CHAPTER 4

DESIGN, SIMULATION AND ANALYSIS OF MEANDER TYPE PLANAR FRACTAL ANTENNAS

Summary- This chapter proposes a new set of miniaturized FAs made out of a rectangular MSA. Firstly a combination of Minkowski cum Koch curves has been proposed whose performances have been analyzed using IE3D electromagnetic simulator. The design involves the use of both microstrip and CPW feed systems. A 44mm X 12mm sized rectangular MSA with square and triangular indentations on its perimeter alternatively laid on a substrate of 52mm x 20mm to convert it into FA. These antennas are recommended for S (2-4 GHz) and C (4-6 GHz) band applications. Secondly the patch and etched thin strip type meandered FAs are proposed. The design has been carried out using copper as antenna material on an FR4 substrate measuring 36mm x 20mm size. The performances of these miniature meander fractal structures have been investigated using Ansoft HFSS 3D electromagnetic simulation tool. Theses antennas are recommended for C, J and X band applications. In both the cases, with the application of fractal concept to the outer edge of a rectangular MSA, the length of the perimeter gets increased thereby increasing the current flow path in the antenna for good radiation characteristics. The multiple resonance ability of the proposed fractal structures has been examined. A good size reduction and multiple resonances are the advantages in these antennas.

4.1 MINIATURIZED MULTIBAND MINKOWSKI-KOCH COMBINED FRACTAL ANTENNAS

In view of the progress of the recent communication systems and increase in application areas with vital requirements such as small size, less weight and better performance, the miniaturized multiband antennas are in great demand. However, being high Q electromagnetic structure, the MSA exhibits single resonance with narrow bandwidth. Many times it is considered as one of the major limitations. On the other hand, fractal antennas have attracted the attention of the researchers because of the features like small size and multiband characteristics (Nathan Cohen et al 1997). A fractal is a rough or fragmented geometric shape that can be subdivided in parts, each of which is a reduced-size copy of the whole (Siti Nuha Shafie et al 2010). The basic monopole fractal lines can be used in the formation of simpler FA models. They can be either in the meander or loop form. The complex FA geometries based on iterative procedure (Gianvittario and Samil 2002), Sierpinski FA as a triangular shaped filled patch and the Koch snow-flake FA (Mirzapour and Hassani 2008) using triangular shaped curves and the Hilbert and Minkowski FA (Vinoy and Pal 2010) design based on the square curves are some examples of previous investigations. In this section, the fractal planar antenna as a combination of Minkowski and Koch curves as shown in Figure 4.1 is considered for examining the performance.

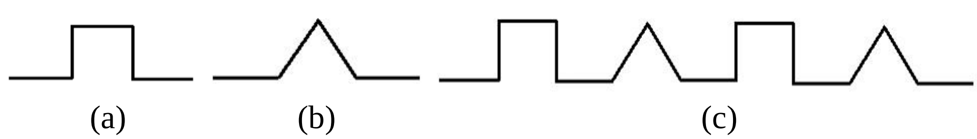
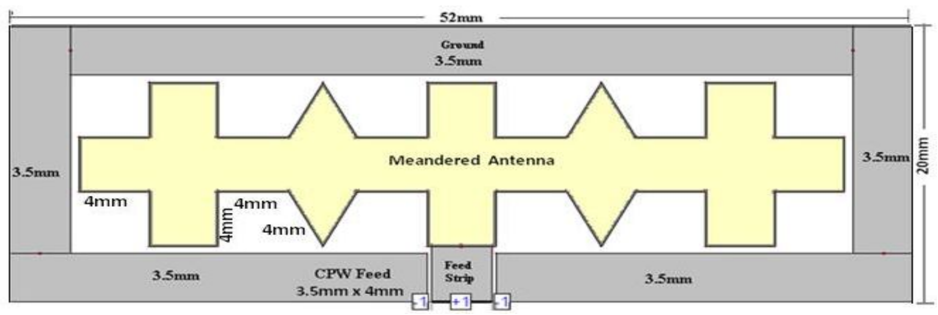


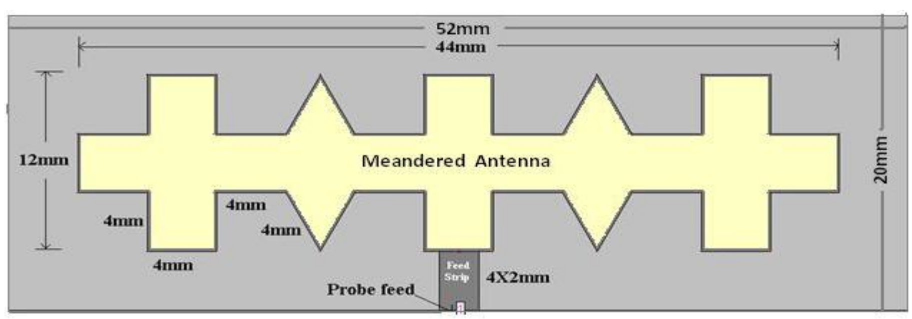
Figure 4.1 Basic Fractal Curves (a) Minkowski Curve (b) Koch Curve (c) Minkowski-Koch Combined Curve

4.1.1 Antenna Design and Dimensions

The basic rectangular MSA is initially considered. The resonance of this basic structure is calculated from the empirical formula provided in Chapter 3 under the Section 3.2.1. The flat edges of this antenna are made to assume square and triangular shapes alternatively to result in meandered fractal structures as shown in Figure 4.2. By this the current flow through the antenna is increased leading to multiple resonances. Compared to the conventional rectangular MSA the path length of this meandered new structure is raised from 144mm to 160mm.



(a)



(b)

Figure 4.2 Minkowski-Koch Fractal Patch Antenna CPW Fed Meandered FA (b) Microstrip Fed Meandered FA

Initially square indentation followed by a triangle alternatively on the perimeter of the rectangular patch is done throughout the whole contour.

The element length for each side of square or triangle indentation is 4mm. There are two antennas designed one fed by CPW and the other fed by microstrip system. In the CPW system, both the antenna and the ground structures are in the same plane on the substrate whereas in the microstrip feed system the antenna and ground plane are separated by the substrate. Both the antennas are fed by 50 ohms microstrip feed. They are centre fed by a 3.5mm x 4mm feed in one case and by a 4mm x 2mm feed in the other. Copper is used for designing the radiating structure. The thickness of the copper layer is 0.016mm. The substrate measuring a size of 52mm x 20mm is FR4 of 1.6mm thick with ε_r of 4.4. The antenna spreads over an envelope of size 44mm x 12mm on the substrate in both the cases.

4.1.2 Simulation

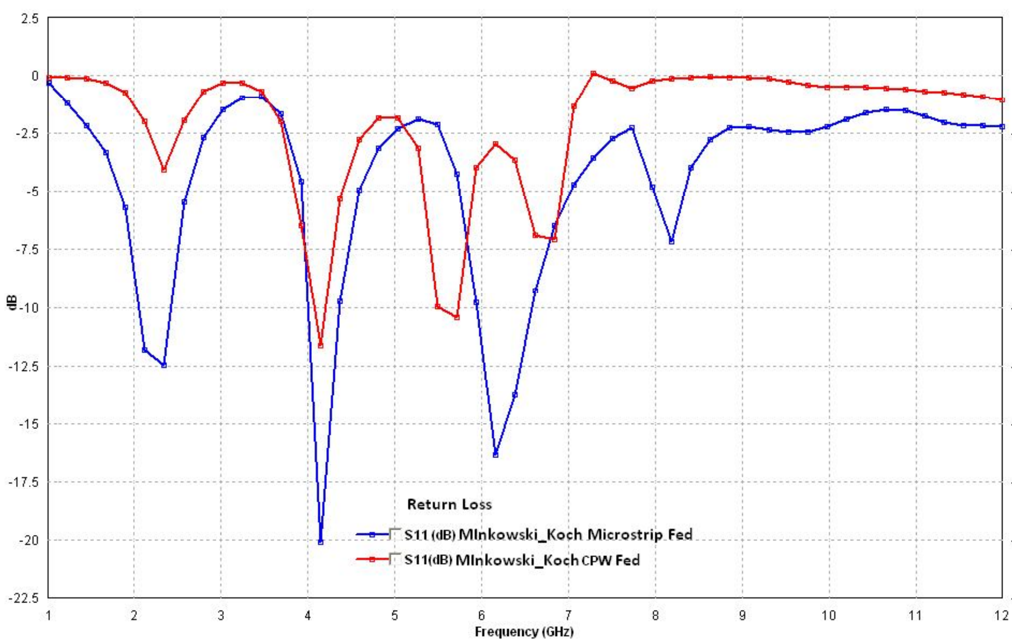
The design and simulation has been performed using IE3D electromagnetic simulation software. Both the meandered FAs have been examined over the sweep range of 1- 12 GHz.

4.1.3 Results and Discussion

The simulation results are compared for knowing the performances of antennas. The increased current flow path in the antennas allows them to resonate at multiple bands. The return loss and VSWR characteristics of both CPW and microstrip fed meandered FAs are shown in Figure 4.3. The curves appearing in red color indicate the performances of CPW fed FA whereas the curves with blue color are meant for microstrip fed FA. The CPW fed FA provides dual resonances at 4.14 GHz and 5.7 GHz with return loss values of -11.57 dB and -10.42 dB respectively. It provides VSWR values of 1.76 and 1.91 corresponding to the resonances. The bandwidths are 140 MHz and 560 MHz corresponding to -10 dB return loss levels.

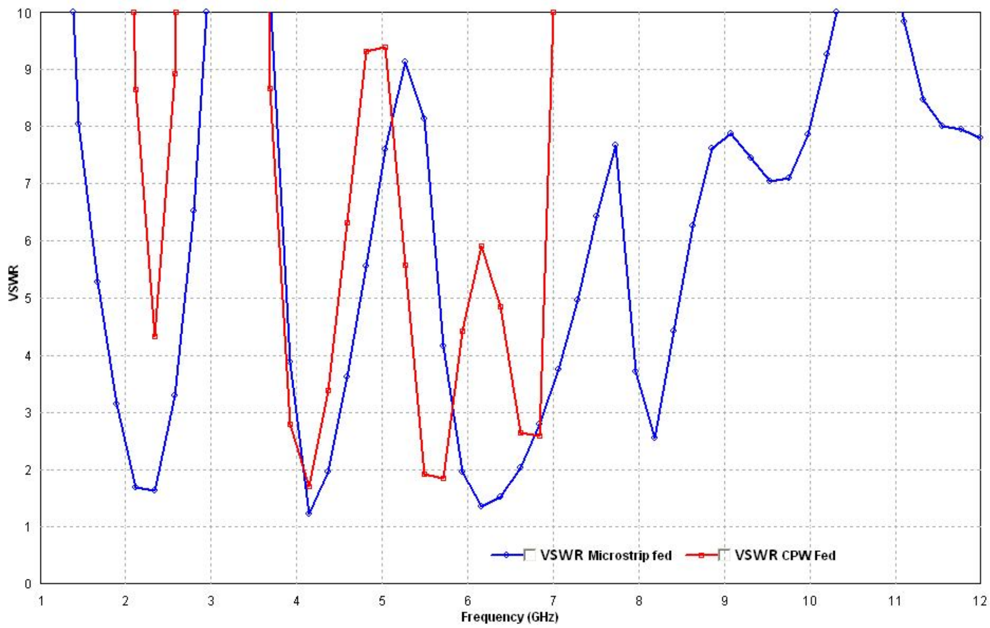
Table 4.1 Performances of Minkowski-Koch Fractal Antennas

Antenna	f_r (GHz)	RL (dB)	f_u (GHz)	f_l (GHz)	BW (GHz)	VSWR	G (dBi)
CPW Fed	4.14	-11.57	4.6	4.2	0.4	1.76	8
	5.7	-10.42	5.73	5.17	0.56	1.91	3
Microstrip Fed	2.35	-12.46	2.434	2.05	0.38	1.6	2
	4.14	-19.83	4.37	3.89	0.38	1.2	2
	6.17	-16.3	6.59	5.93	0.66	1.3	3



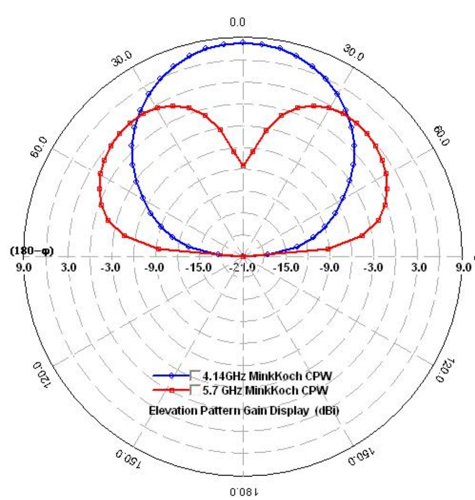
(a)

Figure 4.3 (Continued)



(b)

Figure 4.3 Simulation Results of Both Microstrip and CPW Fed Minkowski-Koch FAs (a) Return Loss (b) VSWR



(a)

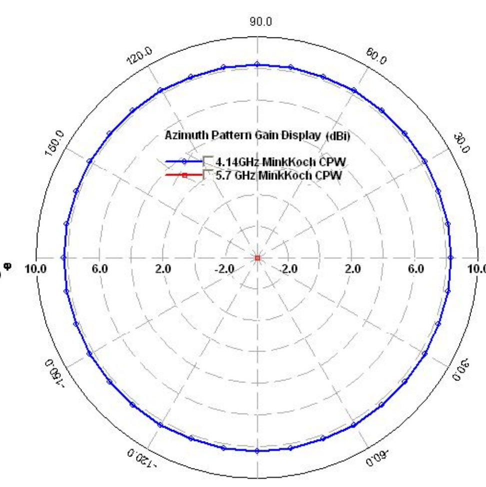


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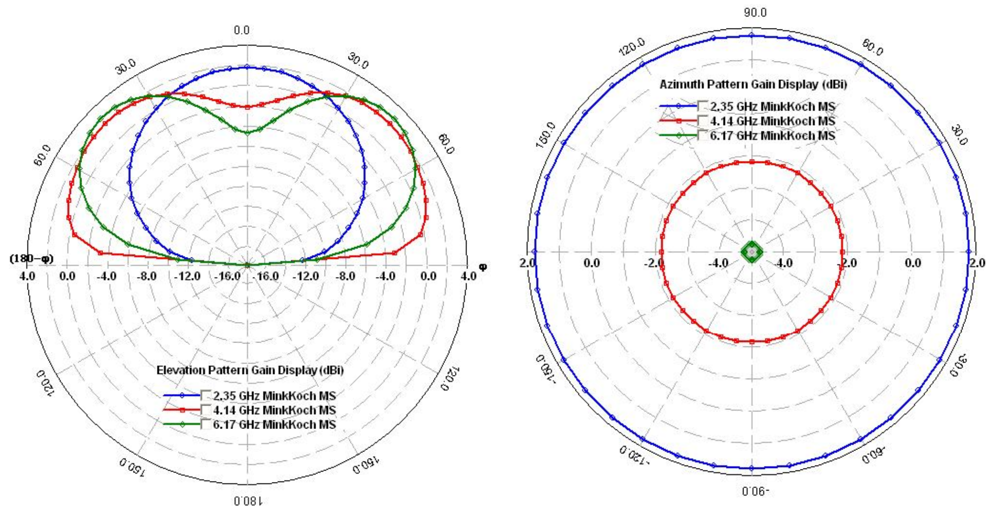
Figure 4.4 (Continued)



(c) (d)

Figure 4.4 Radiation Patterns (a) Elevation Pattern of Microstrip Fed FA (b) Azimuth Pattern of Microstrip Fed FA (c) Elevation Pattern of CPW Fed FA (d) Azimuth Pattern of CPW Fed FA

However the microstrip fed FA provides triple band resonances at 2.35 GHz, 4.14 GHz and 6.17 GHz with return loss of -12.46 dB, -19.83 dB and -16.3 dB respectively. The resonance frequency shifts towards lower region with triple bands. The return loss exhibited by this antenna is very low compared to the CPW fed FA. The VSWR of 1.6, 1.2 and 1.3 at resonances indicate well matched conditions and maintaining the 2:1 VSWR ratio. The VSWR provided by the CPW FA is high compared to microstrip antenna. The bandwidths of 380 MHz for the first two resonances and 660 MHz for the third resonance are achieved by the microstrip fed FA. The Table 4.1 lists all the obtained values.

The radiation characteristics are depicted in Figure 4.4. The Figure 4.4(a) indicates the co-polarization whereas the Figure 4.4(b) presents the cross polarization levels. Though the gain of the CPW fed FA at resonance is more its elevation patterns for the two resonances are narrow when compared to the microstrip fed FA. Also the radiated power is distributed to attain broad radiation patterns. The azimuth patterns in both the antennas are good showing acceptable good cross-polarization levels.

4.1.4 Concluding Remarks

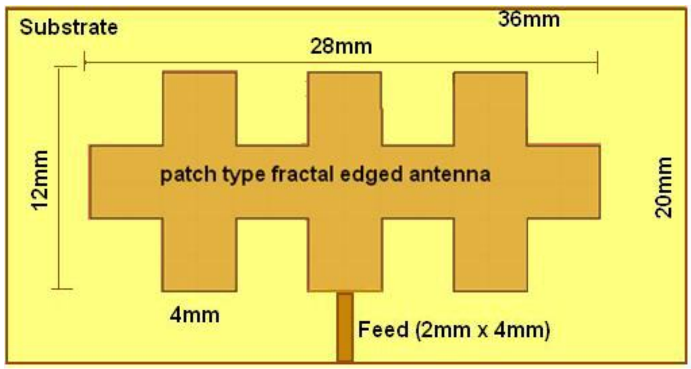
The Minkowski-Koch combined FAs fed by two different systems have been presented in this chapter. They provide dual and triple band resonances with sufficient return loss, VSWR, good bandwidths and appreciable radiation patterns. They can be used in various wireless handheld devices operating in the S (2-4 GHz) and C (4-6 GHz) bands.

4.2 MINIATURE MEANDER FRACTAL ANTENNA

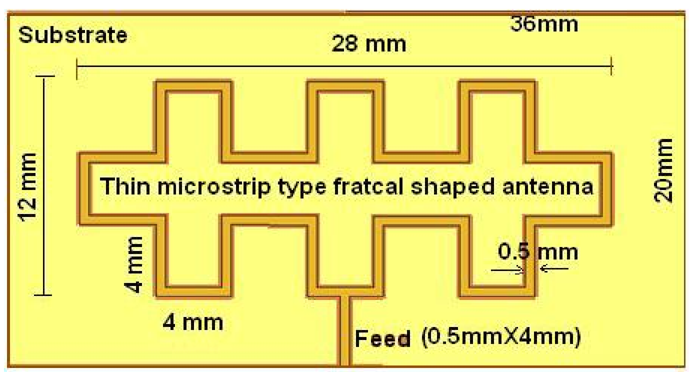
As the technology grows with new ideas, fitting expectations in the antenna design are always coming up. In the past, fractal concepts (Mandelbrot 1983) followed a simple method based on some Euclidean geometry comparatively. However, the wide-spoken attractive FAs do not follow this design. Their complex structures are built up through replication (Douglas Werner and Suman Ganguly 2003) of a base shape. Fractals are abstract objects that cannot be physically implemented. Nevertheless, some related geometries can be used to approach an ideal fractal that are useful in constructing antennas. Usually, these geometries are called pre-fractals or truncated fractals. In other cases, other geometries such as multi-triangular or multilevel configurations can be used to build antennas that might approach fractal shapes and extract some of the advantages over them.

4.2.1 Design of Meander Fractal Antenna

A rectangular MSA is initially chosen. The resonance of this basic structure is found from the details provided in the Section 3.2.1 of Chapter 3. Then with the application of square fractal concept to the outer edge of this patch, the length of the perimeter is increased while retaining the overall dimension unaltered.

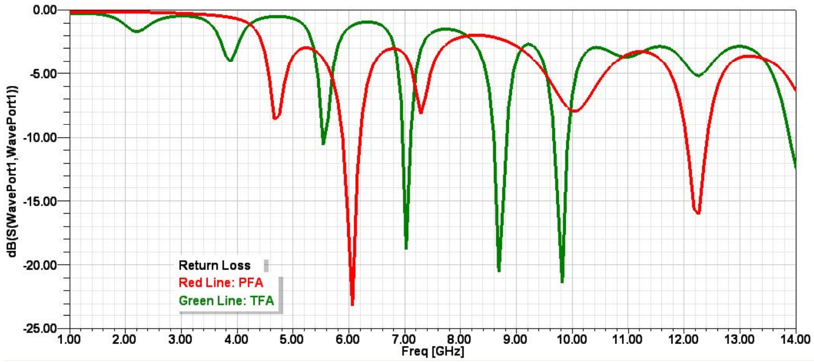


(a)

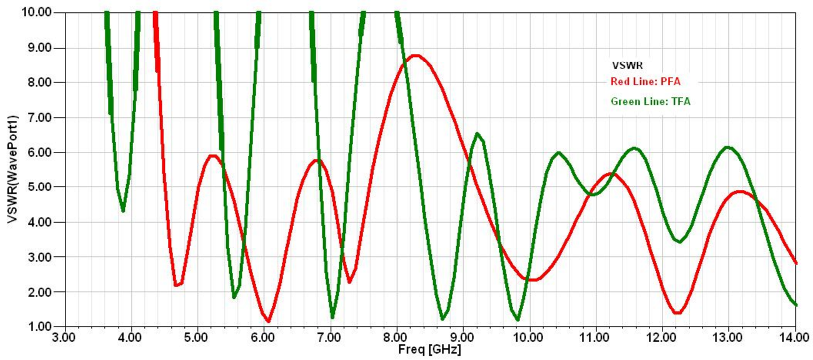


(b)

Figure 4.5 Meandered Antenna and Dimensions (a) PFA (b) TFA



(a)



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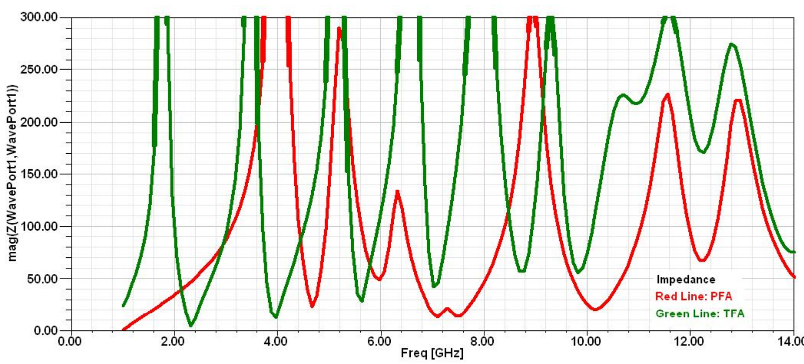
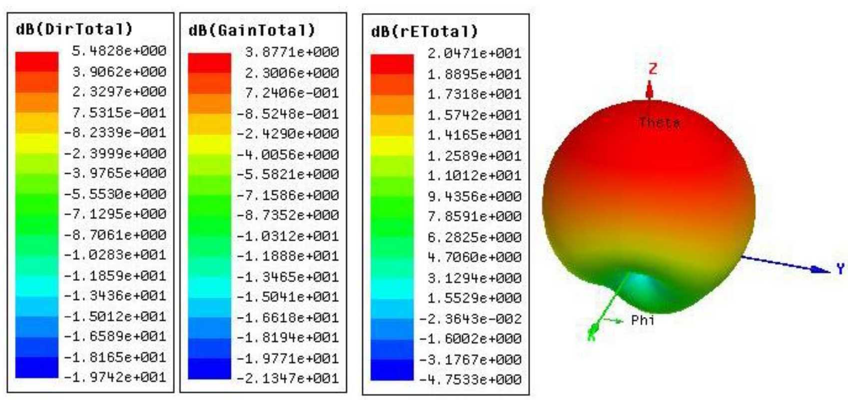


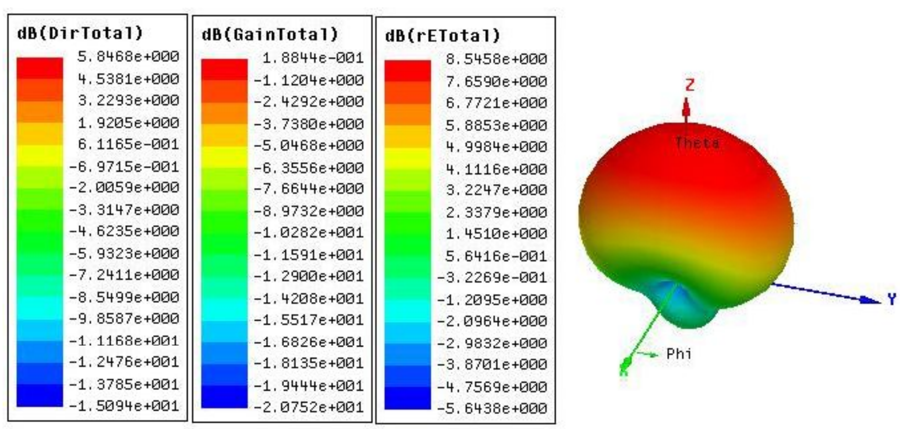
(c)

Figure 4.6 Simulation Results of PFA and TFA (a) Return Loss (b) VSWR (c) Impedance

The meander type patch fractal antenna (PFA) and thin fractal antenna (TFA) proposed in this Chapter use a double side printed substrate board of 36mm x 20mm with thickness 1.6mm and permittivity 4.4 as a dielectric material. A copper based ground plane is fitting the board size at the bottom. The layout of antenna is copper and it occupies an area of 28mm x 12mm on the upper side of the substrate. Due to the inclusions of square indentations on the MSA to take meandered structure the path length for the current gets increased from 80mm to 112 mm. The meandering side length in both the antennas is 4mm whereas the width of the TFA is 0.5mm since the inner area of the antenna is etched out. A small microstrip is used to feed the input to the antenna whose size is 4mm x 2mm for PFA whereas it is 0.5mm x 4mm for TFA. The meandered PFA and TFA obtained as a result of fractal indentations on the basic MSA are shown in Figure 4.5.



(a)



(b)

Figure 4.7 Polar Radiation Characteristics with Directivity, Gain and total E Field (a) PFA at 6.02 GHz (b) TFA at 6.02 GHz

4.2.2 Simulation

Both the antenna design and simulation design have been carried out using Ansoft HFSS 3D electromagnetic simulation tool. Initially, the PFA as shown in Figure 4.5(a), has been designed and simulated. Then, the TFA as found in Figure 4.5(b), having the same layout size and contour has been designed and simulated. The numerical analysis was carried out in the 1-14 GHz sweep frequency range. The whole antenna structure has been kept in air medium surrounded by a rectangular box containing radiation boundary.

4.2.3 Results and Discussions

The results of simulation have been analyzed to know the resonance properties of the proposed antennas. The return loss, VSWR, impedance and radiation characteristics are examined in the following sections.

4.2.3.1 Performance of PFA

The characteristics of return Loss (S_{11} in dB), VSWR and impedance as a function of frequency are depicted in Figure 4.6 whereas the 3D radiation patterns of the antennas are presented in Figure 4.7. The PFA antenna resonates at two frequencies 6.02 GHz and 12.26 GHz with good bandwidths of 180 MHz and 200 MHz with deep return loss of -23.15 dB and -16.07 dB respectively. The VSWR at the resonances are 1.14 and 1.373 which are well within 2:1 VWSR requirement for well matched conditions. The impedances are found to be 57Ω and 68Ω corresponding to the two resonant points. It is interesting to note that the 3D radiation pattern is unidirectional with good amount of power radiating in the z direction. The total radiation field is 20.5 dB which provides a gain of 3.5 dB and a directivity of 5.5 dB in the maximum field direction at 6.02 GHz. The polar radiation pattern is same for 12.26 GHz.

4.2.3.2 Performance of TFA

From the Figure 4.6 the return Loss, VSWR and impedance as a function of frequency are analyzed. This antenna exhibits several interesting characteristics. Being fractal in shape, this resonates at multiple frequencies with an average interval of roughly 1.5 GHz. The return loss at resonances (-10.57 dB at 5.54 GHz, -18.74 dB at 7.02 GHz, -20.51 dB at 8.68 GHz and -21.38 dB at 9.8 GHz) are deeper compared to the PFA. The corresponding bandwidths 50 MHz, 200 MHz, 220 MHz and 300 MHz are broader.

The VSWR values of 1.84, 1.26, 1.2 and 1.19 at all resonant points indicate well matched conditions with impedance values of 43Ω, 36Ω, 57Ω and 55Ω respectively. The radiation pattern is unidirectional with good amount of radiated power and there is negligible backward radiation because of the presence of ground plane under the substrate. The 3D polar plot for the TFA is shown in Figure 4.7. The 3D radiation pattern shows maximum power flowing in the z direction. The total E field of this antenna is 8.55 dB corresponding to a maximum gain of 0.188 dB and directivity of 5.85 dB.

4.2.4 Concluding Remarks

The PFA resonated at two frequencies (6.02 GHz and 12.26 GHz) whereas it is quite interesting to note that the TFA resonated at four frequencies (5.54 GHz, 7.02 GHz, 8.68 GHz and 9.81GHz) with considerable amounts of bandwidths. There is no backward radiation because of the use of separate ground plane at the bottom of the substrate. Comparatively the metalized portion used for antenna layout gets reduced with the thin microstrip type fractal shaped antenna, thereby reducing the space occupied, weight and cost. The TFA provides multiple resonances with comparatively much lower return loss, VSWR and impedance values. At the same time the total E field and gain are lower but it is able to improve the directivity by 0.35 dB. With the application of meander type square fractal shape to the outer contour of the MSA, the length of the perimeter got increased from 92 mm to 112 mm thereby increasing the current flow path and improving the resonance and radiation characteristics while retaining the overall dimension unaltered. These antennas can find place in C (4 - 6 GHz), J (6 - 8 GHz) and X (8 -12 GHz) band wireless applications.