# Antennas for IoT Applications: Challenges and Opportunities

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**Abstract:** Internet of Things (IoT), no mystery is ready to proliferate the coming decade and is receiving a lot of attention over the last few decades amongst researches. Researchers predict that with a number of short-range gadgets, IoT will surpass the number of mobile devices. IoT is predicted to permeate all commercial, consumer and industrial applications. However, while doing this IoT devices face major challenges of vendor neutrality, custom hardware proprietary, standard communication protocol framework, and reliable coverage. While standard organizations are attempting to mitigate these limitations the challenge of reliable coverage for wireless communication depends on the selection of appropriate antenna for particular IoT node/device. Choosing a proper antenna system will determine the effective performance of the IoT node. In this paper,we have explored the opportunities and challenges for RF Engineers working in antenna system design.
**Keywords**-IoT; Reconfigurable; Metamaterials; Fractal

## I. Introduction

IoT is becoming popular due to its ability to incorporate different heterogeneous systems for providing digital services ranging from smart cities to smart homes, smart retailers to smart health care systems, smart wearable devices to smart connected devices in personal area network (PAN), smart grid to smart agriculture and smart factories. That being said, IoT is set to provide enormous opportunities but not without challenges such as framework of standard communication protocol, limitations of custom hardware proprietary, vendor neutrality, reliable coverage and connectivity, wide range of frequency band to support while maintaining the prices pressure. With everything connected physically in IoT, wireless communication shall be preferred for communication between IoT nodes/devices. Choosing right components in design of these IoT nodes will critically determine the performance of the IoT nodes. Besides other specifications, choosing right antenna system is one the key design challenge in IoT node design. Newer IoT nodes are integrating more wireless technologies in the same devices making space for antenna highly challenging.An antenna which is an integral part of every wireless system, its performance is very important for transmission and reception of signal. In most cases, the size of the device is directly dependable on the size of antenna which is required for wireless data transmission. Thus, decreasing the size of antenna can significantly decrease the size of overall device. RF engineers when designing an effective antenna system must see that the antennas meet rigorous specifications such as low weight and profile, robust,compact conformal structure, and provide multi-band or broadband operation by grabbing as much spectrum as possible [1].

Broadband antennas systems in wireless communication must effectively operate over a wide range of frequencies. The design of the ultrawideband system has been widely explored over the last decade because of its resourceful applications in short and long-range wireless communications, radarimagingapplications (such as remote sensing and localization) [1].

The next-generation wireless devices are expected to operate at multiple frequencies. Having separate antenna for each operational frequency can make the system bulky. These demands of emerging multifunctional wireless communication systems require innovative design solutions to incorporate the requirements of antenna systems without increasing design complexity. Multiband and frequency reconfigurable antennas have been increasingly popular choice amongst researchers due to its capability to integrate several wireless standards with frequency selectivity in a single package providing multi-band or broadband operations[2-4]. Frequency reconfigurable antenna design using PIN diode, RF MEMS (Micro-electromechanical) switch and optical switcheshave been demonstrated by researchers. However, deploying these devices to get the desired multiband and frequency reconfigurable characteristics is still a challenging scenario.

## II. Contributions

The key objectives of this review paperareto present the challenges in the design and analysis of antennas specifically for IoT applications and corresponding opportunities for innovative design solutions. The main contributions are as follows:

- Critical literature review for identifying current research developmentsin multiband and frequency reconfigurable antenna design.
- Identify gaps in research through detailed literature review and challenges in antenna design for IoT applications.
- Opportunities for RF engineers in developing innovative design solutions to meet specifications of the antenna system for IoT applications.

## III. Antenna Design Techniques

***a) Feeding Techniques:*** At the transmitter side in a wireless communication system, the last block is usually a power amplifier (PA) whose output is fed to the antenna using a transmission line. Feeding refers to transmission of the electromagnetic (EM) waves from PA to the antenna. A major challenge in antenna design is concentrated on impedance matching of the antenna with PA and follows with the maximum power transfer theorem (MPTT). The MPTTstates that extreme power can be transferred from sourceto the loadif source and load device impedances are perfectly matched. Thus, any impedance mismatch between antenna and PA can result in power loss, resulting in degraded performance by antenna. The various feeding techniques used for multiband antenna design are as follows:

- Microstrip feed – This technique consists of a directly connected conducting strip to radiating patch etched on the same substrate [7].
- Coaxial feed – In this technique, a microstrip antenna is fed from underneath via a coaxial probe, whose position can be altered to change the input impedance [7].
- Aperture coupled feed – In this technique, an electrically smallcut is made in the ground plane that indirectly couples the radiating field to patch [8].
- Proximity coupled feed – Provides higher bandwidth as compared to all other feeding techniques thereby reducing the spurious radiations [9].

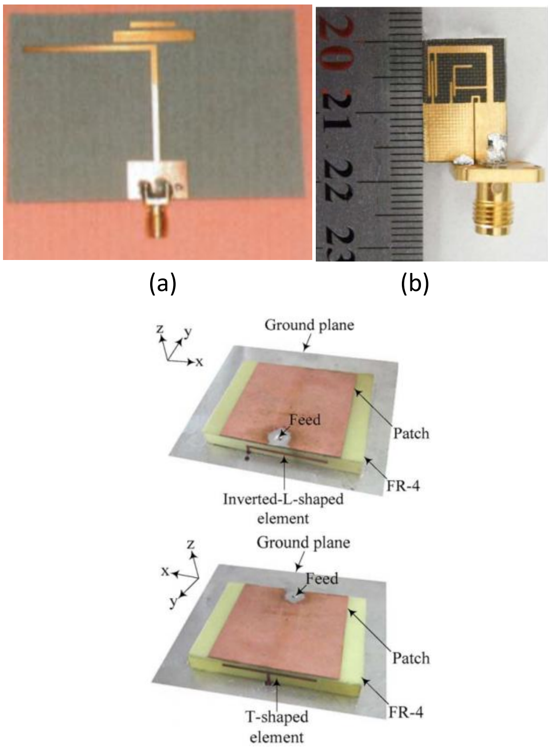
Other recent feeding techniques consist of:

- Co-planar waveguide (CPW) feed – Provides the advantage of readyincorporationof antenna with existing MMIC circuits as both feedline and ground plane co-exists on same side of the substrate [10].
- Asymmetrical Coplanar Stripline (ACS) feed – Provides approximate 50% reduction in antenna size as compared to CPW feed [3,11].

### *b) Multiband antennas*

Multifunctional wireless communication devices have undergone tremendous rapid development over last decade. As stated earlier, antennas are integral part of wireless devices whose design considerations play crucial role during development, specifically for IoT applications. This becomes crucial because IoT devices need to be compact, highly reliable and should provide large coverage. The size of IoT devices becomes comparably important if antenna deployed in these devices is itself large. Also coverage of the device shall depend upon various factors such as communication standard used, electrical parametersof embedded antenna such as gain, efficiency, and radiation pattern. Also modern communication systems demand antenna to operate on multiple frequency bands. These demands can be fulfilled by developing multiband antenna. Multiband operation in antenna system can be achieved by using various techniques such as:

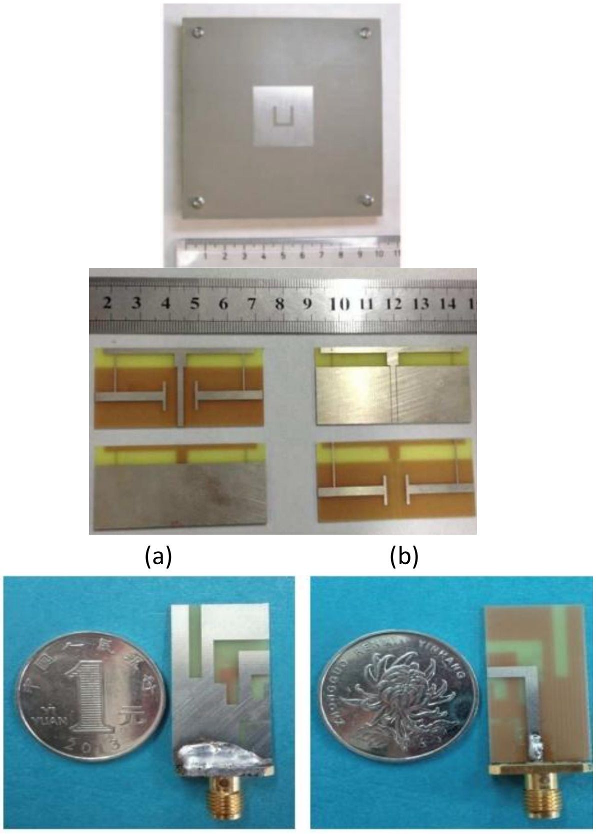
- Use of parasitic elements: Parasitic elements are conducting striplines of length λ/2 (dipole) or λ/4 (monopole). These parasitic elements induce change in current flow at certain frequencies thereby providing multi-band operation without increasing antennas' physical dimensions. Various multiband antenna design using parasitic elements is asdemonstrated in Fig. 1.




(a) (b)

(c) (d)

**Fig. 1 Multiband antenna design achieved using a) elementary dipole antenna [12] b) ACS feed [13] c) Inverted L- shaped element [14] and d) Inverted T-shaped element [14]**

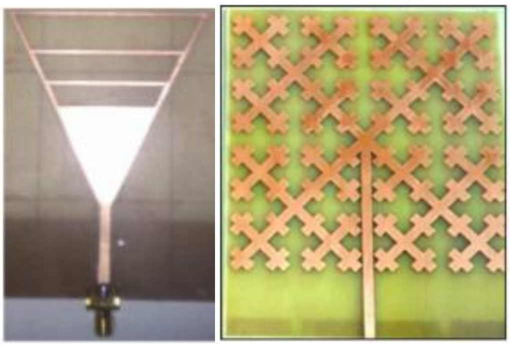


(a) (b)

(c)

**Fig. 2 Multiband antenna design using a) U shaped [15] b) T shaped [16] slots c) L shaped slots in DGS[17]**

- Slots in radiating patch and/or ground plane: An electrically small cut (called as a slot) in the radiating patch and/or the ground plane creates an electrical discontinuity in current path thereby increasing/decreasing the physical antenna size resulting in multi-band operation. Slots can be either of length λ/2 (dipole) or λ/4 (monopole). Various shapes of slots for multi-band antenna operation is illustrated in Fig. 2.
- Fractal antenna structures: The term 'Fractal' linguistically means 'broken (medical term = fractured)' and is derived from the Latin word 'Fractus'. Fractals are self-similar geometrical shapes repeating themselves at different scales. A fractal antenna can offer multi-band operation when it radiates and zooms in on a fractal object. These innovative design solutions can offer improved multifunctionality of modern wireless communication systems. Fractal structures can be used in two ways to enhance antenna design. The first method aims to miniaturize the physical antenna size while the second method aims to use self-similarity and repeating structure of antenna at different scale to provide multi-band operation.Other characteristics which a fractal antenna must provide are: mitigate interference and increased side-lobe distribution. Different fractal geometries are illustrated in Fig. 3.



(a) (b)

**Fig.3 Fractal geometrics to obtain multiband operation a) Self transformation [21] b) X shaped [22]**

Table I provides a literature review of multiband antenna systems using parasitic elements, slot, and fractal geometries.

**Table Iliterature Review Of Multiband Antenna Systems Using Parasitic Elements, Slot, And Fractal Geometries**

| Sr. No | Ref. No. | Year of Publication | Research focus and outcomes |
|---|---|---|---|
| 1 | [12] | 2006 | Simple L shaped parasitic elements based multi-band printed dipole is demonstrated. The proposed antenna provided triband operations for IMT-2000, WLAN (5.0 GHz) and X-band ISM applications. The parasitic elements used were of length λ/2. However, an asymmetrical radiation pattern at higher frequency was observed. |
| 2 | [13] | 2013 | ACS fedcompact antenna for 2.4 and 5.8 GHz Wireless LAN applications arepresented. The antenna had dimensions of 17 × 12 $mm^2$. Multiple parasitic elements were used to achieve multi-band operation. The proposed ACS fed mechanism cannot be used for applications where asymmetrical radiation pattern cannot be accepted. |
| 3 | [14] | 2013 | T and L-shaped parasitic elements are used for achieving multi-band operation at LTE TDD No.34,WLANand Wi-MAX bands operating at 2.0175 GHz, 2.45 GHz, and 3.5 GHz respectively is demonstrated. However, the proposed antenna showed radiation efficiency of about only 60% at 2 GHz. |
| 4 | [15] | 2013 | AU-shaped slotin the rectangular radiating patchis embeddedto achieve the dual-band characteristics. A parametric investigation is carried out for understanding the effect of change in dimensions of U shaped slot on multi-band operation. However, the antenna has large physical dimensions of 100 × 100 $mm^2$. |
| 5 | [16] | 2010 | In this paper, a T shaped antenna loading and T-shaped slotsare used for achieving multiband operation.Two different feeding mechanisms: microstrip line and CPW feed were demonstrated for achieving multiband operations for Wireless LAN and Wi-MAX applications. The antenna has wide dimensions of 58 × 27 $mm^2$. |
| 6 | [17] | 2014 | An L-shaped slot in ground plane was used to provide the multiband operation at 2.4/3.5/5.8GHz. The antenna has dimensions of 16 × 30$mm^2$. An acceptable radiation pattern was obtained at all the operational frequencies. |
| 7 | [18] | 2015 | A compact (21 × 19 $mm^2$) ACS fed F-shaped antenna covering the 2.4/ and.2 GHz Wireless LAN applications is demonstrated. ACS feed antenna provided approximate 50% size reduction while compromising symmetrical radiation characteristics. |
| 8 | [19] | 2014 | A Compact (Antenna size: 17x17.5$mm^2$) ACS feed Rupee shaped antenna providing dual-band antenna action at 3.5/5.5 GHz is presented. |
| 9 | [3] | 2015 | A Compact ACS feed antenna of size: 24x10$mm^2$ providing triple-band antenna operation at 2.4/3.5/5.5 GHz is demonstrated. |
| 10 | [20] | 2017 | Multiband antenna operation for Wi-Fi, WLAN, GPS, Radio Location and fixed-mobile communication applications has been investigated. However, the antenna has extremely large antenna size of 130 × 90 $mm^2$. |
| 11 | [21] | 2011 | In this paper, the multiband antenna design based on rectangular fractal design (self-transformation principle) is presented to generate triple band and quad-band operation. |
| 12 | [22] | 2017 | AnX-shaped fractal antenna with DGS structure for multiband and wideband applications is presented. The proposed antenna provides quad-band operation and has wide dimensions of 88 × 88 $mm^2$. |

***c) Frequency reconfigurable antennas***

The term 'reconfigurability' is defined asthe capability of antenna system to change its electrical characteristics (such as frequency, phase or radiation) by some methods. A reconfigurable antenna is expected to modify its operating frequency, bandwidth, radiation characteristics, and or polarization to incorporate the changing needs of antenna design. A frequency reconfigurable antenna provides flexibility to select the operating frequency of the antenna system and hence is also termed as tunable antennas. They are classified as continuous frequency (provides smooth transition between different operating bands) and switched frequency (provides transition for distinct operating bands) reconfigurable antennas.

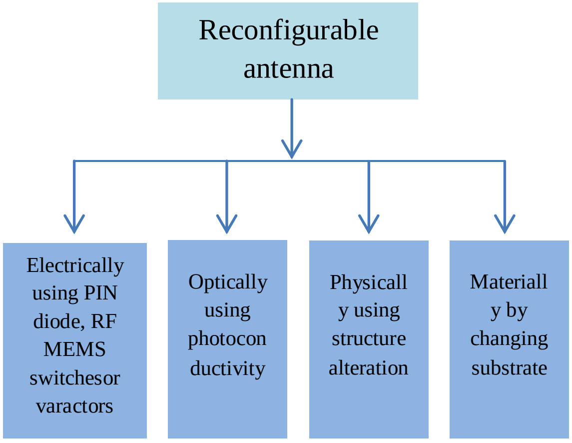



**Fig. 4. Techniques used for achieving reconfiguration or switching**

The reconfiguration or switching characteristics can be achieved by using the following techniques as shown in Fig.4. Table II provides critical literature review of reconfigurable multiband antenna.

## IV. Challenges And Opportunities

a) ***Challenges***: Optimizing the size of antenna so that free space can be used to embed electronic components in IoT devices remains a major challenge for engineers as size of IoT devices in most cases will be directly dependent on the size of the antenna. However, while optimizing the physical size of the antenna, engineers must oversee that the optimum electrical characteristics of the antenna are still achieved.

b) ***Opportunities***: Metamaterials exhibit numerous properties that have a paved path for innovative antenna design solutions. Metamaterials that have zero-index property not only allows the implementationof highly compact and efficient antennas but also provides antenna with higher performance characteristics(gain and directivity) in comparison to conventional antenna design where material-loadedantennas are used [5-6]. Using metamaterial in antenna design can provide new innovative design solutions.

**Table Ii: Critical Literature Review Of Reconfigurable Multi-Band Antenna**

| Sr. No. | Ref. No. | Year of Publication | Research focus and outcomes |
|---|---|---|---|
| 1 | [23] | 2017 | PIN and varicap diode is embedded for achieving fine and discrete reconfiguration to provide multi-band operation. Both PIN diode and varactor diode were switched (ON/OFF) using microcontroller EBN. The antenna has large dimensions of 120 × 40 $mm^2$. |
| 2 | [24] | 2013 | A slot in a ground plane that is activated by 3 PIN diode switches provides 6 different reconfigurable frequencies ranging from 1.7 GHz through 3.5 GHz. The directional radiation patternis achieved by placing a reflector at the back of antenna |
| 3 | [25] | 2009 | A cedar-shaped antenna using self-similarity and space-filling fractal configuration/shape is suggested. RF switches are placed in between the apertures and are enabled/disabled to demonstrate frequency reconfiguration. However, the fractal properties decreased the antenna's working frequencies and uniformity in the radiation patterns. |
| 4 | [26] | 2018 | A reconfigurable antenna operating at 10 different frequencies between 2.2 to 6 GHz is designed. Frequency reconfiguration is achieved by using two PIN diodes. However, the antenna has extremely large dimensions making it unsuitable for IoT applications. |

| | | | |
|---|---|---|---|
| 5 | [27] | 2017 | Multiband and wideband frequency reconfigurable antenna operating over the frequency range 2 to 6 GHz is designed. The antenna has a bulky dimension of 88 x 81mm$^2$ |
| 6 | [28] | 2017 | Frequency reconfigurable Quintuple antenna of dimensions 30 x 8.4 mm$^2$ fabricated on RT/duroid 5880 is investigated. The antenna has very compact dimensions. However, RT/duroid substrates at costlier as compared to FR-4 glass epoxy substrates. |

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