New Compact Microstrip Patch Antennas: Design and Simulation Results

Yaqeen S. Mezaal

Electronic and Communication Engineering Department, Cankaya University, 06530 Ankara, Turkey; yakeen_sbah@yahoo.com

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 ($\lambda_g$), 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
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\textsuperscript{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 designers\textsuperscript{3-5}.

The most commonly used miniature antennas are shorted patches and Planar Inverted F Antennas (PIFAs) as reported in\textsuperscript{5-9}. Additional reduction of antenna sizes has been achieved by using patch resonators\textsuperscript{10-12}. 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\textsuperscript{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 specifications\textsuperscript{14-16}. 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 geometry\textsuperscript{14} 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:

\[
L = 8h + e = 21 \text{ mm}
\]  

(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.

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:

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

(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:
An effective relative dielectric constant \( \varepsilon_e \), for the square patch antenna can be computed from Equation (4)\textsuperscript{17, 18}

\[
\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \frac{1}{\sqrt{1 + 12H/A}}
\]  

(4)

All the same, \( \varepsilon_e \) in this study has been calculated using the approximated equation that can be adopted in patch antennas as stated in\textsuperscript{19}:

\[
\varepsilon_e = \frac{\varepsilon_r + 1}{2}
\]  

(5)

Relatively, the projected antennas have been designed using a single layer of FR4 substrate with a relative dielectric constant (\( \varepsilon_r \)) 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.

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.
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, 106            | 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 (λg), 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 λg x 0.259 λg) and (0.269 λg x 0.269 λg) 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 φ = 0°. RHCP and LHCP are determined from the following formulas at their resonant frequencies:

\[
LHCP = \frac{E\theta - jE\phi}{\sqrt{2}}
\]

(7)

As it can be observed from Figures 5-8, PPC-LHCP and PPC-RHCP responses are within 0° 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.
PPC-TPWR patterns are satisfactory for both Antennas 1 and 2.

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

This study is supported by the Scientific and Technological Research Council of Turkey (TUBITAK).

6. References

1. Shrivervik AK, Zurcher JF, Staub O, Mosig JR. PCS Antenna Design: The Challenge of Miniaturization. IEEE Antennas and Propagation Magazine. 2001 Aug; 43(4):12–27.
2. Nisha ASA. Hybrid Coupled Feed Circularly Polarized Patch Antenna for Military Applications. Indian Journal of Science and Technology. 2015 Nov; 8(29). Doi no:10.17485/ijst/2015/v8i29/63684.
3. Vazquez MM. ACE small terminal antennas activities: a review of the state of the art. Proceeding of the 18th International Conference on Applied Electromagnetic and Communications (ICECom 2005); Croatia. 2005. p. 29–32.
4. Garg TK, Gupta SC, Pattnaik SS. Metamaterial Loaded Frequency Tunable Electrically Small Planar Patch Antenna. Indian Journal of Science and Technology. 2014 Jan; 7(11). Doi no:10.17485/ijst/2014/v7i11/50178.
5. Kan HK, Waterhouse RB. Small printed-wing antenna suitable for wireless handset terminals. Microwave and Optical Technology Letters. 2001 Aug; 30(4):226–29.
6. Chair R, Luk KM, Lee KF. Miniature multilayer shorted patch antenna. Electronics Letters. 2000 Jan; 36(13):3–4.
7. Chair R, Luk KM, Lee KF. Miniature shorted dual-patch antenna. IEE Proceedings of Microwave, Antennas and Propagation; UK. 2000; 147(4):273–76.
8. Kuo JS, Wong K-L. A low-cost microstrip-line-fed shorted-patch antenna for a PCS base station. Microwave and Optical Technology Letters. 2001; 29(3):146–48.
9. Virga KL, Rahmat-Samii Y. Low-profile enhanced-bandwidth PIFA antennas for wireless communications packaging. IEEE Transactions on Microwave Theory and Techniques. 1997; 45(10):1879–88.
10. Ghiyasvand M, Bakhtiari A, Sadeghzadeh RA. Novel Microstrip Patch Antenna to Use in 2×2 Sub Arrays for DBS Reception. Indian Journal of Science and Technology. 2012 July; 5(7). Doi no:10.17485/ijst/2012/v5i7/30493.
11. Kumar G, Ray KP. Broadband Microstrip Antennas, Artech House Inc.: Boston. 2003.
12. Palaniswamy V, Crag R. Rectangular Ring and H-Shape Microstrip Antenna; Alternatives to Rectangular Patch Antenna. Electronic Letters. 1985; 21(19): 874–76.
13. Choi J-Y. Design and Analysis of Squared Patch Antenna with Multi Squared Slots. Indian Journal of Science and Technology. 2015 Oct; 8(26). Doi no: 10.17485/ijst/2015/v8i26/80432.
14. Gianvittorio JP, Rahmat-Sami Y. Fractal antennas: A novel miniaturization technique and applications. IEEE Antennas Propagation Magazine. 2002 Feb; 44(1):20–36.
15. Choukiker YK, Rai S, Behera SK. Modified half-circle fractal antenna using DC theorem for 2.4/5.2 GHz WLAN application. Proceedings of National Conference on Communication, IISc; Banglore. 2011. p. 1–4.
16. Ali JK. A new microstrip-fed printed slot antenna based on Moore space-filling geometry. Proceedings of Loughborough Antenna and Propagation Conference, LAPC; Loughborough: UK. 2009 Nov. p. 449–52.
17. Ammam M. Design of Rectangular Microstrip Patch Antennas for 2.4 GHz Band. Applied Microwave and Wireless. 1997 June; 9(6):24–34.
18. Waterhouse RB. Microstrip Patch Antennas: A Designer's Guide. Kluwer Academic Publishers; 2003.
19. Mezaal YS, Eyyuboglu HT, Ali JK. New microstrip bandpass filter designs based on stepped impedance Hilbert fractal resonators. IETE Journal of Research. 2014 July; 60(3): 257–64.
20. Mezaal YS, Ali JK, Eyyuboglu HT. Miniaturised microstrip bandpass filters based on Moore fractal geometry. International Journal of Electronics. 2014 Oct. p. 1–14.