diodes	Vehicular IoT Communication Platforms
Vamsee Krishna et al. (2019)	8 × 27.5	3	1, 2.4, 10 and 18	PIN diodes	IoT and Wireless Applications
Boufrioua (2020)	55 × 55		4 to 5.5	PIN diodes	Wireless Communications
Tu and Sang (2021)	30 × 30	8	0.9; 1.8; 2.6; 5, 2.4; 3.3; 5.5; 8.2	PIN diode	IoT
Allam et al. (2019)	33 × 31	6	2.47, 7.18, 12.14, 8.4, 3.42, 14.55	PIN Diode	IoT
AL-Muttairy and Farhan (2020)	33.5 × 16	2	2.4 and 5	PIN Diode	IoT
Singh et al. (2020)	25 × 25	5	3.85, 4.14, 4.43, 4.91, and 6.01	PIN Diode	IoT
Ullah et al. (2021)	37 × 35	4	2.1, 2.45, 3.2, and 3.5	PIN Diode	Portable Wireless Applications
Akinola et al. 2021)	23 × 23.4	4	16, 16.5, 21.9, and 21.7	Diode	Covid-19 Tracking
Rajagopalan et al. (2013)	100 × 120	2	2.0–2.6 and 2.6–3.2	RF-MEMS	Cognitive Radio
Rajagopalan et al. (2013)	50 × 50	4	4.5, 3.5, 2.4, and 1.8	PIN Diode	RF Harvesting
Proposed	7 × 7	2	28 and 60	Structural change	IoT and 5G applications

and Left-Hand Circular Polarization (LHCP) as presented in Fig. 10.2. The RF signal can travel numerous paths to reach its target in a wireless environment, causing multi-path fading, path, and shadowing losses. As a result, information loss occurred to the variation in polarization of the transmitted signal. This may be prevented by adopting polarization-diversity antennae. Reconfiguring the feed or changing the radiating structure can both be used to achieve polarization variety (Karthika and Kavitha 2021). The literature reported in Lee and Choi (2017); Chen et al. (2019); Al-Yasir et al. (2018); Ingle et al. (2021); Rao and Govardhani (2021), Balcells et al. (2010) reports various polarizations-reconfigurable antennae and techniques for IoT applications.

A polarization reconfigurable antenna with felt fabric as substrate material for wearable IoT is presented. As shown in Fig. 10.3, PIN diodes are connected to the edge truncations of the radiating patch to achieve three possible reconfigurable polarizations, which includes linear polarization, Right-hand, and Left-hand circular polarization. The antenna resonates at a 2.4 GHz ISM band with an average gain of 5.96 dBi among all three polarizations (Lee and Choi 2017). Overall Structure of polarization reconfigurable antenna with switches is reported in Fig. 10.1 of Lee and Choi (2017). In Al-Yasir et al. (2018), authors have designed and fabricated a prototype of a microstrip antenna that can be reconfigured between right hand and left-hand circular polarization. The circular polarization reconfigurability is achieved by adjusting the DC biasing of PIN diodes. The antenna has a fractional bandwidth

Fig. 10.2 Basic classification of polarization in antenna
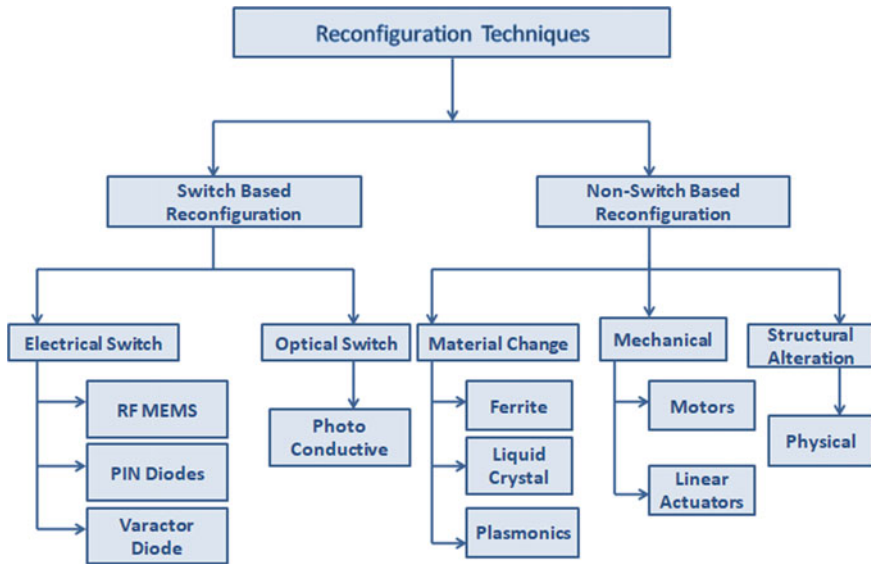
Fig. 10.3 Categorization of reconfiguration techniques (Karthika and Kavitha 2021)

of 9.11%, with a maximum realized gain of (3.1–4.8) dBic at 3.5 GHz. A Scopus data-based bibliometric study of a circularly polarized reconfigurable antenna is presented in Ingle et al. (2021), which helps researchers in this area quickly study various circularly polarized reconfigurable antennas published between 2002 and 2021. Authors in Rao and Govardhani (2021) have designed a rectangular microstrip antenna with a defective ground structure that can be reconfigured between linear and Right-hand circular polarization (RHCP) using a PIN diode for WLAN applications. In Balcells et al. (2010), a millimeter-wave antenna resonating at 60 GHz is designed with the ability to reconfigure between right-handed, circular polarization (CP), or linear polarization (LP) using RF-MEMS switches.

Hybrid/Combined/Compound Reconfigurable Antenna

Any antenna's properties, such as frequency of operation, radiation pattern, and polarization, can be reconfigured based on the use cases. Space vehicles, radar and military, and aviation applications demand a fast and secure link between the communication end-users (Schaffner et al. 2000). Its performance may be hampered by electromagnetic interference and pollution. The single reconfiguration would not be a practical option for these applications. As a result, it requires a cognitive antenna that can transition between different operating frequencies, polarization types, and radiation patterns (Karthika and Kavitha 2021). Palsokar and Lahudkar (2020); Barakali (2019) presents antennas with pattern and frequency reconfigurability. Figure 10.5 of Palsokar and Lahudkar (2020) represents the prototype of the fabricated antenna

which has the ability to switch between pattern and frequency reconfigurability. A few compound reconfigurable antennas are reported in Barakali (2019); Schaffner et al. (2000); Kamran Shereen et al. (2019).

Classification of Reconfiguration Techniques (Karthika and Kavitha 2021)

The technique used to reconfigure an antenna plays a vital role because it changes the current distribution of the radiating structure by connecting and disconnecting various elements of the structure. As demonstrated in Fig. 10.3, many switching mechanisms employ switches such as electrical, optical and also mechanical switches, external adjustment, and the use of reconfigurable materials, etc. (Mathur et al. 2021). Switching techniques for the reconfigurable antennas are reported in Ojaroudi Parchin et al. (2020).

Proposed Antenna Structure and Dimensions

The constructed antenna structure and its overall dimensions are presented in Fig. 10.4a–c. Figure 10.4a shows the patch layer, and Fig. 10.4b presents the bottom layer of the proposed slotted patch antenna for 28 GHz frequency, and Fig. 10.4c presents the bottom layer for 60 GHz frequency. The top layer of the antenna consists of radiating slotted patch antenna and an insert feed line with a quarter-wave transformer with the full ground. An antenna's ground is known to use a defective ground structure (DGS) to minimize antenna size and increase bandwidth (Mahlaoui et al. 2017). The bottom layer of the antenna is made DGS by etching a square slot of 0.2 mm width on a full ground plane. The outer layer of the slot is of 3.62×2.2 mm^2 size; the shift in frequency from 28 to 60 GHz is achieved by defective ground structure or the slot made in the bottom layer of the proposed antenna. The proposed antenna is realized on FR4 material substrate (thickness $= 0.8$ mm and $\varepsilon_r = 4.4$). The overall antenna is etched on a substrate material possessing size of $7 \times 7 \times 0.8$ mm^3, which can be employed to the Internet of Things (IoT) devices and portable wireless devices. Slot S$_1$ on the patch has 0.05×1.8 mm^2, and width is kept unchanged for all the slots, and the length of each adjacent slot is reduced by 0.2 mm. The gap between two adjacent slots is 0.2 mm is maintained. The detailed dimensions of the constructed antenna are noted in Table 10.2. The simulated antenna structure is shown in Fig. 10.5. The antenna is designed using HFSS simulation tool. The reconfigurability of an antenna is achieved using structural change in the ground.
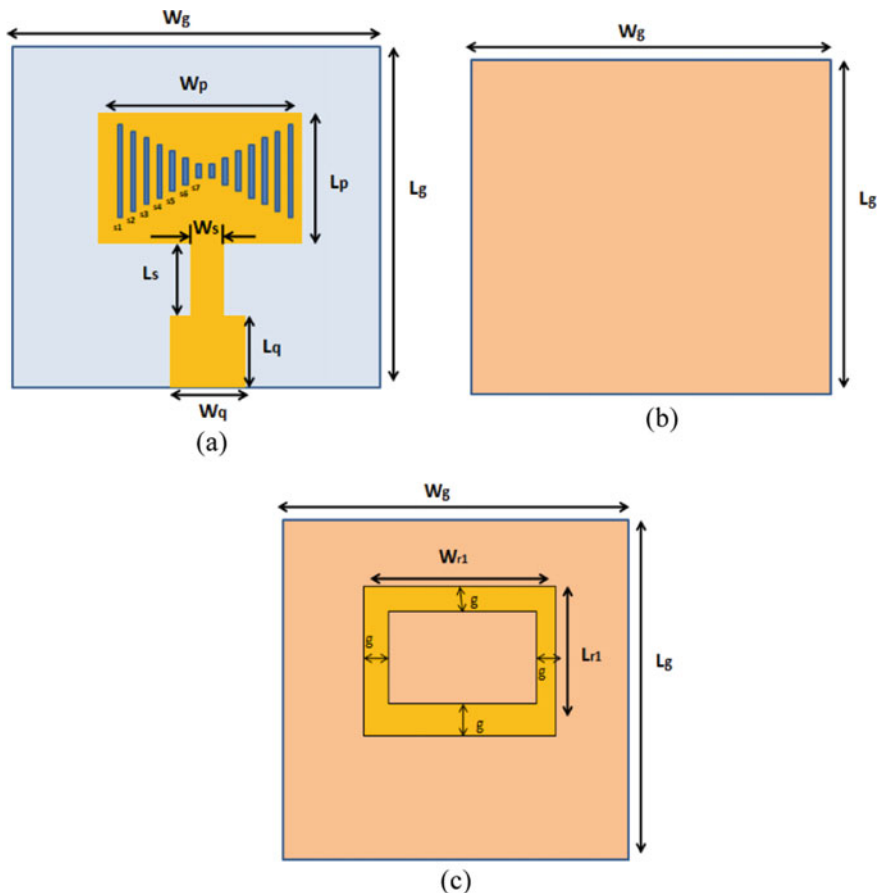
Fig. 10.4 a The top layer and **b** the bottom layer of the constructed antenna for 28 GHz. **c** the bottom layer of the constructed antenna for 60 GHz

Simulation Results and Discussions

The performance of the proposed slotted patch antenna is analyzed; HFSS version 15 was used in the simulations. Figures 10.6 and 10.10 illustrate the S_{11} characteristics of the constructed antenna at 28 and 60 GHz frequencies, respectively. The reflection coefficient of -24.99 dB at 28 GHz with a bandwidth of 2490 MHz is shown in Fig. 10.6. Similarly, -24.18 dB reflection coefficient and bandwidth of 6800 MHz is achieved at 60 GHz as reported in Fig. 10.10. The VSWR at all the resonating frequency ranges is less than two ($<$2) for both 28 and 60 GHz antenna modes. The realized gain of 6.54 dB is achieved at 28 GHz and 2.27 dB at 60 GHz, as shown in Figs. 10.7 and 10.11, respectively. Figures 10.8 and 10.12 illustrate realized 2D gain polar plots along with the XZ and YZ plane of the simulated

Fig. 10.5 Constructed antenna structure in simulation environment
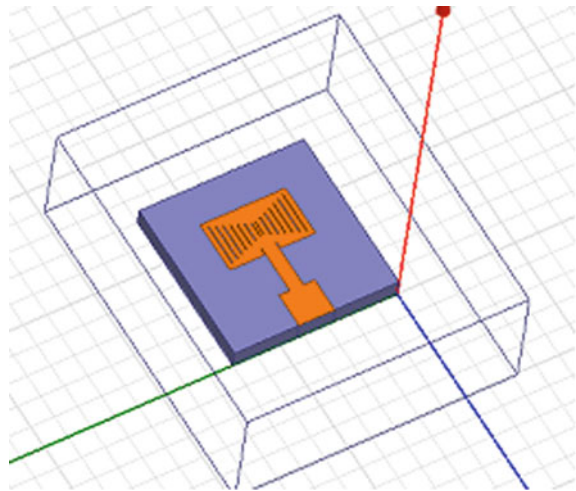
Table 10.2 Dimensions of the proposed antenna structure

Dimensions of patch layer		Dimensions of ground layer	
Symbol	Dimension (mm)	Symbol	Dimension (mm)
W_g	7	W_g	7
L_g	7	L_g	7
W_p	3.62	W_{r1}	3.62
L_p	2.2	L_{r1}	2.2
W_s	0.58	W_{r2}	3.6
L_s	1.35	L_{r2}	2.18
L_q	1.47	G	0.02
w_q	1.53	–	–

antenna with full and defected ground, respectively. From Figs. 10.9 and 10.13, it is observed that the antenna with the full ground obtained a radiation efficiency of 81% at 28 GHz frequency, and the antenna with defected ground structure achieved a radiation efficiency of 83% at 60 GHz frequency.

Conclusion

This chapter presents a review of various reconfigurable antennas for IoT, and a reconfigurable microstrip slot antenna is proposed for emerging 5G and IoT applications. A compact antenna at 28/60 GHz with multiple slots on the rectangular patch and defected ground structure is designed and simulated. The simulated antenna exhibits good performance characteristics, such as a realized gain of 6.54 dB at 28 GHz and
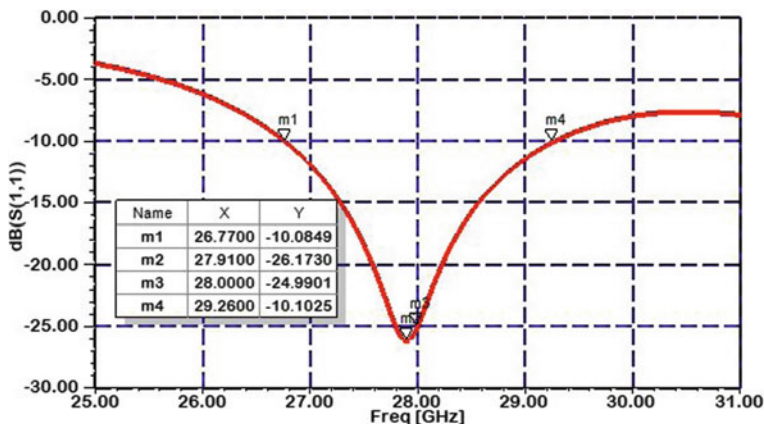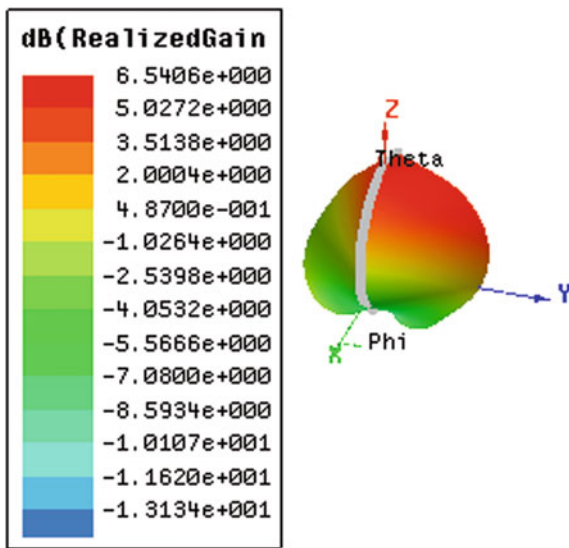
Name	X	Y
m1	26.7700	-10.0849
m2	27.9100	-26.1730
m3	28.0000	-24.9901
m4	29.2600	-10.1025

Fig. 10.6 S$_{11}$ characteristics of a simulated antenna with the full ground

Fig. 10.7 3D realized gain
plot of the simulated antenna
with the full ground

2.27 dB at 60 GHz. A bandwidth of 8.8 and 11.25% at 28 GHz, 60 GHz, respec-
tively, is achieved. The radiation efficiency of 81% at 28 GHz and 83% at 60 GHz
are obtained. An antenna is constructed using an FR4 substrate with an overall size
of 7 mm × 7 mm × 0.8 mm. An inset feed with a quarter-wave transformer is used
for good impedance matching.

Fig. 10.8 Polar plot along with the XZ and YZ plane of a simulated antenna with full ground
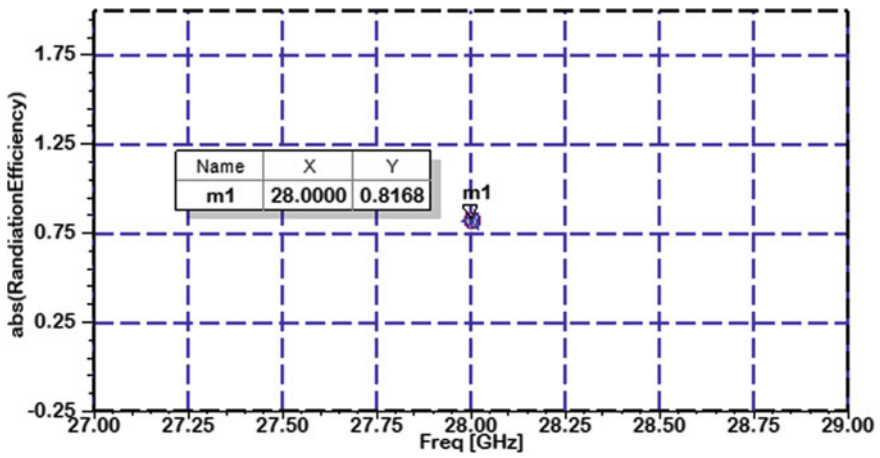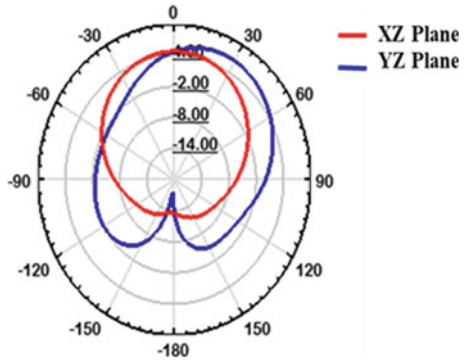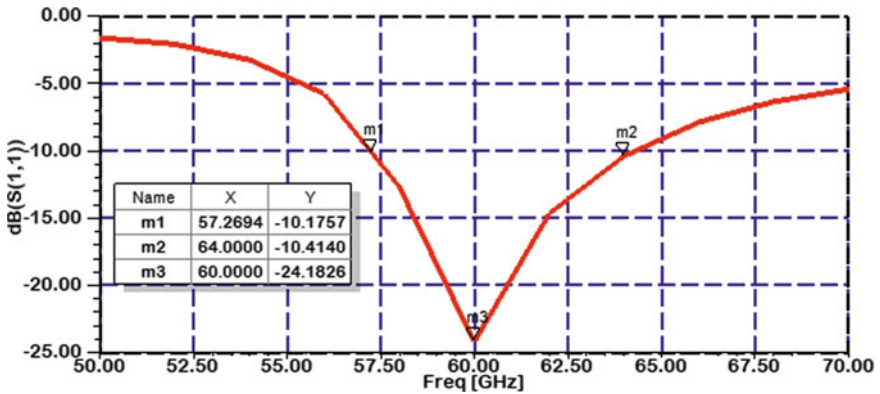

Fig. 10.9 Radiation efficiency versus Frequency plot of a simulated antenna with the full ground

Name	X	Y
m1	28.0000	0.8168

Fig. 10.10 S_{11} characteristics of a simulated antenna with defected ground structure (DGS)

Name	X	Y
m1	57.2694	-10.1757
m2	64.0000	-10.4140
m3	60.0000	-24.1826

Fig. 10.11 3D realized gain plot of a simulated antenna with defected ground structure (DGS)
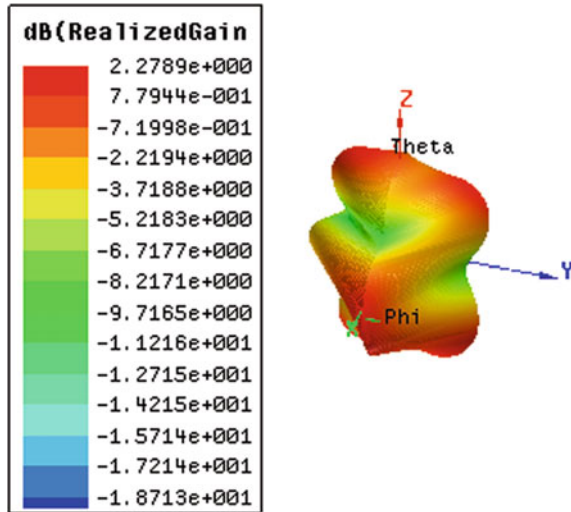
Fig. 10.12 Polar plot along with the XZ and YZ plane of a simulated antenna with defected ground structure (DGS)
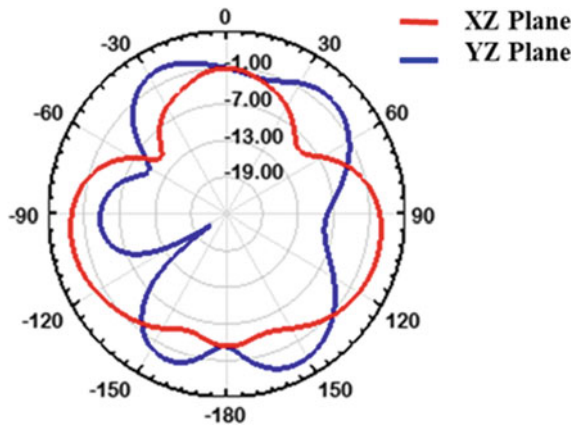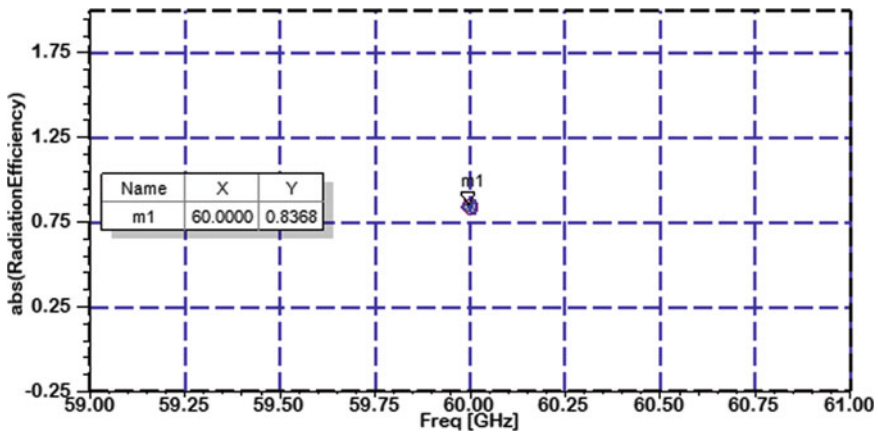
Fig. 10.13 Radiation efficiency versus frequency plot of a simulated antenna with defected ground structure (DGS)

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