Sierpinski-Based Conical Monopole Antenna

Petr VŠETULA, Zbyněk RAIDA

Dept. of Radio Electronics, Brno University of Technology, Purkyňova 118, 612 00 Brno, Czech Republic

xvsetu00@stud.feec.vutbr.cz, raida@feec.vutbr.cz

Abstract. *Planar Sierpinski monopole exhibits a multi-band behavior, but its parameters in operation frequency bands are not optimal. By mapping the Sierpinski monopole on a conical surface, a symmetrical three-dimensional (3-D) structure is obtained. In this way, a larger bandwidth and a better radiation pattern is achieved. The symmetrical 3D Sierpinski-based monopole is an original contribution of this paper.*

In the paper, different versions of the conical Sierpinski-based monopole are designed, and results of simulations performed in CST Microwave Studio are mutually compared. Then, the simulated versions of the conical monopole are optimized according to specified criteria. The optimized conical Sierpinski-based monopole is manufactured and its properties are experimentally verified. Results of measuring the Sierpinski-based conical monopole antenna are published here for the first time.

Keywords

Sierpinski monopole, multi-band antenna, conformal antenna, fractals, conical monopole.

1. Introduction

In today's communication devices, multi-band antennas play a relevant role. The multi-band behavior of the antenna can be obtained by applying self-similarities of fractals [1]. The number of operation frequency bands depends on the number of fractal iterations then [2].

In this paper, ways of converting a planar version of the Sierpinski monopole to the conformal, conical antenna are discussed. Following the described way, two versions of the conical monopoles can be created. The designed antennas are modeled in CST Microwave Studio and their properties are mutually compared. The first kind of the conical monopole antenna was published in [3], and the second one is an original contribution of this paper.

The designed conical Sierpinski-based monopole is optimized using particle swarm optimization (PSO) and the Nelder-Mead simplex algorithm to reach a proper impedance matching in specified frequency bands. The optimized antenna is measured and results are compared with simulations.

In Section 2, properties of a planar Sierpinski monopole and the modified gasket monopole antenna are briefly reviewed [4]. In Section 3, planar versions of antennas are projected to the conical surface [4]. Section 4 deals with the optimization of designed antennas, and Section 5 presents experimental results. Section 6 concludes the paper.

2. Planar Sierpinski Monopole

The planar Sierpinski monopole of the third order (Fig. 1) is created by 3 self-similar elements (equilateral triangles). The antenna is attached to the perfectly electrically conducting ground plane. At the antenna input, the SMA connector is assumed [4].

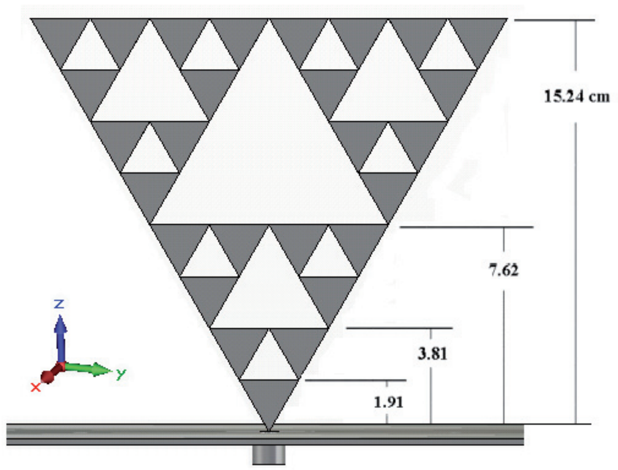


Fig. 1. Sierpinski monopole.

In frequency response of the return loss (Fig. 2), the multi-band behavior can be observed (the first band reaches $|S_{11}| = -9.74$ dB, the next three bands exhibiting $|S_{11}| < -10$ dB for the reference impedance 50 Ω) [4].

The lowest operation frequency is determined by the dimensions of the basic bowtie monopole. The higher operation frequencies are determined both by the basic bowtie structure and the triangular slots (the higher fractal iterations) [4].

In the left-hand part of Tab. 1, magnitudes of S_{11} at the input of the planar Sierpinski monopole at the operation frequencies are summarized. Obviously, S_{11} does not reach the optimal values and bandwidths are narrow.

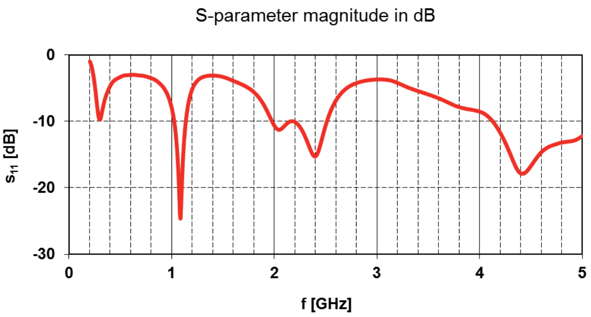


Fig. 2. Frequency response of the planar Sierpinski monopole return loss.

In order to improve the impedance matching, the concept of the modified gasket monopole antenna (Fig. 3) can be adopted [3]. The vertical distance of the slot from the ground plane equals to the height of the smallest triangles of the Sierpinski structure [4].

Sierpinski monopole			Modified gasket monopole		
f [GHz]	S_{11} [dB]	BW [MHz]	*f* [GHz]	S_{11} [dB]	BW [MHz]
0.29	–9.74	71	0.31	–8.17	145
1.08	–24.63	25	1.18	–21.34	51
2.39	–15.28	180	2.66	–17.65	126
4.41	–17.89	243	4.63	–33.33	48

Tab. 1. Return loss of the conventional Sierpinski monopole (left) and the modified gasket monopole (right) at operation frequencies. Planar structure assumed.

Frequency response of S_{11} of the modified gasket monopole is depicted in Fig. 4. In the right-hand part of Tab. 1, magnitudes of S_{11} at operation frequencies are compared with the values of the Sierpinski monopole. The responses are similar.

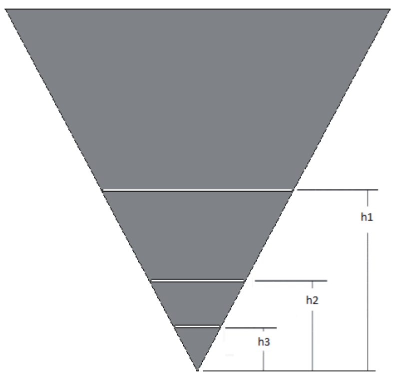


Fig. 3. Planar gasket monopole antenna.

Radiation patterns of both planar antennas exhibit asymmetries caused by their asymmetrical geometry (Fig. 14 and Fig. 15). In order to obtain the omni-directional pattern in the horizontal plane, geometries of planar antennas are projected into the conical surface [4].

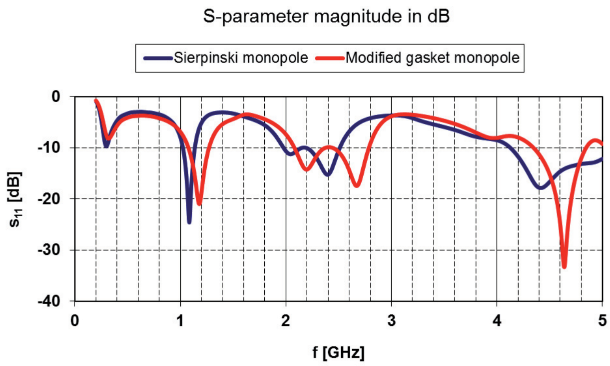


Fig. 4. Frequency response of return loss of the planar Sierpinski monopole (blue) and the gasket monopole antenna (red). Planar structures.

3. Conical Sierpinski-Based Monopole

In order to improve the symmetry of the radiation and to make the bandwidth wider, the planar structure is mapped [3] to the conical surface (Fig. 5).

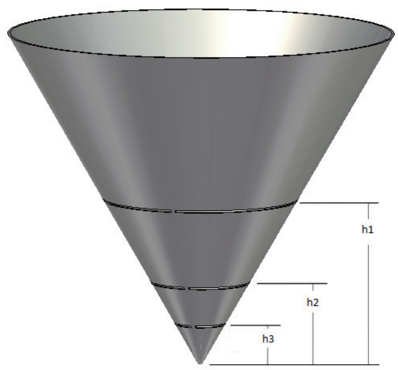


Fig. 5. Conical gasket monopole antenna.

Thanks to the conical shape, the omni-directional radiation and wider operation bandwidth are reached [3]. Heights of segments of the conical gasket monopole are identical with lengths of segments of the planar antenna.

Frequency response of the reflection coefficient at the antenna input S_{11} is depicted in Fig. 7. Magnitudes of the reflection coefficient in operation frequency bands are summarized in the right part of Tab. 2.

Next, the layout of the planar Sierpinski monopole was mapped to the conical surface (Fig. 6). The mapping resulted in an asymmetrical geometry. Heights of triangles of the conical antenna are identical with heights of triangles of the planar Sierpinski monopole.

The frequency response of the magnitude of the reflection coefficient S_{11} at the input of the conical Sierpinski-based monopole (Fig. 7) is similar to the characteristics of the planar Sierpinski monopole.

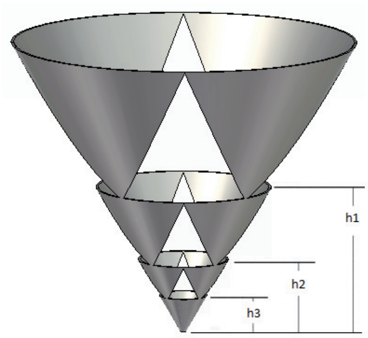


Fig. 6. Conical Sierpinski-based monopole.

Values of S_{11} of the conical Sierpinski-based monopole in operation bands are given in the left-hand part of Tab. 2. Operation bands of the conical gasket monopole are shifted downwards, and the improvement of bandwidth with lower frequency is visible.

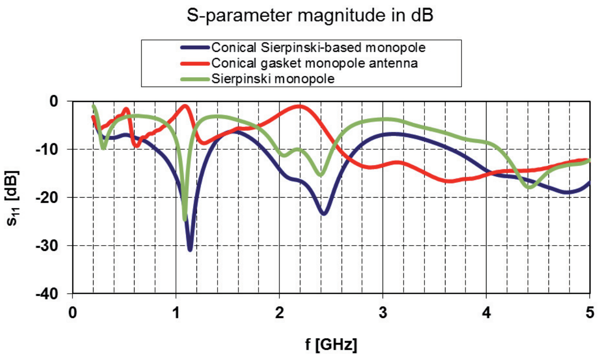


Fig. 7. Frequency response of return loss of the conical Sierpinski-based monopole (blue) and the gasket one (red). Conical structures.

Radiation patterns of the conical gasket monopole are depicted in Fig. 17. Here, the power improvement as well as the similarity of the radiation spectrum is obvious. The conical Sierpinski-based monopole produces two beams (Fig. 16), similar to a conventional monopole. Due to the symmetry of the structure in the vertical plane, an omni-directional radiation character was achieved.

Conical Sierpinski-based monopole			Conical gasget monopole antenna		
f [GHz]	S_{11} [dB]	BW [MHz]	*f* [GHz]	S_{11} [dB]	BW [MHz]
0.38	–7.57..	-	0.24	–6.94..	-
1.13	–31.01..	76	0.60	–10.21..	231
2.42	–23.37..	16	1.25	–8.84..	368
4.74	–18.97..	476	2.87	–13.21..	-

Tab. 2. Magnitude of S_{11} at the input of the conventional Sierpinski-based monopole (left) and the conical gasket monopole antenna (right) at operation frequencies. Conical structures assumed.

4. Optimization

The conical gasket monopole and the conical Sierpinski-based monopole were optimized to meet impedance matching conditions in the bands of GSM 900, GSM 1800 and Wi-Fi (see Tab. 3).

Band	Frequency [GHz]	Bandwidth [GHz]
GSM 900	0.9	0.89 – 0.96
GSM 1800	1.8	1.71 – 1.88
Wi-Fi (802.11b)	2.4	2.40 – 2.47

Tab. 3. Operation frequency bands [5].

The return loss was asked to be $|S_{11}| < -10$ dB in all the frequency bands. In order to meet this goal, the optimization routine computed the heights of slots. The upper diameter of the monopole and the height of the whole structure remained the same.

The optimal parameters are listed in Tab. 4. Frequency response of the return loss is depicted in Fig. 8. Whereas the optimization of the conical gasket monopole was not successful, the Sierpinski-based monopole shows better results.

The geometry of the optimized conical Sierpinski-based monopole is depicted in Fig. 9.

Parameter	Height [mm]	
	Optimized conical Sierpinski-based monopole	Optimized conical gasket monopole
h1	124.184	85.5871
h2	49.5876	28.8998
h3	46.6387	19.6753

Tab. 4. Resulting parameters of the optimized conical monopoles.

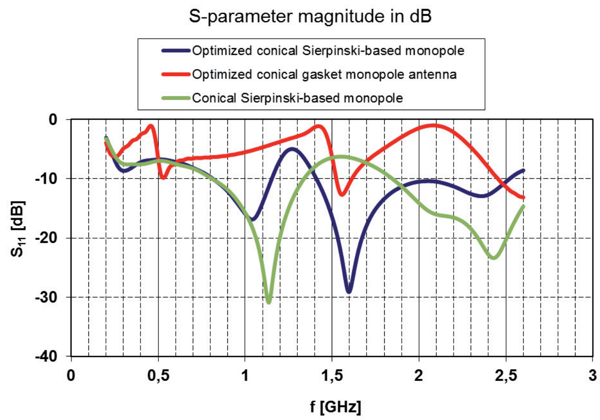


Fig. 8. Frequency response of return loss of the Sierpinski-based monopole (blue) and the gasket one (red). Conical optimized structures.

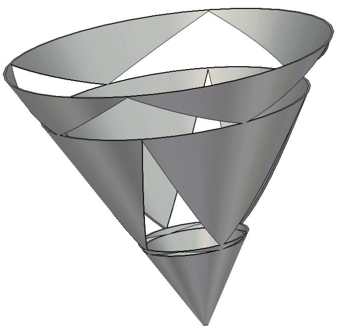


Fig. 9. Optimized conical Sierpinski-based monopole.

5. Experimental Verification

In order to fabricate the antenna, a planar layout (Fig. 10) is developed. The developed layout is printed on a thin substrate, and the substrate is formed into the cone.

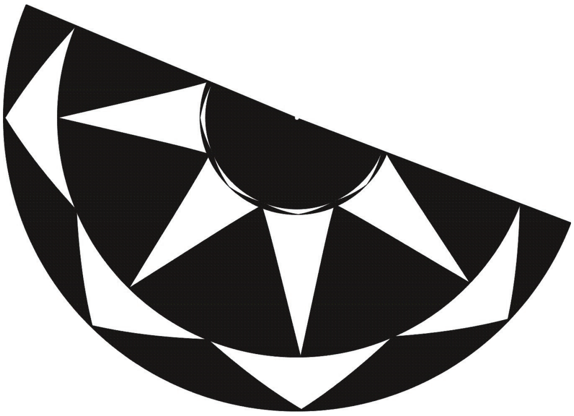


Fig. 10. The developed cone shell.

A thin substrate FR-4 of height $h = 0.8$ mm and dielectric constant $\varepsilon_r = 4.4$ was used. The antenna was fed by a SMA connector. The produced antenna is shown in Fig. 11.

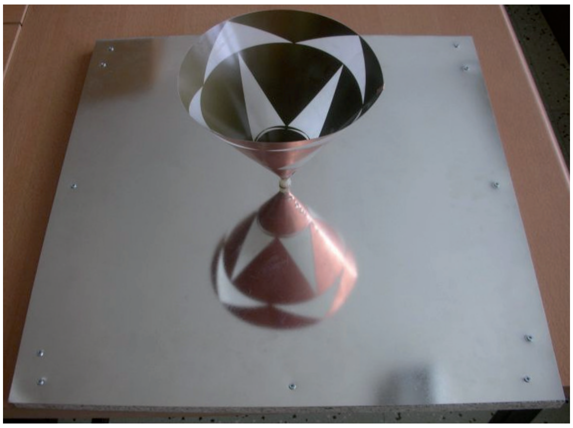


Fig. 11. The produced optimized conical Sierpinski-based monopole.

Fig. 12 shows the comparison of the computed and measured frequency response of the return loss of the Sierpinski-based antenna. The correspondence between measurements and computations is quite good.

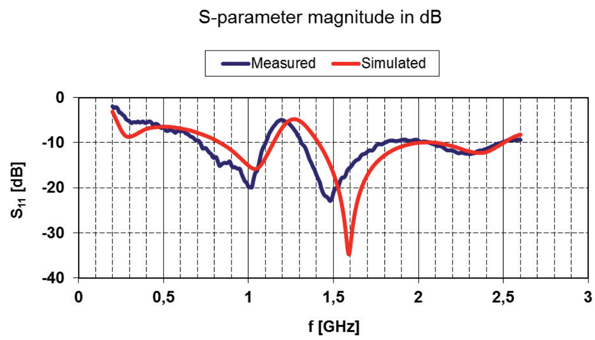
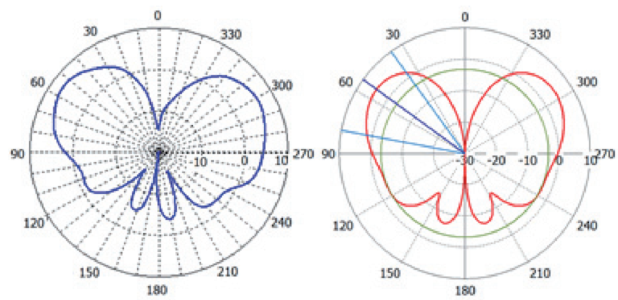


Fig. 12. Frequency response of return loss of the measured (blue) and the simulated (red) optimized fabricated conical Sierpinski-based monopole.

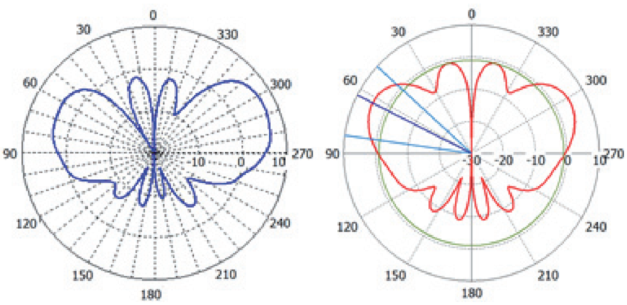
In Tab. 5, values of the return loss in operational bands are listed. Fig. 13 presents the comparison of measured and computed radiation patterns of the optimized conical Sierpinski-based monopole in E plane. Thanks to the symmetry of the monopole, the characteristics are depicted for φ = 0˚ and φ = 180˚ only. The correspondence between computations and measurements is obvious.

Measured		Simulated		
f [GHz]	S_{11} [dB]	*f* [GHz]	S_{11} [dB]	BW [MHz]
1.02	–19.92..	1.04	–15.85..	165
1.48	–22.92..	1.59	–34.79..	47
2.31	–12.51..	2.36	–12.29..	-

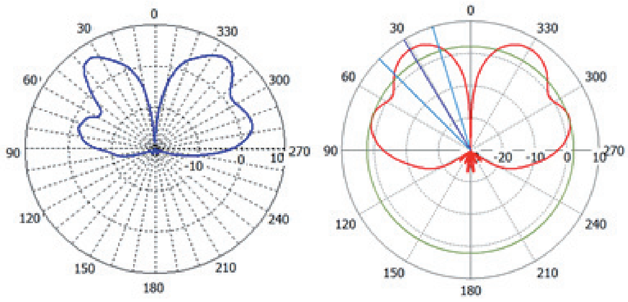
Tab. 5. Return loss of optimized conical Sierpinski-based monopole.



a) 1.02 GHz



b) 1.48 GHz



c) 2.31 GHz

Fig. 13. Radiation patterns of measured (blue) and simulated (red) conical Sierpinski-based monopole.

6. Conclusions

Conical fractal antennas were derived from the planar Sierpinski structure. By mapping the planar layout to the conical surface, better omni-directional radiation and wider bandwidth were reached.

The conical gasket monopole exhibits the shift of operating bands and the impedance matching is worse compared to the conical Sierpinski-based monopole. The bandwidth of both the antennas was increased.

Radiation properties of both the conical monopoles were improved. Moreover, resonances in similar operation frequency bands were reached.

Operation bands were tuned for the conical Sierpinski-based monopole, and the resultant antenna was fabricated. The measured results slightly differ from the simulations.

The conical Sierpinski-based monopole exhibits good impedance matching and good radiation properties. On the other hand, the size of this monopole is large and the manufacturing is complicated.

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About Authors

Petr VŠETULA was born in Kyjov, Czech Republic in April 1985. He graduated at the Faculty of Electrical Engineering and Communication (FEEC), Brno University of Technology (BUT), in 2010.

Zbyněk RAIDA received Ing. (M.Sc.) and Dr. (Ph.D.) degrees from the Brno University of Technology in 1991 and 1994, respectively. Since 1993, he has been with the Dept. of Radio Electronics, FEEC BUT as assistant professor (1993 to 1998), associate professor (1999 to 2003), and professor (since 2004). In 1997, he spent 6 months at the Laboratoire de Hyperfrequences, Universite Catholique de Louvain, Belgium as an independent researcher. Zbynek Raida has authored or coauthored more than 100 papers in scientific journals and conference proceedings. His research is focused on numerical modeling and optimization of electromagnetic structures, application of neural networks to modeling and design of microwave structures, and on adaptive antennas. Prof. Raida is a member of the IEEE Microwave Theory and Techniques Society and since 2003 Senior Member of IEEE. He chaired the MTT/AP/ED joint section of the Czech-Slovak chapter of IEEE (2001- 2003).

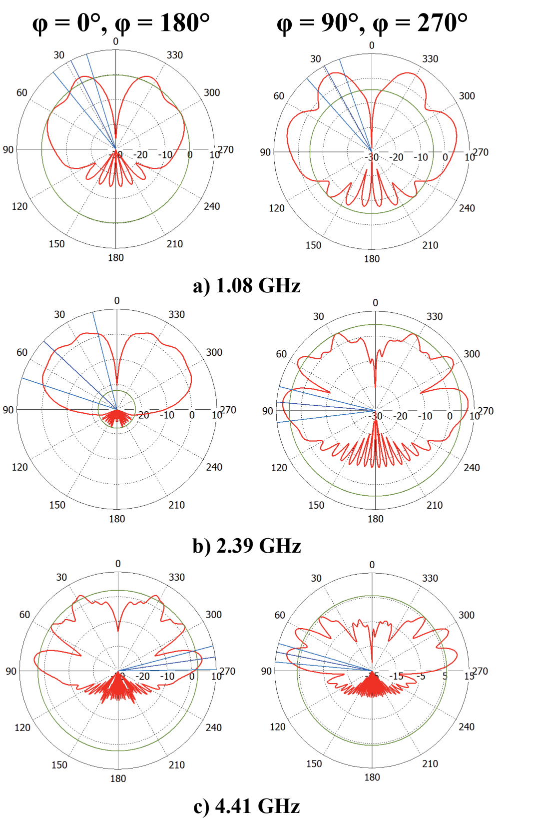

Fig. 14. Simulated radiation patterns of planar, conventional Sierpinski monopole.

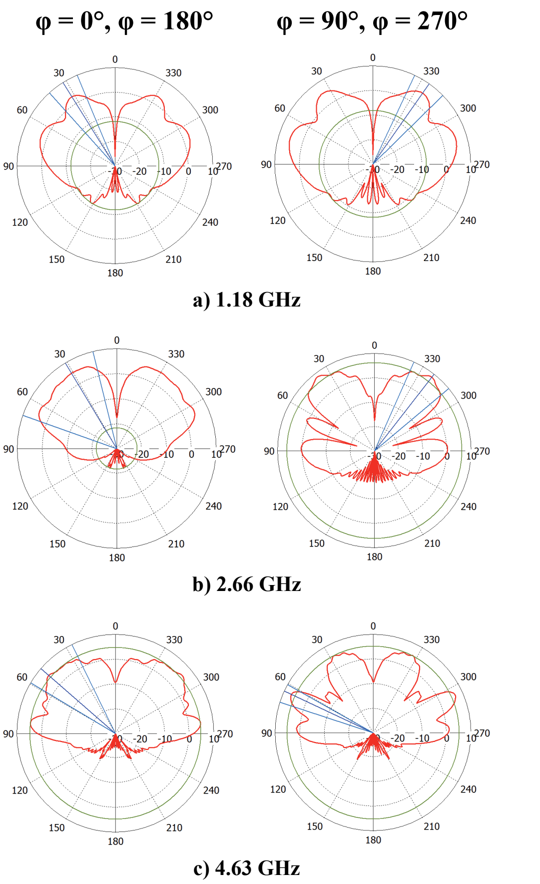

Fig. 15. Simulated radiation patterns of planar, modified gasket monopole.

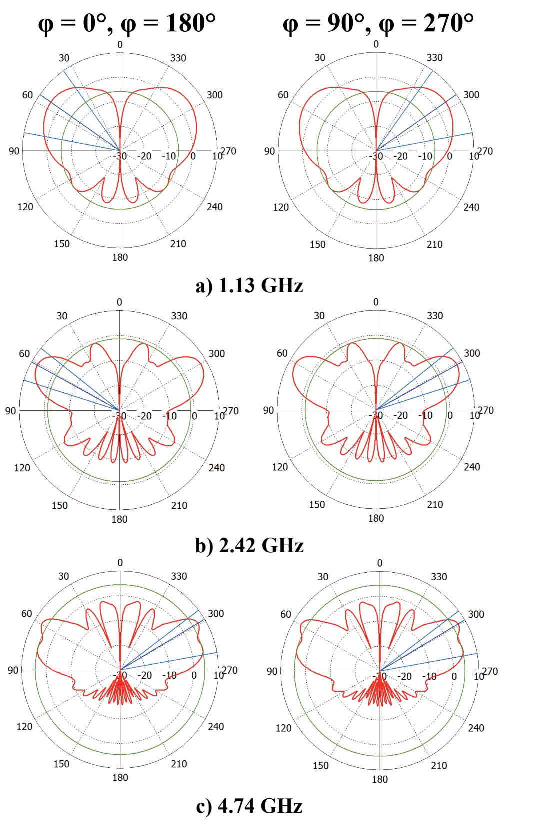

Fig. 16. Simulated radiation patterns of conical Sierpinski-based monopole.

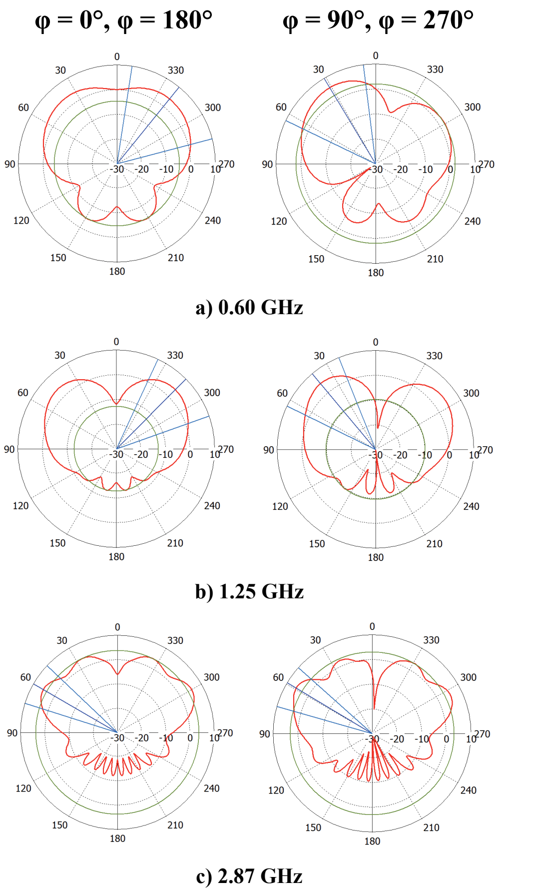

Fig. 17. Simulated radiation patterns of conical gasket monopole antenna.