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PAPER

Design and Analysis of Wideband Stair Step-Shaped Rectangular Ring Microstrip Antenna with DGS for IoT Applications

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ABSTRACT

A novel miniature wideband rectangular ring antenna is proposed for 4.6–6.2 GHz which is compatible with IoT applications. The wideband response of the proposed antenna is achieved by a partial ground and stair step structure. Because modifying the width and etching the ground plane does not improve the impedance matching over a large bandwidth, a triangular shape DGS is inserted in the partial ground plane to increase the antenna bandwidth with enhanced return loss. The wideband features of the antenna were explored here by incorporating different DGS shapes such as triangles, rectangle, pentagon, circle, and oval in the partial ground. The results have been successfully verified through measurement. The simulated fractional bandwidth is greater than 29% at 4.6–6.2 GHz whereas the measured fractional bandwidth is 27.6% at 4.75–6.2 GHz. In both cases, the maximum return loss is greater than 55 dB. The gain of the antenna is greater than 2.6 dB with good efficiency and nearly omnidirectional radiation pattern in shape. Due to its compact size and outstanding performance, the suggested stair step-shaped rectangular ring antenna could be a promising choice for IoT and wireless applications.

KEYWORDS

Wideband microstrip antenna, Internet of things, WLAN, Defected Ground Structures

1 INTRODUCTION

The Internet of Things (IoT) is an advantage since it has the intelligence and behavior to interact and independently, update administration center operations in real-time applications. Many IoT applications use different transmission devices for interconnection between gadgets. For all of these node ends of intelligent devices, proper antenna selection is equally important to modern communication standards. Finding the best radiator for wireless applications is still a difficult technical challenge [1–4]. For IoT wideband applications, the key antenna requirements are (1) miniaturization (2) larger operational bandwidth (3) technical simplicity of implementation

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and development with the electronic devices. IoT antenna miniaturization has been the subject of several literature studies since it is a crucial technological consideration for IoT devices in terms of their potential for integration with electronic circuits. In the context of antenna miniaturization, a number of wideband IoT antenna topologies have been proposed [5–10]. In order to support a variety of applications including medical, science, industry, personal communications, and remote internet access the next generation of wireless networks will require frameworks with wideband capacities in high-portability settings. Remote organizations incorporate IoT and, wireless local area network (WLAN) support for which IEEE 802.11 has the authority regarding the norms for the vigorous and robust WLANs work in the 5–6 GHz band. IEEE 802.11a gives rapid connectivity, high speed, broadband, and high-capacity fast data transfer rate between note pads, PCs, wireless appliances, and other remote advanced machines [11–15]. In recent decades, microstrip antennas have been acknowledged for their simple and compact structure, lightweight, wide impedance bandwidths, low price, omnidirectional radiation patterns, and relative ease of fabrication. These antennas are suitable for wireless applications because of the variety of patch and feed structures. A significant amount of research has been conducted on wideband and ultra-wideband antenna in which different patch shapes usually involve circular [16], U shape [17], inverted T shape [18], M shape [19], A shape [20], rhombus shape [21], and many others. Along with these various shapes, scientists are also working on a variety of strategies and structures for acquiring wide bandwidth, such as the CPW-fed technique and defective ground structures [22–26]. The substrate of microstrip patch antennas also plays an important role in obtaining wideband.

The present paper proposed a novel miniature wideband rectangular ring antenna with a partial ground structure for IoT applications. This antenna provides a wideband from 4.6 to 6.2 GHz which covers the whole 5.15–5.825 GHz IoT, WLAN & WiMAX band. Different structures in ground planes have been employed to simulate these antennas. The simulated and measured results show that impedance matching is improved by inserting a simple triangular-shaped DGS in the partial ground plane.

2 ANTENNA GEOMETRY

The geometrical configuration of the proposed rectangular ring antenna with a partial structure is shown in Figure 1. It is designed on FR-4 substrate material with permittivity εr = 4.3 and tanδ = 0.002. The dimensions of the proposed rectangular ring antenna at 5.5 GHz are calculated by using standard design equations. To increase the bandwidth antenna geometry is optimized by reshaping the lower side to a stair shape and etching the ground beneath the patch.

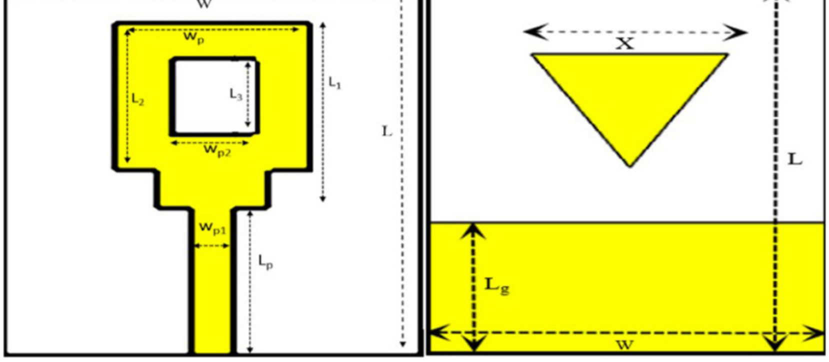


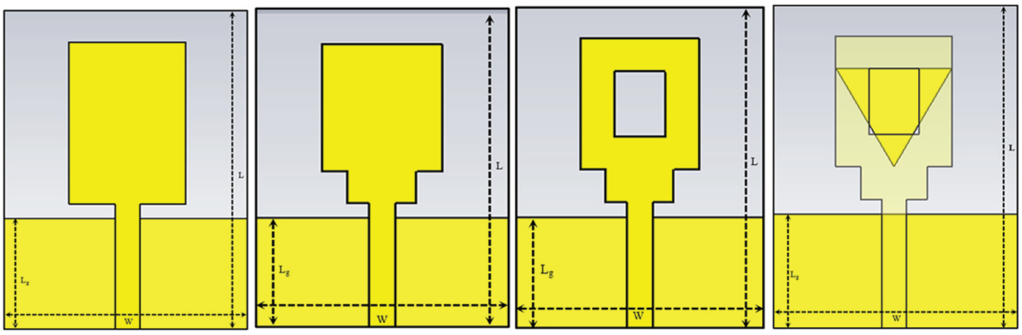
Fig. 1. Geometry of proposed wideband stair-step rectangular ring antenna

A triangular shape defected ground structure is also inserted to optimize the wideband in the desired band. A simple 50-ohm microstrip feed line is used to feed the antenna. The substrate's overall floor area is 15 × 20 × 1.6 mm^3. The size of the partial conducting ground plane is 15 × 7 mm^2. CST Microwave Studio Suite (CST MWS) simulator is used to optimize the design parameters of the antenna. The optimized dimensions of all parts of the designed antenna layout are listed in Table 1.

Table 1. Optimized dimensions of the proposed stair step rectangular antenna

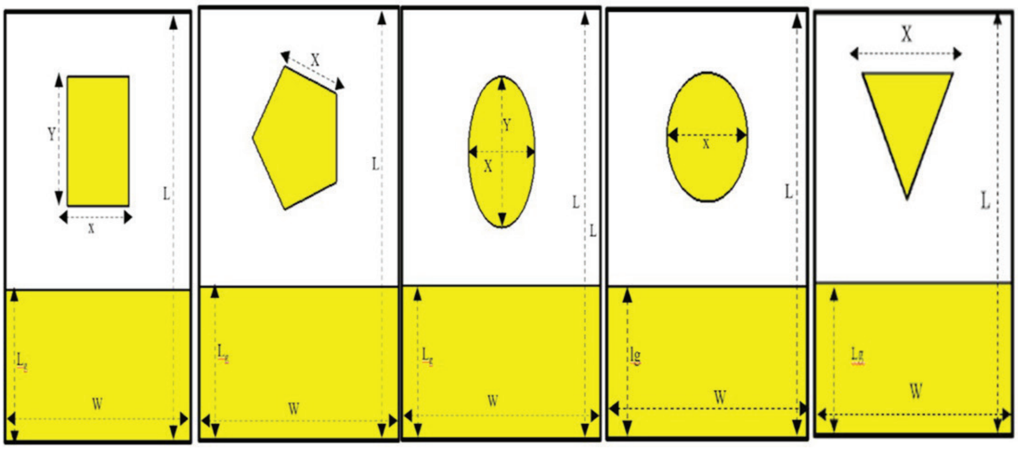
FR-4 Substrate (L, W, H)	Feed Line (Wf, L1)	Rectangular Patch (W1, L1)	Partial Ground (W, Lg)	Rectangular Slot (L3, Lg)	Sides of Equilateral Triangle	Step (L1, L2)
15*20*1.6mm	1.5*7mm	7*8mm	15*7mm	3*6mm	4mm	3*2mm

A lot of effort has been done to improve the bandwidth in the proposed antenna configuration. Here different stages of the design evolution are explained thoroughly. To obtain the desired response, large clusters of resonant frequencies should be produced within the desired frequency range by pushing the return loss below 10 dB. One method for improving return loss was to widen the fringing fields by increasing the total radiation of the patch. To achieve this goal, the antenna width is modified to a new shape named a stair-step and shown in Figure 2 under Stage II.



Stage-I Stage-II Stage-III Stage-IV

Fig. 2. Various successive intermediate stages of the proposed rectangular ring shape antenna



(a) Rectangular (b) Pentagon (c) Oval (d) Circle (e) Triangle

Fig. 3. Various DGS shapes in the partial ground of the proposed rectangular shape stair-step antenna

In such a configuration, the fringing fields from the patch edges will try to reach the partial ground plane over a number of frequencies, resulting in broadening the bandwidth. Return loss for stage I is also shown in Figure 4 which indicates that antenna bandwidth has increased significantly. Now, to increase the impedance bandwidth with improved return loss characteristics a rectangular slot is cut on the top of the patch as indicated in stage III. The return loss characteristics improve a lot as shown in Figure 4.

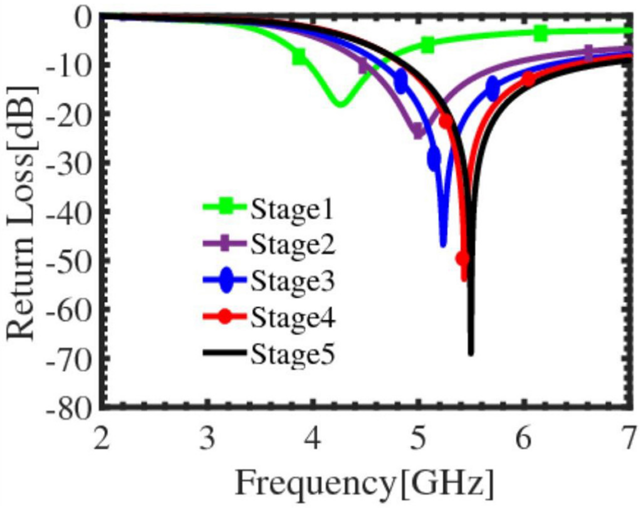


Fig. 4. Simulated return loss for different design stages of proposed rectangular shape antenna

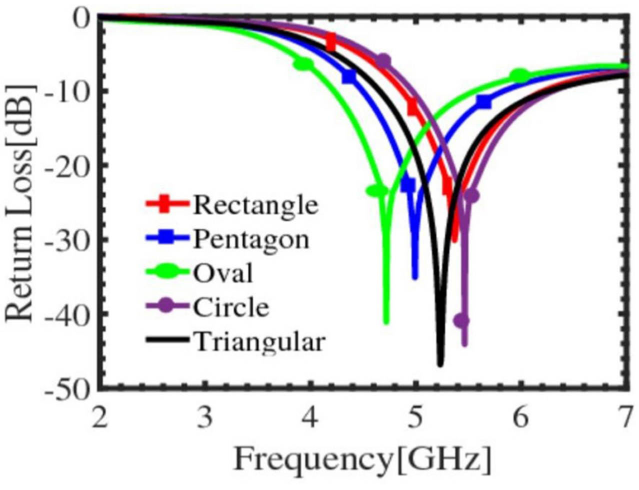


Fig. 5. Reflection coefficient of the proposed rectangular shape antenna with different DGS under stage III

Further, to improve the impedance matching different shapes DGS structures were introduced in the partial ground exactly below in Figure 3 different shapes are added to the partial ground of the proposed stair step rectangular ring antenna. These different shapes are square, hexagon, oval, circle, and triangle with equal surface area to enhance the S11 parameter of the proposed The return loss parameters with different shapes are shown in Figure 5. During this analysis, it is observed that return loss is enhanced for triangular ground structures from –39 dB to –56 dB.

The proposed antenna is fabricated and verified here in Figure 6 which shows the front view and back view of the fabricated antenna prototype. Figure 7 shows simulated and measured return loss graphs. The simulated fractional bandwidth is greater than 29% at 4.60–6.2 GHz. The measured fractional bandwidth is 27.6% at 4.75–6.2 GHz centered at 5.25 GHz.

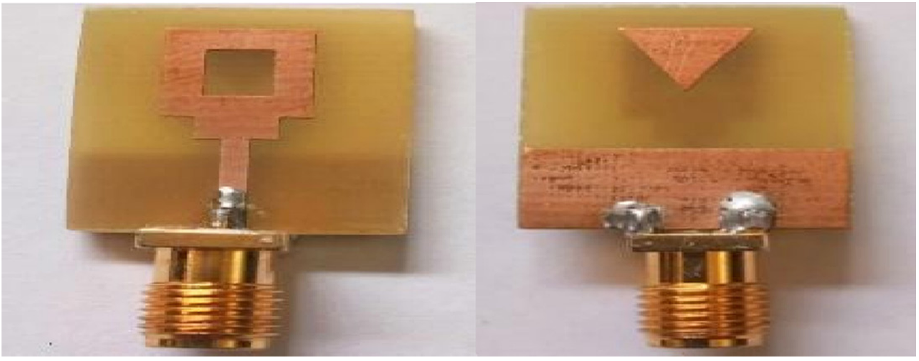


Fig. 6. Fabricated photograph of the wideband rectangular ring antenna

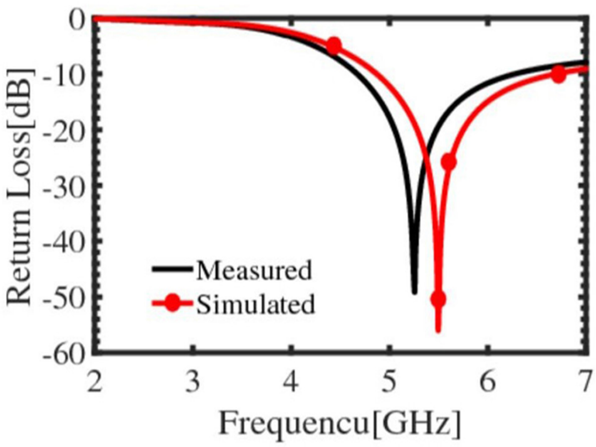


Fig. 7. Simulated and measured return loss of the proposed rectangular shape antenna

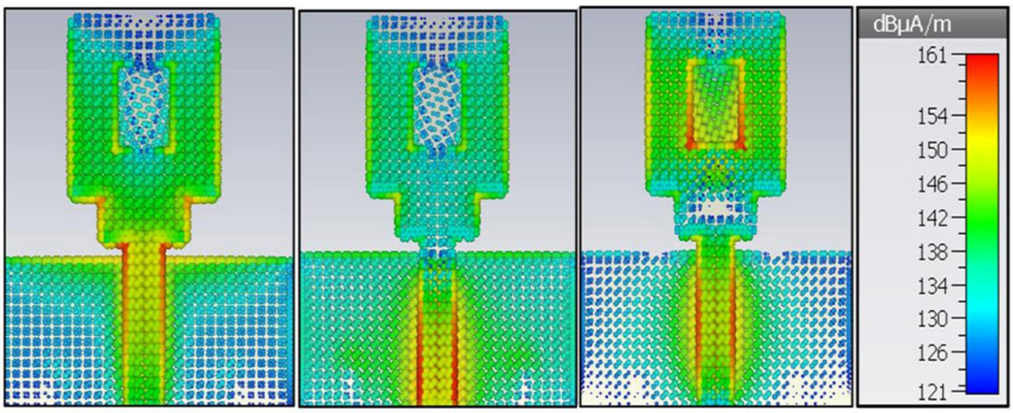


Fig. 8. Surface current distribution at different frequencies 4.6 GHz, 5.2 GHz, and 6.2 GHz

In both cases, the maximum return loss is greater than 50 dB. The simulated results show better impedance matching and wider bandwidth by modifying the staircase step width and inserting a triangular DGS in the partial ground plane. The simulated surface current distribution at multiple sampling frequencies of 4.6, 5.5, and 6.2 GHz is displayed in Figure 8 to demonstrate wideband operation.

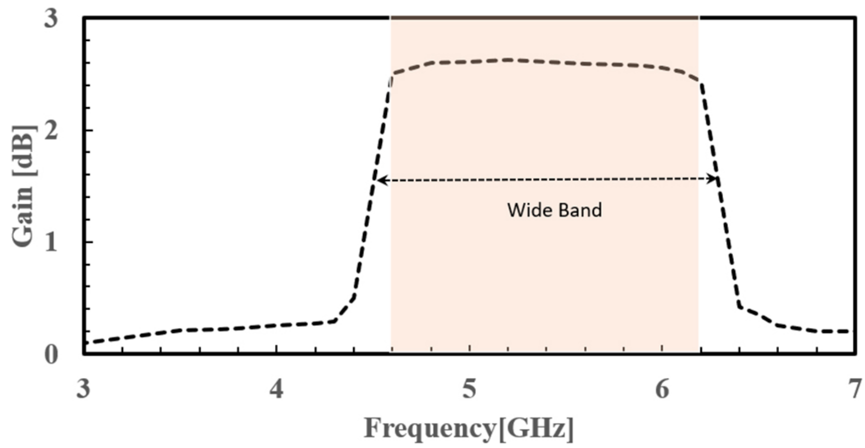


Fig. 9. Simulated gain of proposed rectangular stair step antenna

As can be seen in Figure 8. the high surface current traverses at both the feed and rectangular-shaped strip. It has been found that rectangular patch with rectangular cut and stair step shape width produce the initial –10 dB response at 4.60 GHz. It has been discovered that the heavy surface current is dispersed on the triangular patch and partial ground plane at the sampling frequency of 5.2 GHz. The measured and simulated radiation pattern at various frequencies is shown in Figure 9. It should be observed that a bidirectional radiation pattern in the shape of the dumbbell is obtained. The gain of the antenna is greater than 2.5 dB with better efficiency is shown in Figure 9 which is constant through the complete band and an omnidirectional radiation pattern is observed as shown in Figure 10.

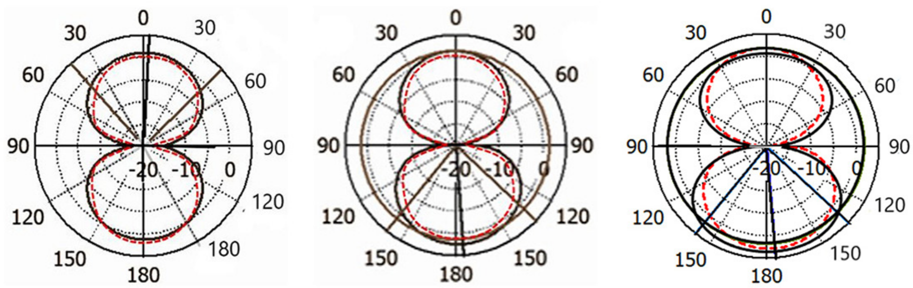


Fig. 10. Measured and simulated radiation pattern of proposed rectangular shape antenna at frequency (a) 4.6 GHz (b) 5.2 GHz (c) 6.2 GHz

3 CONCLUSION

A wideband stair step-shaped rectangular ring microstrip antenna with the partial ground is proposed here. The characteristics of a rectangular ring monopole antenna are enhanced by modifying the geometry i.e., modifying the width to the stair step, etching a rectangular slot at the center of the patch, and making the partial ground. Because changing the width and etching the metal of ground does not improve impedance matching over a wide bandwidth, a triangular shape DGS was introduced inside the partial ground to improve the antenna bandwidth while maximizing the return loss. The prototype is fabricated on 20*15*0.6 mm^3 on a commercially available FR4 substrate. The simulated fractional bandwidth is greater than 29% at 4.9–6.5 GHz cantered at 5.5 GHz whereas the measured fractional bandwidth is 27.6% at 4.75–6.2 GHz cantered at 5.2 GHz. Due to its compact size and outstanding performance, the suggested rectangular ring patch is an ideal choice for broadband IoT applications.

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