Progress In Electromagnetics Research Letters, Vol. 36, 113–120, 2013

IMPROVED BANDWIDTH WAVEGUID BANDPASS FILTER USING SIERPINSKI FRACTAL SHAPED IRISES

Abbas A. Lotfi-Neyestanak[1,*], Seyed M. Seyed-Momeni[2], and Mohammad R. Haraty[2]

[1]Department of Engineering, Shahr_e_Rey Branch, Islamic Azad University, Tehran, Iran

[2]Faculty of Enginnering, Scince and Research Branch, Islamic Azad University, Tehran, Iran

Abstract—This paper presents a novel waveguide band pass filter using Sierpinski fractal-shaped irises. The bandwidth of the proposed filter is more than 5.5 times in comparison to similar waveguide filter with rectangular shape iris. The offered filter is designed and simulated using Ansoft HFSS and then fabricated. The results show less than 0.5 dB insertion loss and return loss better than 13 dB in operation frequency band for the proposed filter.

1. INTRODUCTION

Waveguide band pass filters are frequency-selective circuits or devices that perform valuable functions in microwave equipment used in communications, electronic warfare, radar, automatic test equipment and various microwave multiplexers [1, 2].

Waveguide band pass filters with cavity have benefits such as characteristic stability and small losses, but there are major challenge in designing them, for example high weight and dimension. Previous researches contain many different filtering structures that employ directly coupled microwave resonators of various shapes, such as inductive and capacitive irises with stub and circular or arbitrary shaped posts, rods and diaphragms [3–6].

In the approach direct-coupled waveguide resonator filters are designed by starting from a prototype with inverter-coupled lumped-element resonators. The resonators are then replaced by the distributed equivalent elements by equating the susceptance slops of

Received 8 October 2012, Accepted 1 December 2012, Scheduled 4 December 2012
* Corresponding author: Abbas Ali Lotfi-Neyestanak (alotfi@iust.ac.ir).

the actual resonators to those of the lumped-element resonators at the band pass center frequency. Inverters are then replaced by their practical equivalents that involve a shunt reactance surrounded by waveguide pieces with negative lengths [1, 8].

In the last several years, microwave filters have been used in various types of applications in communication systems. However, in recent years the rapidly growing demand for portable systems has lead to the need for low profile and cost effective systems [7].

Using fractal iris is one of the techniques to compact the size of filters. Fractal geometry optimizes the shape of the filter in iteration to increase its electrical size. Fractals are geometrical shapes, which are self-similar, that means some of their parts have the same shape as the whole object but at a different scale [9, 10].

Fractal-shaped antenna elements present various advantages: wide bandwidth, multiband, miniaturization, and high directivity [10, 11].

In [12], a waveguide band pass filter with Koch fractal-shaped irises is presented. By applying first iteration Koch fractal-shaped irises, the bandwidth is increased and the overall size is reduced in comparison to a waveguide filter with rectangular-shaped irises.

To fabricate a waveguide bandpass filter, many approaches such as filling waveguide by multi-layer dielectrics [13] or by using substrate integrated waveguides (SIWs) can be found in literature [14]. However its disadvantage is the large length which, can be reduced to some extent by using folded and half-mode SIWs [14].

In this paper, a novel waveguide bandpass filter with Sierpinski geometry as a periodic structure is designed and fabricated. The advantages of the proposed structure are its greater bandwidth in comparison with conventional waveguide filter with rectangular iris.

2. THEORY AND DESIGN

In this section, we provide a common step by step design for a band pass waveguide filter based on Chebyshev approximation. The approximate center frequency is located at 9.25 GHz and the filter bandwidth is about 1.5 GHz, the ripple in pass band is 0.5 dB.

A WR-90 waveguide (0.9 in × 0.4 in) is selected as the primary frame for the waveguide filter. The guide wavelength can be calculated as:

$$\lambda_g = \frac{1}{\sqrt{(0.08472f)^2 - (1/2a)}} \tag{1}$$

where a is the waveguide width in inches and f the frequency in GHz. With respect to the Chebyshev filter design equation the orders of filter have obtain to $n = 5$ and lamped elements prototype for equivalent low pass filter with 0.5 dB ripple by considering $g_0 = 1$, $g_{n+1} = 1$ and $w' = 1$ are extracted from [1]. For $n = 5$, we have:

$$\begin{aligned}\frac{K_{01}}{Z_o} &= \frac{K_{56}}{Z_o} = \sqrt{\frac{\pi}{2}\frac{w_\lambda}{g_0 g_1 w'_1}} \\ \frac{K_{12}}{Z_o} &= \frac{K_{45}}{Z_o} = \frac{\pi w_\lambda}{2w'_1}\frac{1}{\sqrt{g_1 g_2}} \\ \frac{K_{23}}{Z_o} &= \frac{K_{34}}{Z_o} = \frac{\pi w_\lambda}{2w'_1}\frac{1}{\sqrt{g_2 g_3}} \\ w_\lambda &= \frac{\lambda_{g1} - \lambda_{g2}}{\lambda_{g0}}\end{aligned} \tag{2}$$

and

$$\begin{aligned}&\frac{X_{j,j+1}}{Z_o} = \frac{\frac{K_{j,j+1}}{Z_o}}{1 - \left(\frac{K_{j,j+1}}{Z_o}\right)^2} \\ &\frac{X_{01}}{Z_o} = \frac{X_{56}}{Z_o} \qquad \frac{X_{12}}{Z_o} = \frac{X_{45}}{Z_o} \qquad \frac{X_{23}}{Z_o} = \frac{X_{34}}{Z_o}\end{aligned} \tag{3}$$

All parameters are defined in [1]. By considering the ratio $a/\lambda = 0.12$, we can obtain the gap between each pair of irises. Therefore, we have:

$$d_1 = d_6 = 0.337,\ d_2 = d_5 = 0.193,\ d_3 = d_4 = 0.175$$

and the separation between irises in inches is found by using the following formula [1].

$$\theta_j = \pi - \frac{1}{2}\left(\tan^{-1}\frac{2X_{j-1,j}}{Z_o} + \tan^{-1}\frac{2X_{j,j+1}}{Z_o}\right) \quad j = 1, \ldots, n \tag{4}$$

and then these angles in radians are converted to lengths in inches by using the rule that:

$$l_i = \frac{\theta_i \lambda_{g0}}{2\pi} \quad i = 1, \ldots, n \tag{5}$$

so that we have:

$$l_1 = l_5 = 0.702,\ l_2 = l_4 = 0.748,\ l_3 = 0.752$$

In this design, we used Sierpinski fractal iris to enhance the bandwidth of proposed filter instead of rectangular one.

As it can be seen in Figure 1, in Sierpinski fractal, the triangle is decreased to 1/2 height and width, make three copies, and position the three shrunken triangles so that each triangle touches the two other

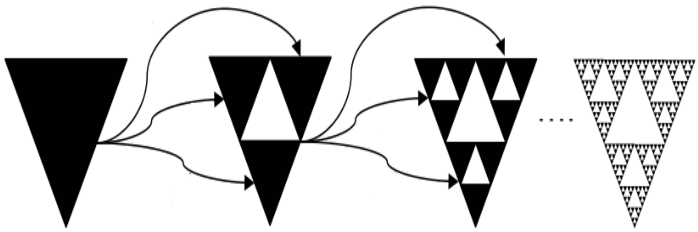


Figure 1. The construction stages of the Sierpinski triangle.

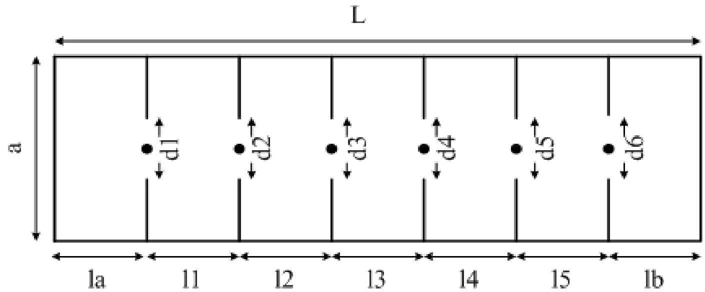


Figure 2. Horizontally intersected view of proposed filter.

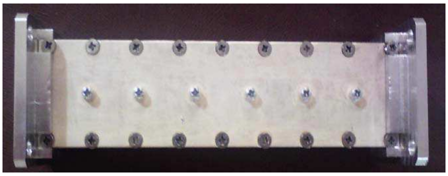
Table 1. Characterizing parameter values of the proposed filter ($a = 0.9$ inch, $L = 5.264$ inch).

parameters	$d_1 = d_6$	$d_2 = d_5$	$d_3 = d_4$	$l_a = l_b$	$l_1 = l_5$	$l_2 = l_4$	l_3	a	L
Values (inches)	0.337	0.193	0.175	0.778	0.702	0.748	0.7518	0.9	5.264

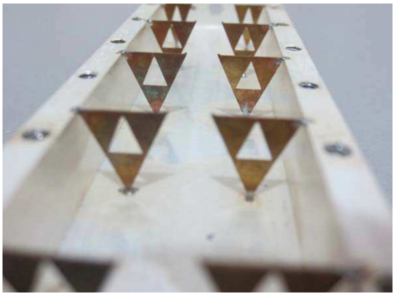
triangles at a corner. With similar iteration for each smaller triangle, the Sierpinski fractal can be made. This fractal is strictly self-similar because its parts are identical replicas of the whole structure. The self-similarity in the Sierpinski fractal geometry can be used to achieve multiple bandwidths and increase bandwidth of each single band.

3. FABRICATION AND MEASUREMENT

The proposed filter with Sierpinski fractal iris, shown in Figure 2, was fabricated based on the dimensions specified in Table 1. The Filter was fabricated on WR90 waveguide. A photograph of the fabricated filter is shown in Figure 3.



(a)



(b)

Figure 3. Photograph of the fabricated filter. (a) Top view. (b) Inside view.

Table 2. Comparison of different irises for a waveguide filter at X-band.

Iris types							
Bandwidth (MHz)	260 Ref. [12]	1410	1380	1290	1680	1320	1450
Band Path Ripple (dB)	1	1	1	1	1	1	0.5
Fabrication E: Easy, D: Difficult	E	E	D	D	D	E	E
Bandwidth Enlargement	1 times	5.42 times	5.31 times	4.96 times	6.46 times	5.08 times	5.58 times

A comparison of different irises with conventional rectangular shape iris [12] is presented in Table 2. As it can be seen, by using the Sierpinski fractal iris, the bandpass of the proposed filter can be increased while the bandpass ripple is decreased into 0.5 dB. It is also easy to fabricate compared to its counterparts.

The measured and simulated results of the fabricated filter with are in good agreement. The measured insertion loss in the pass band

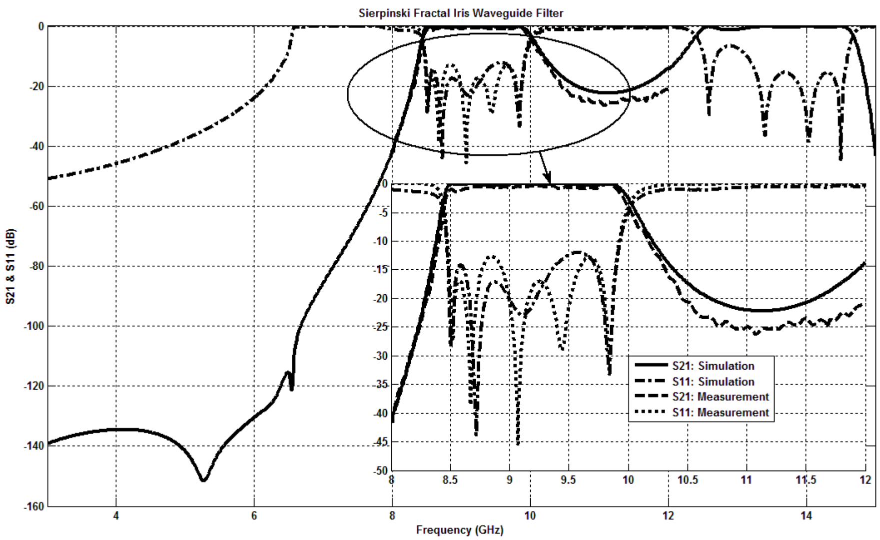


Figure 4. Simulated and measured S-parameters for the proposed filter.

remains less than 0.5 dB, and the return loss is better than 10 dB throughout the pass band. The filter was simulated with Ansoft's High-Frequency Structure Simulator (HFSS$^{\text{TM}}$) and the return-loss was measured using the Agilent 8722ES Network Analyzer (50 MHz–40 GHz).

Each fractal structure is formed from a collection of scaled versions of the primary generator. Therefore, different resonant frequencies that are dependent on the scaling factor of the fractal will be created. If these resonant frequencies are sufficiently close to each other, they will overlap, and consequently, overall bandwidth will increase. On the other hand, the overall size of the proposed filter is extremely decreased. This means that this new structure operates in the center frequency equal to a waveguide filter with rectangular irises, but with a considerable lower volume.

The simulated and measured S-parameters responses of the proposed filter, which are in good agreement, are presented in Figure 4. Since the cutoff frequency of WR-90 is 6.56 GHz, below this frequency nothing can pass through the waveguide. As can be seen from the figure, this filter has also a wide passband with fairly low loss at X-band compared to the conventional filter. It can also be tuned for use in the dual band (X/Ku).

4. CONCLUSION

In this paper, a novel Sierpinski fractal waveguide for a center frequency of 9.25 GHz with 1.45 GHz bandwidth has been simulated and fabricated. This filter can be used in a variety of X-band applications such as phase array antenna systems, satellite and space communications. The simulation and measurement results show good agreement. By using fractal-shaped irises, the filter bandwidth is increased while the overall size of structure is decreased.

REFERENCES

1. Matthaie, G. L., L. Young, and E. T. Jones, *Microwave Filters, Impedance Matching Networks and Coupling Structures*, Artech House, Norwood, MA, Feb. 1980.
2. Pozar, D. M., *Microwave Engineering*, Addison-Wesley, 1990.
3. Levy, R., R. V. Snyder, and G. Matthaei, "Design of microwave filters," *IEEE Trans. Microwave Theory Tech.*, Vol. 50, 783–793, 2002.
4. Khalaj-Amirhosseini, M., "Microwave filters using waveguides filled by multi-layer dielectric," *Progress In Electromagnetics Research*, Vol. 66, 105–110, 2006.
5. Bahrami, H., M. Hakkak, and A. Pirhadi, "Analysis and design of highly compact bandpass waveguide filter utilizing complementary split ring resonators (CSRR)," *Progress In Electromagnetics Research*, Vol. 80, 107–122, 2008.
6. Lotfi Neyestanak, A. A. and D. Oloumi, "Waveguide band-pass filter with identical tapered posts," *Journal of Electromagnetic Waves and Applications*, Vol. 22, Nos. 17–18, 2475–2484, 2008.
7. Cameron, R. J., R. Mansour, and C. M. Kudsia, *Microwave Filters for Communication Systems: Fundamentals, Design and Applications*, Wiley-Interscience, Hoboken, NJ, 2007.
8. Ghorbaninejad, H. and M. Khalaj-Amirhosseini, "Compact bandpass filters utilizing dielectric filled waveguides," *Progress In Electromagnetics Research B*, Vol. 7, 105–115, 2008.
9. Puente, C., J. Romeu, R. Pous, and A. Cardama, "On the behavior of Sierpinski multiband fractal antenna," *IEEE Trans. Antennas Propag.*, Vol. 46, No. 4, 517–524, 1998.
10. Kordzadeh, A. and F. H. Kashani, "A new reduced size microstrip patch antenna with fractal shaped defects," *Progress In Electromagnetics Research B*, Vol. 11, 29–37, 2009.
11. Anguera, J., J. P. Daniel, C. Borja, J. Mumbrü, C. Puente,

T. Leduc, N. Laeveren, and P. Van Roy, "Metallized foams for fractal-shaped microstrip antennas," *IEEE Antennas Propag. Mag.*, Vol. 50, No. 6, 20–38, Dec. 2008.

12. Oloumi, D., A. Kordzadeh, and A. A. Lotfi Neyestanak, "Size reduction and bandwidth enhancement of a waveguide bandpass filter using fractal-shaped irises," *IEEE Antennas and Wireless Propagation Letters*, Vol. 8, 2009.
13. Khalaj-Amirhosseini, M., "Microwave filters using waveguides filled by multi-layer dielectric," *Progress In Electromagnetics Research*, Vol. 66, 105–110, 2006.
14. Wang Z., X. Li, S. Zhou, B. Yan, R.-M. Xu, and W. Lin, "Half mode substrate integrated folded waveguide (HMSIFW) and partial H-plane bandpass filter," *Progress In Electromagnetics Research*, Vol. 101, 203–216, 2010.