# A Novel Circular Monopole Fractal Antenna for Bluetooth and UWB Applications with Subsequent Increase in Gain Using Frequency Selective Surfaces

**Divyanshu Upadhyay, Indranil Acharya and Ravi Prakash Dwivedi**

**Abstract** In this paper a novel monopole circular fractal disk is analyzed in details. The antenna is mounted on a FR4 substrate having a dimension of 30 × 35 mm$^2$. A 50 Ω impedance matched microstrip line is used as feeding mechanism for the antenna. The antenna exhibits stable radiation patterns and has a bandwidth of 9.64 GHz. A U-shaped slot having appropriate dimensions is etched from the patch in order to make the antenna compatible for Bluetooth applications. In the later section, different types of Frequency Selective Structures (FSS) are introduced for enhancing the gain of the antenna. A gain of 8.94 dB is observed with the introduction of slot type FSS structures beneath the ground plane. All the analysis of the antenna is done in HFSS 2013.

**Keywords** Fractal antenna · Bandwidth · UWB technology · Notch · U-shaped slot · Frequency selective surface · Gain · Return loss

## 1 Introduction

In 2002 Federal Communication Commission (FCC) authorized the unlicensed use of 7.5 GHz bandwidth (from 3.1 to 10.6 GHz) as the official band for Ultra-wideband applications [1]. Since its inception, there has been a tremendous

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S.C. Satapathy et al. (eds.), *Information Systems Design and Intelligent Applications*, Advances in Intelligent Systems and Computing 434,
DOI 10.1007/978-81-322-2752-6_33

demand for antennas operating in this band because of its inherent advantages of being compact, having low power consumption, high data rate within short distance, phase linearity and stable omni-directional radiation pattern [2–5]. UWB technology is widely used in medical imaging, breast cancer detection, indoor/outdoor communication, radars and military surveillance. Many antennas have been designed for UWB applications. But the main challenge lies in its miniaturization. A perpetual tradeoff exists between the achievable bandwidth and the antenna physical dimension. Antennas with high dielectric constant values reduce its resonant frequency but at the cost of a reduced bandwidth [6]. Fractal geometry, a concept of mathematics can be extended for designing UWB antennas because of its several unique features. They have a unique property of space-filling meaning which implies that large apparent electrical lengths can be obtained within a limited given volume. Since the radiation pattern of an antenna is immensely affected by its electrical length, this efficient packing by fractal concept serve to be quite indispensible. Although inherently narrowband, some fractal antennas do have wideband characteristics like the snowflake fractal antenna for C-band frequency applications [7]. A trademark feature of snow flake antennas is that they have an impedance bandwidth of 49 %. Another interesting property of fractal antennas is self-similarity that leads to antennas operating at multiple frequencies thus serving as a potential candidate for UWB applications as specified by FCC [8]. Notable in this regard is the Desecrates Circle Theorem (DCT) which led to the discovery of novel UWB antennas which are compact in size [9]. The self-similarity approach discussed above is utilized here in case of a circular monopole disk fractal antenna.

In the first part, a novel monopole fractal antenna is studied. The designed antenna is compact in size and exhibits wideband characteristics. Moreover with the incorporation of certain incisions in the patch, the antenna is made to operate in the ISM band (2.36 GHz). In order to mitigate interference between co-existing systems in the UWB range (viz. WiMAX, C band, WLAN etc.), a notch is created mainly to discard WLAN frequency (5.15–5.35/5.725–5.825 GHz). The later section of the paper is mainly concerned with enhancing the gain of the antenna without interfering the wide bandwidth. The concept of Frequency Selective Surface (FSS) is adopted in this regard. FSS structures have unique characteristics of suppressing surface waves and acting as a high impedance surface that reflects in phase plane waves. But in order to obtain maximum reflection, the position of the FSS with respect to the antenna becomes indispensible. In this paper, three different FSS surfaces viz. Jerusalem cross structure, Tri-pole FSS and slot-type structures are employed and a comparative analysis is carried out in HFSS 2013.

## *1.1 Basic Antenna Structure*

The geometric representation of the antenna is shown in Fig. 1. The optimized dimensions are shown in Table 1. The antenna under consideration is placed on

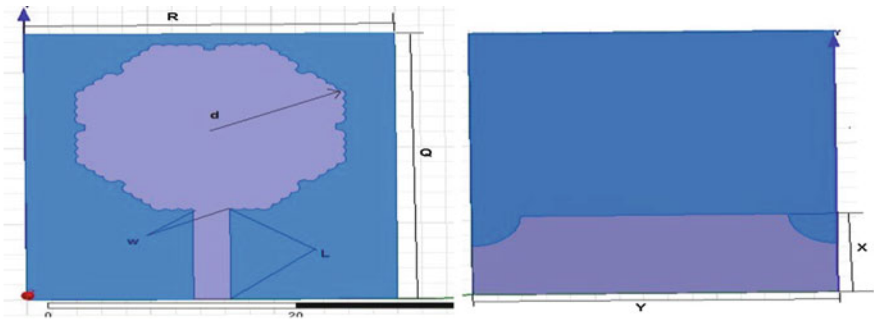



**Fig. 1** Structure of the proposed antenna

**Table 1** Optimized dimensions of the basic proposed antenna

| Dimensions of the antenna | Optimized value (in mm) |
|---|---|
| R | 30 |
| Q | 35 |
| L | 11.86 |
| w | 3 |
| d | 11.347 |
| X | 10.5 |
| Y | 30 |

FR4 epoxy substrate of thickness 1.6 mm. A 50 Ω microstrip line having length (L mm) and width (w mm) is used as feed and matching section.

Two circles each having radius of 4 mm is removed from the sides of the modified ground plane. This provides a better impedance matching and results in a wider bandwidth formation.. The basic structure consists of a circular patch having radius 7 mm. In the first iteration, eight circles each having radius 2.7475 mm is placed on the radiating patch thereby leading to an increase of 1.58 in the overall circumference value. In the second iteration, five circles each having radius 1.3737 mm is placed upon each smaller circle. In the third iteration, three circles each of radii 0.68685 mm is paced upon the smaller circles. This process can be repeated till infinity, but for the antenna under consideration the above procedure is constrained to three iterations only. The transition between the different iterations is demonstrated in Fig. 2.

## 1.2 *Results Obtained*

Figures 3 and 4 show the return loss and the gain of the antenna. It can be observed from the $S_{11}$ plot that the antenna resonates at frequencies 3.43, 5.79, 8.76 and 11.37 GHz having return loss of −40.57, −34.74, −27.29 and −39.75 dB

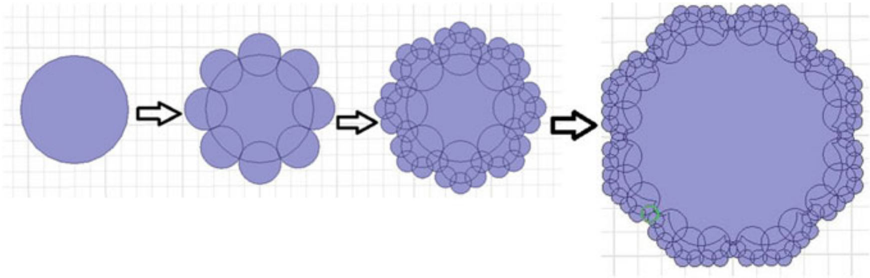


**Fig. 2** Transition between the different iterations

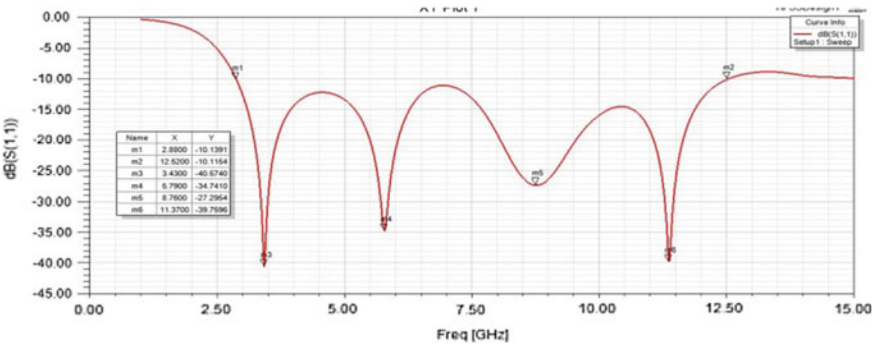



**Fig. 3** Return loss of the planar monopole antenna

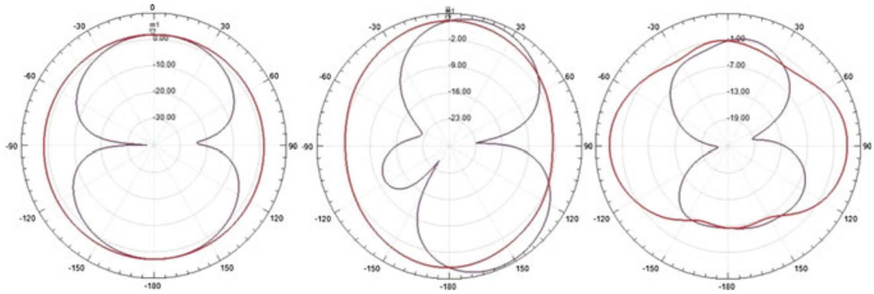



**Fig. 4** Radiation pattern of the antenna at different frequencies

respectively. A wide bandwidth of 9.64 GHz is obtained between 2.88 GHz. At 3.5 GHz a gain of 1.83 dB is obtained.

The radiation pattern of the antenna is displayed in Fig. 4 having resonant frequencies at 3.5, 6 and 9 GHz respectively.

Radiation patterns are obtained by varying theta (θ) and phi (ϕ) angles. Here, only theta values are varied but phi remains constant to zero value.

### *1.3 Creating Notch on the Basic Antenna for Discarding WLAN Frequencies*

In this case an inverted U shaped incision is etched out from the patch of the normal antenna. Figure 5 shows the geometric representation of the antenna with an inverted U-shaped slot.

The dimensions of the notch slot are represented as: t = 8.5 mm, g = 0.6 mm, p = 2 mm and z = 3 mm. By varying the length of the slot (t) different variation in the stop band can be obtained. As can be inferred from Fig. 6, with increase in the length of the slot, an increase in the bandwidth of the stop band is obtained.

## 2 Modified Antenna for ISM Band (Bluetooth) and UWB Applications

In order to make the antenna compatible for ISM band as well as UWB applications, a U-shaped slot is inserted from the patch. Figure 7 shows the geometric representation of the modified antenna. The dimensions of the slot are as follows: n = 0.5 mm, j = 4.2 mm, u = 7 mm, s = 17.4 mm.

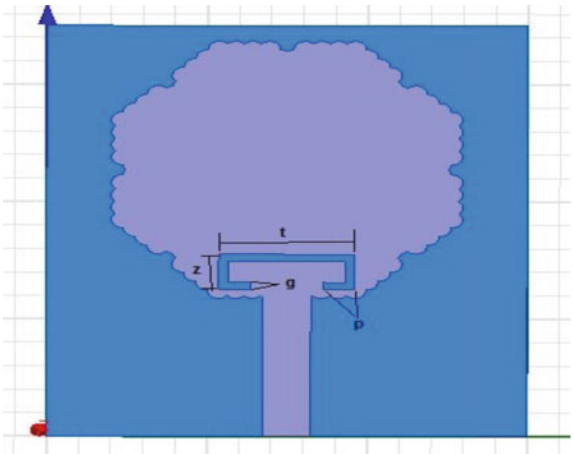



**Fig. 5** Basic antenna with inverted U-shaped slot

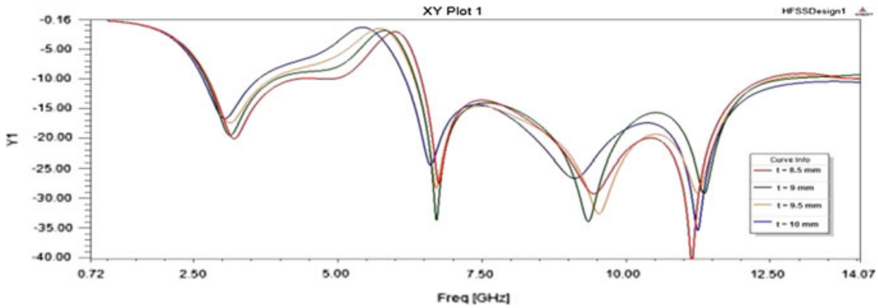
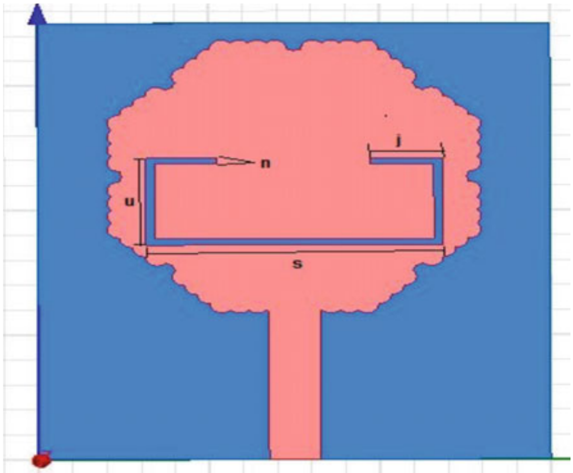



**Fig. 6** $S_{11}$ plot showing variation of the stop band with change in the dimension of slot length (t)

**Fig. 7** Geometric representation of the modified antenna




## 2.1 *Results Obtained*

Figure 8 shows transmission coefficient of the antenna. From the $S_{11}$ plot, it can be obtained that the antenna resonates at frequencies 2.4, 3.91, 5.78, 7.93 and 11.44 GHz having return loss of −14.82, −22.28, −26.38, −34.08 and −27.76 dB respectively. A wide bandwidth of 9 GHz is obtained between 3.4 and 12.4 GHz.

The radiation pattern of the modified antenna is shown in Fig. 9 at frequencies 3.5, 6 and 9 GHz respectively.

The gain obtained is 1.60 dB at a frequency of 3.5 GHz. Here the gain is obtained by varying θ and ϕ values respectively.

The surface current distribution of the modified antenna is shown in Fig. 10. It can be observed that the incorporation of the slot in the patch, current density around its upper corners increases. This leads to more propagating modes and at the

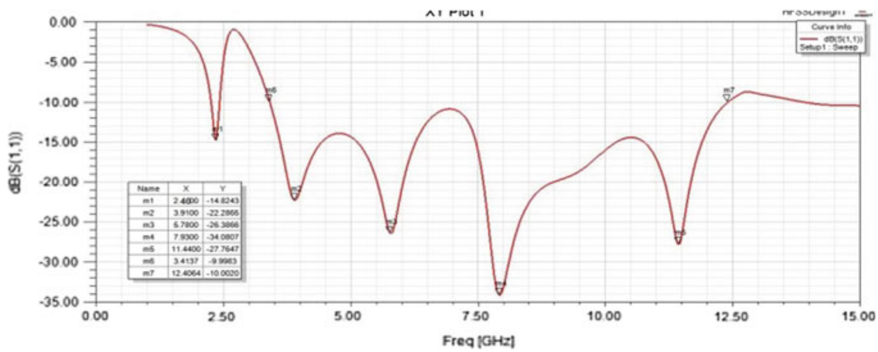



**Fig. 8** Return loss of the modified antenna

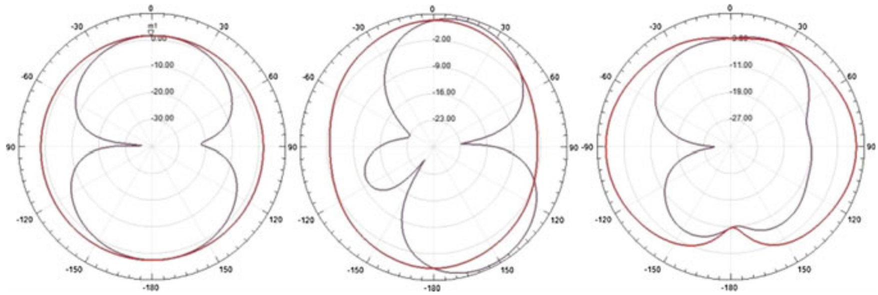



**Fig. 9** Radiation pattern of the modified antenna at different frequencies

same time creates a null (at approximately 2.55 GHz) as the currents in the exterior and the interior of the slot are oppositely directed.

## 3 Frequency Selective Surface Design

The proposed UWB circular fractal antenna is basically a low gain antenna and the gain is considered as matter of great concern for wireless application. The two important techniques, Electromagnetic Band Gap (EBG) and the Frequency Selective Surface (FSS), are used for enhancing the gain of the antenna. The Frequency Selective Surface (FSS) is an important alternative to EBG due to its compactness and low profile configuration [10]. A Jerusalem cross-pair FSS having dimensions of unit cell 8.4 mm × 8.4 mm and the gap between each unit cell is taken as 1 mm. The structure of this type of FSS is shown in Fig. 11.

A Tripole-pair FSS is the combination of various unit cells of double periodical arrangements of tripoles and the gap between each unit cell is taken as 1 mm. The structure of this type of FSS is shown in Fig. 12.

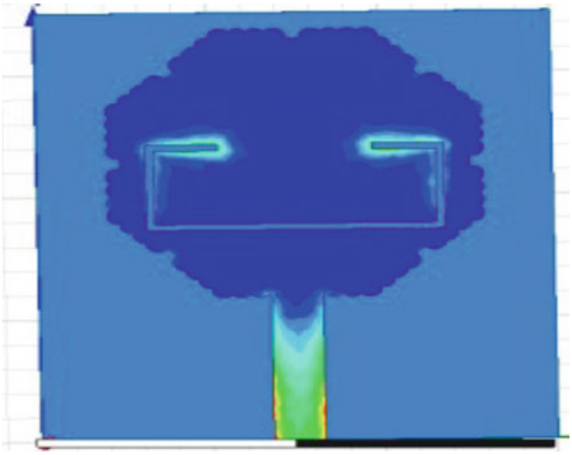


**Fig. 10** Current distribution on the modified antenna

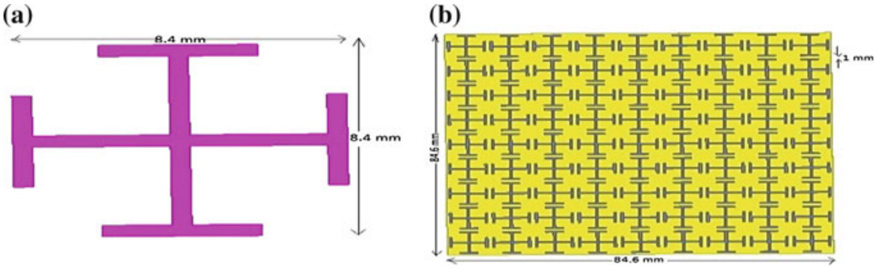



**Fig. 11** Jerusalem cross-pair FSS **a** Unit cell **b** 9 × 9 FSS

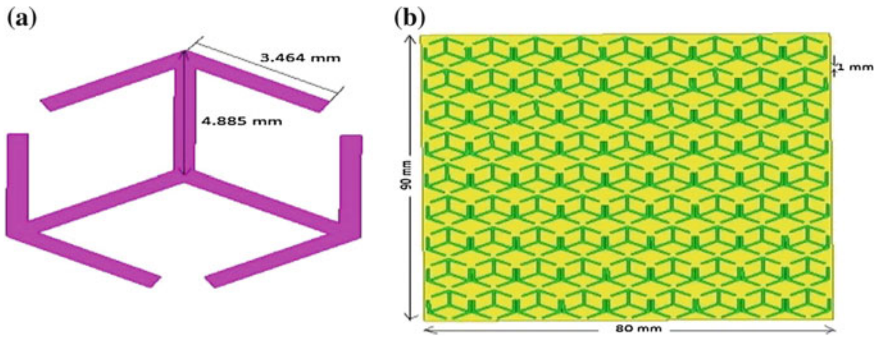



**Fig. 12** Tripole-pair FSS **a** Unit cell **b** 9 × 9 FSS

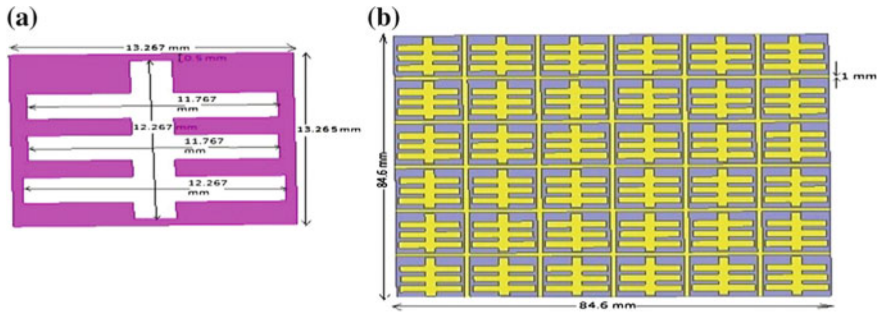



**Fig. 13** Slot-pair type FSS **a** Unit cell **b** 6 × 6 FSS

A new slot-pair type FSS is introduced with its unit cell dimensions of 13.267 mm × 13.265 mm and gap between the unit cells is taken to be 1 mm. By etching various slots in the unit cell, a capacitive effect is created and this effect gives rise to lower resonance frequency as compared to the above FSS structures (Fig. 13).

A common substrate, Rogers RT/duroid 5880™ is chosen for these FSS structures (dielectric constant value: 2.2 and thickness 0.8 mm).

## 3.1 Results Obtained

Figure 14 shows the comparative return loss plots of UWB circular fractal antenna with different FSS structures. The FSS structures were placed at height of h = 21.635 mm.

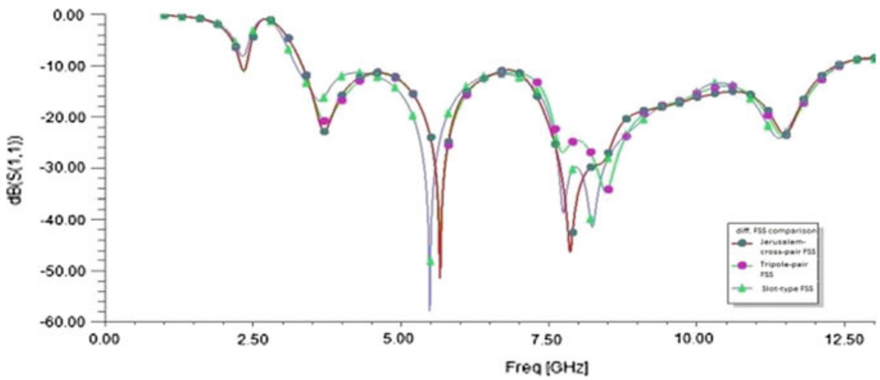



**Fig. 14** Comparative return loss plots of UWB circular fractal antenna with different FSS structures

From the above comparative plot of return loss, it is shown that the coupling between the patch and the FSS layer affects the characteristics of the antenna. The coupling effect occurs due to the reflection of the waves, which are radiated from the antenna structure, in certain frequency bands from the FSS layer. Then, the reflected waves from the FSS layer fall back on the patch antenna and affect the current distribution on the patch. The electromagnetic waves, which are radiated by the antenna, act as an excitation source to illuminate the FSS layer. The FSS layer forces the distribution of these EM waves in the space and controls the phase and hence the unit cells of the FSS get excited and the whole structure works as an aperture antenna [11].

The radiation pattern plots of UWB circular fractal antenna with different FSS structures are shown in Figs. 15, 16 and 17 at resonant frequencies of 3.5, 6 and 9 GHz.

Table 2 shows the gain comparison between different FSS structures used in UWB circular fractal antenna at a chosen frequency of 3.5 GHz. It is shown that slot-pair type FSS has resulted in gain enhancement of the antenna by a factor of 2 (approx.) as compared to other FSS structures. This type of FSS has shown compactness and more capacitive loading effect than other FSS.

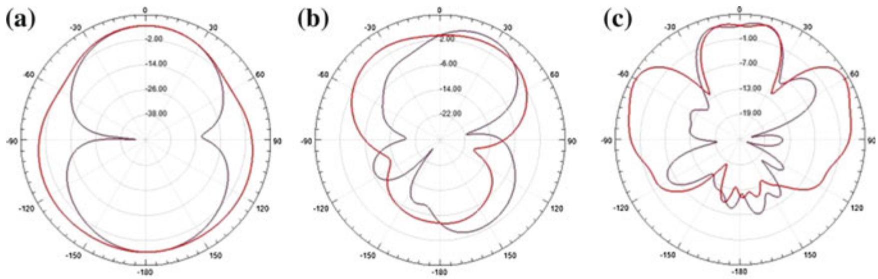



**Fig. 15** Radiation patterns of UWB circular fractal antenna with Jerusalem cross-pair FSS at **a** 3.5 GHz, **b** 6 GHz, **c** 9 GHz

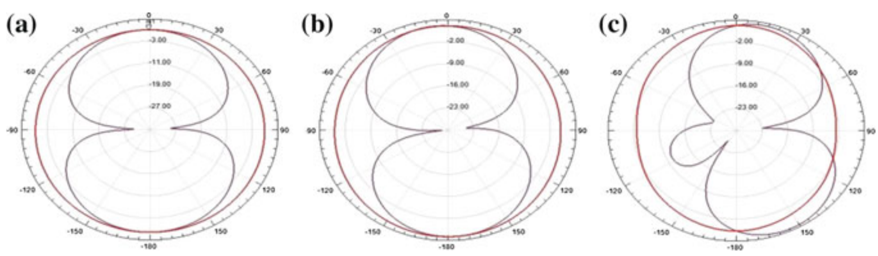



**Fig. 16** Radiation patterns of UWB circular fractal antenna with Tripole-pair FSS at **a** 3.5 GHz, **b** 6 GHz, **c** 9 GHz

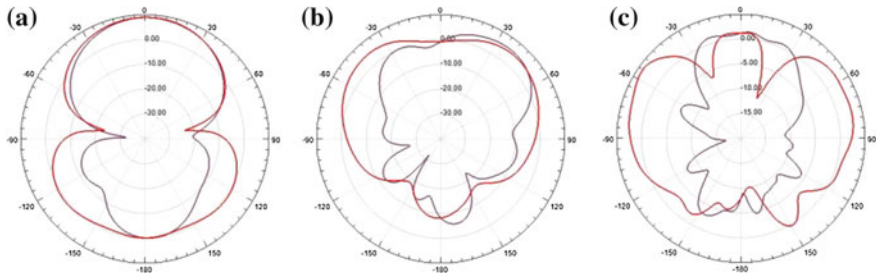


**Fig. 17** Radiation patterns of UWB circular fractal antenna with Slot-pair type FSS at **a** 3.5 GHz, **b** 6 GHz, **c** 9 GHz

**Table 2** Gain Comparison between different FSS structures

| FSS Structures | Gain (in dB) |
|---|---|
| Jerusalem-cross pair type | 4.77 |
| Tripole-pair type | 4.93 |
| Slot-pair type | 8.94 |

## 4 Conclusion

In this paper a novel fractal monopole antenna is analyzed in details. The antenna is compact and has a bandwidth of 9 GHz and exhibits stable radiation patterns thus serving as a potential candidate for UWB applications. Moreover with the insertion of a U-shaped slot, the same antenna is made to work for Bluetooth applications and at the same time retaining its ultra-wideband features. In order to mitigate interference between co-existing systems, an inverted U-shaped slot is inserted in the patch near the feed line which efficiently rejects WLAN frequencies. The later section of the paper is mainly concerned with increasing the gain of the antenna by placing different types of FSS structures at an optimal distance beneath the antenna. A comparative analysis is carried out in which it is found that the slot-type FSS gives the most acceptable gain enhancement of 8.94 dB from 1.6 dB. The designed antenna can be effectively used for short range communication, medical spectroscopy and various other bio-medical applications like detecting breast cancer.

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