Mansoura Engineering Journal

Volume 35 | Issue 1 Article 5

11-17-2020

Analysis and Design of Microstrip Filters Using Photonic Band Gap Ground Plane with Fractal Periodic Pattern.

Hamada Elsaied
Toshiba Company, Egypt, hamada80e@yahoo.com

Maher Abd Elrazzak
Almansoura University, Faculty of Eng., Egypt, maher1@iee.org

Recommended Citation

Elsaied, Hamada and Abd Elrazzak, Maher (2020) "Analysis and Design of Microstrip Filters Using Photonic Band Gap Ground Plane with Fractal Periodic Pattern.," *Mansoura Engineering Journal*: Vol. 35 : Iss. 1 , Article 5.
Available at: https://doi.org/10.21608/bfemu.2020.123545

Mansoura Engineering Journal, (MEJ), Vol. 35, No. 1, March 2010

Analysis and Design of Microstrip filters using Photonic band gap ground plane with fractal periodic pattern

تحليل و تصميم مرشحات الموجات الدقيقة باستخدام الفتحات الضوئية للطبقة الأرضية مع توزيعها بشكل متجزء (Fractal)

Hamada M. Elsaied[*] , and **Maher M. Abd Elrazzak**[**], ***Senior member, IEEE***
Maher1@ieee.org, hamada80e@yahoo.com

* Toshiba Company, Egypt., ** Almansoura university, Faculty of Eng., Egypt.

الملخص العربى

فى هذا العمل يتم تحليل و تصميم مرشحات الموجات الدقيقة باستخدام الفتحات الضوئية للطبقة الأرضية مع توزيعها بشكل متجزء (Fractal). يتم ذلك باستخدام اربعة تصميمات لهذه المرشحات و هى أولا مرشحات الترددات المنخفضة التي تستخدم اشكال مقطوعة فى الطبقة الأرضية المعدنية (Defected ground) من الشرائح الدقيقة ، ثانيا مرشحات الموجات الدقيقة ذات الترددات المنخفضة باستخدام شكل منكووسكى المتصل فى شكل حلزوني، ثالثا المرشحات التى تعمل كمانع للإشارة عند ترددات مختلفة، وأخيرا مرشحات انترديجتكاب ذات المدى العريض التى تعمل كمانع للإشارة عند ترددات مختلفة.كلا المرشحات التى تشمل أشكال انترديجتكاب ومنكووسكى مقطوعة فى الطبقة الأرضية المعدنية تعمل كمرشح مانع للإشارة عند ترددات مختلفة.أشكال منكووسكى المتصلة ببعض تستخدم في تصميم مرشحات الموجات الدقيقة ذات الترددات المنخفضة وهو مرشح عريض المدى. النتائج التحليلية وضحت أن مرشحات الموجات الدقيقة ذات الترددات المنخفضة لأشكال منكووسكى المتصلة فى شكل حلزوني والغير متصلة تعمل في مدى ترددى من ٠ – ٣ جيجا هرتز عندما تكون سمك الفتحة المثقوبة في الطبقة الأرضية المعدنية من الشرائح الدقيقة ٥, ٠ مم ولكن المرشح الغير متصل يتميز بوجود نطاقات لاتسمح بمرور الاشارة عند مضاعفات تردد العمل (f_0). وعندما يكون سمك الفتحة ٢, ٠ مم سيزيد مدى الترددات حتى ١٠ جيجا هرتز. يمكن ان نتحكم فى المدى الترددي للمرشح عن طريق زيادة او نقصان عدد العناصر للأشكال المتجزاة (Fractal). الأشكال الغير متصلة من عناصر المنكووسكى وانترديجتكاب تستخدم فى الشرائح الدقيقة ليعمل كمرشح مانع للإشارة عند مضاعفات تردد العمل (f_0) .يتم التحليل باستخدام برنامج سونيت لعمل التصميمات والتحليل للشرائح الدقيقة مع معادلات رياضية تعتمد على الدائرة المكافئة للمرشح.

Abstract — In the present work, four different techniques are used in designing the microstrip low pass filters (LPF). These techniques include LPF with fractal defected ground structure (DGS), LPF with continuous minkowiski fractal element, multi-stop band filter with discontinuous minkowiski element, and finally a wide multi-stop filter with separated interdigcap shape. A microstrip PBG filter of minkowiski element and interdigcap shape was designed to operate as a multifrequency band stop filter. With an appropriate fractal geometry of minkowiski and interdigcap elements, a wide stop-band at different frequencies are obtained. A continuous sinusoidal fractal slots are designed to work as a wide LPF. A novel fractal DGS for the microstrip LPF is proposed. The proposed fractal DGS can provide better band gap, and slow-wave characteristics. The numerical results show that a LPF of continuous and discontinuous fractal minkowiski elements in ground plane is obtained with a bandwidth 0 – 3 GHz for a slot width 0.5mm. However, if the slot width is taken equal 0.2 mm, the bandwidth is increased up to 10 GHZ. With suitable choice of number of elements, one can control the filter bandwidth. With a discontinuous fractal minkowiski and interdigcap element in ground plane, the filter response is forced to have a stop band at resonance frequency of f_0 and repeated at $2f_0$, .. etc. The numerical results obtained using an analytical technique with the aid of a numerical package (Sonnet) which is used in microstrip analysis.

Accepted March 4, 2010.

I. Introduction

Photonic band gap (PBG) structures are periodic structures in which the propagation of electromagnetic waves is prohibited in some frequency bands or directions. The realization of this operation was obtained initially by a class of periodic directions that is the photonic analogous of semiconductors and were used in optical regions [1]. However, PBG properties are scalable and applicable to the microwave and millimetric-wave range, finding multiple applications such as the improvement of antenna radiation features [2,3], use as broadband absorbers and reflectors, the design of broadband filters, high efficiency amplifiers, power dividers, ... etc. In microstrip technology, a PBG structure is obtained by creating a proper periodic pattern drilled in the substrate or etched in the ground plane. The planner etched PBG configurations have attracted interest due to their ease of implementation and their compatibility with microwave integrated circuits (MICs) and monolithic microwave integrated circuits (MMICs) [4-8]. The slots in the ground plane may have either a circular shape [4-6] or a sinusoidal or a triangular profile [7]. The operational characteristics of the filter are controlled by the size and the distance of the ground slots [8].

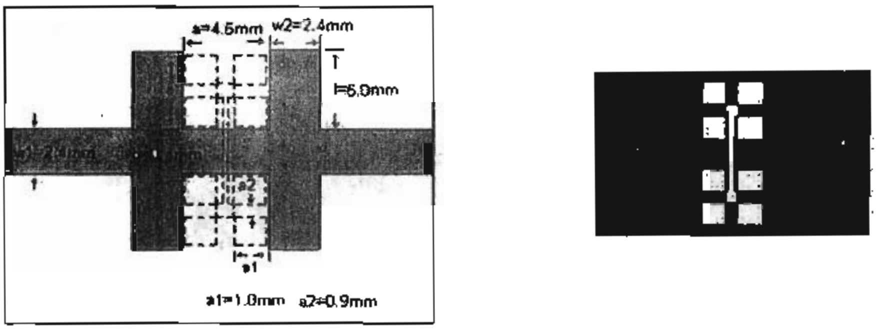
In the present work, a LPFs with a wide band-stop response is realized using PBG structures etched in the ground plane. A fractal technique is used in implementation of the PBG pattern. The fractal pattern is carried out using either Minkowiski curve or interdigcap shape in ground plane. A continuous Minkowiski curve has been used in the design of wide LPF. In addition, Interdigcap shape enable the filter to have wide multi-stop band. The numerical results obtained using an analytical technique with the aid of a numerical package (Sonnet) which is used in microstrip analysis.

II. Filter structure

Four different types of filter structures are presented. The first one is shown in Fig.1 in which the schematics of the proposed LPF with fractal DGS is presented. The DGS is etched on the metallic ground plane. The dimensions of the etched lattice are shown in Fig.1. A dielectric substrate of RT / Duroid 5880 with 0.762 mm thickness and dielectric constant ε_r of 2.22 has been used. The line width w is chosen for characteristic impedance of 50 Ω. A two cross-junction open stubs on the top metal plane are used to achieve good matching conditions for the microstrip line.

The second case, Minkowiski fractal shape is used in defecting the ground plane, Fig. 2. The Minkowiski element used in designing the fractal is shown in Fig. 2. a. This element is of length 5.6 mm which is divided into eight equal segments as shown in Fig. 2.a. Eight and twelve continuous Minkowiski fractal are used in the present analysis, Fig. 2 b, c. The substrate is taken of dielectric constant $\varepsilon_r = 10.2$, and height $h = 0.5$ mm. The microstrip line is of 0.5 mm wide.

The third case uses the, Minkowiski fractal element shown in Fig. 2.a. However, the elements obtaining the slotted fractal shape are discontinuous and separated by a certain distance. The configuration consists of nine separated fractal slots is shown in fig. 3. This structure acts as a PBG leading to get multiple stop-band.



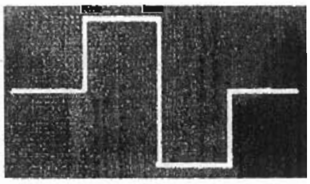
(a) Top view ((b) Bottom view

Fig. 1. Fractal defected ground structure

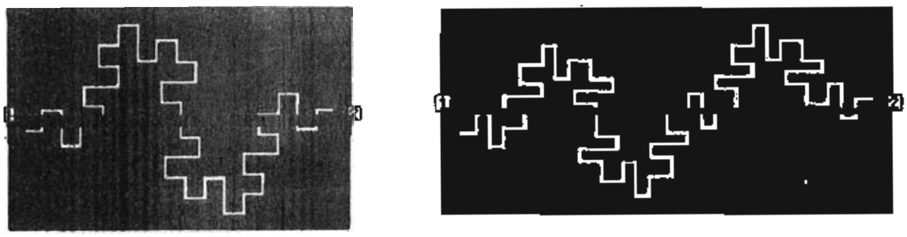
The final case, a fractal of interdigcap shape is used, shown in Fig. 4. The dielectric substrate constant ε_r = 10.2 and height h = 0.5 mm, and microstrip line is 0.5mm wide and has characteristic impedance Z_o = 50 Ω. The slots are etched in the ground plane. The configuration consists of nine fractal slots etched in the ground plane as shown in fig. 4. The generator slot of the fractal curve is interdigcap slot of terminal width 0.8 mm, finger width 0.4 mm, number of finger pairs are 4, finger spacing 0.5 mm, end gap equal 0.5 mm, and overlap equal 1mm.

III. Equivalent circuit model

Fig. 5 shows the equivalent circuit of the proposed fractal DGS [9]. The band gap characteristics can be explained by a parallel LC resonator (L_r and C_r). The radiating effects are taken into account and represented by R_r. The equivalent circuit parameters can be derived from the S-parameters based on the electromagnetism (EM) simulation . Once the S-parameters are obtained, these parameters can be extracted by using the relationship between the S-parameters and the ABCD parameters as follows:



(a) Minkowiski element aperture with a slot of length 5.6mm



(b) Eight continuous Minkowiski fractal slots . (c) Twelve continuous Minkowiski fractal slots

Fig. 2. Minkowiski fractal slots in ground plane

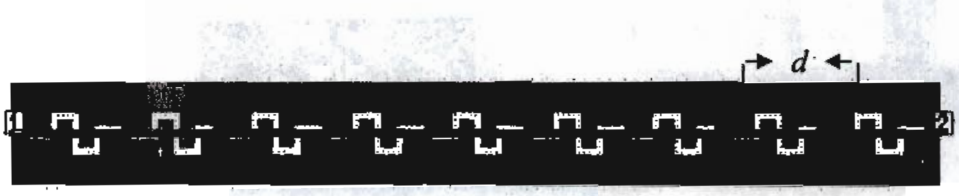
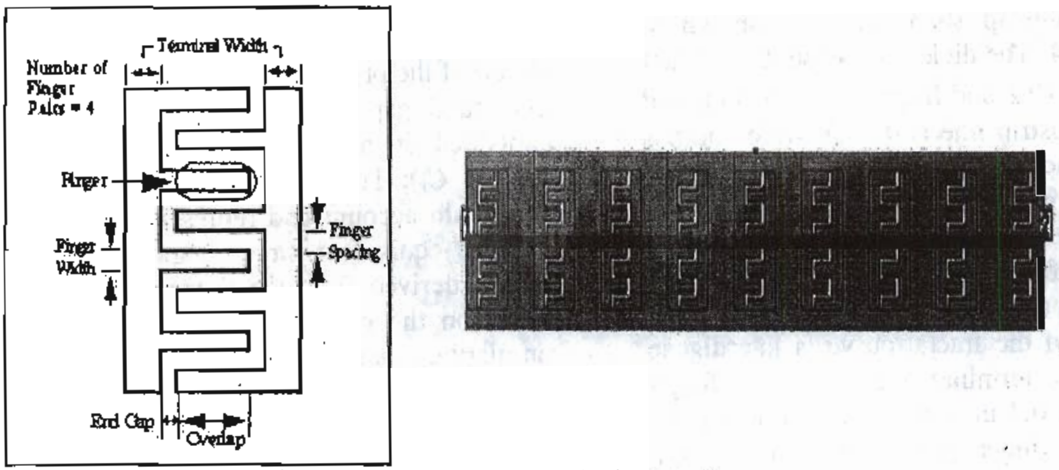


Fig.3. The proposed PBG structure with separated Minkowiski fractal elements etched in the ground plane



(a) Interdigcap shape. (b) Nine interdigcap

Fig. 4 Filter structure with the interdigcap.

$$B = \frac{(1+S_{11})\times(1+S_{22}) - S_{12}S_{2}}{2S_{12}} = \frac{1}{Y_r}$$

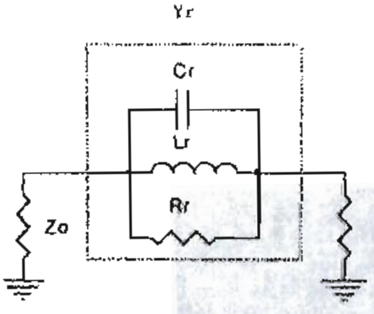


Fig. 5. Equivalent circuit of a microstrip fractal DGS]

$$Y_r = \frac{1}{R_r} + jB_r = \frac{1}{R_r} + j(2\pi f_o C_r + \frac{1}{2\pi f_o L_r})$$

$$C_r = \frac{B_r}{2\pi f_o \left(\frac{f_c}{f_o} - \frac{f_o}{f_c}\right)}$$

$$L_r = \frac{1}{(2\pi f_o)^2 . C_r}$$

where f_o and f_c are the resonant frequency and 3-dB cutoff frequency, respectively

IV. Numerical analysis and discussion

The LPF with fractal DGS shown in Fig.1 is analyzed. Fig. 6, shows its scattering parameters compared with that of [10]. The results show that the filter has a low-pass band of 0.0 - 3.2 GHz at -10 dB, and a wide stop band at its higher end.

Fig.7 shows the input impedance of the LPF of Fig.1. The results shows that the input impedance is almost real during the pass band and equal 50 Ω which is suitable to be connected with the coaxial line for improving the power- handling capability of the filter [11].

The LPF of continuous fractal shape shown in Fig. 2 is analyzed for different slot widths and different number of Minkowiski elements. Fig. 8 and Fig. 9 show the scattering parameters for 8 and 12 Minkowiski elements with slot width 0.2mm. These figures shows that the pass band of the filter is decreased from 10 GHz at 8 elements to 8 GHz at 12 elements. Fig. 10 and Fig.11 shows the same results for slot width equal 0.5 mm. With increasing the slot width, the pass band decreases significantly for the two cases.

The input impedance for the case of 8 elements with slot width = 0.2 mm is shown in Fig. 12, and its loss factor is shown in Fig. 13, the dielectric constant of a lossy material can be expreseed as a complex quantity of the form $\varepsilon^* = \varepsilon' + j\varepsilon''$ [12]. The real part ε' represents the "true" dielectric constant of the material in lossless form; i.e., the measure of displacement currents for a particular electric field in the material if it were lossless. The imaginery part ε" represents the dielectric "loss factor" of the material; i.e., the losses due to conduction and relaxation effects. However, subsurface formation materials often have appreciable conductivity and thus a significant loss factor ε" which is greater in magnitude than ε' . Since loss factor is necessarily measured to some extent when attempting to measure ε', the attainment of accurate values of ε' was until recently largely frustrated by the presence of a significant loss factor. Fig. 13 shows that the loss factor is 0dB in the pass-band of the filter.

In order to design a multiple stop-band filter, a PBG structure of Fig. 3 with nine apertures elements of Minkowiski fractal were etched in a discontinuous distribution in the ground plane. The period, d shown in Fig. 3 is taken 16 mm. The results of scattering parameters are shown in Fig.14, where it can be seen that multiple stop-band performance was obtained. The first stop-band regions appears at a frequency of about f_0, which is a function of the period of the structure, and is calculated approximately with the following expression:

$$\beta d = \pi, \qquad (1)$$

where d is the period of the PBG pattern (Fig. 3), The cell distance between a half guide wavelength, λ_g if β equals to $2\pi/\lambda_g$. and β is the wave number in the dielectric slab, defined by:

$$\beta = \frac{2\pi f_o}{C}\sqrt{\varepsilon_{eff}}\ , \qquad (2)$$

where f_0 is the center frequency of the stop-band, ε_{eff} is the effective permittivity of the filter, and C is the speed of light in free space. From equation 2, the f_0 is equal 3.1 GHz which is agree with the results shown in Fig. 14. Additional stop-band regions appear at multiples of f_0.

Finally, a LPF of a periodic interdigcap in ground plane is designed. In this case, the following periodic condition must be satisfied:

$$\beta d = \pi /2 \qquad (3)$$

Using equations (2) and (3), the period d can be calculated for a required stop-band. Three different cases of stop bands are designed at frequencies 8.8 GHz, 8.1 GHz, and 7.75 GHz. From equations 2, and 3, the obtained periodical distance required for these frequencies are 3.2, 4.2, and 4.7 mm, respectively

Fig. 15 shows the scattering parameters for the case in which d=3.2 mm. In this case the center frequency of the stop band obtained from equations 2, and 3 is 8.8 GHz which is agree with the obtained results shown in Fig. 15. . The second stop is centered at ≈ $2f_0$.

In Fig. 16 and Fig. 17, the S_{11} and S_{12} for the last two cases of d=4.2, and d=4.7 mm are presented where the first stop band is centered at 8.1 and 7.75 GHz for the two cases, respectively. This agree with the results obtained from equations 2, and 3. In all three cases, the frequency rejection bands were wide and the rejection level was satisfactory. The loss factor is almost 0 dB during the pass band of the filter as shown in Fig. 18.

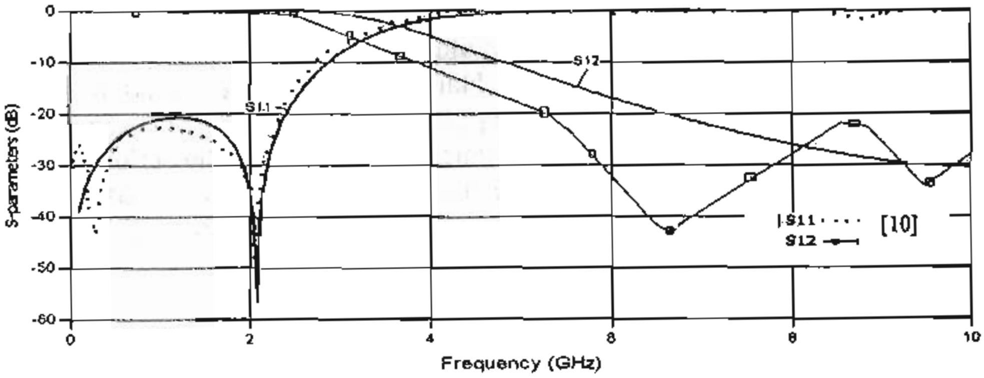
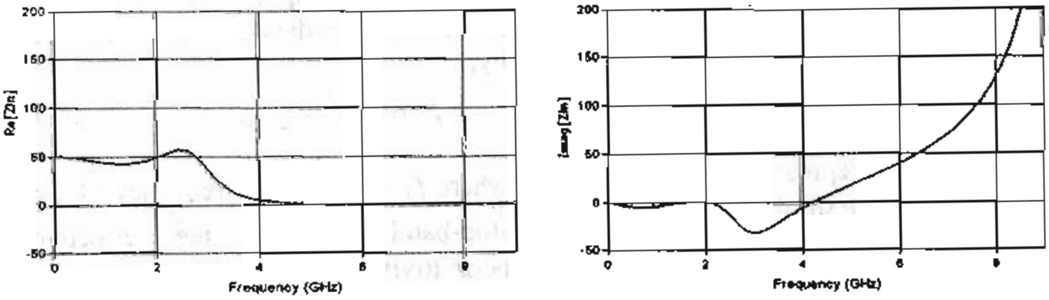


Fig. 6. Simulated S- parameters of Fig .1 for fractal DGS in ground plane



(a) (b)

Fig. 7. Input impedance for fractal GDS of Fig 1. (a) Real Part (b) Imaginary Part.

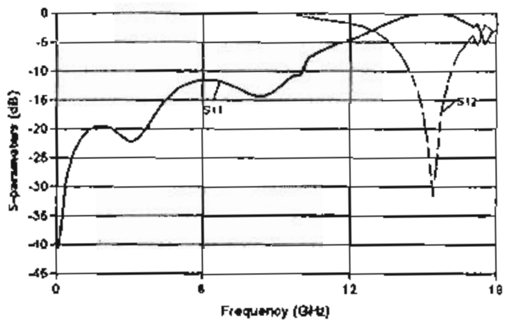


Fig. 8. S-parameter of eight continuous fractal slots on ground plane width of slot 0. 2mm of Fig. 2. b.

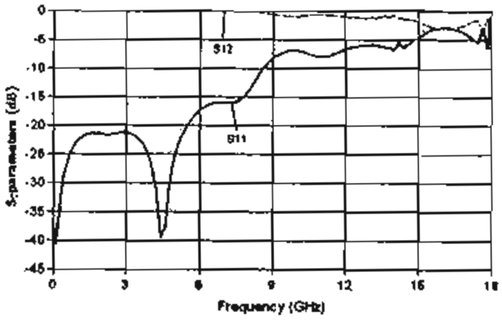


Fig. 9. S-parameter of twelve continuous fractal slots on ground plane width of 0.2mm of Fig. 2.c

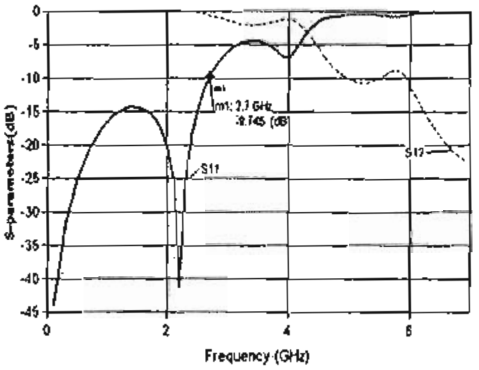


Fig. 10. S-parameter of eight continuous fractal slots on ground plane width of slot 0.5mm of Fig. 7.

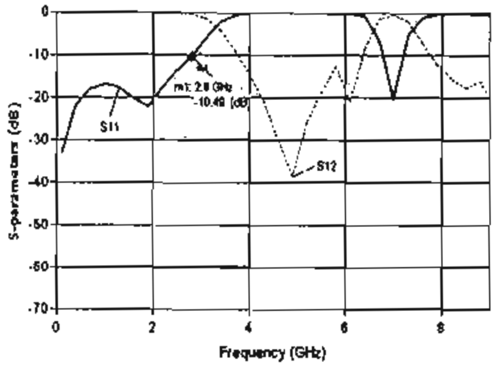
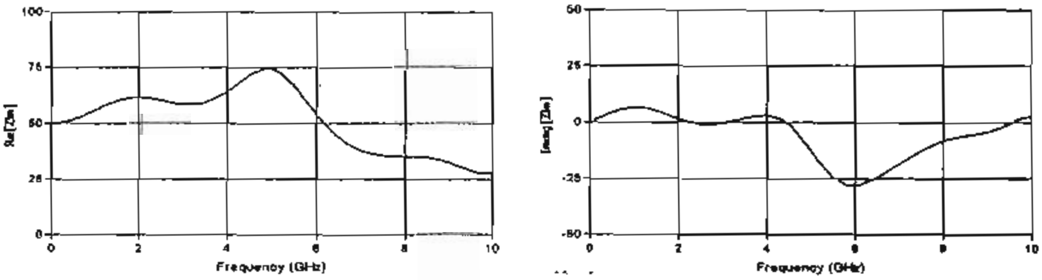


Fig. 11. S-parameter of twelve continuous fractal slots on ground plane width of 0.5mm of Fig. 7. a



(a) (b)

Fig. 12. Input impedance of the filter shown in Fig. 2.b.

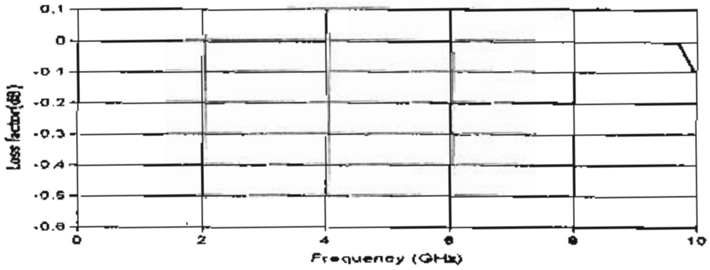


Fig.13. Loss factor of the filter shown in Fig. 2. b.

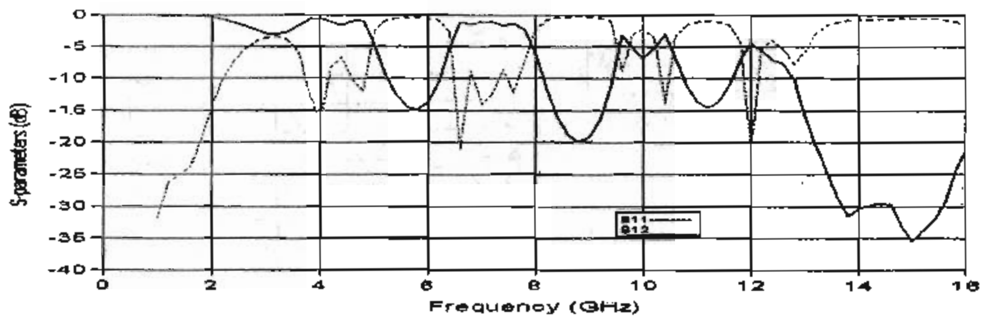


Fig. 14. S-parameters for the PBG Microstrip structure with nine Minkwiski apertures(dm = 5.6mm, *d* =16mm)

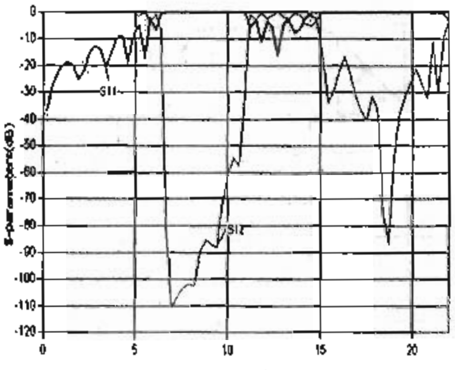


Fig.15 S-parameters for fractal shape for space equal 3.2mm

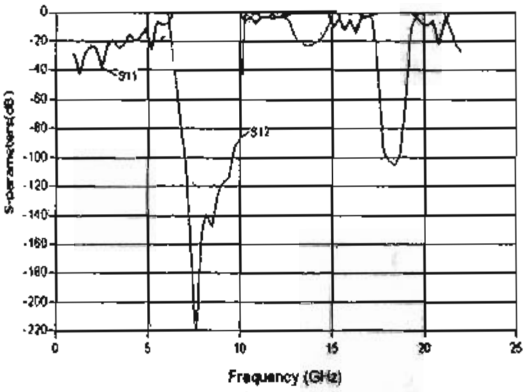


Fig. 16 S-parameters for fractal shape for space equal 4.2mm.

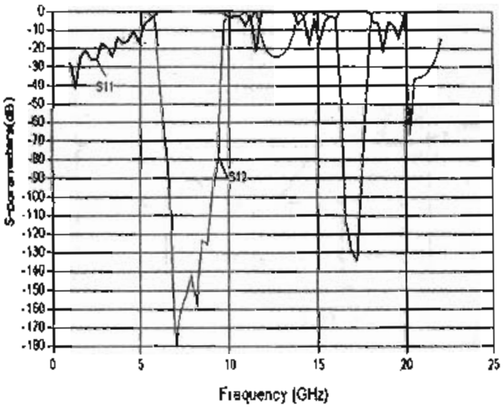


Fig. 17 Scattering parameter for fractal shape space equal 4.7mm.

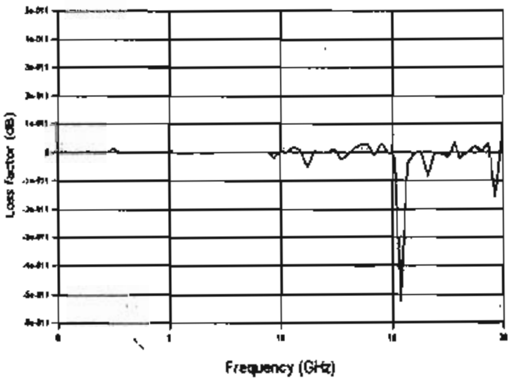


Fig. 18. Loss factor for interval 4.7 mm.

V. Conclusion

A novel PBG microstrip structure with an array of fractal Minkowski element and interdigcap shape etched in the ground plane has been presented. The configuration acts as a LPF with multiple stop bands at the higher end of the filter pass band. The center frequency of the stop band ranges are controlled via the geometry of the fractal aperture array. Wide rejection bands with a high rejection level and satisfactory low ripple outside the stop frequency regions were obtained. The band-stop filter are simulated and analyzed via numerical package "Sonnet" and verified by an analytical formula. From the numerical results, a LPF of continuous and discontinuous fractal Minkowiski elements in ground plane is obtained with a bandwidth 0 – 3 GHz for a slot width 0.5mm. However, if the slot width is taken equal 0.2 mm, the bandwidth is increased up to 10 GHZ. With suitable choice of number of elements, one can controle the filter bandwidth. A discontinuous fractal Minkowiski and interdigcap element in ground plane force the filter to have a stop band at resonance frequency of f_0 and repeated at f_0, $2f_0$, $3f_0$ … etc. In addition, a simple LPF with a novel fractal DGS has been presented. This filter has the same frequency response like that of fractal continuous Minkowiski filter.

References

[1] E. Yablanovich, "Inhibited spontaneous emission in solid-state physicsand electronics", *Phys Rev Lett,* vol. 58, pp. 2059–2062, 1987.

[2] N. Yousefzadeh, C. Ghobadi, and M. Kamyab," Consideration of mutual coupling in a microstrip patch array using fractal elements," *Progress In Electromagnetics Research,* PIER 66, 41-49, 2006.

[3] M. N. A Karim, M. K. A. Rahim, H. A. Majid, O. Ayop, M. Abu, and F. Zubir,"Logic periodic fractal koch antenna for UHF band application," *Progress In Electromagnetics Research,* PIER 100, 201-218, 2010.

[4] M.A. Laso, G. Lopetegi, T. Errol, M.J. Benito, M.J. Garde, and M. Corolla, " Novel wideband photonic bandgap microstrip structures", *Microwave Opt Technol Lett.* vol. 24, pp. 357–360, 2000.

[5] V. Radisic, Y. Qian, R. Coccioli, and T. Itoh, "A novel 2D photonic bandgap structure for microstrip lines", *IEEE Microwave Guided Wave Lett,* vol. 8 , pp. 69–71, 1998.

[6] N.C. Karmakar, "Nonuniform distributions of photonic bandgap microstripline structures", *Int J Electron 90,* pp.65–77, 2003.

[7] T. Lopetegi, M.A. Laso, M.J. Erro, D. Benito, M.J. Garde, F. Falcone, and M. Sorolla, " Novel photonic bandgap microstrip structures using network topology", *Microwave Opt Technol Lett,* vol. 25, 33–36, 2000.

[8] F.R. Yang, K.P. Ma, Y. Qian, and T. Itoh, "A uniplanar compact photonic bandgap (UC-PBG) structure and its applications for microwave circuits", *IEEE Trans Microwave Theory Tech,* vol.47, pp. 1509–1514,1999.

[9] J.S. Park, J.H. Kim, J.H. Lee, et al., "A novel equivalent circuit and modeling method for defected ground structure and its application to optimization of a DGS low pass filter", *IEEE MTT-S 1,* pp. 417–420, 2002.

[10] Hai W. Liu, Zheng F. Li, and Xiao W. Sun, "A novel Fractal defected ground structure and its application to the Low-pass Filter", Shanghai Jiaotong University, Department of Electronic Engineering, Shanghai 200050, P. R. China, May 2003.

[11] S.G. Jeong, D.K. Hwang, Y.C. Jeong, et al., "amplifier design using λ/4 high impedance bias line with defected ground structure (DGS) ", *IEEE MTT-S* 2 , pp.1161-1164, 2002.

[12] Linfeng Chen and Vijay K. Varadan,"*Microwave electronics: measurement and materials characterization*" John Wiley and Sons. p. 8, eq.(1.15), 2004.