A Novel Design of Compact 2.4 GHz Microstrip Antennas
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Abstract- A novel design of compact 2.4 GHz microstrip antennas, where the radiating patch is designed in fractal configuration, namely, square and pentagon shape respectively, is proposed. The newly designed microstrip provides an optimized patch area resulting into a substantial reduction in size compared to a typical microstrip patch designed at the same frequency of operation. It was found that the characteristics of the novel fractal patch antennas are comparable to the conventional patch antenna, while their gain and radiating efficiency are noticeably improved.

I. INTRODUCTION

Wireless communication plays a major role in our daily existence, with antennas being of continuously increasing significance. Microstrip antennas are a type of antennas that is popular with wireless communication equipment because of its outstanding physical properties, such as light weight, low profile, low production cost, conformability, reproducibility, reliability, and ease in fabrication and integration with solid state devices and wireless technology equipments [1]. However, the size of a conventional microstrip antenna is typically large when designed in microwave frequency regime, causing problems for mounting on transmitter/receiver and repeater systems. These antenna types also have limitations in terms of their narrow bandwidth, low gain, and weak radiating patterns. The gain reduction is caused by the overall reduction in the antenna size. It can also be attributed to the substrate characteristics which may lead to surface wave excitation and hence a reduction in gain. Therefore, it is challenging to design microstrip antennas to have better radiating properties and in the same time have a smaller size. There are several techniques used to decrease the size of the radiating patch which leads to a smaller antenna size, such as: using superstrates to generate high dielectric constant [2], incorporating a shorting pin in a microstrip patch [3], using short circuit [4], cutting slots in radiating patch [5-7], by partially filled high permittivity substrate [8], or by fractal microstrip patch configuration [1,9-10]. Still, it remains quite difficult to miniaturize microstrip antennas since these efforts generally conflict with electrical limitations or cost considerations [1].

This paper proposes a size reduction technique for microstrip antennas by using a novel fractal radiating patch, yet improving the radiating properties, including returning loss, impedance (VSWR) bandwidth and gain. With the appropriate designed fractal, the electric field can be spreading around the radiating patch effectively. The fractal patches are designed in quadrilateral and pentagonal shape in order to improve the spreading fields.

Gain and other radiating characters of a signal resulting from the novel designs are compared to those of the conventional microstrip antennas as well as the most recent attempt of fractal approach [9-10] CST Microwave Studios (CST MWS), one of the high reliable electromagnetic (EM) softwares, is used to validate and design the antennas. Not only the returning loss is improved, but these novel microstrip antennas presented here also have the area of patch smaller than other antennas operating in the same frequency. The simulation results also show that the gain and impedance bandwidth are visibly improved.

II. ANTENNA DESIGN

For microstrip antennas, the width (W) and length (L) of the radiating patch and the effective permittivity of the microstrip structure \((\varepsilon_e)\) which support the operation at the required resonant frequency (or the free-space wavelength \(\lambda_0\)) can be designed as follows, using the formulas given in [11].

\[
W = \frac{\lambda_0}{2} \sqrt{\frac{\varepsilon_e + 1}{2}}
\]

\[
L = \frac{\lambda_0}{2} \sqrt{\frac{\varepsilon_e}{\varepsilon_e - 2\Delta L}}
\]

\[
\Delta L = 0.412 \frac{r}{r} \left( \frac{\varepsilon_e + 0.3}{t} \left( \frac{W}{t} + 0.264 \right) \right)
\]

\[
\frac{\varepsilon_e}{2} + \frac{\varepsilon_e - 1}{2} \sqrt{\frac{1 + 12 \frac{t}{W}}{W}}
\]

Figure 1a shows a conventional microstrip antenna, having square radiating patch, with patch dimensions \(L \times W = 30 \text{ mm} \times 30 \text{ mm}\), designed to operate at 2.4 GHz, the standard frequency for wireless LAN. A printed circuit board (PCB) with the permittivity \(\varepsilon_r = 4.4\) (compared to the commercial PCB, FR-4) is used as the dielectric substrate placed on top of the group plane to form the microstrip antenna. The thickness of the substrate is 1.6 mm. A feed line with the dimension \(L \times W = 978-1-4244-3388-9/09/$25.00 ©2009 IEEE 766\)
W of 1 mm X 5 mm is located in the center of the microstrip. The feed line and the radiating patch are made of copper. Figure 1b presents the returning loss of the microstrip of Figure 1a. It is shown that this antenna has the operating frequency at 2.37 GHz.

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Figure 2 illustrates the fractal radiating patch [1] being generated by applying an iterative sequence to the starting structure, which in the present case is a square patch (dimension = 30 mm x 30 mm). Figure 2a is a simple structure, while Figure 2b and Figure 2c is 1st iteration, and 2nd iteration fractal, respectively. The triangle shape is being used as a fractal in this case.

![Fig. 1. Geometry of a conventional square microstrip patch](image1)

![Fig. 1.](image2)

![Fig. 1.](image3)

**Fig. 1.** Geometry of a conventional square microstrip patch

L = W = 30 mm and its returning loss

A return loss comparison plot of the microstrip with the triangular fractal patch shown in Figure 2 is presented in Figure 3. It can be seen that with the higher iteration, the returning loss is improved. The values are -16.10 dB, -23.45 dB and -26.38 dB, for the original, 1st iteration, and 2nd iteration fractal, respectively. This result matches Gupta’s [1].

Next, the fractal patch of quadrilateral shape is presented. With the quadrilateral shape proposed here, the radiating length and shape can be improved. Figure 4a and 4b illustrate 1st and 2nd iteration fractals. Their returning loss is presented in Figure 5. Again, the result of 2nd iteration (-31.85 dB) is better than that from 1st iteration (-24.36 dB). Furthermore, the patch area is reduced from 0.555L^2 to 0.296L^2 while the contour length of the radiating patch is increased from 0.555L^2 to 0.296L^2.

![Fig. 2. Fractal Patch Antennas Generation](image4)

**Fig. 2.** Fractal Patch Antennas Generation

![Fig. 4.](image5)

**Fig. 4.** Fractal Patches of Quadrilateral Shape of (a) 1st Iteration and (b) 2nd Iteration

![Fig. 5.](image6)

**Fig. 5.** Returning Loss Comparison of Quadrilateral Shape Fractal: solid-circle for 1st iteration and solid-triangle for 2nd iteration fractal

Next, the fractal patch of pentagonal shape is presented. For this pentagonal case, a circular shape of the conducting patch is taken out from the middle. This is done by using the array concept [12] which normally improves the radiating properties of antennas. The generated gap makes the radiating patch behave like two separate patches placed next to each other. This causes wave combination, acting as a feed line. As shown in Figure 7, the returning loss result of 2nd iteration (-34.70 dB) is better than that of 1st iteration (-25.00 dB).

![Fig. 6.](image7)

**Fig. 6.** Fractal Patch of Pentagonal shape for 1st and 2nd iteration. For this pentagonal case, a circular shape of the conducting patch is taken out from the middle. This is done by using the array concept [12] which normally improves the radiating properties of antennas. The generated gap makes the radiating patch behave like two separate patches placed next to each other. This causes wave combination, acting as a feed line. As shown in Figure 7, the returning loss result of 2nd iteration (-34.70 dB) is better than that of 1st iteration (-25.00 dB).
Fig. 6. Fractal Patches of Pentagonal Shape of (a) 1st Iteration and (b) 2nd Iteration.

Fig. 7. Returning Loss Comparison of Pentagonal Shape Fractal: solid-circle for 1st iteration and solid-triangle for 2nd iteration fractal.

The comparison of the returning losses of all structures is shown in Figure 8. The fractal patch of pentagonal shape with the 2nd iteration presents the best result at -34.70 dB. However, it can be seen that the peaks of the returning losses are shifted but still located around the desired frequency, at 2.4 GHz. However, the location of the peak can be controlled by adjusting the patch width by this technique.

Fig. 8. The returning losses of for original patch, for triangle 1st iteration, for triangle 2nd iteration, for square 1st iteration, for square 2nd iteration, for Pentagonal 1st iteration, for Pentagonal 2nd iteration.

The impedance bandwidth (VSWR <1.5) and gain of the conventional and proposed microstrip antennas are also observed. The VSWR bandwidth plot (comparison of the 7 microstrips in the same order of those results in Figure 8) is shown in Figure 9. Table I presents the comparison of VSWR bandwidth and gain of the proposed and conventional microstrip antennas.

Fig. 9. The returning losses of for original patch, for triangle 1st iteration, for triangle 2nd iteration, for square 1st iteration, for square 2nd iteration, for Pentagonal 1st iteration, for Pentagonal 2nd iteration.

TABLE I

<table>
<thead>
<tr>
<th>Patch Structure</th>
<th>VSWR Bandwidth (MHz)</th>
<th>Gain (dBi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>31.75</td>
<td>3.859</td>
</tr>
<tr>
<td>Triangular, 1st</td>
<td>38.07</td>
<td>4.215</td>
</tr>
<tr>
<td>Triangular, 2nd</td>
<td>43.03</td>
<td>4.371</td>
</tr>
<tr>
<td>Quadrilateral, 1st</td>
<td>39.69</td>
<td>4.391</td>
</tr>
<tr>
<td>Quadrilateral, 2nd</td>
<td>44.80</td>
<td>4.462</td>
</tr>
<tr>
<td>Pentagonal, 1st</td>
<td>39.05</td>
<td>4.394</td>
</tr>
<tr>
<td>Pentagonal, 2nd</td>
<td>44.85</td>
<td>4.782</td>
</tr>
</tbody>
</table>

It can be seen that the pentagonal patch with 2nd iteration also gives the best result in terms of VSWR bandwidth (44.85 MHz) and gain (4.782 dBi). These values represent an improvement of 41.26% and 23.92% respectively, compared to those of conventional microstrip antenna.

Applying this effective fractal technique, not only those significant parameters mentioned above are enhanced, but the area of the radiating patch is reduced significantly. Table 2 shows the comparison of the length and area of the radiating patch of the proposed and conventional microstrip antennas. The radiating patch with the fractal in pentagonal shape (2nd iteration) has the longest contour length, 18.370L, and smallest...
area, $0.187L^2$, with $L$ being the length and width of the conducting patch.

<table>
<thead>
<tr>
<th>Triangular shape</th>
<th>Quadrilateral shape</th>
<th>Pentagonal Shape</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line Area</td>
<td>Line Area</td>
<td>Line Area</td>
</tr>
<tr>
<td>4L $L^2$</td>
<td>4L $L^2$</td>
<td>4L $L^2$</td>
</tr>
<tr>
<td>1st iteration</td>
<td>5.33L $0.777L^2$</td>
<td>6.666L $0.555L^2$</td>
</tr>
<tr>
<td>2nd iteration</td>
<td>7.11L $0.758L^2$</td>
<td>15.555L $0.296L^2$</td>
</tr>
</tbody>
</table>

**CONCLUSIONS**

Four novel microstrip antennas operating at 2.4GHz, the standard wireless frequency, are proposed. Fractal technique together with the array arrangement concept is used to design the radiating patch. These new antennas demonstrate improved properties: returning loss, VSWR bandwidth, gain. Moreover, the radiating patch area is smaller as compared to the conventional antennas and other fractal patch antennas. The 2nd iteration of the pentagonal shape presents the best performance, resulting in an increase of 115.5%, 41.26% and 23.92% respectively, in returning loss, VSWR bandwidth and gain, in comparison with conventional antennas. The area of the radiating patch decreases with 81.3%. These new antenna designs not only improve VSWR bandwidth, gain, returning loss, but also can provide a smaller size of radiating patches, which will cause an overall reduction in antenna size.

**ACKNOWLEDGMENTS**

This research was supported by the Telecommunications Research and Industrial Development Institute, TRIDI, and Faculty of Engineering, Khon Kaen University, Khon Kaen 40002, Thailand.

**REFERENCES**