Design and Simulation of Bow-Tie Shaped Hexagonal Rings Quasi Fractal Antenna for Satellite Applications

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Abstract

Objective: To design a frequency reconfigurable fractal antenna for satellite applications. Methods: Using fractal geometries, a novel structure has been developed to operate the antenna at X (8-12 GHz), Ku (12-18 GHz) and Ka (26.5-40 GHz) bands. Findings: Frequency reconfigurable antennas are generally equipped with PIN diodes or MEMS switches etc., by controlling the switch conditions (ON or OFF) the proposed antenna can be operated either at X or Ku or Ka band. Various parameters of the antenna like reflection coefficient, gain, VSWR, radiation pattern, bandwidth were also determined. Application: This proposed antenna is compact in size and good impedance matching is achieved compared to existing antennas and hence it is very suitable to satellite applications.

Keywords: Frequency Reconfigurable Antenna, Quasi Fractal, FEKO, MEMS, MOM

1. Introduction

Reconfigurable antennas are the future antennas for wireless and satellite applications. The structure of the antenna is not changed, by using the electrical and mechanical methods we make the antenna to work under different applications i.e. the frequency, radiation pattern and other characteristics are changed. Reconfiguration makes a single antenna equivalent to multiple antennas with constant functionalities. Reconfigurable antenna with fractal shape can be used to radiate at high frequencies. Due to the self-similar property, many fractal shapes have been applied to antennas and array designs, including Koch, Hilbert, Peano, Minkowski, and Sierpinski, which demonstrates both compactness and multiband behavior. Therefore, the fractal antennas are very conducive to design reconfigurable antennas. Bow-Tie shaped hexagonal rings fractal geometries using RF-MEMS switching elements were proposed for frequency-reconfigurable applications.

The proposed antenna structure radiates in frequency bands like X-band, Ku-band and Ka-band by changing the state of the switches.

2. Design of Frequency-Reconfigurable Bow-Tie Shaped Hexagonal Rings Quasi Fractal Antenna and Methodology

Figure 1 shows the geometry of the proposed Frequency Reconfigurable Antenna. The two arms of antenna are printed on top of the substrate. It is fed with coaxial cable which is converted by a micro strip transmission line. ‘l’ is the total length of the antenna arm, ‘W’ is the...
width of the antenna arm, ‘a, b’ refers to the lengths of the hexagonal rings. Here we design the antenna for three order hexagonal rings that are connected with switches.

\[ L = 12.5\text{mm}, W = 20\text{mm}, a = 2\text{mm}, b = 4\text{mm} \]
\[ Ls = 30\text{mm}, Ws = 30\text{mm}, h = 0.256\text{mm} \]

**Figure 1.** Bow-Tie shaped hexagonal rings quasi fractal antenna.

Reconfigurability is done through the switches (red color rectangles) M1 and M2 that connects the hexagonal rings. Switches are considered as ideal and its dimensions are 0.25 mm x 0.5 mm. Two switches on each side of the antenna can control three states of operation. Practical switch operations can be controlled by dc biasing voltage applied simultaneously. The proposed antenna is simulated using FEKO software version 2017.1 and the Electro Magnetic Field solver used is MoM (Method of Moments). If M1 and M2 both are in ON state, the antenna will radiate in X-band (11.02GHz). When M1 is in ON state and M2 is in OFF state the antenna will radiate in Ku-band (14.71GHz). When M1 and M2 both are in OFF state the antenna will work under Ka-band (27.5GHz).

**Figure 2.** Top view of the BTSHRQFA with substrate.

**3. Simulation Results and Discussion**

The simulation of the bow-tie shaped hexagonal rings quasi fractal antenna is done with the FEKO software using MOM analysis.

**Case-1: When Both Switches M1 and M2 are ON**

When both switches M1 and M2 are in ON state, the antenna can work under X-band (8GHz-12GHz). Various parameters of the antenna are tabulated in following Table 1.

| Frequency | Reflection coefficient | SWR | Gain | VSWR BW |
|-----------|------------------------|-----|------|---------|
| 11.02GHz  | 0.0069                 | 1.014 | 1.27dB | 0.67GHz |

The antenna can radiate in X-Band at frequency of 11.02GHz with a \( S_{11} \) as 0.00696 as shown in Figure 3. For an antenna the effective reflection coefficient must be less than 0.33 and the SWR must be in between 1-2. Here we get the approximation results of the designed antenna up to those limits. The dimensions of the substrate are 30mm x 30mm x 0.256mm.

\[ \text{VSWR} = \frac{1+\Gamma}{1-\Gamma} \]

\( \Gamma \) is the reflection coefficient that can be measured with help of voltages or the impedances of the antenna.
Figure 3. Reflection Coefficient of the antenna under X-band.

The directivity and the gain of the antenna is less, in order to increase the gain we may extend the design with help of some reflector materials or by decreasing the impedance matching. There are many chances to increase the directivity and gain of the antenna. The radiation pattern of the farm fields in polar graph and standing wave ratio is shown in Figure 4 and 5 respectively.

Case-2: Switch M1 is ON and Switch M2 is OFF

When the switch M1 is in ON state and M2 is in OFF state the antenna can radiate in Ku-band (12GHz-18GHz). The results of the antenna are listed in Table 2. The antenna can work under Ku-band effectively as the results are up to the good approximation. The reflection coefficient of the antenna under Ku-Band is 0.0503 as shown in Figure 6. This is less than 0.33 which is good approximation and has efficient working of the antenna, the SWR is shown in Figure 7, and the radiation pattern of the far fields in polar graph is shown in Figure 8.

Figure 4. Far- Field radiation pattern in X-band.

Table 2. Parameters of antenna under Ku-band

| Frequency     | Reflection Coefficient | SWR  | Gain       | VSWR BW |
|---------------|------------------------|------|------------|---------|
| 14.71GHz      | 0.0503                 | 1.106| 3.7823dB   | 0.67GHz |

Figure 5. SWR of antenna under X-band.

Figure 6. Reflection Coefficient under Ku-Band.
Figure 7. SWR of antenna under Ku-Band.

Figure 8. Far Field radiation pattern under Ku-band.

Figure 9. Reflection Coefficient of antenna under Ka-Band.

Figure 10. SWR of antenna under Ka-Band.

4. Conclusion

Bow-Tie shaped hexagonal rings quasi fractal antenna using Frequency Reconfiguration has been proposed in this study. The designed antenna can radiate in X-Band (8GHz-12GHz), Ku-Band (12GHz-18GHz) and Ka-Band (26.5GHz-40GHz) effectively with less power loss. Reconfiguration technique can be done with MEMS switches which help for the frequency reconfiguration by changing the length of the antenna.

Table 3. Parameters of antenna under Ka-band

| Frequency | Reflection Coefficient | SWR | Gain   | VSWR BW |
|-----------|------------------------|-----|--------|---------|
| 27.5GHz   | 0.21                   | 1.55| 2.25dB | 0.74GHz |

Case-3: When M1 and M2 both are in OFF State

When both the switches M1 and M2 are in OFF state the antenna can work under Ka-Band (26.5-40GHz). The parameters of the antenna are listed in the Table 3. The Reflection Coefficient of the antenna under Ka-Band is 0.21 which is good to approximation can be shown in
5. References

1. Raman S, Mohanan P, Timmons N, Morrison J. Microstrip-fed pattern- and polarization-reconfigurable compact truncated monopole antenna. IEEE Antennas Wireless Propagation. 2013; 12:710-3. https://doi.org/10.1109/LAWP.2013.2263983

2. Cetiner BA, Crusats GR, Jofre L, Biyikli N. RF MEMS integrated frequency reconfigurable annular slot antenna. IEEE Antennas Wireless Propagation. 2010; 58(3):626-32. https://doi.org/10.1109/TAP.2009.2039300

3. Kulkarni N, Sharma SK. Frequency reconfigurable micro strip loop antenna covering LTE bands with MIMO implementation and wideband micro strip slot antenna all for portable wireless DTV media player. IEEE Antennas Wireless Propagation. 2013; 61(2):964-8. https://doi.org/10.1109/TAP.2012.2223433

4. Cai Y, Guo YJ, Bird TS. A frequency reconfigurable printed Yagi-Uda dipole antenna for cognitive radio applications. IEEE Antennas Wireless Propagation. 2012; 60(6):2905-12. https://doi.org/10.1109/TAP.2012.2194654

5. Anagnostou DE. Design, fabrication, and measurements of an RF-MEMS-based self-similar reconfigurable antenna. IEEE Antennas Wireless Propagation. 2006; 54(2):422-32. https://doi.org/10.1109/TAP.2005.863399

6. Kingsley N, Anagnostou DE, Tentzeris M, Papapolymerou J. RF MEMS sequentially reconfigurable Sierpinski antenna on a flexible organic substrate with novel DC-biasing technique. Journal of Microelectromechanical Systems. 2007; 16(5):1185-92. https://doi.org/10.1109/JMEMS.2007.902462

7. Lizzi L, Massa A. Dual-band printed fractal monopole antenna for LTE applications. IEEE Antennas and Wireless Propagation Letters. 2011; 10:760-3. https://doi.org/10.1109/LAWP.2011.2163051

8. Li DT, Mao JF. A Koch-like sided fractal Bow-Tie dipole antenna. IEEE Antennas and Wireless Propagation Letters. 2012; 60(5):2242-51. https://doi.org/10.1109/TAP.2012.2189719

9. Werner D, Ganguly S. An overview of fractal antenna engineering research. IEEE Antennas and Wireless Propagation Letters. 2003; 45(1):38-57. https://doi.org/10.1109/LAWP.2003.1189650

10. Baliarda CP, Borau CB, Rodero MN, Robert JR. An iterative model for fractal antennas: Application to the Sierpinski gasket Antenna. IEEE Antennas and Wireless Propagation Letters. 2000; 48(5):713-9. https://doi.org/10.1109/8.855489

11. Parron J, Romeu J, Rius JM, Mosig JR. Method of moments enhancement technique for the analysis of Sierpinski pre-fractal antennas. IEEE Antennas and Wireless Propagation Letters. 2003; 51(8):1872-6. https://doi.org/10.1109/TAP.2003.815428

12. Best SR. Operating band comparison of the perturbed Sierpinski and modified Parany gasket antennas. IEEE Antennas and Wireless Propagation Letters. 2002; 1:35-8. https://doi.org/10.1109/LAWP.2002.802584

13. Li L, Wu Z, Li K, Yu S, Wang X, Li T, Li G, Chen X, Zhai H. Frequency-Reconfigurable Quasi-Sierpinski Antenna Integrating With Dual-Band High-Impedance Surface. IEEE Transactions on Antennas and Propagation. 2014; 62(9):4459-67. https://doi.org/10.1109/TAP.2014.2331992

14. Chen KM, Misra DK. X-band microwave life detection system. Bioelectromagnetics. 1984; p. 15-9.

15. Knott EF, Shaeffer JF, Tuley MT. Radar cross section. SciTech Radar and Defense Series (2nd edition). SciTech Publishing. 2004; p. 1-374.

16. Schaub KB, Kelly. Production testing of RF and system-on-a-chip devices for wireless communications. Artech House microwave library. Artech House. 2004; p. 1-93.

17. Munson RE, Haddad H, Hanlen J. Micro strip reflect array antenna for satellite communication and RCS enhancement or reduction. United States Patent. 1987; p. 1-14.

18. Schindler MJ, Miller ME. A 3 bit K/Ka band MMIC phase shifter. IEEE 1988 Microwave and Millimeter-Wave Monolithic Circuits Symposium. Digest of Papers. 1988; p. 95-8.