

New Compact Microstrip Patch Antennas: Design and Simulation Results

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Abstract

Objectives: To design new multi-band antennas based on patch resonator with comparative results to each other. Both antennas are compact in size and have high quality responses which can be applied in many handheld and personal communication devices. **Methods/Analysis:** New microstrip patch antennas based on modified first iteration of Minkowski fractal geometry and applying central small square cut in the main resonator have been presented in this paper with and without inserting corner square patches. Both antennas have designed using single layer and dual feeds to operate as multi frequency devices. The antennas have been modeled and optimized by using the Microwave Office (MWO) simulator based on the method of moments. The projected antennas have been designed using FR4 substrate with a relative dielectric constant of 4.4 and a substrate height of 1.6 mm. Compared with the microstrip patch antenna without inserting corner patches using same main patch resonator dimensions and substrate specifications, the designed antenna with corner patches exhibits more operational frequencies as well as as greater frequency ratios with respect to the first fundamental frequency. **Findings:** New microstrip antennas based on patch resonator with and without inserting corner patches have been proposed. The first antenna exhibits multi-frequency behavior, where resonances appear to take place at frequencies of 2.49, 3.03 and 6.63 GHz, within 2 to 7 GHz frequency range. The second antenna exhibits a higher number of resonant frequencies that appear at 2.14, 2.55, 5.03, 5.81, 5.9 and 6.14 GHz respectively under same previous frequency range. The first three operational frequencies have decreased or shifted by inserting corner square patches due to increased electrical physical dimensions of the second antenna. Also, these corner patches act as EM perturbation elements to stimulate the second antenna with more resonant frequencies within 2-7 GHz frequency sweeping range. Theoretically, there is an important relation between antenna dimensions and guided wavelength. This relation specifies if antenna dimension is less than quarter guided wavelength (λ_g), then the antenna is impractical because radiation resistance, bandwidth and gain are decreased and therefore the antenna size is enlarged. By the way, the dimensions of Antennas 1 and 2 have been found to be $(0.259 \lambda_g \times 0.259 \lambda_g)$ and $(0.269 \lambda_g \times 0.269 \lambda_g)$ respectively according to their fundamental frequencies which are satisfactory. Both antennas have small sizes and high quality responses which can be applied in many handheld and personal communication devices. **Novelty/Improvement:** In this paper, new multi-band antennas based on patch resonator have been proposed. The proposed resonators have been initiated from the transformed version of the first iteration of Minkowski fractal geometry. These antennas have compact dimensions with good return loss and radiation pattern performances which are desired features to be adopted in many communication devices

Keywords: Compact Antenna, Electronic Design Automation (EDA), Microstrip Patch Antenna, Multi-frequency Antenna, Radiation Patterns

1. Introduction

Microstrip antennas have many advantageous properties such as the reasonable cost value and ease of modeling and fabrication. These make them very attractive for the microwave designers since the early days they appear. In many cases, where the antenna size is considered an

important limitation, their large physical size make them improper to be used in many applications. So, there is rising attention to compact microstrip antennas, resulting from the expansion of handheld devices and personal communications as in mobile phones, computers and navigation devices which are using wireless access points. For handheld wireless terminals, the antenna is

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an essential element. However, because of the market and end-user requirements, the antenna must be hidden properly. Therefore, it is very necessary to design miniature antennas that can be integrated in the device structure sufficiently^{1,2}.

The antenna size does not generally depend on its fabrication technology as in electronic chips but somewhat by physical laws. High-quality antenna performances are realized when the antenna is resonant and its size is comparable to the wavelength. At the operating frequencies of mobile communications and wireless networks, this indicates that the antenna must be relatively large. A number of techniques and approaches have been introduced to lessen the antenna size and retain good radiation characteristics. The compactness property of antennas is in the hugest importance in the present and future wireless applications for the microwave designers³⁻⁵.

The most commonly used miniature antennas are shorted patches and Planar Inverted F Antennas (PIFAs) as reported in⁵⁻⁹. Additional reduction of antenna sizes has been achieved by using patch resonators¹⁰⁻¹². However, the drop in antenna dimensions is continuously carried out at the expense of gain, bandwidth and efficiency.

Other methods have been considered to reduce the antenna size such as the use of material loading and geometry optimization in addition to slotted microstrip patch antennas^{1,13}. These antennas had proved to be satisfactory in producing miniaturized elements. On the other hand, fractal geometries have been adopted extensively in the design of compact antennas with different electrical specifications¹⁴⁻¹⁶. These geometries are fundamentally identified by their self similarity and space filling properties. In this paper, two multi-band antennas based on patch resonator have been proposed with comparative results to each other. The proposed resonators have been developed from the transformed version of the first iteration of Minkowski fractal geometry. Both antennas have small sizes and high quality responses which can be applied in numerous handheld and personal communication devices.

2. The Proposed Antenna Modeling

The first proposed microstrip patch antenna is illustrated in Figure 1. The structure of this antenna is based on deformation the first iteration of Minkowski fractal

geometry¹⁴ and applying small central square cut in the main patch resonator. The construction of this antenna can be initiated from the smallest square patch generator illustrated in Figure 1. This patch generator has side length (h) of 2.5 mm. The overall length (L) of the main microstrip patch resonator can be determined from the following equation:

$$L=8h+e=21 \text{ mm} \quad (1)$$

Where e is the spacing between moderate size square patches in Figure 1. This spacing has been adjusted to be 1mm. Also, it is worthy to indicate that the central square cut of the modeled antenna has a dimension same as e . Two via port feeds have adopted in the first antenna design as illustrated by Figure 1.

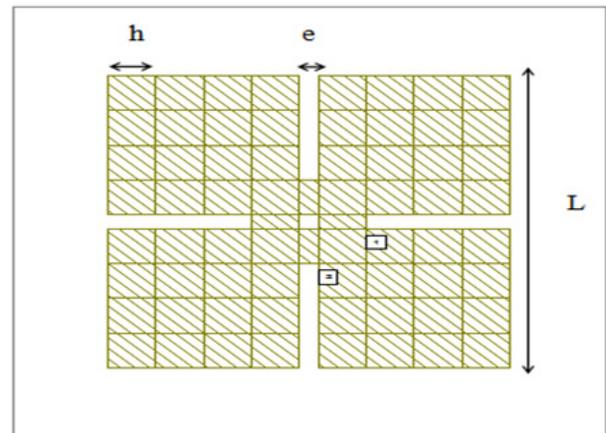


Figure 1. The topview geometry of the first microstrip patch antenna (Antenna 1).

The second microstrip antenna has been developed from the first modeled antenna, but with the insertion of square patches of 5 mm length in the corner sides of the main resonator as shown in Figure 2 using the same dielectric specifications. In this case, the overall side length for the second microstrip patch antenna can be determined by:

$$Y=L+(2W-2h)=26 \text{ mm} \quad (2)$$

An important issue in the smallness of microstrip antennas comes from the actuality that resonating devices have to comprise absolute dimensions related to the guided wavelength, according to evaluated resonant frequency (f). The guided wavelength can be evaluated by:

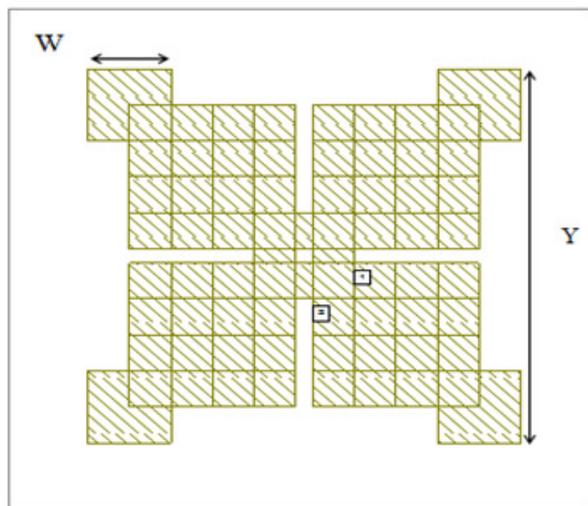


Figure 2. The topview geometry of the second microstrip patch antenna (Antenna 2).

$$\lambda_g = \frac{c}{f\sqrt{\epsilon_e}} \tag{3}$$

An effective relative dielectric constant ϵ_e for the square patch antenna can be computed from Equation (4)^{17,18}

$$\epsilon_e = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left(\frac{1}{\sqrt{1 + 12H/A}} \right) \tag{4}$$

All the same, ϵ_e in this study has been calculated using the approximated equation that can be adopted in patch antennas as stated in¹⁸:

$$\epsilon_e = \frac{\epsilon_r + 1}{2} \tag{5}$$

Relatively, the projected antennas have been designed using a single layer of FR4 substrate with a relative dielectric constant (ϵ_r) of 4.4 and a substrate height (H) of 1.6 mm.

3. Performance Evaluation

The antennas have been designed and optimized by using the Microwave Office (MWO) simulator based on the method of moments. This simulator computes the antenna response by dividing first the resonator in tiny fitted grids by solving linear equations set derived from an integral EM equations. The grid size here has been selected to be 0.5 mm. The antennas have been run under frequency range from 2 GHz to 7 GHz with frequency step of 0.01 GHz. Appropriate boundary conditions are assigned, and

then meshing is carried out on the modeled antennas to acquire the ending improved mesh. In meshing, it is familiar that smaller grid size will give a more precise solution. However, this requirement will also necessitate more time for the computer to solve the study. Therefore, it is required to select the suitable balance between evaluation time and an adequate accuracy level.

Figure 3 depicts the return loss response of the first antenna. This graph points to the multi-frequency behavior of this antenna, where resonances appear to take place at frequencies of 2.49, 3.03 and 6.63 GHz, within 2 to 7 GHz frequency range.

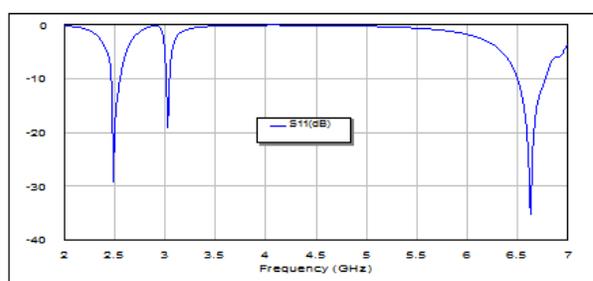


Figure 3. The return loss response of the first antenna.

The simulated return loss response of the second patch antenna has been illustrated in Figure 4. As it can be perceived from this graph, the second antenna exhibits a higher number of resonant frequencies that appear at 2.14, 2.55, 5.03, 5.81, 5.9 and 6.14 GHz respectively under same previous frequency range. The first three operational frequencies have shifted decreasingly by inserting corner square patches due to increased electrical physical dimensions of the second antenna. Also, these corner patches act as EM perturbation elements to induce the second antenna with more resonant frequency within 2-7 GHz frequency sweeping range.

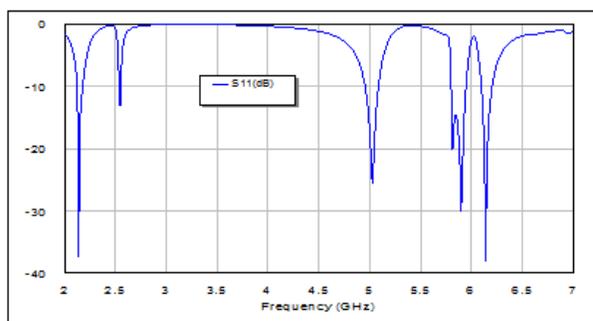


Figure 4. The return loss response of the second antenna.

The simulated result parameters for Antennas 1 and 2 are summarized in the Table 1. It is understandable from the table that for both antennas, the increased value of frequency ratios is obtained with respect to their fundamental frequency. Also, Antenna 2 has more and larger frequency ratios as compared to Antenna 1. These antennas have numerous resonant frequencies with reasonable return loss values and miscellaneous bandwidths. The highest bandwidth can be seen at f3 for Antenna 1 with a magnitude 278.6 MHz, while the smallest one can be observed at F2 for Antenna 2 with a magnitude of 19 MHz.

Table 1. Simulated results for antennas 1 and 2.

Antenna #	Resonant Frequency (GHz)	Return Loss (dB)	10dB Bandwidth (MHz)	Frequency Ratio
1	f1=2.49	-29.15	88
1	f2=3.03	-19.207	33	f2/f1=1.217
1	f3=6.63	-35.214	278.6	f3/f1=2.663
2	F1=2.14	-37.379	57
2	F2=2.55	-13.113	19	F2/F1=1.192
2	F3=5.03	-25.627	131.7	F3/F1=2.35
2	F4=5.81, F5=5.9	-20.034, -30.015	147	F4/F1=2.715, F5/F1=2.757
2	F6=6.14	-38.088	106	F6/F1=2.869

In theory, there is an important relation between antenna dimensions and guided wavelength. This relation specifies if antenna dimension is less than quarter guided wavelength (λ_g), then the antenna is impractical because radiation resistance, bandwidth and gain are decreased and therefore the antenna size is enlarged¹⁸. By the way, the dimensions of Antennas 1 and 2 have been found to be $(0.259 \lambda_g \times 0.259 \lambda_g)$ and $(0.269 \lambda_g \times 0.269 \lambda_g)$ respectively according to their fundamental frequencies which are realistic to be incorporated in many handheld and personal communication devices.

Figures 5-6 and Figures 7-8 illustrate the PPC-LHCP (principal plane cut left hand circular polarization) and PPC-RHCP (principal plane cut right hand circular polarization) respectively at $\varphi = 0^\circ$. RHCP and LHCP are determined from the following formulas at their resonant frequencies:

$$RHCP = \frac{E\theta + jE\varphi}{\sqrt{2}} \quad (6)$$

and

$$LHCP = \frac{E\theta - jE\varphi}{\sqrt{2}} \quad (7)$$

As it can be observed from Figures 5-8, PPC-LHCP and PPC-RHCP responses are within θ sweeping from -90 to 90 degrees at fixed φ and assigned resonant frequency. Each antenna possesses a specific radiation pattern in accordance with resonant frequency in the of PPC-LHCP and PPC-RHCP cases. However, these patterns are tolerable in antenna design theory.

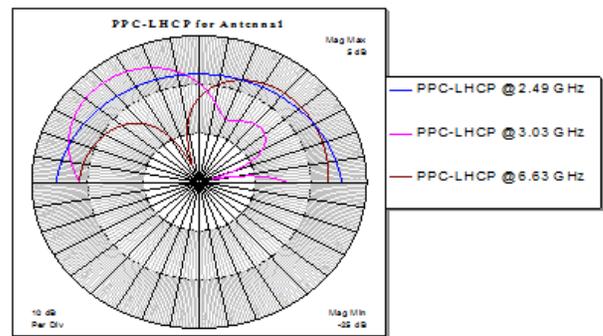


Figure 5. PPC-LHCP radiation patterns for Antenna 1.

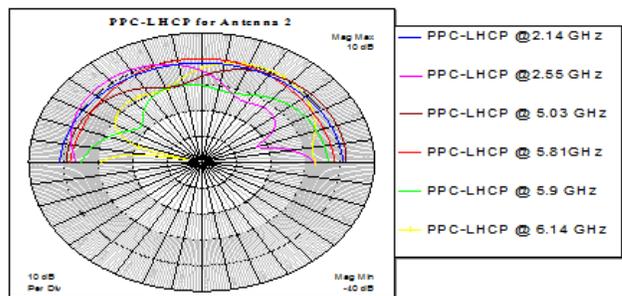


Figure 6. PPC-LHCP radiation patterns for Antenna 2.

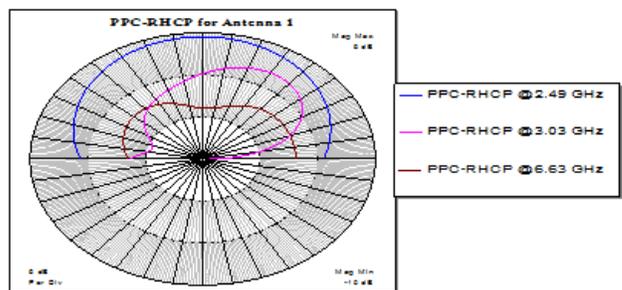


Figure 7. PPC-RHCP radiation patterns for Antenna 1.

Figures 9-10 describe PPC-TPWR (PPC total power) radiation patterns at $\varphi = 0^\circ$ and resonant frequencies. PPC-TPWR represents the available total power from $E\varphi$ and $E\theta$ fields regardless of polarization. The resulting

PPC-TPWR patterns are satisfactory for both Antennas 1 and 2.

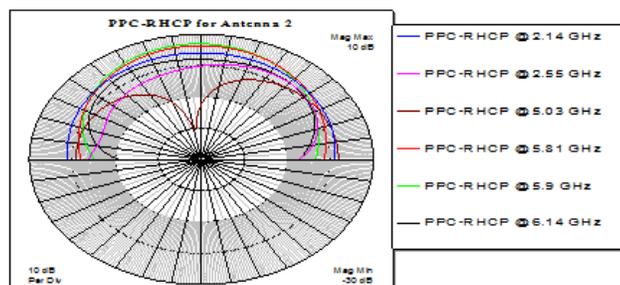


Figure 8. PPC-RHCP radiation patterns for Antenna 2.

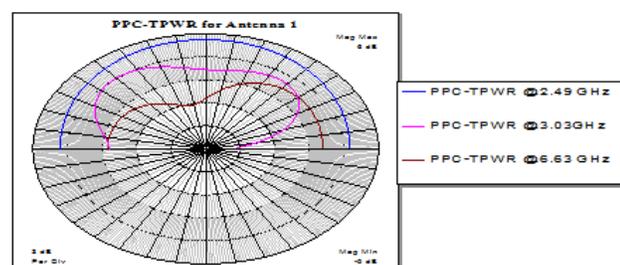


Figure 9. PPC-TPWR radiation patterns for Antenna 1.

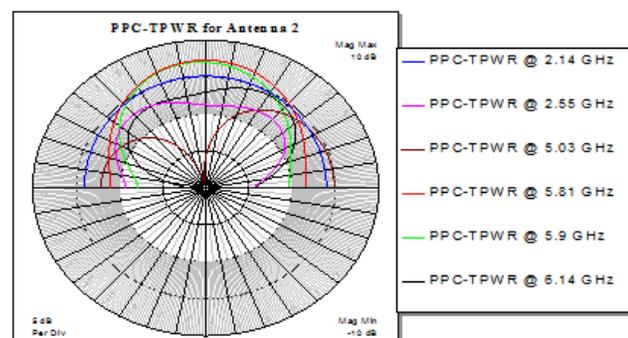


Figure 10. PPC-TPWR radiation patterns for Antenna 2.

The interchanging of via port (feed) locations has huge effects on the antenna return loss responses in addition to PPC-LHCP and PPC-RHCP radiation patterns. The best possible antenna performances have been extracted using MWO simulator at feed locations as illustrated in Figures 1-2. The fundamental frequency of the modeled antennas can be changed by scaling the overall dimensions of the main patch resonators as similar as fractal resonators depicted in^{19,20} to attain the planned frequency application. Corner patches dimension scaling can be exploited for minor frequency tuning.

4. Conclusion

New microstrip patch antennas based on modified first iteration of Minkowski fractal geometry and applying central small square cut in the main resonator have been presented in this paper. Both antennas have designed to work as multi band antennas using single layer and dual feeds with and without inserting corner square patches under substrate specifications with a relative dielectric constant of 4.4 and a substrate thickness of 1.6 mm. The projected antennas have compact dimensions with good return loss and radiation pattern performances which can be used in many communication devices.

5. Acknowledgement

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6. References

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