CHAPTER 5

DESIGN AND DEVELOPMENT OF NOVEL MULTISTANDARD COMPACT FRACTAL ANTENNA FOR MULTIBAND WIRELESS APPLICATIONS

This chapter deals with the design, development, fabrication and testing of novel multistandard compact fractal antenna for multiband wireless applications. The introduction and the needs of development of multistandard antennas is discussed. Later, the formulation of iterative function systems, and guides to the design of fractal antenna are explained. The chapter concludes with the significance of fractal monopole antenna and the effect of different dielectric constants simulation.

5.1 INTRODUCTION

At present, reconfigurable RF transceivers diminish the manufacturing cost of the primitive transceivers. These transceivers are proficient in switching to and fro and for more than one standard. The RF transceivers are capable of utilizing the reconfigurable hardware architecture (Pan et al 2008). New-fangled multiband antenna, operating for more than one standard will serve the needs of wireless market. A typical reconfigurable multistandard wireless system is depicted in Figure 5.1.

Koch curve and Sierpinski gasket fractal antennas are fused to shape a novel Sierpinski Koch which is linearly tapered along with a balanced network. The fused antenna is more advantageous compared to monofractal
A compact dual band planar branched monopole antenna for Digital Communication Service (DCS) and Wireless Local Area Network (WLAN) applications measure 30 mm × 30 mm which is a monopole antenna configuration (Suma et al 2006). A modified Sierpinski fractal monopole antenna for Industrial, Science and Medicine (ISM) bands handsets provide a maximum shrinkage with multiband performance has been reported (Wojciech 2009).

Courtesy: www.slideshare.net/hossamfaded48/multi-standard-multiband-receivers-for-wireless-applications

Figure 5.1 Reconfigurable Multistandard RF Transceivers
Currently, the developed antenna designs, incorporating self-similar property of fractal geometry insist to achieve miniaturization with multiband performance have been reported (Sundaram et al 2007). Design of miniaturized square structure is obtained by modifying with the aid of fractal antenna. The antenna measures 36 mm × 36 mm × 36 mm in size. In this design, aperture coupling on a RT Duroid 5880 substrate, the feed line and the antenna are separated by a slot structure (Yang Yan et al 2008).

Size reduction and bandwidth enhancement of snowflake fractal antenna through air filled structures and capacitive coupling are achieved through the techniques (Mirzapour et al 2008). The bandwidth enhancement is achieved through air filled and capacitive feed.

Internal antennas are capable of covering, Global System for Mobile communication (GSM 850/900/1800/1900 MHz) and Universal Mobile Telecommunication System (UMTS 824-894/890-960/1710-1850/1900/1920-2170 MHz) frequency bands. The implementation of 4G devices increases the bandwidth requirement to crown Long Term Evolution 2300 MHz and 2500 MHz (LTE 2300-2400 and 2500-2690) frequency bands. The amalgamation of global-operability Radio Frequency IDentification (RFID) readers enables wireless sensors and Zig-bee based controllers in a smart phone is a state-of-the-art technology. This necessitates the antenna operability over the additional bands 860-956 MHz, 2.2 GHz and 2.3 GHz bands. The size of multiband internal antenna has to be preferably below the credit (Ting Zhang et al 2011). A modified fractal square crown antenna is visualized to have multiband resonance with a small deviation in frequency which is separated on a FR4 substrate. The antenna measures 10 mm × 10 mm with dual band in operation (Wang Yong and Shaobin 2008).

A microstrip Sierpinski carpet antenna is proposed using transmission line, feed for multiple operations. The structure demonstrates a
bandwidth of 47% at 7.93 GHz. The obtained radiation patterns with multiple lobes at higher bands are due to asymmetric geometry of the fractal structure with respect to the feed point (Mohammad kamal et al 2005). Microstrip Sierpinski carpet antenna design integrates various telecommunication services such as GSM (900 MHz; 1800 MHz) Wireless Local Area Network (WLAN), Global Position Systems (GPS), and High PERformance LAN (HIPERLAN) on a single device. The structure is a self-similar fractal antenna. The designed antenna exhibits a fractional bandwidth of 1.6%, 1.8%, 5%, 12.96% and 4.7% at 2.59 GHz, 3.48 GHz, 3.99 GHz, 5.2 GHz and 7.93 GHz correspondingly. The accomplishment is carried on a substrate with $\varepsilon_r = 4.5$, and thickness 1.6 mm. The antenna measures 38 mm $\times$ 38 mm (Rahmin 2005 et al).

A Linear dipole fractal antenna has been investigated for Ultra High Frequency (UHF) using empirical method and genetic algorithms. The antenna shows an impedance bandwidth of 9.9%. The improvement in percentage bandwidth is achieved through balun network (Eason et al 2001). Multiband resonance with improvement in a self-similar fractal antenna is achieved through switches. These switches are formed in a fractal antenna through 2 mm $\times$ 1 mm copper strips bridging (Anagnostau et al 2003).

A irregular shaped fractal antenna for Ultra Wide Bandwidth (UWB) radio systems measures 65 mm $\times$ 56 mm on a substrate with a thickness of 2 mm, and $\varepsilon_r = 2.8$. The change in delta value of irregular curve from 1.5 to 1.9 has been investigated. The radiation pattern with multilobe, along the planes are distorted to a greater extent. At lower frequencies, the pattern changes are suitable along the horizontal plane (Krupenin et al 2006). Research on fractal antennas and use of slot computing techniques, summarizes fractal antenna designs that have improved performance compared to conventional fractal antennas. These antennas measure 27 mm
which is a main radiation element. The Coplanar Wave guide (CPW) centre strip is of 20.142951 mm in length and 1.5 mm in width. The ground plane measures 20.5 mm and 18.4 mm in width and length respectively. The impedance bandwidth varies from 14% to 25% for the first and 8.5% to 10.5% for the second resonances (Rowdra Ghatak et al 2007).

The combined fractal dipole wire antenna is in a combination of two different fractal geometries such as Koch and Hilbert curves. Initially, Hilbert curve is adopted for the first iteration, and later Koch curves for each lines of Hilbert curve is replaced. The resulting curve-length increases throughout the geometry. The antenna measures 7 cm × 7 cm covering frequencies from 100 MHz to 3 GHz (Mustafa Khalid 2010). A CPW fed self-affine fractal antenna for low profile and multiband performance has been investigated for mobile communication systems. The geometry measures 60 mm in length and width and 5 mm in height. The substrate selected is RT Duroid substrate. It has a thickness of 0.787 mm, and the dielectric constant is 2.2. The antenna resonates for 1.11 GHz, 1 GHz, 0.96 GHz and 0.93 GHz (Tae Hwan Kim et al 2005).

The Fractal antennas designed for wireless communications has many discontinuities in structure. The discontinuity structure enhances radiation at higher frequencies. Miniaturization and multiband frequencies are achieved by incorporating these fractals. The antenna covers ISM band with a modified Sierpinski gasket monopole. The antenna measures 88.75 mm in length and 46.6 mm in width on a FR4 substrate. The overall length of antenna is 108.7 mm which includes the feed line and main radiating element (Nicolaescu et al 2008).

A dual band antenna designed to operate at L and S band is proposed. A multilayer stack concept has been incorporated. The layers are Duroid material, foam and glass epoxy substrates. The relative permeability
is 3, $h = 60$ mil, and 1.057 for the first substrate. For the second substrate, the relative permeability is $h = 10$ mm and 4 mm respectively. The first antenna measures 72.45 mm $\times$ 72.4367 mm and 48.5557 mm for “L” band application. The second antenna measures 31.1 mm $\times$ 31.7048 mm $\times$ 38.5095 mm for “S” band application. The values of “L” and “S” band correspond to the sides of a triangular patch antenna. The “S” band antenna resonates at 2.487 GHz frequency which exhibits a bandwidth of 170 MHz. The “L” band antenna resonates at 1.176 GHz frequency by providing a bandwidth of 30 MHz. The antenna exhibit a dual band, of 40 MHz bandwidth is reported (Rajeev Kumar Kanth et al 2009).

The analysis of Hilbert curve using Finite Difference Time Domain (FDTD) method is proposed. The experimental and computational results gave good agreement. The resonant frequency for the first iteration is 1300 MHz, for the second iteration is 1000 MHz, and for the third iteration is 700 MHz correspondingly. The size reduction of the antenna is achieved from one iteration to other, thereby shift in resonant frequency is observed. The outer dimensions of the antenna remains the same due to which the total volume gets reduced by incorporating these fractal geometries (Wang Hongjian and Gao Bengqing 2002). A genetic algorithm technique in a combination with an iterative function systems approach for generating fractal geometries is a method through which the optimized antenna Voltage Standing Wave Ratio (VSWR) is less than 2 for each specified target frequencies. The conventional dipole measures 12.24 cm, where the fractal antenna measures 5.5 cm $\times$ 1.22 cm with 3 load locations (Werner and Werner 2001).

A crown microstrip antenna developed on a substrate, whose relative permeability is 2.53 and 1/8 of thickness is assumed for the substrate. Reduction of 12% is achieved for the first and the second iterations. The
A large VSWR with two circularly polarized band is visualized (Dehkhoda and Tavakoli 2004). A modified Sierpinski gasket monopole is presented, which is designed to operate at 2.4 GHz and 5.2 GHz. The antenna measures 46.6 mm in width and 108.7 mm in length. The structure is realized on a Rogers substrate with relative permeability of 3.38 and loss tangent is 0.0027. The bandwidth operates from 2.78 GHz - 1.93 GHz and 4.55 GHz - 4.32 GHz (Wojciech 2006). The proposed multiband antenna measures 120 mm × 80 mm in dimension. The multiband antenna is an irregular structure, obtained from real image of fractal jet fluid. The antenna resonances at 7.5 GHz, 12.9 GHz, 15.4 GHz, 18.8 GHz, 24.9 GHz and 27.7 GHz with a return loss of -17 dB, -32 dB, -14 dB, -16 dB, -9 dB, and 18 dB respectively. The antenna is intended to operate at higher frequency bands (Hatem Rnilli et al 2009).

A fractal based ground plane is designed for a triangular monopole antenna to obtain dual band characteristics for IEEE 802.11 standard. The modified ground plane is a Sierpinski gasket which has undergone two iterations with a scaling factor of 2. The ground plane measures 104 mm and the structure is implemented on a low cost FR 4 substrate whose relative dielectric constant is 4.5, thickness is 1.55 mm and loss tangent is 0.02. The antenna resonates for 4.675 GHz - 5.556 GHz with a relative bandwidth of 17.2% on a solid ground plane. Fractal based ground planes display 2.397 GHz - 2.552 GHz and 4.645 GHz - 6.194 GHz with a relative bandwidth of 6.26% and 28.6% respectively (Joan Gemio et al 2009). A biband fractal antenna design is proposed for RFID applications on a FR 4 substrate. The antenna measures 1.6 mm × 16 mm × 105 mm. The structure has a gain of 2.3 dBi at 0.868 MHz, and 3.3 dBi at 2.45 GHz. The return loss of the antenna as -30 dB for 0.868 GHz and 31 dB for 2.45 GHz with a narrow bandwidth is observed (Ahmed Ibrahim et al 2006).
The Hilbert curve fractal antenna fed by a CPW for multiband wireless applications is presented. The fractal antenna measures 88 mm × 88 mm on a FR4 substrate. The relative dielectric constant is 4.4. The thickness of substrate is 1.6 mm, and loss tangent is 0.02. The antenna resonates for 1.52 GHz, 1.90 GHz and 2.48 GHz with a narrow bandwidth (Niruth Prombutr and Prayoot Akkaraekthaline 2007).

The antenna design based on Minkowski geometry for WLAN applications is proposed. The fractal monopole antennas using first and second iterations measures 28 mm × 28 mm and 21.5 mm × 18 mm. A detailed study has been carried out for different ground planes. The antenna operates at 3.5 GHz and 5.8 GHz covers 802.11 a/b/g and Worldwide Microwave Access (WiMAX) communications. The overall dimension of antenna is 35 mm and 30 mm (Luo Q et al 2009).

The necessity for radio spectrum, which is a limited resource, mainly motivated the next generation wireless communication services offering multimedia application on mobile broadband networks. The LTE wireless standards show potential in this circumstance with its capacity to interconnect with other access technologies. These technologies provide interoperability for the next generation. These developments are mainly due to the demand in radio frequency spectrum (Mopidevi 2011). The octaband antenna, proposed for two wide frequency bands (698- 960 MHz/1710- 2690 MHz) is capable of covering 700/GSM 850/GSM 900/DCS 1800/ Personal Communication Service, (PCS) 1900/Wide band Code Division Multiple Access, (WCDMA) 2100 and LTE for the 4G mobile set on a polyester material. The octaband antenna measures 7 mm × 11 mm × 46 mm (Chan-Woo Yang 2011).

Consequently, this chapter aims at the appraisal of novel self-similar multistandard fractal antennas for wireless applications. The novel
self-similar multistandard antennas are capable of crowding near by bands are presented. The antenna flaunts a wide range of applications. The performance is compared with the developed structure in the previous chapter.

5.2 NOVEL SELF-SIMILAR FRACTAL GEOMETRY

Novel self-similar geometry for the next generation wireless transceivers is studied in this chapter. These classes of geometries in antenna make it flexible in controlling the bandwidth. The iterated image looks similar in all possible means of the parent geometry.

These geometries are governed by eliminating the three groups of islands in the set repeatedly as shown in Figure 5.2. The obtained replicas look as the original. It reveals a self-similar property of fractal geometry. Similarly, for each subset, the process of exclusion is frequently applied. Thereby, the volume of the initial geometry gets compact.
5.2.1 Iterative Function Systems

The pattern repeats infinitely. They are governed by the Iterative Function Systems (IFS). The patterns obtained through such transformation are identical. The set and subset are assumed as shown in Figure 5.2. The elimination of the geometry is within the arrow mark for convenience. The equation (5.1) describes the initial geometry, i.e., the initiator. The equation (5.2) reveals that the subset $A$ contains 9 subsets. The equations (5.3) to (5.40) reveals the process of elimination for a self-similar fractal antenna in each subset.

Let $W(A)$ be a set, where $A$ is initiator

$$W(A) = \bigcup_{i=1}^{9} A_i$$

where, $W(A)$ is called as Hutchinson operator (Peitgen 1992) which is spanned by,

$$W(A_1), W(A_2), \ldots \ldots \ldots W(A_9)$$

where $n = 9$, which is known as subsets of $W(A)$ (equation 5.1).

Equation (5.2) holds true for values of $(A_1, A_2, \ldots, A_9)$ except $A_5$, $A_7$ and $A_8$

$$W(A_1) = \bigcup_{i=1}^{9} A_i - (A_5 + A_7 + A_8)$$

Repetition holds true

$$W(A_1) = \left[ (0,0), \left( \frac{x}{3} \right), \left( \frac{x}{3}, \frac{y}{3} \right), \left( 0, \frac{y}{3} \right) \right]$$
\[ W(A_2) = \begin{bmatrix} \frac{x}{3}, 0 & 2x, 0 & 2x, y, 0 & x, y, 0 \\ \end{bmatrix} \] (5.5)

\[ W(A_3) = \begin{bmatrix} \frac{2x}{3}, 0 & x, 0 & \frac{y}{3}, 0 & \frac{2x, y}{3} \\ \end{bmatrix} \] (5.6)

\[ W(A_4) = \begin{bmatrix} 0, y, \frac{x}{3}, \frac{y}{3}, \frac{2y}{3}, 0, \frac{2y}{3} \\ \end{bmatrix} \] (5.7)

\[ W(A_5) = \begin{bmatrix} 0, y, \frac{x}{3}, \frac{y}{3}, \frac{2y}{3}, 0, \frac{2y}{3} \\ \end{bmatrix} \] (5.8)

\[ W(A_6) = \begin{bmatrix} \frac{2x}{3}, \frac{2y}{3}, \frac{x}{3}, \frac{y}{3}, \frac{2y}{3}, 0, \frac{2y}{3} \\ \end{bmatrix} \] (5.9)

\[ W(A_7) = \bigcup_{i=9}^{9} A_i - (A_i, j = 5, 7, 8) \] (5.10)

\[ W(A_8) = \begin{bmatrix} 0, 0, \frac{x}{9}, \frac{y}{9}, \frac{2x}{9}, 0, \frac{2x, y}{9}, \frac{x, y}{9} \\ \end{bmatrix} \] (5.11)

\[ W(A_9) = \begin{bmatrix} \frac{x}{9}, 0, \frac{2x}{9}, 0, \frac{2x, y}{9}, \frac{x, y}{9} \\ \end{bmatrix} \] (5.12)

\[ W(A_{10}) = \begin{bmatrix} \frac{x}{9}, 0, \frac{2x}{9}, 0, \frac{2x, y}{9}, \frac{x, y}{9} \\ \end{bmatrix} \] (5.13)

\[ W(A_{11}) = \begin{bmatrix} 0, y, \frac{x}{9}, \frac{y}{9}, \frac{2y}{9}, 0, \frac{2y}{9} \\ \end{bmatrix} \] (5.14)

\[ W(A_{12}) = \begin{bmatrix} \frac{2x}{9}, \frac{y}{9}, \frac{x}{3}, \frac{y}{3}, \frac{2y}{3}, 0, \frac{2y}{3} \\ \end{bmatrix} \] (5.15)
\[ W(A_{31}) = \left[ \begin{array}{ccc} 2x & 2y & x \\ 9 & 9 & 3 \\ \frac{2x}{9} & \frac{y}{3} & \frac{2x}{3} \end{array} \right] \]

(5.16)

\[ W(A_{32}) = \bigcup_{i=1}^{9} A_{3i} - (A_{2i}, j = 5, 7, 8) \]

(5.17)

\[ W(A_{31}) = \left[ \begin{array}{ccc} x & 0 & 0 \\ 3 & \frac{4x}{9} & \frac{4y}{9} \\ \frac{x}{3} & \frac{y}{9} & \frac{x}{3} \end{array} \right] \]

(5.18)

\[ W(A_{32}) = \left[ \begin{array}{ccc} 4x & 0 & 0 \\ \frac{5x}{9} & \frac{5y}{9} & \frac{4x}{9} \\ \frac{4x}{9} & \frac{4y}{9} & \frac{x}{3} \end{array} \right] \]

(5.19)

\[ W(A_{33}) = \left[ \begin{array}{ccc} 5x & 0 & 0 \\ \frac{2x}{3} & \frac{5y}{9} & \frac{2x}{9} \\ \frac{2x}{3} & \frac{2y}{9} & \frac{5x}{9} \end{array} \right] \]

(5.20)

\[ W(A_{34}) = \left[ \begin{array}{ccc} x & y & 0 \\ \frac{4x}{9} & \frac{4y}{9} & \frac{x}{3} \\ \frac{4y}{9} & \frac{4x}{9} & \frac{2y}{9} \end{array} \right] \]

(5.21)

\[ W(A_{35}) = \left[ \begin{array}{ccc} 5x & y & 0 \\ \frac{2x}{3} & \frac{2y}{9} & \frac{2x}{9} \\ \frac{2y}{9} & \frac{2x}{9} & \frac{5x}{9} \end{array} \right] \]

(5.22)

\[ W(A_{36}) = \left[ \begin{array}{ccc} 5x & y & 0 \\ \frac{2x}{3} & \frac{2y}{9} & \frac{2x}{9} \\ \frac{2y}{9} & \frac{2x}{9} & \frac{5x}{9} \end{array} \right] \]

(5.23)

\[ W(A_{37}) = \left[ \begin{array}{ccc} 5x & 2y & 0 \\ \frac{2x}{3} & \frac{2y}{9} & \frac{2x}{9} \\ \frac{2y}{9} & \frac{2x}{9} & \frac{5x}{9} \end{array} \right] \]

(5.24)

\[ W(A_{38}) = \bigcup_{i=1}^{9} A_{3i} - (A_{3i}, j = 5, 7, 8) \]

(5.25)

\[ W(A_{39}) = \left[ \begin{array}{ccc} 2x & 0 & 0 \\ \frac{7x}{9} & \frac{7y}{9} & \frac{2x}{9} \\ \frac{7y}{9} & \frac{7x}{9} & \frac{2y}{9} \end{array} \right] \]

(5.26)
\[ W(A_{3_2}) = \left[ \frac{7x}{9}, \frac{8x}{9}, \frac{8x}{9}, \frac{7x}{9}, \frac{y}{9} \right] \] (5.27)

\[ W(A_{3_3}) = \left[ \frac{8x}{9}, \frac{8x}{9}, \frac{y}{9}, \frac{8x}{9}, \frac{y}{9} \right] \] (5.28)

\[ W(A_{3_4}) = \left[ \frac{2x}{3}, \frac{7x}{9}, \frac{y}{9}, \frac{2x}{3}, \frac{2y}{9} \right] \] (5.29)

\[ W(A_{3_5}) = \left[ \frac{8x}{9}, \frac{8y}{9}, \frac{2y}{9}, \frac{8x}{9}, \frac{3}{3} \right] \] (5.30)

\[ W(A_{3_6}) = \left[ \frac{8x}{9}, \frac{2y}{9}, \frac{2y}{9}, \frac{8x}{9}, \frac{3}{3} \right] \] (5.31)

\[ W(A_{3_7}) = \bigcup_{i=1}^{9} A_{4_1} - (A_{4_1}, j = 5,7,8) \] (5.32)

\[ W(A_{4_1}) = \left[ \frac{0}{9}, \frac{y}{9}, \frac{x}{9}, \frac{2x}{3}, \frac{2x}{3} \right] \] (5.33)

\[ W(A_{4_2}) = \left[ \frac{x}{9}, \frac{0}{9}, \frac{2x}{9}, \frac{0}{9}, \frac{4y}{9} \right] \] (5.34)

\[ W(A_{4_3}) = \left[ \frac{2x}{9}, \frac{0}{9}, \frac{x}{3}, \frac{4y}{9}, \frac{x}{3}, \frac{4y}{9} \right] \] (5.35)

\[ W(A_{4_4}) = \left[ \frac{0}{9}, \frac{4y}{9}, \frac{x}{9}, \frac{4y}{9}, \frac{5x}{9}, \frac{5y}{9} \right] \] (5.36)

\[ W(A_{4_5}) = \left[ \frac{2x}{9}, \frac{4y}{9}, \frac{x}{9}, \frac{4y}{9}, \frac{x}{9}, \frac{5y}{9} \right] \] (5.37)
\[ W(A_{10}) = \left[ \begin{array}{c}
\frac{2x}{9} \\
\frac{5y}{9}
\end{array} \right] x \left[ \begin{array}{c}
\frac{5y}{3} \\
\frac{2y}{3}
\end{array} \right] \] (5.38)

\[ W(A_{16}) = \bigcup_{i=1}^{9} A_{6i} - (A_{6j}, j = 5, 7, 8) \] (5.39)

Similarly for \( W(A_{61}) \)......\( W(A_{69}) \)

\[ W(A_{93}) = \bigcup_{i=1}^{9} A_{9i} - (A_{9j}, j = 5, 7, 8) \] (5.40)

Upto except \( W(A_{95}), W(A_{77}) \) and \( W(A_{98}) \)

Using the IFS coefficient, the remaining iterations are obtained from the initial geometry. The scaling factor of the self-similar geometry are given as

\[ D = \frac{\log 6}{\log 3} = 1.6309 \] (5.41)

where, \( D \) is called as Hausdorff dimension (Falconer 1990).

The equation reveals that six copies are retained through repetitive iteration. The geometry is scaled one-third down from the set and subset. According to the IFS, removal from set is done. The initial geometry is called as initiator. A rectangular patch which is scaled down by a factor of three, along with its length and width outcome in nine subsets is obtained. The acquired copies are equal in dimension as illustrated by IFS. In this novel geometry, the course of action for eradication is represented in Figure 5.2. The progression of elimination is applicable to the bottom edge, the right topmost edge, and towards the left side or the right side of the initial
geometry. The consequential geometry will be a mirror image or rotated image of the above structure.

5.3 GENERATION OF SELF-SIMILAR FRACTAL GEOMETRY

Presently, multistandard transceiver crowns a variety of wireless applications i.e., multiband frequency is needed for RF boards. This category deals with the designing of novel self-similar fractal geometry for wireless applications. Here, a fractal antenna on a lossy substrate is proposed with better bandwidth to satisfy the needs of multistandard transceivers. The antenna is compact on a fractal geometry platform. Figure 5.3 depicts various generations of a novel self-similar fractal antenna, iterated from K0 to K3. Figure 5.4 depicts the layout of geometry.

The initiator has been divided into a number of iterations which is governed by the IFS. The antenna designed for 2.4 GHz is intended for WLAN applications is chosen. The assessment aims to fulfill the requirements of next generation multistandard transceiver on a fractal geometry. The self-similar fractal geometry, discussed in module 5.2 is considered. IFS in later section holds a true value.
Figure 5.3 Generation of self-similar fractal geometry (a) Initiator $K_0$ (b) First iteration $K_1$ (c) Second iteration $K_2$ and (d) Third iteration $K_3$ (All dimensions are in mm)
**Figure 5.4** Layout of novel compact self-similar fractal geometry
(a) 3D View and (b) Side view

The structures are simulated, fabricated, and measured on a substrate whose relative permeability is 4.4 in thickness 1.6 mm, and loss tangent 0.02. It incorporates coaxial feed technique. The simulated return losses for various iterations are depicted in Figure 5.5. Initially, the initiator K0 resonates at two different centre frequencies at 2.317 GHz and 1.903 GHz with a return loss (S11) of <10 dB. The first iteration of novel fractal antenna resonates near 2.46 GHz with S11= -17.807 dB, and 31 MHz bandwidth. Hence, it confirms 12.19% miniaturization as shown above. The second iteration of fractal antenna resonates at three centre frequencies at 1.898 GHz, 2.289 GHz and 4.079 GHz. The size reduction undergone by the fractal geometry is 9.483% and 7.863% for the first two centre frequencies.

For remaining iterations, miniaturization is achieved. It is obvious that lowering of resonant frequency occurs mainly due to the elimination of conductor area.
The removal of conductor area depends on IFS. The source is that the current does not flow through a straight path. It seizes the highest electrical path when compared to the initiator. The electromagnetic energy attempts to penetrate around the edges of patch. Thereby, they demonstrate a miniaturization of antenna.

5.3.1 Effect of Change in Feed Position

The iterations are governed by the IFS. The initiator K0 is divided into a number of stages which reveals the self-similarity concept of fractal geometry. When the initiator undergoes various stages of iterations, the effect of feed setting at that port position do not favour for transmission of signal.
This is mainly due to the elimination of conductor area in a substrate. The feed position has to be optimized for better return loss. The effect of change in feed setting for iterations K1 and K2 are depicted in Figures 5.6 and 5.7, and the corresponding values are tabulated in Table 5.1 and Table 5.2.

![Figure 5.6](image)

**Figure 5.6** Effect of change in feed location for first iterated novel compact self-similar fractal antenna

The first column represents the various port positions. The second column represents the centre frequency in terms of GHz. The third column represents the return loss (S11) in dB and the fourth column represents the bandwidth in MHz. It is observed from Table 5.1 that the multiple resonances have been put on view by the novel fractal structure.
Table 5.1  Simulated return loss for the effect of change in feed locations for first iterated novel self-similar fractal antenna

<table>
<thead>
<tr>
<th>S.No</th>
<th>Port positions</th>
<th>Centre Frequency in GHz</th>
<th>S11 in dB</th>
<th>B.W in MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>36.60,10.70</td>
<td>2.52</td>
<td>-10</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.08</td>
<td>-16.067</td>
<td>50</td>
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<td></td>
<td></td>
<td>5.05</td>
<td>-13.134</td>
<td>65</td>
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<td></td>
<td></td>
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<td>-17.807</td>
<td>31</td>
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<td></td>
<td></td>
<td>3.14</td>
<td>-19.84</td>
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<td>4.94</td>
<td>-15.538</td>
<td>115</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.23</td>
<td>-10.408</td>
<td>40</td>
</tr>
<tr>
<td>4</td>
<td>22.12,4.26</td>
<td>3.51</td>
<td>-19.211</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.95</td>
<td>-15.4</td>
<td>256</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.24</td>
<td>-13.523</td>
<td>95</td>
</tr>
<tr>
<td>5</td>
<td>3.75,11.47</td>
<td>2.45</td>
<td>-24.226</td>
<td>256</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.49</td>
<td>-21.878</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.98</td>
<td>-13.887</td>
<td>47</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.94</td>
<td>-15.538</td>
<td>46</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.23</td>
<td>-10.408</td>
<td>120</td>
</tr>
</tbody>
</table>
For the first port position, the structure has undergone four resonances. The first resonance shows a very narrow bandwidth near the design frequency. The bandwidths are visualized only at higher values of frequencies. For the second, the third, and the fifth feed settings of first iterated novel, the fractal antenna has a good agreement of bandwidths compared to first feed positions. Whereas, the structure is not displayed at the design frequency.

![Graph showing S11 in dB vs Frequency in GHz for different port positions](image)

**Figure 5.7** Effect of change in feed location for second iterated novel self-similar fractal antenna
From the above Figure 5.7, it is seen that the effect of change in feed positions for seven ports are studied. The studies of feed positions are necessitated primarily to sort out the propagation of signal high in feed position. The corresponding values are tabulated in Table 5.2.

**Table 5.2** Simulated return loss for the effect of change in feed location for second iterated novel self-similar fractal antenna

<table>
<thead>
<tr>
<th>S.No</th>
<th>Port positions</th>
<th>Centre Frequency in GHz</th>
<th>S11 in dB</th>
<th>B.W in MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>28.3,11.60</td>
<td>1.903</td>
<td>-15.021</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.317</td>
<td>-13.42</td>
<td>134</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.627</td>
<td>-12.206</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.622</td>
<td>-18.34</td>
<td>94</td>
</tr>
<tr>
<td>2</td>
<td>28.1,12.60</td>
<td>1.914</td>
<td>-18.697</td>
<td>44</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.027</td>
<td>-18.974</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.613</td>
<td>-26.904</td>
<td>180</td>
</tr>
<tr>
<td>3</td>
<td>14.1,3.10</td>
<td>1.898</td>
<td>-12.729</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.289</td>
<td>-13.369</td>
<td>180</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.079</td>
<td>-14.789</td>
<td>53</td>
</tr>
<tr>
<td>4</td>
<td>2.2,3.90</td>
<td>2.541</td>
<td>-13.778</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.049</td>
<td>-13.014</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.589</td>
<td>-15.22</td>
<td>101</td>
</tr>
<tr>
<td>5</td>
<td>2.8,11.80</td>
<td>2.541</td>
<td>-17.753</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.049</td>
<td>-13.287</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.589</td>
<td>-11.068</td>
<td>33</td>
</tr>
<tr>
<td>4</td>
<td>2.2,4.20</td>
<td>1.897</td>
<td>-10.231</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.324</td>
<td>-13.108</td>
<td>106</td>
</tr>
</tbody>
</table>
The table illustrates that a novel compact fractal antenna has numerous resonances with large bandwidth. The first feed position has four resonances with a bandwidth covering from 17 MHz to 94 MHz. The second feed position from 44 MHz to 50 MHz. But the resonance has not covered the design frequency or near by frequencies. The third, fourth and fifth position has close by design frequency which is acceptable. By incorporating fractal geometry for next iteration, the feed position has a tendency to converge the design frequency.

5.3.2 **Effect of Change in Transmission Line Feed Position**

The effect of transmission line feed is made for the third iterated fractal antenna. A quarter wave transmission line is introduced to improve the bandwidth of the proposed antenna.

![Figure 5.8](image)

**Figure 5.8** Effect of change in feed locations for third iterated novel self-similar fractal antenna
Table 5.3  Simulated return loss for the effect of change in feed location for third iterated compact self-similar fractal antenna

<table>
<thead>
<tr>
<th>S.No</th>
<th>Port position</th>
<th>Centre Frequency in GHz</th>
<th>S11 in dB</th>
<th>B.W in MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20.09</td>
<td>2.476</td>
<td>-17.205</td>
<td>14</td>
</tr>
<tr>
<td>2</td>
<td>21.48</td>
<td>2.477</td>
<td>-25</td>
<td>50</td>
</tr>
<tr>
<td>3</td>
<td>25.15</td>
<td>2.03</td>
<td>-17.99</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.476</td>
<td>-23.749</td>
<td>20</td>
</tr>
<tr>
<td>4</td>
<td>0.51</td>
<td>1.761</td>
<td>-11.624</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.474</td>
<td>-20.482</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.47</td>
<td>-12.343</td>
<td>22</td>
</tr>
<tr>
<td>5</td>
<td>21</td>
<td>1.5</td>
<td>-20</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.476</td>
<td>-23.749</td>
<td>20</td>
</tr>
</tbody>
</table>

The transmission line feed position is varied from one end of the fractal antenna to another to cram the effect of bandwidth. Figure 5.8 depicts the simulated return loss of various feed position of the fractal antenna. The corresponding values of transmission feed are tabulated in Table 5.3. The first column represents the port position of transmission line feed and the second column represents the centre frequency in terms of GHz. Its return loss in dB is shown in the next column. The last column represents the bandwidth in MHz.

The bandwidth improvement for distance $d = 20.09$ mm is visualized clearly, when $d = 25.15$ mm with bandwidths of 51 MHz and 20 MHz are obtained for centre frequencies 2.03 GHz and 2.476 GHz respectively. The obtained percentage bandwidths are 2.5% and 0.8%. The
shift in resonant frequencies has occurred appropriate to the fractal iteration. For port position $d = 0.51$ mm. The bandwidth achieved for first resonance is not clearly observed at lower frequencies. The frequency notches at design value. This might be due to the mismatch in impedance of the transmission line and the main radiating element. Multiple resonances are achieved for all the remaining feed positions.

Figure 5.9 Prototype of third iterated novel compact self-similar fractal antenna

Figure 5.9 depicts the prototype of novel third iterated self-similar fractal antenna which is simulated at a very elevated mesh frequency with supplementary number of cells per width in agilent momentum. The corresponding measured values are depicted in Figure 5.10, by plotting frequency along x axis in GHz, and magnitude in dB along y-axis. The prototype model is fabricated on a FR4 substrate with eight portion of ferric chloride, and two portion of hydrochloric acid. The prototype measured at $< -10$ dB references using a vector network analyzer are tabulated in Table 5.4.
Figure 5.10 Measured return loss of third iterated novel compact self-similar fractal antenna

The first column represents the centre frequency, the second column the bandwidth in MHz, the next two columns the upper and lower cut off frequencies, and the last column represents the percentage bandwidth in MHz. The comparison between simulated and measured return loss of third iterated novel compact fractal antenna is shown in Figure 5.11. The mesh stop frequencies are limited to 3 GHz due to the limitations in network analyzer measurements. The simulation at high mesh for third iteration is obtained and fabricated.
Table 5.4 Measured return loss of a compact self-similar fractal antenna

<table>
<thead>
<tr>
<th>S.No</th>
<th>Centre Frequency in GHz</th>
<th>S11 in dB</th>
<th>B.W in MHz</th>
<th>f₁ in GHz</th>
<th>f₂ in GHz</th>
<th>% B.W</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.53</td>
<td>-12.87</td>
<td>84</td>
<td>1.478</td>
<td>1.572</td>
<td>6.14</td>
</tr>
<tr>
<td>2</td>
<td>1.793</td>
<td>-32.6</td>
<td>378</td>
<td>1.73</td>
<td>2.108</td>
<td>21.08</td>
</tr>
<tr>
<td>3</td>
<td>1.919</td>
<td>-32.69</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>2.04</td>
<td>-33.51</td>
<td>483</td>
<td>2.108</td>
<td>2.591</td>
<td>21.52</td>
</tr>
<tr>
<td>5</td>
<td>2.244</td>
<td>-19.55</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>2.486</td>
<td>-27.14</td>
<td>115</td>
<td>2.748</td>
<td>2.874</td>
<td>4.5</td>
</tr>
</tbody>
</table>

The simulated results shown in earlier figures are up to 4 GHz in x-axis. It is a low mesh in advanced design systems momentum. The fractal antenna put on display combines bandwidth at two regions for 378 MHz and 483 MHz with a percentage bandwidth of 21.08% and 21.52% respectively. It is observed that the percentage bandwidth is more than 20% which corresponds to wide bandwidth. The work also covers from 1.53 GHz with a bandwidth of 84 MHz and 2.822 GHz with 115 MHz bandwidths. The measurements are obtained for return loss (S11) < -10 dB references. The VSWR and reflection coefficient are calculated using return loss is presented in Table 5.5. From the chart it is clear that, VSWR and reflection coefficient are within microwave benchmark.
Figure 5.11 Comparison between simulated and measured return loss of third iterated compact self-similar fractal antenna

Figure 5.12 represent the simulated radiation pattern of third iterated novel compact self-similar fractal antenna at various iterations. The simulated plots correspond to electric and magnetic planes. The plots are obtained using agilent advanced design simulation on a radiation plot window. The radiation patterns are measured in an anechoic chamber and the corresponding plots are depicted in Figure 5.13. The measured plots are directional in nature.
Table 5.5  Calculated VSWR and Reflection coefficient of novel compact self-similar fractal antenna

<table>
<thead>
<tr>
<th>S.No</th>
<th>Centre Frequency in GHz</th>
<th>S11 in dB</th>
<th>VSWR</th>
<th>VSWR in ratio</th>
<th>Reflection coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.53</td>
<td>-12.87</td>
<td>1.588</td>
<td>1.588:1</td>
<td>0.227</td>
</tr>
<tr>
<td>2</td>
<td>1.793</td>
<td>-32.6</td>
<td>1.048</td>
<td>1.048:1</td>
<td>0.023</td>
</tr>
<tr>
<td>3</td>
<td>1.919</td>
<td>-32.69</td>
<td>1.047</td>
<td>1.047:1</td>
<td>0.023</td>
</tr>
<tr>
<td>4</td>
<td>2.04</td>
<td>-33.51</td>
<td>1.048</td>
<td>1.048:1</td>
<td>0.021</td>
</tr>
<tr>
<td>5</td>
<td>2.244</td>
<td>-19.55</td>
<td>1.235</td>
<td>1.235:1</td>
<td>0.105</td>
</tr>
<tr>
<td>6</td>
<td>2.486</td>
<td>-27.14</td>
<td>1.091</td>
<td>1.091:1</td>
<td>0.043</td>
</tr>
<tr>
<td>7</td>
<td>2.822</td>
<td>-16.32</td>
<td>1.36</td>
<td>1.36:1</td>
<td>0.152</td>
</tr>
</tbody>
</table>

Figure 5.12  Simulated radiation pattern of third iterated novel compact self-similar fractal antenna at 1.7 GHz (E₀, copolarization and Eᵦ, cross polarization)
Figure 5.12 (Continued)
Figure 5.12  (Continued)
Figure 5.13 Measured radiation pattern of third iterated novel self-similar fractal antenna at 2.5 GHz ($E_0$ copolarization and $E_\phi$ cross polarization)
Figure 5.13 (Continued)

5.3.3 Comparison of Performances Between Self-Affine and Self-Similar Fractal Geometries

Comparison of performances between the measured self-affine fractal cantor antenna with slot appearance shown in legend blue color graph, and novel self-similar fractal geometry which involves a step appearance represented in green color, presented in the earlier chapters are compared with multistandard next generation novel compact antennas. The graph conveys the frequency in GHz along x axis, and S11 along y axis in dB. Figure 5.14 depicts the comparison between the proposed structures.
Figure 5.14 Comparison between measured return loss of a self-affine fractal cantor antenna, novel self-similar fractal antenna and novel self-similar fractal antenna

5.3.4 Corollary of Dielectric Substrate

The proposed novel self-similar fractal antenna is compared with the substrate which is specific in RT Duroid, Rogers, and FR4. The relative dielectric constants are 2.2, 3.38, 4.4 and 4.6. The height of the substrates is 0.787 mm, 0.787 mm, and 1.6 mm. The significance of comparison is to show the influence of dielectric substrate. Figure 5.15 shows the comparison between the choices of substrate. The material which has high dielectric constant shows a return loss lower than resonance. Owing to the raise in electrical dimension, the bandwidth is reduced due to increase in quality factor. Apart from these two varieties of FR4 with relative dielectric constant
4.4 and 4.6 are selected which exhibit similar performance. The heights of the substrate also impinge on the antenna tuning to resonance. For accomplishment, FR4 with relative dielectric constant 4.4 is chosen. It is an unsettled and low cost substrate.

![Graph](image)

**Figure 5.15** Comparison between various dielectric substrate for novel third iterated self-similar fractal antenna

### 5.3.5 Corollary of Ground Plane

The proposed novel self-similar fractal antenna viewed as a monopole antenna with partial ground plane is considered. The performance of the fractal monopole antenna is simulated for FR4 substrate. The substrate specifications for FR4 holds true. The current distribution does not favour
and the reflection towards the input port is more. The return loss is in the order of -7 dB which is of maximum value. Figure 5.16 depicts the novel-self similar fractal monopole antenna. The ground plane and the main element shall be optimized for better return loss.

![Diagram](image)

**Figure 5.16** Layout of novel self-similar fractal monopole antenna  
(a) Front view and (b) 3D geometry of monopole antenna

### 5.3.6 Results and Discussion

The simulated novel compact fractal structure has been fabricated with a substrate, whose relative permeability is 4.4, h = 1.6 mm, and loss tangent 0.02. The optimized structure measures 40 mm × 30 mm × 1.6 mm in thickness. The resonant frequencies are listed in Table 5.4 are obtained using Agilent vector network analyzer E5062A which ranges from 300 KHz to 3 GHz, and test bed with <10 dB as references. The simulated and measured return loss matches as shown in Figure 5.10. At design frequency, the
antenna has a return loss of $-13.92\, \text{dB}$, which corresponds to VSWR of 1.5 in ratio 1.5:1.

The VSWR of the compact antenna is almost equal to one, and near by one for all multiband resonances. The obtained bandwidth is 378 MHz and 483 MHz with resonant frequencies of 1.793 GHz, 1.919 GHz, 2.04 GHz, 2.244 GHz and 2.486 GHz respectively. The percentage bandwidths are 21.08% and 21.52% [about $\lambda_0 = 0.1673\, \text{m}(16.73\, \text{cm} / 167.3\, \text{m})$; $0.239\, \lambda$ and $\lambda_0 = 0.133\, \text{m}(13.36\, \text{cm} / 133.6\, \text{mm})$; $0.299\, \lambda$]. The remaining bandwidth is 6.14% [about $\lambda_0 = 0.196\, \text{m}(19.607\, \text{cm} / 196.07\, \text{mm})$; $0.20\, \lambda$] and 4.5% [about $\lambda_0 = 0.106\, \text{m}(0.106\, \text{m} / 106\, \text{mm})$; $0.3\, \lambda$].

The measured radiation patterns are depicted in Figures 5.13 and 5.15 for 1.9 GHz, 2 GHz, 2.4 GHz and 2.5 GHz. The pattern at 0 degree is maximum and has side lobes. It is said to be linearly polarized. In H-plane, the signal rejects at 0 degrees. The gain of novel antenna at design frequency is 4.46 dBi. The plot represents the $\theta$ and $\phi$ polar coordinates. Simulation treatment for fractal monopole antenna has been done. The return loss displayed by the antenna is very low in the order $-7\, \text{dB}$.

The prototype eliminates the complications involved in tuning, shorting techniques and aperture feed techniques. A few comparison listed in the survey are displayed in Table 5.6. The model on a lossy low cost substrate will serve the current trends of reconfigurable multistandard transceiver. The prototype designed for WLAN 2.4 GHz has a nature of covering wideband wireless applications. It includes ISM band, Bluetooth IEEE 802.11, IEEE 802.15, PCS (1900), DCS (1800), WiMAX (2.3/2.5GHz) UMTS (2100), World Wide Area Network (WWAN) and LTE (2300) standards which fulfills the requirement.
5.4 SUMMARY

i) The novel self-similar fractal geometry designed for WLAN wireless applications are developed on a lossy substrate whose relative dielectric constant is 4.4, loss tangent is 0.02, and the thickness of the substrate is 1.6 mm. The optimized antenna measures 40 mm × 30 mm × 1.6 mm, and feed line 30 mm × 3 mm. The novel antenna is compact compared to the manuscripts presented in the survey.

ii) Simulations are carried out using Agilent ADS momentum. Initially, the design is studied to evaluate the performance of patch antenna /initiator using coaxial feed technique. The initiator is segmented into subsets and is governed by IFS. The antenna reveals a volume reduction from one stage to another and thereby maintains its uniqueness.

iii) The effect of various feed locations is studied due to the elimination of conductor area. The simulated structure exhibits a miniaturization of 9.483% for first iteration and 7.863% for second iteration. The shift in resonant frequency and the lowering of return loss is observed in all the iterations. It is primarily due to the outcome of lengthy sporadic transmission line of fractal geometry.

iv) In the opening section, the evaluation of various design issues and techniques involved in designing an antenna has been outlined. The novel self-similar epitome with simple coaxial feed technique is offered. The complications presented in the survey are eliminated in the proposed structure.

v) It is observed that VSWR and reflection coefficient values are maintained as a benchmark of microwave for design
frequency of WLAN applications. All the resonances undergone by the antenna are within a brink range of VSWR and reflection coefficient. The antenna presents a diversity of resonance, covering the adjoining frequency bands. It is mainly due to congenital of fractal geometry.

vi) The radiation patterns are measured as discussed earlier. The radiation patterns of electric and magnetic fields are calculated. The novel antenna is assumed as reference antenna. The measurements are obtained for $E_\theta$ and $E_\phi$ planes which corresponds to co polarization and cross polarization. It is sensible that radiation characteristics of antenna has directional pattern.

vii) The radiation patterns with variations along the edges are visualized which is due to a lossy substrate. The consequence of dielectric substrate has been studied from various materials. Simulation treatment for fractal monopole antennas has been done.

viii) Fractal antenna covers a variety of wireless applications. The cost of the substrate is effective when compared to RT Duroid, Taconic, Arlon, and many others.
<table>
<thead>
<tr>
<th>S.No</th>
<th>References</th>
<th>Substrate/Size</th>
<th>Frequency in GHz/Bandwidth/ Return loss</th>
<th>Mode/Description</th>
</tr>
</thead>
</table>
| 1    | A multifractal cantor antenna for multiband wireless applications          | FR4                                          | 2.2 GHz, 3 GHz, 5 GHz and 6.9 GHz      | 1. Monopole fractal antenna  
2. Both the sides of the substrate are used.                                    |
| 2    | A compact dual band planar branched monopole antenna for DCS/2.4 GHz WLAN applications | FR4, relative dielectric constant 4.36, Size: 30mm × 30mm | Dual band                              | 1. Monopole antenna  
2. Both the sides of the substrate are used.                                    |
| 3    | A novel P-shaped printed monopole antenna for RFID applications            | RT Duroid 5880, Size: 36 mm × 36 mm × 36 mm | Multiband                              | 1. Aperture coupling  
2. Feed line and Antenna are separated by slot structure.                        |
| 4    | The Irregular-Shaped Fractal Antennas for Ultra Wideband Radio Systems     | RT Duroid, Size: 65 mm × 56 mm               | UWB                                    | Irregular shaped fractal, change in delta value of fractal leads to ultrawideband. |
| 5    | Research on Fractal antennas and its use on soft computing                | RT Duroid and thickness 1.5748 mm, Size: 20.5 mm × 18.4 mm | 14% to 25% for first and 8.5% to 10.5% of impedance bandwidth | 1. CPW antenna  
2. The main element on one substrate and feed line on the other substrate.       |
| 6    | Proposed self-similar fractal antenna                                     | FR4 substrate, Size: 40 mm × 30 mm × 1.6 mm | Seven resonances are obtained.         | Transmission line feed                                                          |