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Analysis of multiband rectangular patch antenna with defected ground structure using reflection coefficient measurement

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ABSTRACT
In this paper, a novel quad band antenna to operate at four different frequency bands is designed and simulated using Computer Simulation Technology (CST) Microwave Studio software. To achieve better performance of the antenna, various parameters were optimized using parametric analysis. During this analysis, various antenna parameters were need to be measured. The proposed antenna uses asymmetrical 'U' and 'T' shaped radiating elements printed on an FR-4 substrate with dimensions of 1.6 × 34 × 20 mm^3. The measurement of various antenna parameters like reflection coefficient, return loss, radiation intensity are key tasks to be performed in the antenna measurement laboratory before going to the real time application. A stair case defected ground structure with rectangular center slot is used to attain a better bandwidth. The antenna resonates at four different frequencies 3 GHz, 4.8 GHz, 9 GHz, 13.2 GHz with operating bandwidths of 980 MHz, 2.05 GHz, 3.84 GHz, and 3.82 GHz respectively. The S_{11} value at these resonant frequencies is measured as -23.6 dB, -29.4 dB, -34.2 dB, -49.05 dB respectively. The voltage standing wave ratio of the proposed antenna at four resonant frequencies is equal to one. The gain of the antenna is consistent throughout the four pass bands. The antenna is suitable for Bluetooth (2.4) GHz, WLAN (5.125-5.35) GHz and (5.725-5.825) GHz, WiMAX (5.25-5.85) GHz, C-band (3.7-4.2) GHz and Ku-band (12-18) GHz.

Section: RESEARCH PAPER

Keywords: Measurement; defected ground; sensing; WLAN; WiMAX planar monopole antenna

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1. INTRODUCTION

The contemporary telecommunications sector has evolved in response to the increasing demands of customers for smart gadgets. In contrast to their predecessors, these devices are capable of handling many applications at the same time. Global Positioning System (GPS), Wireless Fidelity (Wi-Fi), Global System for Mobile Communication (GSM), Bluetooth, and Worldwide Interoperability for Microwave Access (WiMAX), all have their own operating frequency bands. The addition of a separate antenna for each application increases the device's size and makes it more uncomfortable to use. Due to this the demand for antennas operating at multiple frequencies is increasing. High data rates in wireless communication systems are quite common these days. As a result, contemporary gadgets must have a single antenna that can operate in many frequency bands. Lot of research has been going on in the field of multiband antennas by many researchers and several methods were devised in recent years. The authors of [1] reported a coplanar waveguide (CPW)-fed rectangle antenna with modified ground and open complementary split ring resonator (OCSRR) loading that could operate in three bands. In [2] U shaped antenna with partial ground plane to resonate at three different frequencies is presented. In [3] authors designed 'nine' and 'epsilon' shaped antennas along with switches to realize triple band operation for use in Wi-Fi, WiMAX and WLAN applications. In [4] a five band antenna with kite shaped radiating patch with 'C' and 'G' shaped slots in the ground plane was realized. Authors in [5] used meta material technique to design dual band antenna. A CPW fed meta material based multiband antenna was reported in [6]. In [7] a small CPW-fed monopole antenna for dual band operation was presented. The authors used the state of the art substrate integrated waveguide technique and slots to get dual frequency response and wide bandwidth in [8]. As reported in [9] increase in gain parameter is achieved by using antenna arrays. Several techniques, such as frequency-selective surface [10]-[12] and electromagnetic band-gap structure [13]-[15], have been studied by several researchers to create multiband antennas. To improve the polarization performance of the link budget, circularly polarized antennas are frequently employed in WLAN and satellite applications as reported in [16]-[18]. In every wireless communication system, the antenna is extremely crucial. The well-designed antenna reduces receiver complexity and improves receiver performance. The antenna's size, shape, and design will be controlled by the antenna's application [19], [20] and operating frequency. A simple rectangular patch was used in this project, and a portion of it was removed to create a symmetrical U-shaped structure. A portion of the left and right arms are cut from that structure, which leads to asymmetrical U shape and to that shape one vertical strip combined with a horizontal strip, is added to the centre to form a T-shaped structure. To achieve better bandwidth, a staircase defected ground structure along with centre rectangular slot was used. Proposed antenna resonates at multiple frequencies owing to its structural modifications. This antenna is applicable to a wide range of modern portable wireless applications, Bluetooth (2.4) GHz, WLAN (5.125-5.35) GHz and (5.725-5.825) GHz, WIMAX (5.25-5.85) GHz, C-band (3.7-4.2) GHz and Ku-band (12-18) GHz. To achieve multiband operation other designs used slots and modified the shapes of radiating elements which is also complex. In this design staircase defective ground structure was employed to get wider bandwidth at resonating frequencies. Defected Ground Structure (DGS), apart from conventional antennas, produces discontinuities on the signal plane, which disrupts shielded current distribution on the signal plane. As a result, the apparent permittivity of the substrate fluctuates as a function of frequency and plays a vital role in the antenna's performance. Various parameters such as radiation pattern, S_{11}, VSWR, gain, are measured and analysed for the final design of the antenna. Furthermore, getting the multiband operation owing to its less structural complexity is the most outstanding feature of this design.

General procedure for designing any antenna was discussed in section 2. The evaluation steps of the proposed antenna design were discussed in Section 3. In section 4 parametric analysis through performance measures measurement of the proposed antenna is discussed. Section 5 deals with results and discussion. In Section 6 literature comparison of the proposed antenna was done with earlier reported structures.

2. ANTENNA DESIGN PROCEDURE

Any antenna design technique begins with study of various antennas for a certain application. Then, potential design approaches must be studied. Later, patch dimensions such as width and length are determined to get design criteria. Geometrical parameters and material qualities must then be accurately specified in the following stage. The simulation process is done by finalizing one simulator among the available simulators. Using the simulator's parametric analysis feature, simulation work is carried out until the best possible result is obtained. When the required behaviour is achieved, the simulation is terminated. The antenna fabrication operation is then initiated, and the desired antenna prototype is created. To validate the design technique, the fabricated antenna behaviour is evaluated and compared to that of the simulated ones. If the required behaviour is not obtained, the geometric parameters of the antenna as well as the material qualities must be modified. Simulation is again carried out with modified parameters. This is continued until the desired behaviour of the proposed antenna is obtained. Figure 1 clearly displays the antenna general design procedure.

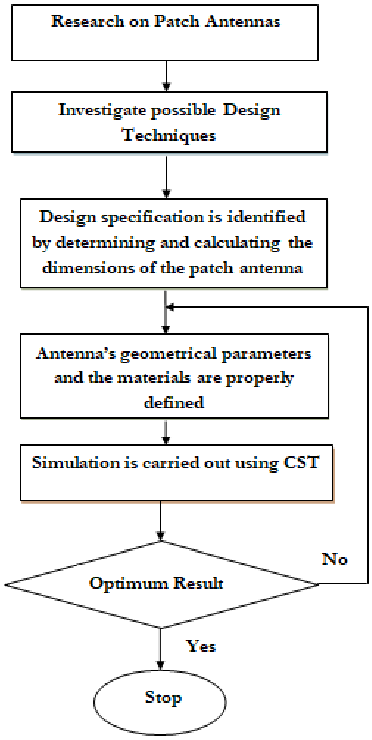

Figure 1. Antenna general design procedure.

3. EVALUATION STEPS OF THE PROPOSED ANTENNA DESIGN

The planned antenna has been designed in three phases, as illustrated in Figure 2. Figure 2 i) show a typical rectangular patch antenna with a simple micro strip line in Step 1. In Step2 a portion of patch is removed to get symmetrical U-shaped antenna as depicted in Figure 2 ii) which leads to multiband response. In Step3 as shown in Figure 2 iii) portions of left and right arms are cut leading to asymmetrical U-shaped structure and centre horizontal and vertical arms are added leading to T shaped structure.

This is the proposed design. This proposed antenna refines impedance matching and achieves better performance in terms

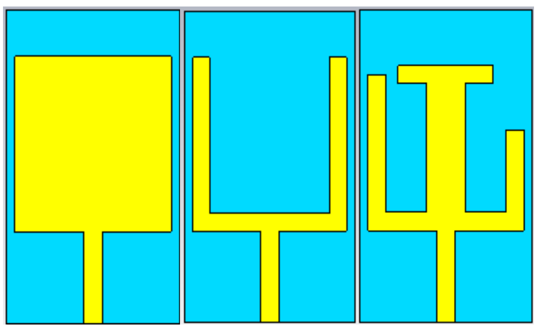

Figure 2. Steps in the design of the proposed multiband antenna.

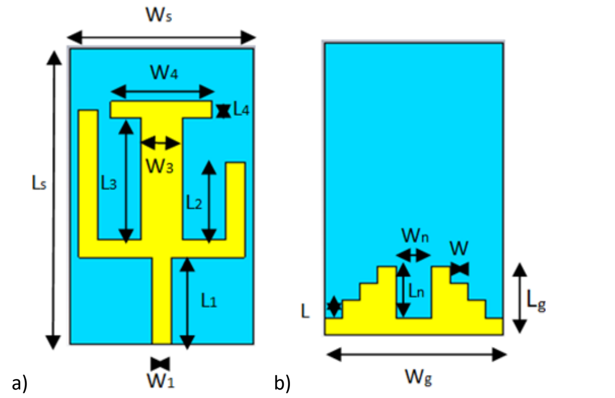

Figure 3. Designed antenna architecture: a) Front view, b) Back view, W_S = 20 mm, L_S = 34 mm, L_1 = 10 mm, L_2 = 9 mm, L_3 = 14 mm, L_4 = 2 mm, W_1 = 2.2 mm, W_3 = 4.4 mm, W_4 = 11 mm, W_g = 20 mm, W = 2 mm, L = 2 mm, L_n = 8 mm, W_n = 4 mm.

of wider bandwidth and VSWR. Gain is also considerable throughout the pass bands.

Figure 3 depicts the design for the proposed multi band planar antenna with asymmetrical U and T shaped patch structure. From the simple normal rectangular patch, a portion is removed to realize symmetrical U-shaped patch structure. Portions of left and right arms were cut and centre horizontal and vertical arms were added leading to T shaped patch structure at the centre. This structure deals with defected ground technology. Defected ground plane with stepped staircase along with centre rectangular slot has been added beneath the substrate, to extend the bandwidth. Substrate dimensions are $20 \times 34 \times 1.6$ mm^3. The material chosen is FR-4, which has good mechanical properties with a thickness of 1.6 mm, a dielectric permittivity of 4.4, and a loss tangent of 0.02. The antenna was fed by 50 Ω micro strip line.

Simulation of the proposed antenna has been carried out by using CST Micro Wave Studio. The antenna was optimized using the CST Microwave Studio's parametric analysis tool. The antenna is capable of resonating at four distinct frequencies. Antenna 1 only resonates at two frequencies, the first at 3 GHz and the second at 4.8 GHz. Antenna 2 resonates at four separate frequencies, although the bandwidth at the pass bands and impedance matching were not ideal. Antenna 3 resonates at four separate frequencies, with a wide bandwidth and good impedance matching, as well as significant gain at all four resonant frequencies. Antenna 3 is the proposed construction, which resonates at four distinct frequencies. Simulated S_{11} of different antennas as depicted in Figure 2 are shown in Figure 4.

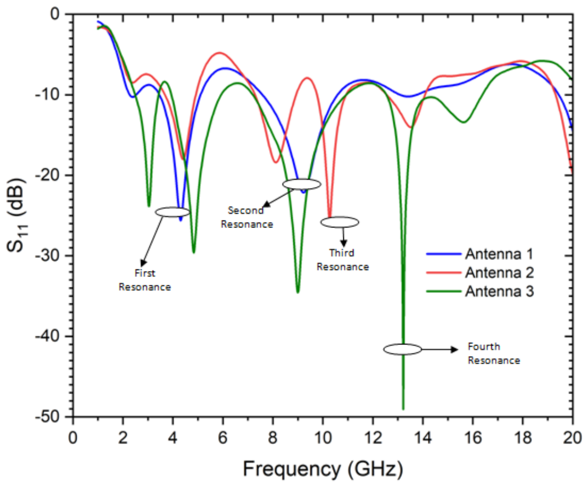

Figure 4. S_{11} of different antennas as depicted in Figure 2.

4. PARAMETRIC STUDY OF THE PROPOSED ANTENNA

To obtain the optimal design, parametric analysis is the greatest choice accessible when utilising simulators. Study of effect of changing various parameters like feed length L_1, right arm length L_2 and length of T strip L_3 has been carried out to optimize the proposed design. Effect of varying L_1: Figure 5 clearly displays the effect of changing the value of feed length L_1. The feed length L_1 was tested for three different lengths. The findings show that as the length of the feed increases, the antenna only resonates at two frequencies, with L_1 = 10 mm yielding the best results with four resonant frequencies.

Effect of varying L_2: To investigate the impact of changing the right arm length L_2 all other previously optimized parameters were held constant at their optimum values, while L_2 is changed between 9 mm to 12 mm. The second, third, and fourth resonances do not vary significantly when the value is increased, but impedance matching at the first resonant frequency decreases, and L_2 =9 mm provides the best performance in terms of improved bandwidth and impedance matching. Figure 6 displays the impact of changing the values of right arm length L_2.

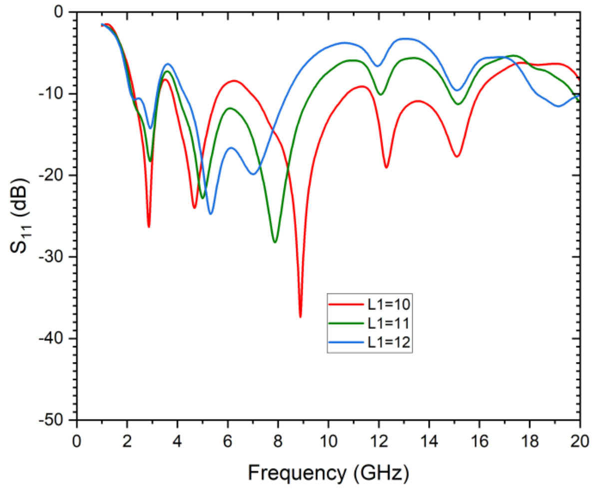

Figure 5. Optimized S_{11} variation for various values of L_1.

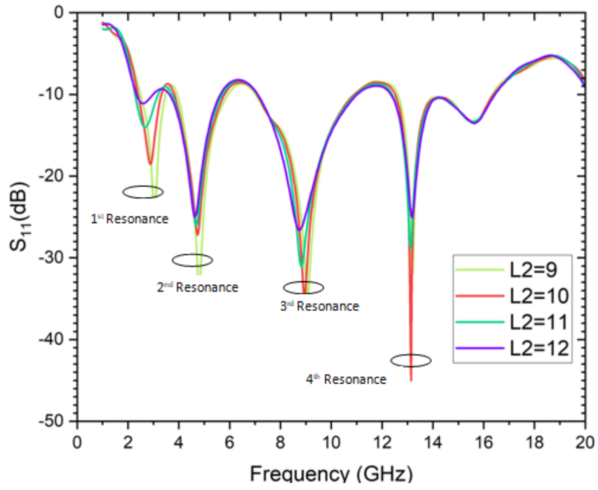

Figure 6. Optimized S_{11} variation for various values of L_2.

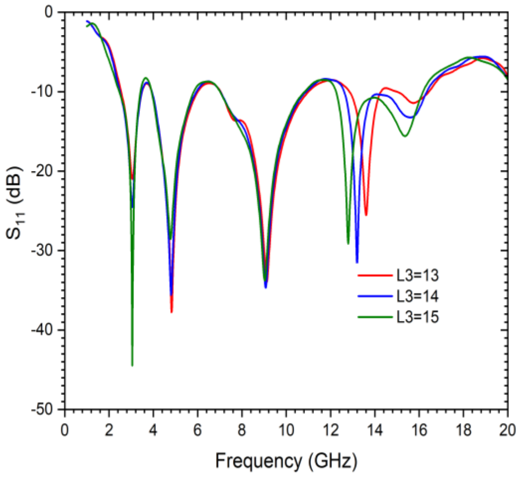

Figure 7. Optimized S_{11} variation for various values of L_3.

Effect of varying L_3: To explore the influence of length of T strip L_3, it was varied from 13 to 15 while all other parameters were kept at their previously optimized levels. For different values of L_3, there wasn't much of a variation in the first three resonances. For L_3 = 14 mm, a wider bandwidth and improved impedance matching were achieved as portrayed in Figure 7.

As surface current distribution helps in understanding the behaviour of the antenna Figure 8 portrays the surface current distribution of the proposed antenna at four resonant frequencies. Different portions of the antenna are responsible for radiations at four resonant frequencies. Radiation at 3 GHz is directed by the right arm of the U structure as well as centre T strip right portion. At 4.8 GHz, the lower part of the U structure right arm is responsible for radiation. The lower part of the U shape is responsible for 9 GHz radiation. At 13.2 GHz, both the centre arm and the upper section of the U shape are responsible for radiation.

5. RESULTS AND DISCUSSION

The designed antenna's simulated S_{11} and gain variations with respect to frequency can be seen in Figure 9. The antenna is simulated by CST Microwave Studio which uses finite integration method. The four resonant frequencies are occurring at 3 GHz, 4.8 GHz, 9 GHz, and 13.2 GHz. The return loss at these frequencies is -23.6 dB, -29.4 dB, -34.2 dB, -49.05 dB, respectively. These values clearly indicate good impedance matching at all the four resonant frequencies. The pass bands around these resonances are 2.484 GHz to 3.389 GHz, 3.923 GHz to 5.974 GHz, 7.232 GHz to 10.921 GHz, and 12.551 GHz to 16.363 GHz with bandwidths of 0.905 GHz, 2.051 GHz, 3.689 GHz and 3.812 GHz, respectively. Wide bandwidths at four resonant frequencies are also identified.

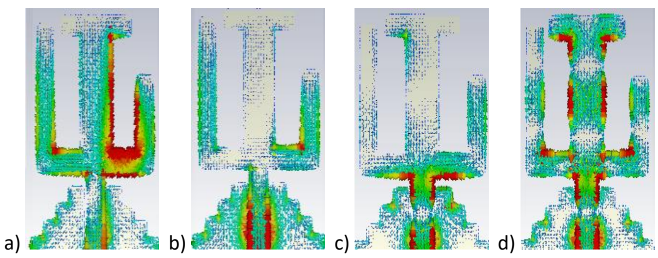

Figure 8. Surface current distribution at resonant frequencies: a) 3 GHz, b) 4.8 GHz, c) 9.0 GHz and d) 13.2 GHz.

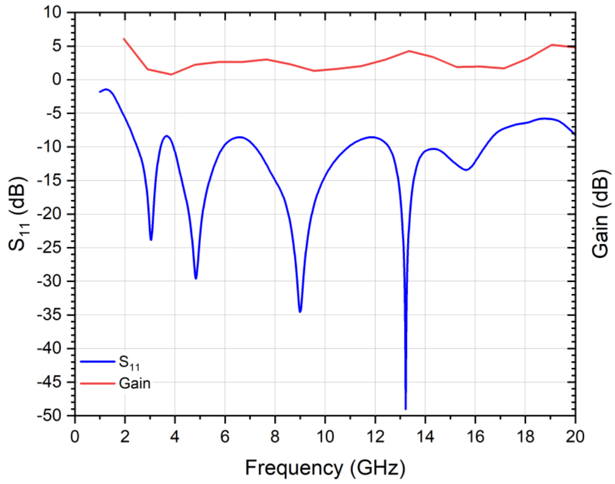

Figure 9. The designed Antenna's simulated S_{11} and Gain.

Considerable gain is observed at four resonant frequencies. Getting the multiband operation owing to its less structural complexity is the most outstanding feature of this design.

The Voltage Standing Wave Ratio (VSWR) measures the mismatch between an antenna and the feed line that connects to it. The range of VSWR values ranges from 1 to infinity. VSWR of less than 2 is deemed adequate for the majority of antenna applications. In the proposed design VSWR of 1 indicates a good match. The proposed quad band antenna's Voltage Wave Standing Ratio (VSWR) is portrayed in Figure 10. From the figure it is evident that at all the four resonant frequencies good VSWR is identified which is almost equal to one. The proposed quad band antenna's far field patterns at 3 GHz, 4.8 GHz, 9 GHZ, 13.2 GHZ are clearly displayed in Figure 10.

6. LITERATURE COMPARISION

The comparison analysis between the proposed antenna and previously published designs for multiband operation is summarized in Table 1. Proposed design is compared in terms of size, frequencies, radiating elements. Compared to earlier reported designs in [1], [2], [3], [4], [5] and [6] proposed antenna is better in terms of size; structural complexity of the proposed antenna is less compared to most of the structures. Gain is consistent in the operating bands and operating bandwidth is also more compared to the most of the structures. VSWR of the

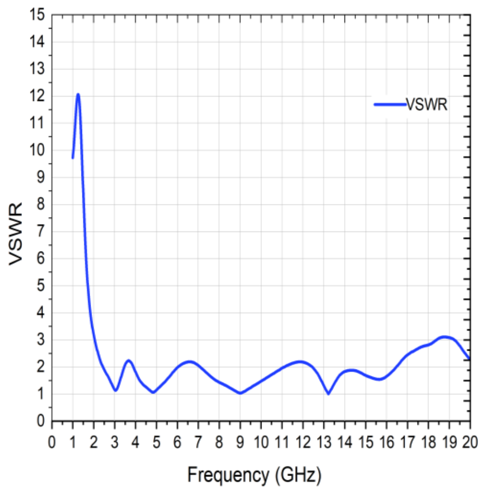

Figure 10. The designed Antenna's simulated VSWR.

Table 1. Comparison of Proposed antenna with earlier reported structures.

S.No	Year	Dimensions in mm²	Frequency in GHz	Radiating element
1	2015	40 × 30	2.4, 3.5, 5.8	Pentagonal radiating patch with two slots
2	2016	43 × 20	2.8, 5.8, 10.8	U shape Monopole antenna
3	2017	35 × 53	2.4, 3.5, 5.5.	Epsilon and nine shaped antennas
4	2018	23 × 23	3.6 ,5.8, 6.3, 8.3, 9.5	Kite-shaped, C- and modified G-shaped slots
5	2019	35 × 25	5.7, 10.3	Metamaterial cell
6	2020	40 × 40	2.9, 2.10, 3.5, 4.5, 5.7, 6.5	Penta-ring SRR
7	Proposed	34 × 20	3, 4.8, 9, 13.2	Asymmetrical U and T shaped patch structures

antenna at resonating frequencies is almost equal to one which is promising. In this design without the necessity of complex structures able to achieve multiband operation by simply removing some portions from the patch and adding additionally centre T strip.

7. CONCLUSIONS

The design of a novel quad band antenna with asymmetrical U and T shaped patch structure for portable wireless applications was presented in this study. The difference of this design with others can be seen through its simple design steps leading to less complex structure. The proposed antenna resonates at 3 GHz, 4.8 GHz, 9 GHz, and 13.2 GHz frequencies with bandwidths 980 MHz, 2.05 GHz, 3.84 GHz, and 3.82 GHz, respectively. Over the working frequency ranges, the antenna has reasonable gains. Bandwidth of the antenna over the operating frequencies is high. The gain, VSWR, and reflection coefficient are taken into consideration for design and analysis operations in the frequency range of 1 GHz to 20 GHz. In comparison to most other designs, this structure is simple and compact, producing quad bands for use in portable electronic devices. The proposed patch antenna is made utilizing printed circuit board technology, which is easy and affordable. This antenna is applicable to a wide range of modern portable wireless applications, Bluetooth (2.4) GHz, WLAN (5.125-5.35) GHz and (5.725-5.825) GHz, WIMAX (5.25-5.85) GHz, C-band (3.7-4.2) GHz and Ku-band (12-18) GHz.

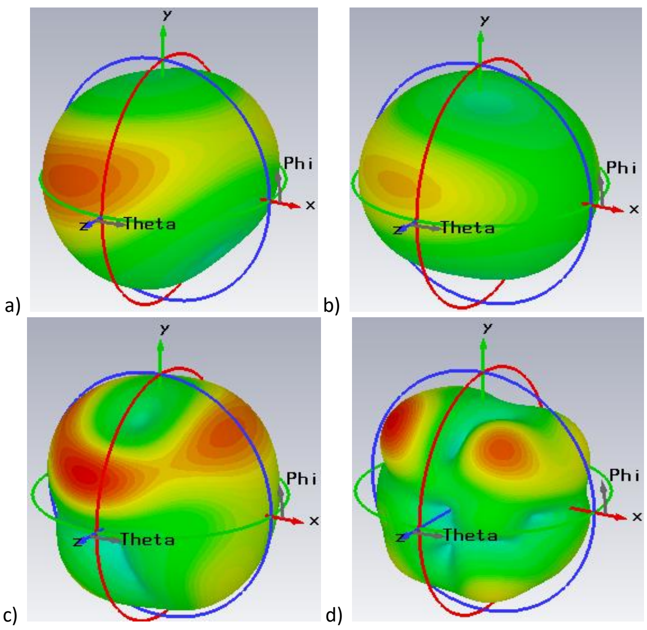

Figure 11. Patterns of radiation at: a) 3 GHz, b) 4.8 GHz, c) 9 GHz and d) 13.2 GHz.

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