CHAPTER 5

DESIGN AND SIMULATION OF A NOVEL CPW FED NEW HILBERT CURVE FRACTAL ANTENNA

Summary - This Chapter covers the investigation the resonant and radiation properties of a new Hilbert curve FA (NHCFA). The IE3D electromagnetic simulation software has been used for carrying out both the design and simulation. The design starts with the basic building block and the advanced fractal structures are derived from it. The antenna structure based on copper material is laid on a 34mm x 30mm sized FR4 substrate board. It is fed by a CPW feed system. The need for double-sided printed board is avoided with CPW feed system. This NHCFA resonates at six frequencies in the 1-16 GHz frequency range, with very low return loss and VSWR values indicating the well matched conditions.

5.1 INTRODUCTION

It is interesting to learn that there have been several approaches for the design of antennas for wireless communications. The recent advancements in engineering and technology, has brought a great scope for many improvements in the designs. However, designing antennas for wireless applications is really challenging, in view of maintaining low profile. Fractals have space filling characteristics and they provide broadband coverage or multiple resonant frequencies and size reduction. Several fractal structures have been reported in the recent years showing various features and benefits. The concepts of Minkowski, Hillbert (Niruth Prombutr and Prayoot
Akkaraaektharin 2008), Koch snowflake, Sierpinski fractals are some of the results of such investigations. They are based on square and triangular metallic lines to take up some new patterned antenna shapes (Vinoy and Pal 2010). Resonance behavior of Peano antennas (Jinhui Zhu et al 2004) and size reduction of ring like geometries (Mirzapour and Hassani 2008) are some good examples of space filling fractal curves.

5.2 DESIGN OF NEW HILBERT CURVE FRACTAL ANTENNA

This Chapter considers the design, simulation and investigation of a planar NHCFA which possesses multiple resonances. The aim is to miniaturize the antenna size and to produce multiband resonances to fit for wireless or wideband applications. The structure of the proposed antenna is Hilbert curve inspired. Since the fractal concept is covered in this design, a basic structure is formed initially and iterations are made to obtain a satisfactorily new structure.

Figure 5.1 Basic Fractal Structure and Iterations (from step 1 to 5)

The iteration steps are depicted in Figure 5.1. A small monopole antenna is the building block appearing in step 1. Then in the step 2 two such monopoles were connected by a small piece of conductor. In step 3 takes the structure appearing in step 2 as its building block. Step 4 was the result of combining two similar copies of step 3. Applying this algorithm the step 6 has
been arrived at as depicted in Figure 5.2. The sixth iterated structure is considered for the investigation through simulation in the planar form. There are three cases considered with dimensional variations. The NHCFA pattern is laid on the substrate and the space occupied by the antenna metallic portion in unaltered in all the cases. The materials and dimensions used in the design are given below.

**The materials**

- **Substrate**: FR4, Thickness = 1.6, $\varepsilon_r = 4.4$
- **Antenna**: Copper, thickness 0.016mm
- **Ground**: CPW, Copper

**Dimensions**

- **Substrate**: $W = 34\text{mm (constant)}, L = 30\text{mm (constant)}$
- **Antenna**: $30\text{mm x 22mm (spread area - constant)}$

**Side length and width of antenna strip ($l, t$)**

- **Case 1**: $(3\text{mm, 1mm})$
- **Case 2**: $(2.5\text{mm, 0.5mm})$ and
- **Case 3**: $(2\text{mm, 0.25mm})$

The antenna is fed by a CPW whose feed strip width is kept same as that of the antenna strip width in each case while the slot widths are treated as constants. The length of the feed strip is 15.75mm. The slot width is 1mm on each side of the feed strip. The Figure 5.2 shows the antenna structure with the dimensions marked for case 3 as an example. The width ($t$), the side
length (l) and the feed width are varied to determine the effect on the performances.

**Figure 5.2 NHCFA Structure**

### 5.3 SIMULATION

The designed NHCFA shown in Figure 5.2 has been simulated using IE3D electromagnetic simulation software with numerical analysis in the frequency range from 1-16 GHz. The source and characteristic impedance have been set to be 50 ohms at the feed point with voltage source of 2V. The width (t), the side length (l) and the feed width are varied according to case 1, 2 and 3 and simulated to determine the effect on the performances of the antenna.
Figure 5.3 Simulation Results of NHCFA for Three Cases (a) Return Loss (b) VSWR
Figure 5.4  Radiation Characteristics of NHCFA (a) Elevation Pattern (case 1) (b) Azimuth Pattern (case 1) (c) Elevation Pattern (case 2) (d) Azimuth pattern (case 2) (e) Elevation Pattern (case 3) (f) Azimuth Pattern (case 3)
5.4 RESULTS AND DISCUSSIONS

The Figure 5.3 represents the simulation results of the proposed antenna. The typical parameters of interest for an antenna are resonant frequency, bandwidth, return loss, VSWR, gain, and radiation pattern. They are obtained from the simulation results and analyzed. In the case 1 the antenna resonates at 9.56 GHz and 12 GHz with return loss values of -10 dB and -12.85 dB. The corresponding VSWR levels are 1.97 and 1.59. The corresponding bandwidths of resonances are 230 MHz and 1.05 GHz. The bandwidth exhibited at the second resonance is large. In the case 2, the triple band resonances occur at 2.534 GHz, 3.8 GHz and 6.5 GHz with reduced return loss levels of -19.91 dB, -22.25 dB and -10.7 dB. The bandwidths provided by the antenna are 370 MHz and 770 MHz. The bandwidth corresponding to the third resonance is very narrow. The obtained VSWR values 1.26, 1.23 and 1.86, show good matched conditions at the respective resonances. In the case 3, fractal antenna performs well when compared to the previous two cases. It offers six resonant frequencies 3.83 GHz, 4.47 GHz, 6.43 GHz, 8.82 GHz, 9.9 GHz and 12.07 GHz with very low return loss value of -21.63 dB, -23.71 dB, -11.36 dB, -18.59 dB, -12.3 dB and -18.97 dB respectively at each resonant frequency. Large bandwidths obtained with type of antenna are 1.35 GHz at the first two resonances and 870 MHz at the last resonance respectively. This is quite wider for many multiband wireless applications. At the resonant frequencies, the VSWR lies in the range from 1.18 to 1.25.

The radiation characteristics of the NHCFA are depicted in Figure 5.4. All the radiation patterns are bidirectional since there is no ground plane at the bottom of the structure. In the case 1 the radiation provided at the first resonance is broad and becomes narrow for the second resonance with gains of 2 dBi and -2.5 dBi respectively.
### Table 5.1 Comparison of Performance of Proposed NHCFA

<table>
<thead>
<tr>
<th>Comparison of parameters</th>
<th>Proposed NHCFA</th>
<th>Jinhu Zhu et al 2004</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antenna Type and material</td>
<td>NHCF; Hilbert curve 6\textsuperscript{th} order, Copper strip</td>
<td>Peano curve 4\textsuperscript{th} order; Copper wire and PEC</td>
</tr>
<tr>
<td>Antenna size</td>
<td>30mm x 22mm, strip; (strip length and width varied within the given area)</td>
<td>70mm x 70mm wire; diameter 0.25mm</td>
</tr>
<tr>
<td>Substrate &amp; size</td>
<td>FR4, 34mm x 30mm</td>
<td>-</td>
</tr>
<tr>
<td>Feed</td>
<td>CPW</td>
<td>Off-centered coaxial feed</td>
</tr>
<tr>
<td>Sweep Frequency</td>
<td>1 - 16 GHz</td>
<td>300 MHz - 2 GHz</td>
</tr>
<tr>
<td>Simulation</td>
<td>IE3D EM Simulator</td>
<td>MoM based Numerical EM Coding (NEC)</td>
</tr>
<tr>
<td>Resonance (GHz)</td>
<td>2, 6 and 6 for each case</td>
<td>0.110, 0.219, 0.329 and 0.578</td>
</tr>
<tr>
<td>Return Loss</td>
<td>Lowest -24 dB</td>
<td>-</td>
</tr>
<tr>
<td>Bandwidth (BW) %</td>
<td>Highest (1.35 GHz) 16.05 %</td>
<td>0.0063%, 0.055%, 0.29% and 1.8%</td>
</tr>
<tr>
<td>Gain</td>
<td>Highest 5 dBi</td>
<td>Gain: 1.28 - 1.74</td>
</tr>
<tr>
<td>VSWR</td>
<td>Lowest 1.14</td>
<td>Lowest 1.25</td>
</tr>
<tr>
<td>Advantage</td>
<td>Compactness, single side printed substrate, multiple resonances with lower return losses, high gain, large BW</td>
<td>Electrically more compact radiation</td>
</tr>
<tr>
<td>Limitations</td>
<td>Practicability of higher iterations</td>
<td>Low efficiency for higher iterations</td>
</tr>
<tr>
<td>Applications</td>
<td>Wireless devices operating in the 3-12 GHz range</td>
<td>Wireless networks and Personal Communication Systems</td>
</tr>
</tbody>
</table>
The gain of the antenna at the resonance frequencies lies between 5 and 7.5 dBi which is a good range. In the case 2 broad radiation patterns are obtained for the first two resonances with gains of 2.5 dBi and 2 dBi respectively and the rest are narrow with little lower gain values. In the case 3 a broad beam of radiation is found for all the resonant frequencies with gain ranging from -15 dBi to 5 dBi. The maximum gain obtained at 6.43 GHz and 8.82 GHz is much appreciable. Also the co-polarization (meaning the elevation patterns) and the cross-polarization (meaning the azimuth patterns) levels in all the three cases are good and satisfactory.

As the length and width of the strips are varied from 3mm to 2mm and 1mm to 0.25mm respectively, it is found that the NHCFA in case 3 is able to raise its number of resonance frequencies with two larger bandwidths, with reduced return losses, improved gain values and broad beams of radiations when compared to the first two cases.

A comparison of the performance of the proposed NHCFA with Peano antenna developed by the previous investigator Jinhui Zhu et al (2004) is provided in Table 5.1. The antenna size is much smaller in NHCFA as noted from the table. Also the NHCFA resonates at multiple frequencies with a deeper return loss, low VSWR, large gain, bandwidths when compared to the performance of Peano antenna. However the overall performance would still be better with higher order iterations since the conducting strips would become electrically closer, excepting the practicability of fabrication.

5.5 CONCLUDING REMARKS

A miniaturized NHCFA has been proposed and its behavior has not only been evaluated in terms of its size reduction but also by its various parameters. In addition to miniaturization, its multiband functionality is well
examined. This NHCFA is found to possess various good characteristics suitable for many wireless standards. It can be used in S (2-4 GHz), C (4-6 GHz), J (6-8 GHz) and X (8-12 GHz) band regions, WiMAX and WiFi based devices and applications.