Rectangular Microstrip Patch Antenna Design for Satellite Image vision System

PhD Synopsis

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Title:
Rectangular Microstrip Patch Antenna Design for Satellite Image Vision System Application

1. Abstract

Emerging advantages of Microstrip patch antennas make them solid aspirant for the field of communication in Satellite application. Thesis comprises Microstrip patch antennas with entire arithmetical calculations, model results, measurement results and the appropriate antenna applications on the working frequencies. These novel designs have frequency ranges from 6 GHz to 15 GHz. These antenna simulations performed by using Ansoft HFSS and fabricated. Rectangular tree fractal antenna measured by Vector network analyzer (VNA). It presents simulation and measured results in provisions of Bandwidth, Return loss and VSWR. Microstrip patch antennas have wide range of applications, however here in this thesis they present WiMAX, WiBRO, RLAN and LMS Satellite Communication applications.

By adopting the tree fractal concept the issues of edge radiation, capacitive and inductive effect on radiation can be resolve. To address RTFA structure with 4 level iterations in L shape and 3 level iterations in U shale also improved impedance matching and return loss. The concept of tree fractal including number of iterations supports multiband frequency operation and wide band application and it can be preferred for 6 GHz to 15 GHz frequency band and also improved bandwidth.

A RTFA novel structure with $L = 30$ mm and $W = 23$ mm along the square patch yielded a triple notch band characteristics at resonant frequency of 7.4 GHz, 10.7 GHz and 13 GHz, as well as an improved resonant return loss (-28.85 dB) and VSWR (1.07) and also bandwidth is enhanced upto 19.23%.

The experimental results have some deviations compared to the simulation results due to machining error and welding error. The result shows operating bandwidth of the proposed rectangle tree fractal antenna (RTFA) covers the entire frequency band from 6 GHz to 15 GHz, and including notch bands of 5.92 GHz – 8.45 GHz for WiMAX, WiBRO, 8.5 GHz – 10.55 GHz for RLAN and 12.75 GHz – 14.5 GHz for LMS is achieved by using defected ground structure (DGS) on the ground plane to improve the impedance characteristics between adjacent resonant frequencies and triple band notch characteristics is proposed by three U-slots on the tree fractal path and effectively suppress the interferences..
2. State of the art of the research topic

The length of the antenna is responsible for determining the resonant frequency. The inductance of the antenna increases as the length increases and the width of the strip effects on the anti-resonance and increase the bandwidth. The feed position from the short strip also affects the resonance frequency and bandwidth of the antenna.

The radiating path is the tree fractal structure which formed by the superposition of several rectangular patches, and multi-frequency resonance characteristics are got by only increasing the tree fractal iterations. The defected ground structure (DGS) on the ground plane to improve the impedance characteristics between adjacent resonant frequencies. Fractal theory is a novel method for antenna design. Literature [1] summarized that fractals had convoluted shapes and could enhance performance when being used in antenna designs. With increasing fractal iteration there is a corresponding increase in total wire length, and it will obtain a lower resonant frequency. Linearity is another method to describe a fractal set. The influence of average Linearity on antenna performance is discussed in literature [2, 3], and with increasing fractal iteration, the lacunarity and resonant frequency are reduced.

This analysis approach is also more practical for the non-pre-fractal antennas. In a word, the complexity of fractal leads to it to summarize a better performance for an antenna, as self-similarity and space filling. Lacunarity is also a characterization of space filling. The fractal antenna can get multiple resonant frequencies even a super-wide bandwidth because of its self-similarity.

Selection of substrate materials and feeding techniques are observed by a series of simulation with a different dimension and structural characteristics of patch. Also optimization of result as per flow chart showed in figure 2.1 and 7.1. It is observed the tree fractal concept is preferred for high frequency band after comparison of slotted patch which include several iteration with normal design.
3. Definition of the Problem

To propose an improved novel tree fractal structure for rectangular microstrip patch antenna design compact, allow the antenna to operate at multiple frequencies between 4 - 16 GHz. It used for most of the satellite applications (Wi-Max). It has three different operating frequency bands have VSWR ≤ 2 which is an acceptable range for short to medium range wireless communication. The Bandwidth of proposed design is higher than the conventional patch antenna which makes it more attractive choice for many applications.
4. Objectives

- To study the MPA design structure, substrate material characteristics, feeding techniques with different patch structure and design parameters.
- Using structural simulator, suggest an approach to address some of the challenges regarding BW enhancement and VSWR.
- To address the impedance matching and reactance variation issues as it occurs in case of most of antenna design structures.
- To implement the idea which optimize existing methods to improve the performance and propose the new design structure which include edge slit/slot at a different angle by applying rectangular tree fractal concept.
- To fabricate simulated design with proper dimension, substrate suitable material with as much as number of iteration and test design using VNA.

5. Scope of the work

- Due to enhancement of bandwidth, it would prefer tree fractal patch for wideband application with its advantages of high speed, high resolution, low power consumption and low interference.
- All these simulations and measurements imply that the antenna can be used satellite communication systems.
- The radiating path is the tree fractal structure, formed by the superposition of several rectangular patches. The multi-frequency resonance characteristics are get by only increasing the tree fractal iterations.

6. Original contribution by the thesis

The original contribution of the thesis is in terms of modifications suggested in antenna design structure for bandwidth enhancement up to 19% with multi-band supporting frequency operation and return loss up to -28dB. By introducing tree fractal concept resolve the issues of impedance matching and capacitive and inductive effect on radiation.

It also observes the original contribution in the research papers listed at the end.
7. Methodologies of Research and Results

Research work is on simulation using HFSS software tool and Testing of final fabricated design using VNA after calibration.

- To make a mathematical model of footprint parameters (definition) in modular form.
- To combine all modules and complete the best full structure of the definition.
- To implement defined structure using application software – HFSS.
- Testing of implemented structure under various defined materials, feeding and footprint parameters.
- Comparison and Optimization of result.

Microstrip patch antennas are developing into a fundamental factor in many emerging industries and operation of these antennas in such devices is expected to several interesting properties. It supports the prospective design of the antenna on rectangular structured slots to operate at multiple frequency bands. SLOTS are design on the rectangular patch and fed by a microstrip feeder line. The combinations of the proposed design allow the antenna to operate at multiple frequencies between 4 - 16 GHz it uses which for most of the satellite applications. It shows that three different operating frequency bands have VSWR ≤ 2 which is an acceptable range for short to medium range wireless communication. The operating bands of frequency are: 6.33 GHz, 9.8 GHz and 13.26 GHz with VSWR ≤ 2. It is also observed that the gain of proposed design is higher and return loss is -28dB lower than the conventional patch antenna. This makes it more attractive choice for many applications and ensures secure and efficient transmission and better transmission of input power.

Selection of dimension parameters is base on the application-oriented frequency band and also taken care about impedance matching and reactance effect Aon radiation. 23×30 square tree fractal patch is design base on primary dimension as per listed in table 7.1 and shown in figure 7.1 according to footprint equations. Height and width of patch control the bandwidth and impedance matching.

\[ L_{\text{required}} = L_{\text{measured}} \times f_{\text{measured}} / f_{\text{required}} \]  \hspace{1cm} (7.1)

\[ Z_{\text{required}} = Z_{\text{in}} \sin^2 (\beta_{\text{new}} / \sin^2 (\beta x)), \text{ where } \beta = 2\pi / \lambda. \]  \hspace{1cm} (7.2)
The design perspective considered suitable value of W/L ratio is 1.5 and height is 0.02\(\lambda\). Impedance matching is most important issue in antenna feeding and it can do it using scaling according to equation 7.1 and 7.2.

Table: 7.1 23×30 Tree fractal patch dimension in mm

<table>
<thead>
<tr>
<th>W</th>
<th>L</th>
<th>Wf</th>
<th>Lf</th>
<th>c</th>
<th>d</th>
<th>t_s</th>
<th>L_1</th>
<th>L_2</th>
<th>L_3</th>
<th>L_4</th>
<th>L_s</th>
<th>W_s</th>
<th>L_{g1}</th>
<th>L_{g2}</th>
<th>W_{g1}</th>
</tr>
</thead>
<tbody>
<tr>
<td>23</td>
<td>30</td>
<td>2.1</td>
<td>9.1</td>
<td>8</td>
<td>12</td>
<td>0.15</td>
<td>8.5</td>
<td>8.2</td>
<td>4.5</td>
<td>5.7</td>
<td>5.6</td>
<td>2.7</td>
<td>2.3</td>
<td>4.9</td>
<td>7.4</td>
</tr>
</tbody>
</table>

Figure: 7.1 23×30 Tree fractal patch design

A patch antenna model with L = 30mm and W = 23mm along the patch square yielded a resonant frequency of 6.33 GHz, 9.8 GHz and 13.26 GHz, as well as an excellent resonant return loss and VSWR is less than 2.0 with different choice of L_2 from 7.5mm to 8.5mm as listed in table 7.2 and shown in figure 7.2 and 7.3.
Table: 7.2 Parameters comparison base on selection of $L_2$

<table>
<thead>
<tr>
<th>Parameter</th>
<th>%BW</th>
<th>VSWR</th>
<th>$S_{11}$(dB)</th>
<th>$G$(dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_2=7.5$ mm</td>
<td>16.2</td>
<td>1.3</td>
<td>-17.62</td>
<td>5.78</td>
</tr>
<tr>
<td>$L_2=8.2$ mm</td>
<td>18.74</td>
<td>1.13</td>
<td>-24.12</td>
<td>6.04</td>
</tr>
<tr>
<td>$L_2=8.5$ mm</td>
<td>15.08</td>
<td>1.22</td>
<td>-19.93</td>
<td>6.5</td>
</tr>
</tbody>
</table>

Figure: 7.2 Parameters comparison base on selection of $L_2$

A patch antenna model with $L = 30$mm and $W = 23$mm along the patch square yielded a resonant frequency of 6.33 GHz, 9.8 GHz and 13.26 GHz, as well as an excellent resonant return loss and VSWR is less than 2.0 with different choice of $L_4$ from 5.2mm to 5.7mm as listed in table 7.3 and shown in figure 7.4 and 7.5.
Table: 7.3 Parameters comparison base on selection of L₄

<table>
<thead>
<tr>
<th>Parameter</th>
<th>%BW</th>
<th>VSWR</th>
<th>S11(dB)</th>
<th>G(dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>l₄=5.2 mm</td>
<td>15.03</td>
<td>1.24</td>
<td>-19.36</td>
<td>6.07</td>
</tr>
<tr>
<td>l₄=5.5 mm</td>
<td>16.65</td>
<td>1.15</td>
<td>-23</td>
<td>6.52</td>
</tr>
<tr>
<td>l₄=5.7 mm</td>
<td>19.23</td>
<td>1.13</td>
<td>-24.37</td>
<td>6.21</td>
</tr>
</tbody>
</table>

Figure: 7.4 Parameters comparison base on selection of L₄

Figure: 7.5 BW and Return loss base on selection of L₄ = 5.7mm

A patch antenna model with L = 30mm and W = 23mm along the patch square yielded a resonant frequency of 6.33 GHz, 9.8 GHz and 13.26 GHz, as well as an excellent resonant return loss and VSWR is less than 2.0 with different choice of tₛ from 0.1mm to 2mm as listed in table 7.4 and shown in figure 7.6 and 7.7.
### Table: 7.4 Parameters comparison base on selection of $t_s$

<table>
<thead>
<tr>
<th>Parameter</th>
<th>% BW</th>
<th>VSWR</th>
<th>S11(dB)</th>
<th>G(dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t_s=0.1$</td>
<td>16.03</td>
<td>1.38</td>
<td>-15.9</td>
<td>6.45</td>
</tr>
<tr>
<td>$t_s=0.15$</td>
<td>19.23</td>
<td>1.1</td>
<td>-26.74</td>
<td>6.17</td>
</tr>
<tr>
<td>$t_s=2$</td>
<td>16</td>
<td>1.12</td>
<td>-25.15</td>
<td>6.05</td>
</tr>
</tbody>
</table>

### Figure: 7.6 Parameters comparison base on selection of $t_s$

![Parameters comparison](image)

### Figure: 7.7 BW and Return loss base on selection of $t_s = 1.5\text{mm}$

![BW and Return loss](image)

A patch antenna model with $L = 30\text{mm}$ and $W = 23\text{mm}$ along the patch square yielded a resonant frequency of 6.33 GHz, 9.8 GHz and 13.26 GHz, as well as an excellent resonant return loss and VSWR is less than 2.0 with different choice of $W_s$ from 2.5mm to 2.7mm and $L_s$ from 4mm to 5.6mm as listed in table 7.5 and shown in figure 7.8 and 7.9.
Table: 7.5 Parameters comparison base on selection of $W_s$ and $L_s$

<table>
<thead>
<tr>
<th>Parameter</th>
<th>%BW</th>
<th>VSWR</th>
<th>$S11$(dB)</th>
<th>$G$(dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$ws=2.5mm &amp; ls=4mm$</td>
<td>16.38</td>
<td>1.16</td>
<td>-22.6</td>
<td>6.15</td>
</tr>
<tr>
<td>$ws=2.7mm &amp; ls=5.6mm$</td>
<td>19.15</td>
<td>1.07</td>
<td>-28.85</td>
<td>6.17</td>
</tr>
</tbody>
</table>

An excellent resonant return loss of -28.85dB, Bandwidth of 19.23% and VSWR of 1.1 with finally preferred exact dimension and comparable similar to testing result of fabricate antenna shown figure 7.10.
8. Achievements with respect to the objectives

- It observes good improvement in Bandwidth using tree fractal structure concept for 4 to 16GHz band width.
- It observes good improvement in VSWR and Return loss using tree fractal structure concept for Wi-Max application.
- Achieve good fabricated design testing result and which similar to simulation result.

9. Conclusion

- Bandwidth is enhancing up to 19% and Return loss is observed up to -28.85dB by applying tree fractal concept in patch design and preferred for wideband application.
- The radiating path is the tree fractal structure formed by the superposition of several rectangular patches, and multi-frequency resonance characteristics are got by only increasing the tree fractal iterations.

10. Publications


Miscellaneous

• Presented work in special session on GUJCOST Sponsored Scholars’ Day in Information & Communication Technology department at Dharmsinh University, Nadiad during 19th, September, 2015

References


13. J. M. C. Dukes, "An investigation into some fundamental properties of strip transmission lines with the aid of an electrolytic tank", *Proc. IEE*, vol. 103, pp. 319-333, 1956


15. S. Ramo, J. R. Whinnery, "8" in Fields and Waves in Modern Radio, New York:Wiley, 1944


23. C. G. Shafer, *Higher mode of the microstrip transmission line*, November 1957


