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Design of Fractal- Based Bandstop Filter for Microwave Radiation Leakage Reduction

Abstract- *There is a continuing concern over the risks associated with the use of microwave ovens because of the probable effects of the radiation leakage on the health of the individuals. In this paper, a new microstrip bandstop filter BSF is presented, designed and measured as an attempt to reduce the radiation leakage from the domestic microwave ovens operating at 2.45 GHz. The proposed BSF is composed of fractal based open-loop resonators coupled with an open-stub transmission line. The open-loop resonators are in the form of modified Minkowski fractal geometry of the 1st iteration. The open stubs have been adopted to increase the selectivity of the filter stopband response. The suggested filter is designed at 2.45 GHz. Modeling and performance assessments of the proposed filter have been evaluated by means of the computer software technique CST Microwave Studio and the Sonnet EM simulator. Simulation results reveal that the modeled filter offers stopband response with high selectivity. A prototype of the proposed filter is fabricated. The size limitations of the microwave oven opening width have been taken into account. Good agreement has been found between measured and simulated results. Four arrays of such a filter have been implemented to cover the microwave oven door frame taking into consideration the opening dimensions such that it well fit it. Measured radiated electric fields from the oven show that it considerably reduces the leaked radiation. By suitable choice of substrate material and carrying out the required dimension scaling, the proposed design idea is flexible and can be generalized for use with a wide variety of microwave equipment in which microwave leakage represents a serious issue.*

Keywords-*Fractal-based BSF; Electromagnetic modeling and simulation; Minkowski fractal geometry; EM leakage reduction.*

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1. Introduction

Microwave ovens have shown a dramatic use for domestic applications. Since it is necessary that the human is in the nearby areas when these appliances are working, there is an increased concern regarding the microwave oven leakage. The most probable leakage path is the gap between the microwave oven body and its door. This door should be projected for preventing electromagnetic leakage. The size of the gap and its geometric configuration will affect the leakage level. Seal structures with pressure latch systems are first used to provide close contact between the door and frontal panel of the oven. This system has shown to be inefficient for long-time functioning due to metal deformation. However, many of the recently manufactured microwave ovens adopt an alternative system consisting of a choke structure of quarter-wavelength in dimension usually accompanied by periodic slits [1]. An attempt, to reduce the RF radiation from the microwave ovens, has been performed as reported in [2], where the metamaterials have been used as mushroom-like periodic structures to design the proposed BSF. In this paper, a new Minkowski fractal based resonators BSF is proposed for the reduction of the RF radiation from microwave ovens. Fractal geometries are distinguished by two exclusive properties; space-filling and self-similarity. These properties have opened new and essential approaches for antennas and electronic solutions in the course of the most recent 25 years. Additionally, fractals give another era of optimized design tools, initially utilized effectively in antennas but applicable in a general manner [3]. In this context, fractal geometries have been applied to the conventional microstrip resonators which are successfully adopted to design compact microwave microstrip filters and planar circuits. Based on the conventional square patch, Sierpinski carpet has been applied to design a dual-mode microstrip bandpass filter [4]. Other fractal geometries, such as Hilbert [5-7], Moore [8] and Koch [9-10] have also been suggested to design compact size BPFs. Peano fractal geometries have been successfully applied to the conventional resonators to produce high performance miniaturized single mode and dual-mode microstrip bandpass filters [11-14]. The considerable space-filling property of this fractal geometry makes it an attractive choice to design

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bandpass filters with high size reduction levels. Owing to its high space-filling property, Minkowski fractal based microstrip resonators have more attracted microwave filter designers to be successfully utilized in the design miniaturized dual-mode microstrip ring resonator BPFs and BSFs [15-24]. Also, Minkowski Island has been applied to construct a hairpin BPF with harmonic suppression.

2. The proposed BSF Filter Design

The idea behind the proposed filter design is based that reported in [25,26], but with a modified configuration. The perimeter of the coupled open-ring resonators besides the substrate parameters governs the stopband resonant frequency. The most important feature of the BSF that makes it different from BPF is that it prevents the signals to pass at a particular frequency. The first stage of the design of the BSF is square open-loop shown in Figure 1. To validate the square open-loop resonator as BSF, it is simulated using a substrate with a dielectric constant of 3.5 and thickness of 1.5 mm.

To enhance the matching with the 50Ω ports, the width of the transmission line is w = 3.342 mm, the overall size of the filter becomes 34×34 mm2 at the center frequency of 2.4 GHz, and level of insertion losses is –24 dB and –3 dB bandwidth is between 2.351 GHz and 2.55 GHz. There are two zeros at the two sides of BSF located at 2.32 GHz and 2.52GHz. These two zeros make the BSF more stable.

The yellow colors represent the copper material. The dimensions of the BSF; Lo = 11.6 mm, s = 0.64 mm, g = 0.95 mm the trace width wc = 0.89 mm.

The presented BSF configurations suggested in this work will consist of four open-loop resonators. Each filter structure will be based on a specified iteration level of the Minkowski fractal structures as demonstrated in Figure 2. The shape modification of the filter structure according to those in Figure 2 is a way to increase the surface current path length. Consequently, this will result in a reduced resonant frequency or a reduced resonator size if the design frequency is to be maintained [18].

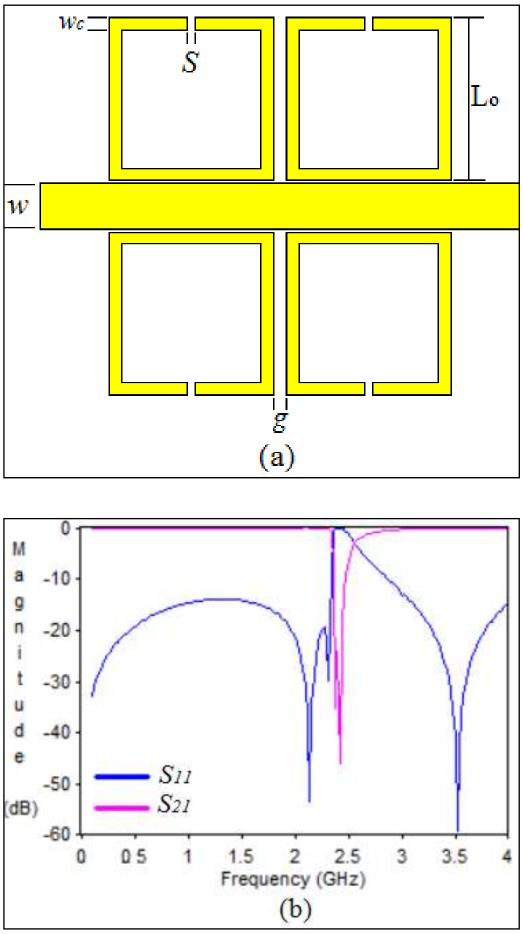


Figure 1: Square open loop BSF (a) Layout of BSF (b) The related response

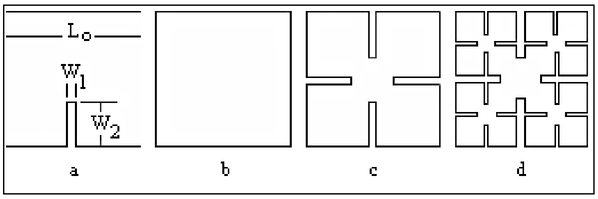


Figure 2: The Minkowski fractal geometry: (a) the generator, (b), (c) and (d) represent the zero, the 1st, and the 2nd iteration levels respectively [18].

It is clear that; using ring structures based on higher iteration levels will permit the design of highly miniaturized filters. The perimeter Pn of the nth iteration is given by [18]:

$$P_n = \left(1 + 2\frac{w_2}{L_o}\right) P_{n-1} \quad (1)$$

where w_2 and Lo are as shown in Figure 2. Equation (1) implies that, as n approaches infinity, the perimeter goes to infinity. Practically, the realized miniaturization level of the designed filter size will depend on the adopted technology to produce the filter prototype.

3. The Fractal Based BSF Design

The overall size of the open stub BSF is 57×24 mm^2. This size wasn't suitable for the dimensions of the frame of the microwave oven. Therefore, the length of shunt stubs reduces to make it suitable for frame's dimensions which don't influence the center frequency of the open-loop Minkowski-like BSF and it improves the frequency response by moving zero at the upper side from stopband, to make it close to bandstop.

For more details, many lengths of shunt stub will be studied.

Figure 3(a) shows the influence of varying the length ls on S11, with and without the stub, ls = 4 mm and ls = 8 mm. As ls increases, the zero at upper side moves toward stopband, but zero at the lower side will slightly move away from stop band and does not change the frequency response. Furthermore, varying ls will not significantly affect on S21, the center frequency of BSF stay at 2.4 GHz but with deep level as implied from the results depicted in Figure 3(b).

From Figure 3, the best results were when the length of the open stub is 8 mm and also is suitable for the dimensions of the oven frame. Figure 4 shows the modeled BSF and the related responses as evaluated by using Sonnet software.

The specification of this filter are: the center frequency at 2.4 GHz, two zeros at 2.2 GHz and 2.6 GHz, the rejection level of insertion loss at the center frequency is –37 dB, the –3 dB bandwidth is between 2.35 GHz and 2.435 GHz, respectively, and overall size is 24×23 mm^2. The last filter is suitable for the dimensions of the microwave oven but isn't used for it because the 2.45 GHz isn't be inside bandwidth; therefore, in the next section, the filter dimensions will be scaled to shift center frequency to 2.45 GHz to be inside the filter stopband. To get more miniaturized BSF, the 2nd iteration Minkowski-like resonators are to be used as open-loop resonators, as shown in Figure 5. From Figure 5(b), using the 2nd iteration fractal structure as open-loop resonators will not get reasonable frequency response, deep level of insertion loss is –7.9 dB because the trace width is become small and spaces between the arms of resonators become tiny. Also, this dimension can't be realized in the practical case. These two reasons prevent the use of the 2nd iteration to design the proposed BSF.

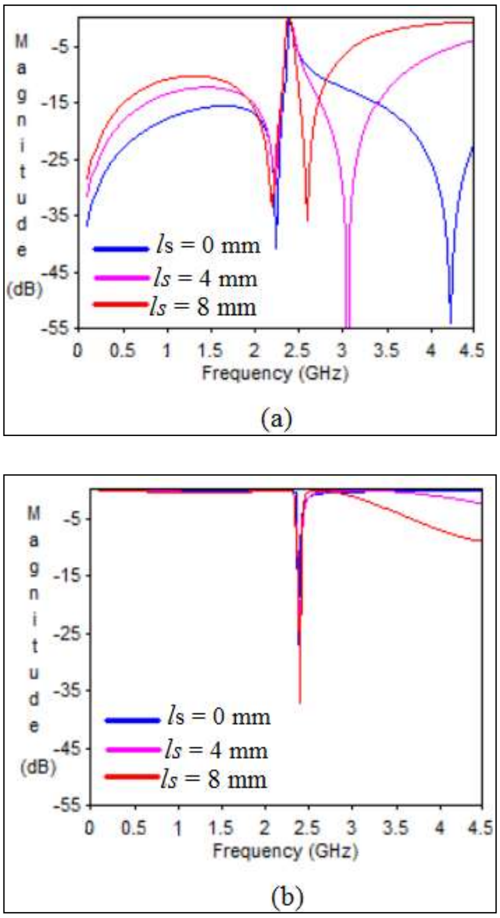
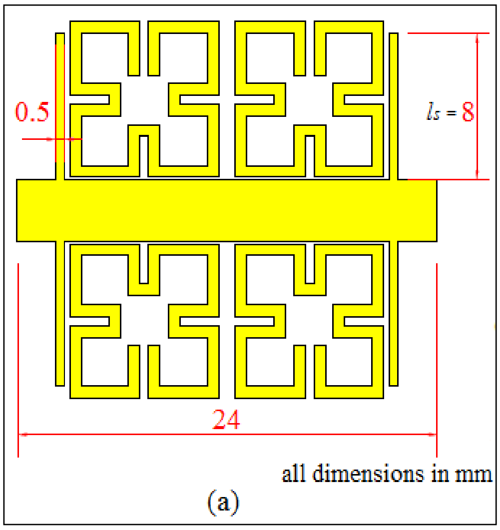
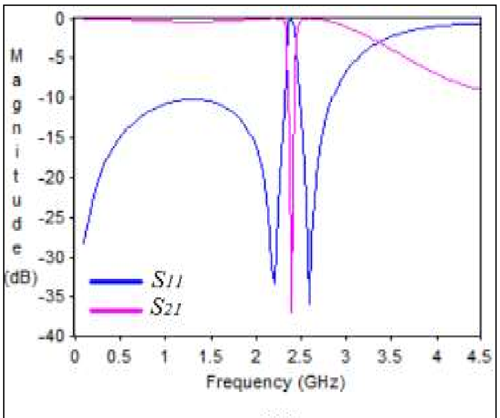


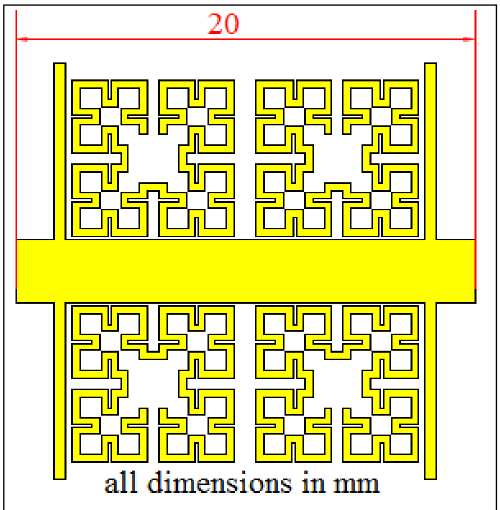
Figure 3: The effect of varying the length of stub a) S_{11} b) S_{21}



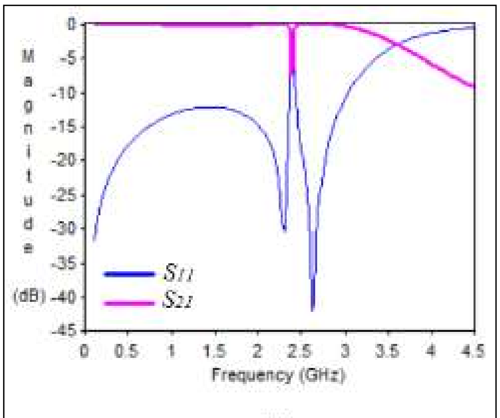


(b)

Figure 4: The modeled BSF based on the 1st iteration Minkowski-like open-loop resonators with open shunt stub a) Layout of BSF b) Frequency response



(a)



(b)

Figure 5: (a) Layout of the BSF after using 2nd iteration (b) Frequency response.

4. Fabricated Model and the Measured Results

To validate the proposed BSF design, it has been fabricated by using the FR4 substrate with dielectric constant of 3.5 and thickness of 1.5 mm. Figure 6 shows a photograph of the fabricated BSF prototype.

Measured results reveal that they are in reasonable agreement with the simulation results. However, some shift in the center frequency to 2.38 GHz, –3 dB bandwidth is between 2.362 GHz and 2.432 GHz and there are little differences in the return loss and insertion loss, as shown in Figure 7. The differences are also because limitations of the fabrication dimensional tolerances that might affect the mismatch of the input and output ports. In the last section, there is a single BSF designed at 2.4 GHz band and suitable for dimensions of the frame of the microwave oven. The commercial microwave oven operates at 2.45 GHz which is out of the stop band of the designed filter.

(a)

(b)

Figure 6: Photographs of the fabricated BSF prototype: (a) Top (b) Bottom.

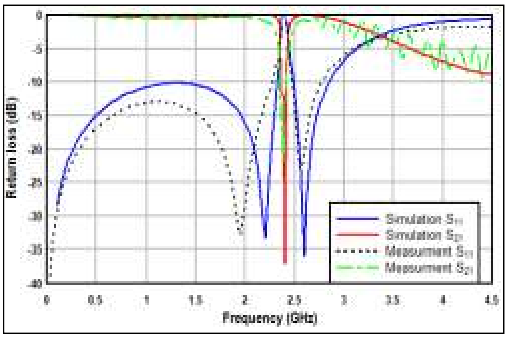


Figure 7: Measured frequency response of fabricated BSF.

5. Application of the Proposed Filter for Leakage Reduction of a Microwave Oven

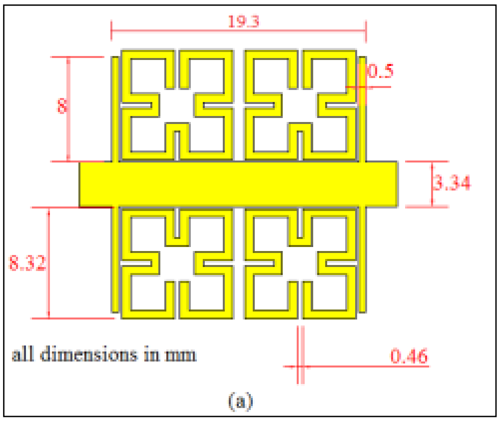
Now to use this filter in the radiation leakage protection applications, the center frequency has to be shifted to 2.45 GHz by scaling down the dimensions of resonators. This process can be carried out by using CST (microwave studio) software since we will need to make this filter in the form of 1-D array affixed to the frame of the oven window. The array requires the design of the ports of which the CST allows.

For the sake of the continuity of presentation, the related issues concerning the radiation reduction of the microwave oven can be found in [27-28]. Figure 8 shows the final layout with the dimensions and frequency responses of the BSF after scaling down the dimensions of resonators.

In this case, the filter properties are: the center frequency at 2.45 GHz, insertion loss -21.26 dB, -3 dB bandwidth equal to 0.2 GHz, and two zeros at 2.333 GHz and 2.766 GHz, respectively.

To make the proposed filter dimensions suitable for the frame of the microwave oven, we need two pairs of arrays; the dimensions of the first pair are 198×24 mm2; therefore a 1-D BSF array consisting of 8 elements is required. The spacing between the two adjacent elements is 24×2 mm^2. The second pair has the dimensions of 288×24 mm^2 and consist of 11 elements with the same spacing between adjacent elements and with two spaces' at the edge having the dimensions of 24×7.5 mm^2 to entirely cover the frame of the oven. The layout and frequency responses of two array pairs are shown in Figures 9 and 10 respectively.

Reasonable results have been obtained from two pairs of filters as shown in Figures 10(a), and (b). In the next section, the proposed filter will be fabricated and finally affixed on the oven's frame to be ready for radiation leakage measurement.



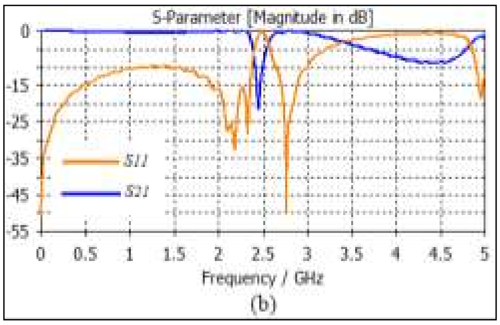


Figure 8: (a) The layout and dimensions of BSF and (b) Frequency response

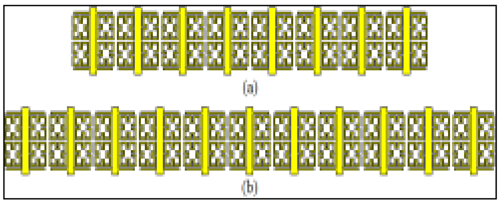
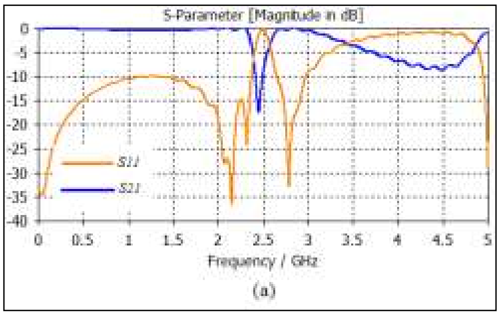


Figure 9: (a) The layout of the 1-D array of 8 elements BSF filter (b) The layout of the 1-D array of 11 elements BSF filter



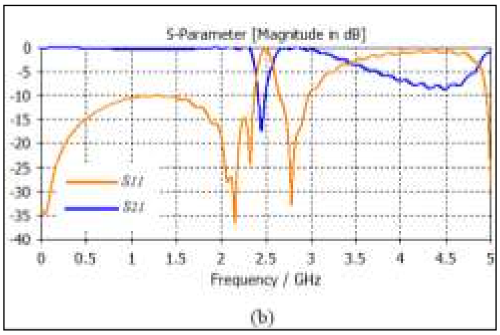


Figure 10: (a) The frequency response of the 1-D array of 8 elements (b) The frequency response of the 1-D array of 11 elements

6. Fabrication of the proposed Filter

As an attempt to reduce the radiation leakage out from the microwave oven, the suggested filter arrays have been fabricated. The two pairs of filter arrays are produced by using the same substrate with a relative dielectric constant of 3.5 and thickness of 1.5 mm. Figure 11 shows the photograph of the fabricated filter prototype.

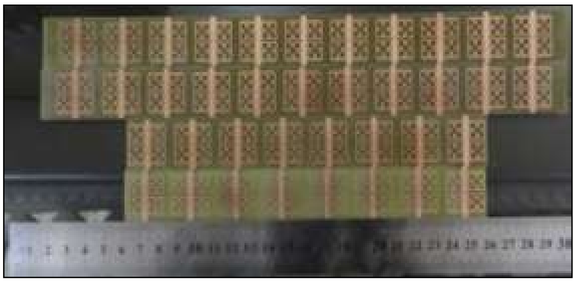


Figure 11: A Photograph of the fabricated filter prototype for radiation leakage reduction of the microwave oven.

Before fixing the proposed filter, the RF field out from the microwave oven has been measured using RF field strength meter shown in Figure 12. After fixing the proposed BSF arrays on the microwave oven, many measurements have been carried out. In this case, the measured values of the field leakage have been found not to exceed 257 μW/cm2, as shown in Figure 13.

Figure 12: The use of the RF field strength meter to measure leakage from the microwave oven without using the proposed BSF arrays.

(a)

(b)

Figure 13: The use of the RF field strength meter to measure leakage from the microwave oven with the existence of the proposed BSF arrays.

In this work only three BSF arrays have been fixed on the frame of the microwave oven. Because of some technical difficulties, the fourth array has not been used. It has been found that the value of field strength leakage is 50μW/cm^2, which does not exceed the Australian

It is worth to note that, a similar attempt, to reduce the RF radiation from the microwave ovens, has been performed as reported in [2]. In this work, the metamaterials have been used as a mushroom-like periodic structure to design the proposed BSF. An FR-4 substrate with dielectric constant 4.5 and thickness 10 mm has been used to fabricate the BSF. Also, the researcher has to affix four FR-4 layers with thickness 2.5 mm to reach the required thickness of 10 mm and made a comparison between his proposed technique and conventional QWC. In summary, he found that the proposed method results in reasonable performance as compared with QWC. Table 1 compares the performance of the proposed work in this report and that reported in [2].

Table 1: Comparison between the proposed work and that reported in [2].

	Thickness of substrate	complexity	leakage
Reference [2]	10 mm	More complexity (used mushroom, posts)	350 μW/cm2 of QWC
This Work	1.5 mm	Uses a single layer	275 μW/cm2

7. Conclusions

A new fractal-based BSF has been presented in this paper as a means for the radiation leakage reduction of the commercially available microwave ovens for domestic applications. The proposed unit cell filter is composed of four coupled Minkowski fractal ring resonators loaded with open stub resonator to enhance the selectivity of the resulting filter performance. The measured results of a fabricated prototype show reasonable agreement with those theoretically predicted. Four arrays of the designed filter have been implemented to cover the microwave oven door frame. Measured radiated electric fields from the oven show that it considerably reduces the leaked radiation. By suitable choice of substrate material and carrying out the required dimension scaling, the proposed design idea is flexible and can be generalized to be used for a wide variety of microwave equipment in which microwave leakage represents a serious issue.

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References

[1] A.M. Rocha, M. Facão, J.P. Sousa, and A. Viegas, "Simulation of electromagnetic leakage from a microwave oven," Proceedings of the EHE '06 International Conference on Electromagnetic Fields, Health, and Environment, 2006.

[2] M. Mishrikey, "Analysis and design of meta-materials," Ph.D. Dissertation, Swiss Federal Institute of Technology Zurich, ETH, Zürich, Nr.18889, 2010.

[3] N. Cohen, "Fractal antenna and fractal resonator primer," Chapter 8 in J. A. Rock and M. van Frankenhuijsen [Eds.], "Fractals and Dynamics in Mathematics, Science, and the Arts: Theory and Applications," Volume 1, World Scientific Publishing, 2015.

[4] Y.S. Mezaal, H.T. Eyyuboglu, and J.K. Ali, "New dual band dual-mode microstrip patch bandpass filter designs based on Sierpinski fractal geometry," 2013 IEEE Third International Conference on Advanced Computing and Communication Technologies (ACCT), 2013.

[5] Y.S. Mezaal, H.T. Eyyuboglu, J.K. Ali, "New microstrip bandpass filter designs based on stepped impedance Hilbert fractal resonators," IETE Journal of Research, Vol. 60, No. 3, 2014, 257-264.

[6] Y.S. Mezaal, H.T. Eyyuboglu, and J.K. Ali, "A novel design of two loosely coupled bandpass filters based on Hilbert-zz resonator with higher harmonic suppression," 2013 IEEE Third International Conference on Advanced Computing and Communication Technologies (ACCT), Rohtak, India, 2013.

[7] Y.S. Mezaal, H.T. Eyyuboglu, and J.K. Ali, "Wide bandpass and narrow bandstop microstrip filters based on Hilbert fractal geometry: design and simulation results," PloS One, Vol. 9, No. 12, 2014, e115412.

[8] Y.S. Mezaal, J.K. Ali, H.T. Eyyuboglu, "Miniaturised microstrip bandpass filters based on Moore fractal geometry," International Journal of Electronics, Vol. 102, No. 8, 2015, 1306-1319.

[9] J.K. Ali, M.F. Hasan, and M.R. Hussan, "Design of miniaturized dual-mode microstrip resonator bandpass filters for modern wireless applications," University of Babylon 2nd Scientific Conference, Babylon, Iraq, 2011.

[10] J.K. Ali, N.N. Hussain, A.J. Salim and H. Alsaedi, "A new tunable dual-mode bandpass filter design based on fractally slotted microstrip patch resonator," Progress In Electromagnetics Research Symposium, Kuala Lumpur, Malaysia, 2012.

[11] J.K. Ali, Y.S. Mezaal, "A new miniature narrowband microstrip bandpass filter design based on Peano fractal geometry," Iraqi Journal of Applied Physics, Vol. 5, No. 4, 2009, 3-9.

[12] J.K. Ali, H. Alsaedi, M.F. Hasan, H.A. Hammas, "A Peano fractal-based dual-mode microstrip bandpass filters for wireless communication systems," Proc. of Progress In Electromagnetics Research Symposium, PIERS; Moscow, Russia, pp. 888-92, 2012.

[13] Y.S. Mezaal, H.T. Eyyuboglu, J.K. Ali, "A new design of dual band microstrip bandpass filter based on Peano fractal geometry: Design and simulation results," Proc. of the 13th IEEE Mediterranean Microwave Symposium, MMS'2013; Saida, Lebanon, 2013.

[14] J.K. Ali, Y. S. Miz'el, "A new miniature Peano fractal-based bandpass filter design with 2nd harmonic suppression," Proc. of 3rd IEEE International Symposium on Microwave, Antenna, Propagation and EMC Technologies for Wireless Communications; Beijing; China, 1019 – 1022, 2009.

[15] J.K. Ali, and H. Alsaedi, "Second harmonic reduction of miniaturized dual-mode microstrip bandpass filters using fractal shaped open stub resonators," Progress In Electromagnetics Research Symposium, Kuala Lumpur, Malaysia, 2012.

[16] J.K. Ali, N.N. Hussain, "A new fractal microstrip bandpass filter design based on dual-mode square ring resonator for wireless communication systems," Iraqi Journal of Applied Physics, Vol. 5, No. 1, 7-14, 2009.

[17] M. Alqaisy, C. Chakrabraty, J. K. Ali, A. R. H. Alhawari, "A miniature fractal-based dual-mode dual-band microstrip bandpass filter design," International Journal of Microwave and Wireless Technologies, Vol. 7, No. 02, 127-133, 2015.

[18] J. K. Ali, "A new miniaturized fractal bandpass filter based on dual-mode microstrip square ring resonator," Proc. of the 5th International Multi-Conference on Signals, Systems and Devices, IEEE SSD '08; Amman, Jordan, 2008.

[19] H.S. Ahmed, A.J. Salim, and J.K. Ali, "A compact dual-band bandstop filter based on fractal microstrip resonators," Progress In Electromagnetics Research Symposium, Prague, Czech Republic, 2015.

[20] M. Alqaisy, J. K. Ali, C.K Chakrabarty and G. C. Hock, "Design of a compact dual-mode dual-band microstrip bandpass filter based on semi-fractal CSRR," Progress In Electromagnetics Research Symposium, Stockholm, Sweden, 2013.

[21] J.K. Ali, and H.T. Ziboon, "A compact bandpass filter based on fractal defected ground structure Resonators," Technical Report, MRG 10–2016, Microwave Research Group, Department of Electrical Engineering, University of Technology, Iraq, 10 July, 2016.

[22] H.S. Ahmed, A.J. Salim, J.K. Ali, and N.N. Hussain, "A compact triple band BSF design based on Minkowski fractal geometry," 18th IEEE Mediterranean Electrotechnical Conference, MELECON 2016, Limassol, Cyprus, April, 2016.

[23] N.N. Hussain, and J.K. Ali, "A new narrow band dual-mode miniaturized bandpass filter design for wireless communication systems," Engineering and Technology Journal, Vol. 27, No. 10, 1937-1951, 2009.

[24] J.K. Ali, N.N. Hussain, "An extra reduced size dual-mode bandpass filter for wireless communication systems," Proc. of Progress In Electromagnetics Research Symposium, PIERS 2011; Suzhou, China, 1467-70, 2011.

[25] J.Joubert, "Spiral microstrip resonators for narrow-stopband filters," IEE Proceedings on Microwave Antennas and Propagation, Vol. 150, No. 6, 2003, 493-496.

[26] H.S. Ahmed, "Fractal based multi-band reject filters," M.Sc. Thesis, University of Technology, Iraq, 2015.

[27] M. Vollmer, "Physics of the microwave oven," Physics Education, Vol. 39, No. 1, 2004, pp. 39-81.

[28] N.M. Zin, M.Z.M. Jenu, and F.A. Po'ad, "Measurements and reduction of microwave oven electromagnetic leakage," Proc. of the IEEE International Conference on RF and Microwave (RFM), Negeri Sembilan, Malaysia, pp. 1-4, 2011.

[29] Australian Radiation Protection and Nuclear Safety Agency, "Radiation emissions from microwave ovens," Australian Radiation Protection and Nuclear Safety Agency 2014.

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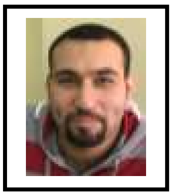

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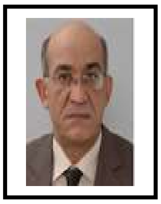

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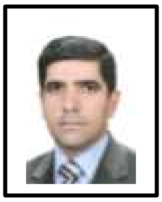

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