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A Study of Periodic Microstrip Structures Using Finite Elementary Lines (FEL) Approach

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Abstract: This "Paper" presents a comparison of the results obtained by means of the Finite Elementary Lines (EEL) approach to those obtained by other authors in the characterization of periodic microstrip structures on the localization, the width at - 20 dB and the depth of the rejection band. Designers of stop-band or pass-band filters find in this approach of FEL a safe and effective way to get inexpensive design and achievement that best meets their expectations.

Keywords: Microstrip Structures, Periodic, Hybrids, Rejection Band, Electromagnetic Bandgap (EBG), Bandwidth, Depth

1. Introduction

The approach of finite elementary lines (FEL), described in detail in [1, 2] and summarized in [3], is an analysis and synthesis tool of microstrip structures. It is characterized by its ease of implementation and speed of computation compared to other approaches such as the method of moments, the finite difference time domain (FDTD) method, the cavity model, etc. It consists on cutting the microstrip structure of arbitrary shape to a number N of infinitely small sections treated as uniform transmission lines. The width of the elementary transmission line of rank n is that of the structure at this position and its length is equal to the length of the structure divided by N. The elementary transmission line is treated as a two port network. Knowing matrices S_i of all elementary two port networks Q_i arranged in cascade allows the determination of the S-matrix of the overall structure.

Periodic structures whose application was previously restricted by the limits of technology are of particular interest in improving the performance of microwave devices such as antennas, waveguides, couplers etc. Disadvantages due to the size of this type of structures at low frequencies disappear with the growing frequency and use of the third dimension can increase the integration density functions in the substrate. The wave propagation in periodic structures has been a subject of continuous interest in recent decades. A study of the early research in this area reveals that various terminologies have been used depending on the application domain, such as photonic bandgap (PBG), width of electromagnetic bandgap (EBG) and frequency selective surfaces (FSS). Periodic structures have attracted much interest among microwave engineers, mainly due to their potential applications in the design of waveguides and transmission line systems, which derive from their attractive slow waves and specifications of band rejection guided waves. With the advent of photonic bandgap materials in the field of the optical band, the development of various periodic structures of planar transmission lines and different EBG structures for integrated microwave circuits has quickly attracted an increasing interest. Applications including a coplanar backed wave guide without leakage and a patch antenna fed by a coupled slot have been highlighted by the exploitation of wide and deep rejection bands and deleting surface waves (or feature called STOP) of periodic structures.

The use of photonic bandgap structures uni-planar compact (UC-PBG), which are thin planar EBG structures without holes, opens the possibility of integrating antennas on high dielectric constant substrates without degradation of performance. The gain and bandwidth of a microstrip antenna can be greatly improved by using an artificial EBG material designed appropriately.

Today, the problems of periodic structures arise quite often in many areas of modern application as the semiconductor nanostructures (e.g. quantum dots and nanocrystals), the super-lattice semi-conductors, photonic crystal structures (PC), metamaterial or waveguides based Bragg gratings.

Ample representative examples are provided to highlight the marvels of EBG structures for both microwave and optical applications. Characterizations of EBG structures and related meta-materials are interesting research frontiers with potential electromagnetic engineering system applications [4].

Sandeep Palreddy [5] has analyzed wideband electromagnetic band gap (EBG) structures and their applications to antennas.

Alka Verma has studied EBG structures and their recent advances in microwave antenna [6].

Jun Kamiya and al Have studied EBG structures using Metamaterial Technology [7].

Artificial periodic structures can be realized in three ways, namely: First, periodization is performed on the metal layer that is the strip or the ground plane should be called periodic metal structure. Second, it is performed on the dielectric substrate by the juxtaposition of two blocks of dielectric for which the constant substrates (ε, μ) are different, making a cell repeated several times to give a periodic dielectric structure. Third, assembling the first two structures makes a hybrid structure.

Microstrip periodic structures behave as filters. They have a property called EBG. The criteria for characterizing an EBG are: center frequency f_0 of the bandgap called rejection band, its width Δf and waving off the transmission gap. These characteristics are closely related to the periodic lattice parameters, such as the lattice step, the index contrast between the two media of periodic dielectric and the metal pattern used.

The purpose of this article is the use of the FEL approach, which is a special case of the method of Finite Elementary Coupled Lines (FECL) [8], in the study of some periodic structures of literature and provide a comparison between the results obtained by this approach and those measured and simulated by the selected authors. A periodic structure with a broad and deep rejection band is also presented.

The article is structured as follows: the second section is reserved for the analysis of a sinusoidal periodic metallic structure. The third section is reserved for the analysis of a periodic dielectric structure. The fourth section is devoted to the study of a hybrid periodic structure. The fifth is dedicated to the discussion of the results. Finally, the last gives a conclusion.

2. Study of a Periodic Metallic Structure

The structure studied is that of [9] shown in Figure 1. It consists of a sinusoidal microstrip line engraved on a dielectric substrate of constant ε_r. The line width is governed by the equations so as to have the characteristic impedance as follows [9]:

$$Z_c = 50\ \Omega - (50\ \Omega - Z_{c\ min}).\ \sin(2\pi.p/L) \leq 50\ \Omega, \text{ for } 0 \leq p \leq L/2 \quad (1)$$

$$Z_c = 50\ \Omega + (Z_{c\ max} - 50\ \Omega).|\sin(2\pi.p/L)| \geq 50\ \Omega, \text{ for } L/2 \leq p \leq L \quad (2)$$

The product ($Z_{c\ min}$. $Z_{c\ max}$) must obey the equation:

$$Z_c = \sqrt{Z_{c\ min} Z_{c\ max}} = 50\ \Omega \quad (3)$$

L is the cell length (period) and p is the position of a cell of the line as described in fig. 1.

These equations governing the characteristic impedance Z_c result in the following equations that give the width w of the mnicrostrip line corresponding to this characteristic impedance:

$$W = W_{50}+(W_{max}-W_{50}).\ \sin(2\pi.p/L), \text{ when } 0 \leq p \leq L/2 \quad (4)$$

$$W = W_{50}-(W_{50}-W_{min}).\ |\sin(2\pi.p/L)|, \text{ when } L/2 \leq p \leq L \quad (5)$$

W_{50} is the width of microstrip matching the characteristic impedance of 50 Ω.

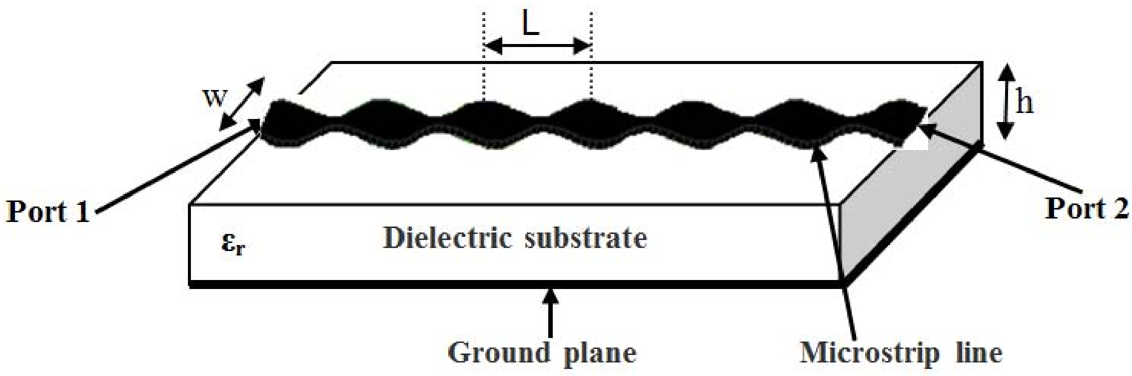
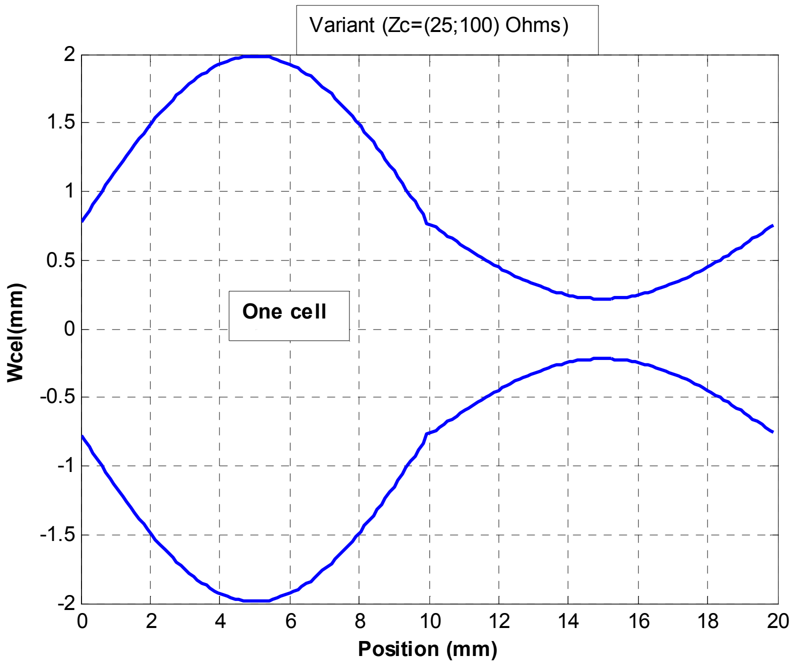
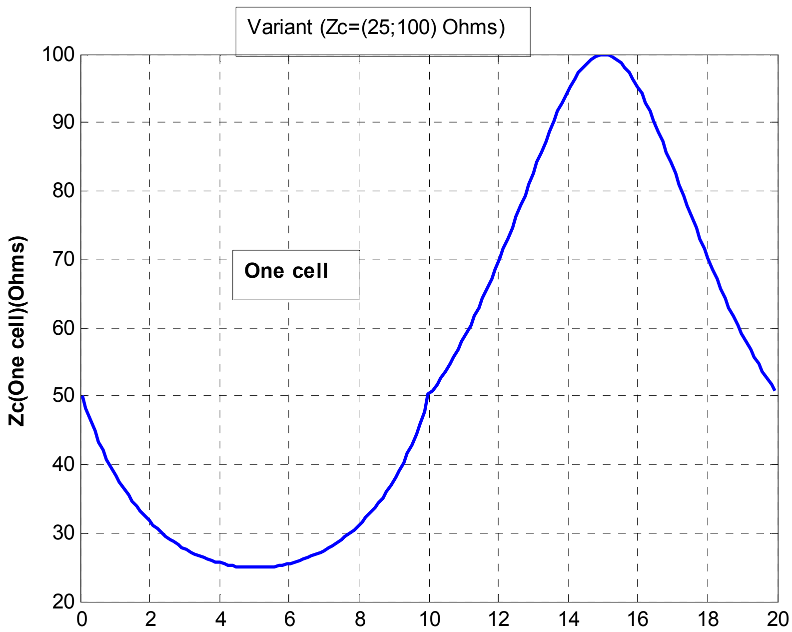


Figure 1. *Sinusoidal microstrip line.*

Figure 2 shows the passage of the periodic line width of the microstrip at its periodic characteristic impedance and vice versa for a cell (ε_r = 2.2 and h = 0.508 mm) for the variant ($Z_{c,\ max}$ = 100 Ω; $Z_{c,\ min}$ = 25 Ω) and (W_{min}, W_{max}) = (0.44mm, 3.97mm).



(a)

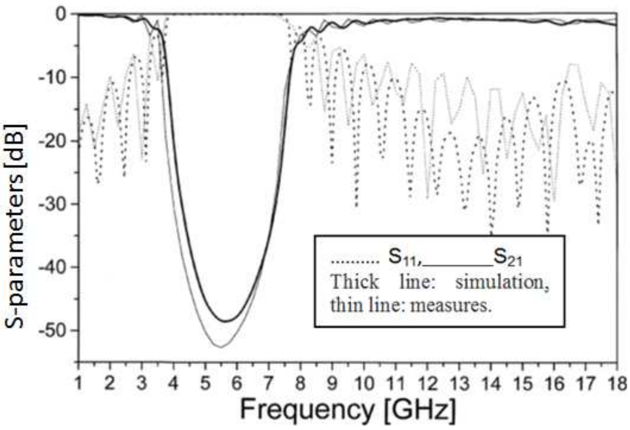


(b)

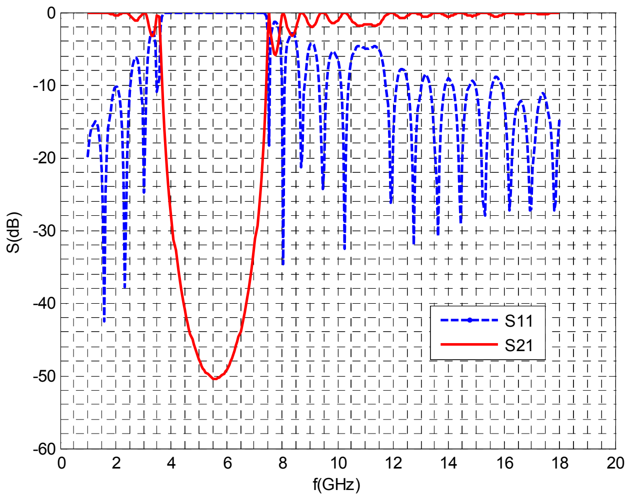
Figure 2. *A cell of the sinusoidal microstrip line: (a) width w and (b) characteristic impedance Z_c.*

2.1. Structure Engraved on a Thin Substrate of Low Dielectric Constant

The curves in Figure 3 reflect the S_{11} and S_{21} parameters of the structure-based substrate dielectric constant $\varepsilon_r = 2.2$ and thickness h = 0.508 mm, variant Z_c = (25 Ω, 100 Ω), 6-cell length L = 20 mm each. The solid line curves correspond to S_{21}, and the dashed to S_{11}. The thick curves correspond to the simulation by IE3D of [9] and the fine curves to measures of [9]. Figure 4 shows the **S**-parameters of the structure shown in Figure 1, simulated by the FEL model. Note the perfect agreement between the simulation results by the FEL approach and measures regarding the rejection band. The bandwidth at - 20 dB is 3.55 GHz (3.75 to 7.3 GHz) centered around 5.6 GHz which corresponds to 63.39%. The depth of rejection at the central frequency is -50 dB. Within this band, the reflection is almost complete. The transmission ripples out of the rejection band are higher – 6 dB. This is an almost ideal band stop filter.



(a)

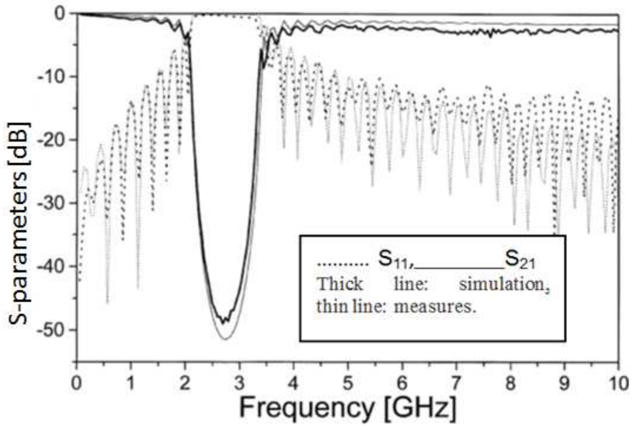


(b)

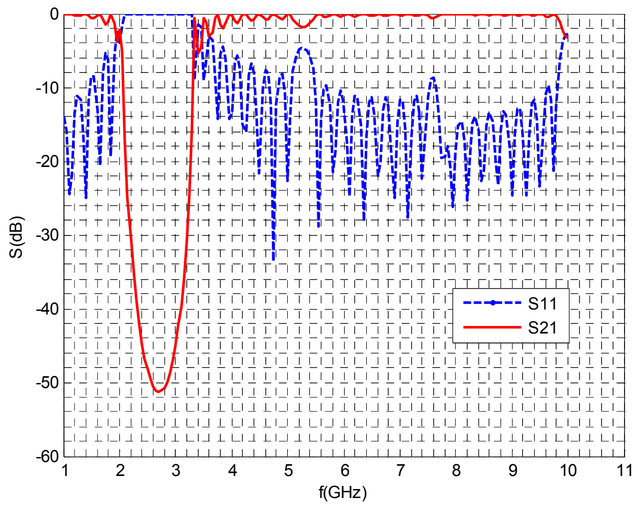
Figure 3. *S-parameters of the microstrip line in Figure 1 with ε_r = 2.2 and h = 0.508mm, variant Z_c = (25 Ω, 100 Ω), 6-cell length L = 20mm each: (a) simulation and measurement of [9] and (b) simulation by FEL approach.*

2.2. Structure Engraved on a Relatively Thick Substrate of High Dielectric Constant

In this section, the FEL model is compared to that of [8] for a second structure. In Figure 4(a) simulated and measured S-parameters by [9] for a sinusoidal line with 9 cells 21.2 mm in length each variant Z_c = (31 Ω, 80 Ω) engraved on the substrate (ε_r = 10.2, h = 0.635 mm) are presented. Figure 4(b) shows the S-parameters provided by the FEL model for the same structure. Both Figures 4(a) and 4(b) show that the structure has a rejection band at - 20 dB from 2.1 to 3.3 GHz and centered around 2.7 GHz with a rejection depth of -50 dB, which means both models are in perfect agreement with each other and with measurements. The rejection band of this second variant is narrower (44.44%) relative to that of the first (63.39%). From figures 3 and 4, we can conclude that according to the need of the application we can synthesize a selective rejection band or a broad rejection band structure centered around the desired frequency.



(a)



(b)

Figure 4. *S-parameters of the microstrip line in Figure 1 with ε_r = 10.2 and h = 0.635mm, variant Zc = (31 Ω, 80 Ω), 9-cell length L = 21.2mm each: (a) simulation and measurements [9] and (b) simulation by FEL approach.*

3. Study of a Periodic Dielectric Structure

In this section, the FEL model is compared to that of [10]. The studied structure is schematically shown in Figure 5. The structure is a microstrip line engraved on a periodic substrate consisting of alternating dielectric of length L_1 = 1.1 mm and constant ε_r = 10.2 and air of length L_2 = 12.7 mm. The substrate thickness is h = 1.27 mm. The number of cells is 5.

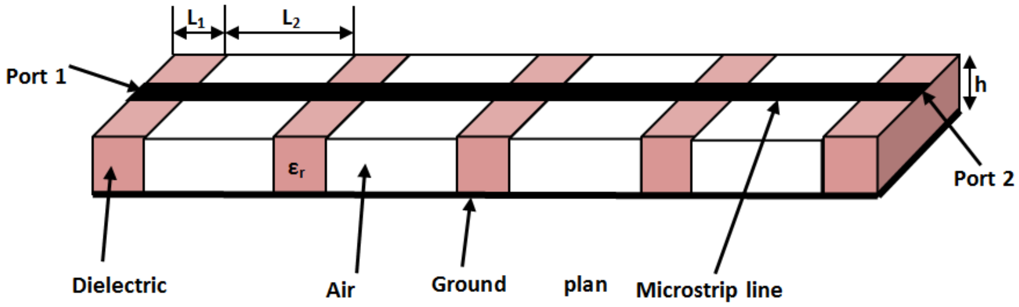


Figure 5. *Periodic dielectric structure.*

On the figures 6 (a) and 6 (b) are presented the **S**-parameters of the structure of Figure 5, measured and simulated by [10] with the software HFSS (High Frequency Structure Simulator).

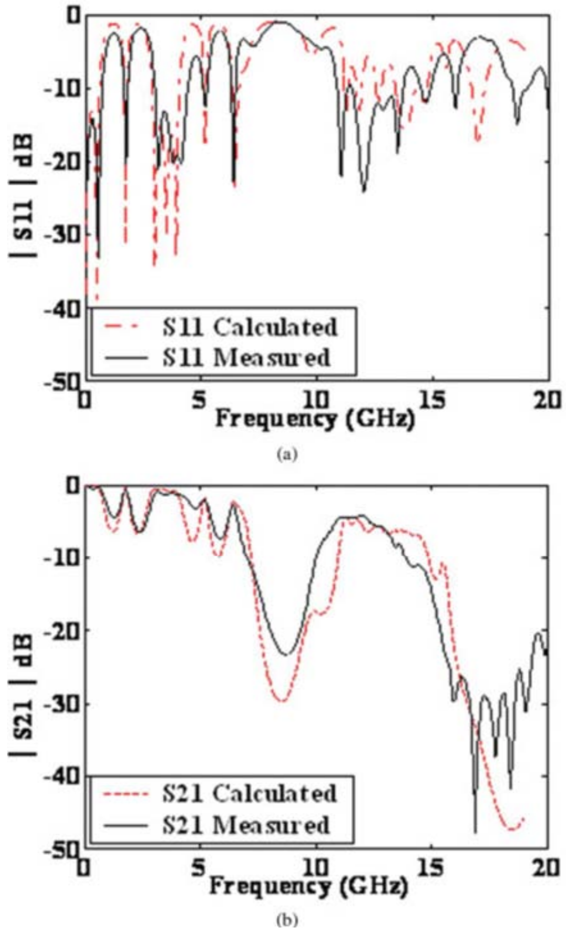


Figure 6. *S-parameters of the microstrip line of Figure 5 made of five cells of alternating between dielectric of length L_1 = 1.1mm and constant ε_r = 10.2 and length of air L_2= 12.7mm. The substrate thickness is h = 1.27, (a): S_{11}, and (b): S_{21}. [Results of the literature ref 10].*

The S-parameters of the structure simulated by the FEL are shown in Figure 7. A good agreement between the measurements and the simulation by the FEL approach of S_{21} is observed, especially for the first rejection band. Note that for both models and measurements, the second rejection is deeper (- 28 dB) than the first (- 22 dB). The first rejection band is centered around 8.5 GHz.

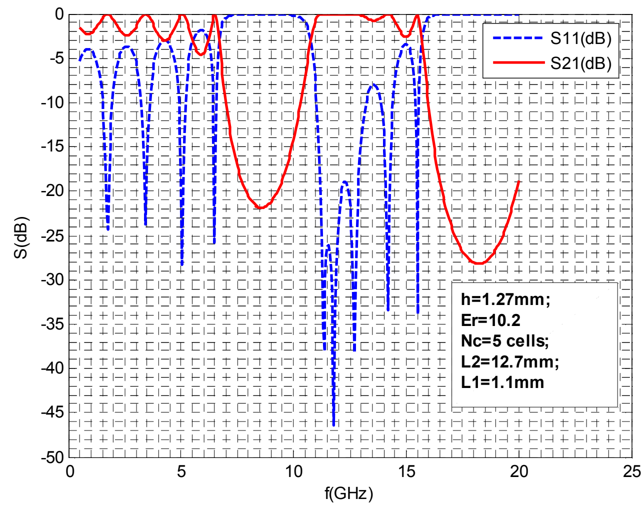


Figure 7. *S-parameters of the microstrip line Figure 5 made of five cells of alternating between dielectric of length L_1 = 1.1mm and constant ε_r = 10.2 and length of air L_2= 12.7mm. The substrate thickness is h = 1.27mm, simulated by the FEL model. Blue dotted curve: S_{11} and red continuous curve: S_{21}. [Results of the FEL approach used in this paper.].*

4. Study of a Hybrid Periodic Structure

To investigate the influence of both ρ_w contrast (ratio between the maximum and minimum widths of microstrip w_{max} / w_{min}) and $\rho_{\varepsilon r}$ contrast ($\rho_{\varepsilon r} = \varepsilon_{rmax} / \varepsilon_{rmin}$) on depth and width at - 20 dB of the rejection band, the structure of [9] is taken and it is combined with the structure of [10] to form a hybrid periodic structure, as shown in Figure 8.

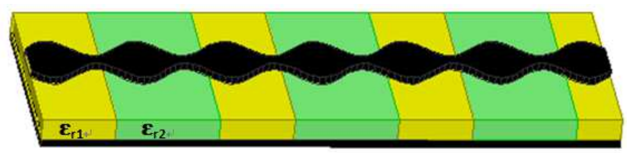


Figure 8. *Biperiodic structure according to the microstrip and to the dielectric substrate.*

In Figure 9 is displayed the characteristic impedance of a hybrid periodic structure. Microstrip lies on six sinusoidal periods. The periodicity of the substrate is achieved by the provision of a dielectric with constant ε_r = 13 and a length L_1 = 20 mm and the air with length L_2 = 80 mm in a juxtaposed manner (Figure 8). L_1 and L_2 are defined in Figure 5.

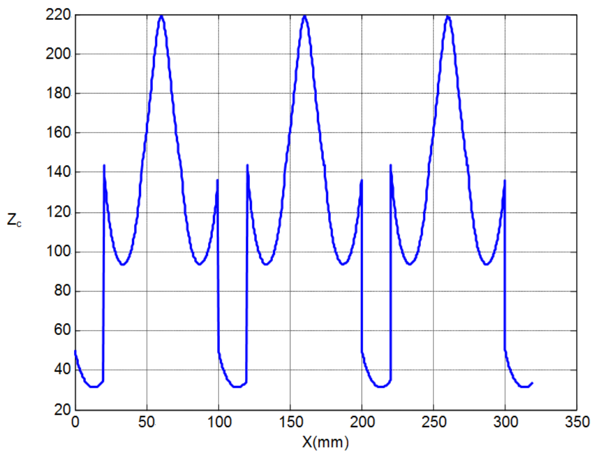


Figure 9. *Characteristic impedance calculated by FEL model for a hybrid structure (fig. 8) formed of a microstrip line engraved on a substrate consisting of alternate juxtaposed dielectric and air L_1 (diel.) = 20mm, L_2 (air) = 80mm; ε_r = 13, h = 0.508mm. The microstrip line is sinusoidal with 6 periods governed by equations (4) and (5), X: Position on the microstrip line.*

Figure 10 shows the S-parameters of the structure of Figure 8 described in the previous section. The width at -20 dB of the band gap lies between 0.70 GHz and 1.50 GHz centered around 1.11GHz, which gives a band of 72.07% with a depth of -35 dB. Here ρ_w = 0.91/0.0855 = 10.64 and $\rho_{\varepsilon r}$ = 13/1 = 13.

Figure 11 shows the S-parameters of the structure described in the preceding paragraph with the changes: ε_r = 10.2 and Z_c(min, max) = (25 Ω, 100 Ω). The bandgap width, in this case, extends between 0.69 GHz and 1.60 GHz, it is centered around 1.15 GHz, so that is a band of 79.13% with a depth of 38.5 dB. Here ρ_w = 1.525/0.0536 = 28.45 and $\rho_{\varepsilon r}$ = 10.2 / 1 = 10.2. It is observed in the last two studied structures that the structure built based on a combination of ρ_w = 10.64 and $\rho_{\varepsilon r}$ = 13 is less efficient in terms of width and depth of the band rejection compared to the structure built by combining ρ_w = 28.45 and $\rho_{\varepsilon r}$ = 10.2.

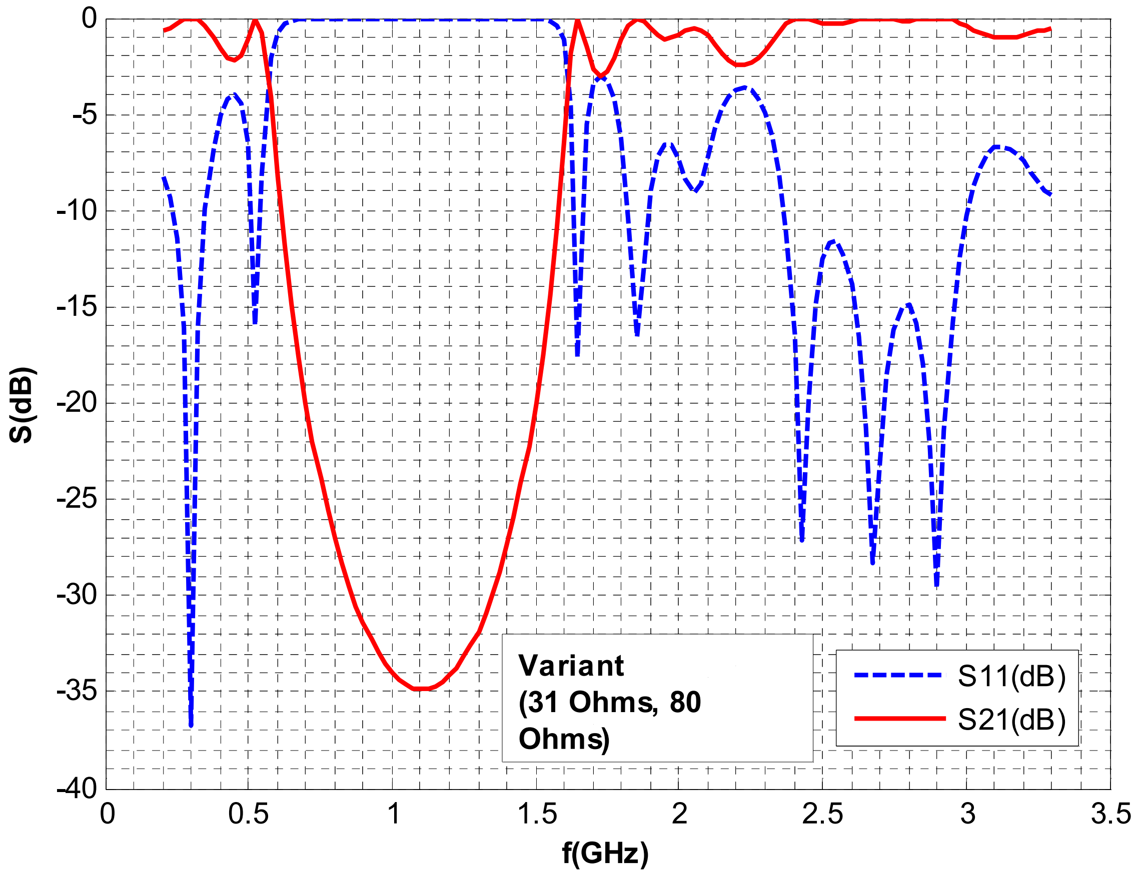


Figure 10. *S-parameters calculated by the FEL approach for a hybrid structure (fig. 8) formed of a microstrip line engraved on substrate made of dielectric and air juxtaposed alternating L_1 (diél.) = 20mm; L_2 (air) = 80mm; ε_r = 13, h = 0.508mm. The microstrip line is sinusoidal variant (31Ω, 80Ω) with 6 periods governed by equations (4) and (5).*

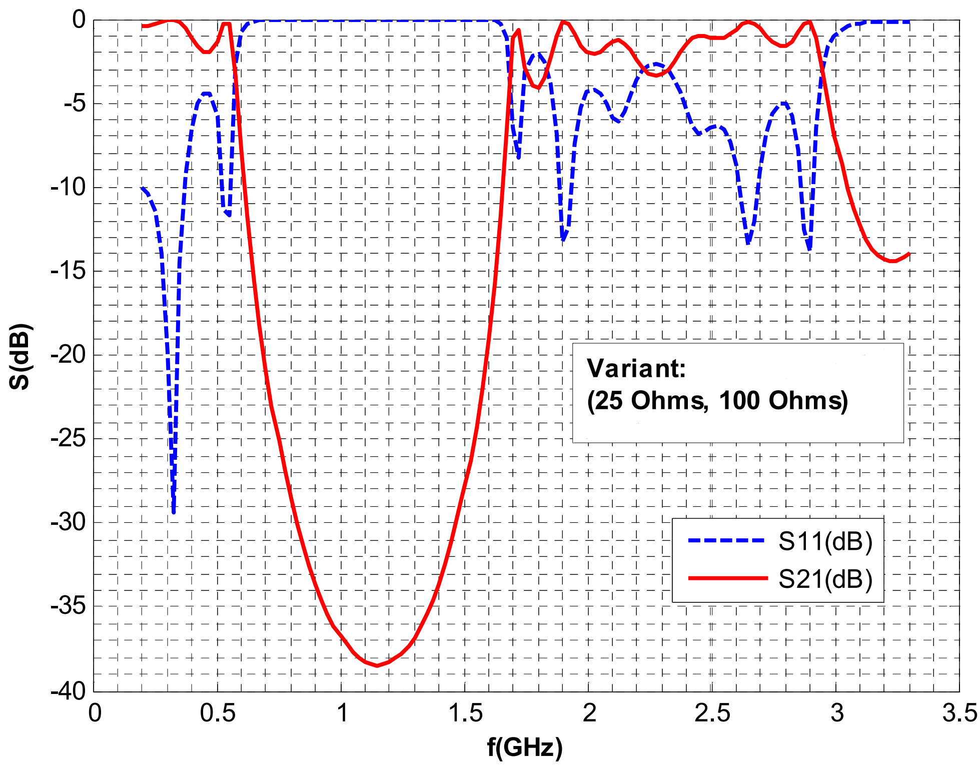


Figure 11. *S-parameters calculated by the FEL approach for a hybrid structure (fig. 8) formed of a microstrip line engraved on substrate made of dielectric and air juxtaposed alternating L_1 (diél.) = 20mm; L_2 (air) = 80mm; ε_r = 10.2, h = 0.508mm. The microstrip line is sinusoidal variant (25Ω, 100Ω) with 6 periods governed by equations (4) and (5).*

The following table summarizes the physical parameters and performance of two proposed hybrid periodic structures.

Table 1. *Physical parameters and performance of the two proposed hybrid periodic structures.*

Case No	combinations				
	ρ_w	$\rho_{\varepsilon r}$	L_o[mm]	h[mm]	Nature of periodicity
1	10.64	13	300	0.508	Sinus, variant (31-80) Ω + alternating (ε_r, 1)
2	28.45	10.2			Sinus, variant (25-100) Ω + alternating (ε_r, 1)

Table 1. *Continued.*

Case No	Central Freq. fc [GHz]	Rejection band at - 20 dB [GHz]	Rejection bandwidth [GHz]	Rejection Bandwidth [%] relative to f_c	Depth [dB]
1	1.11	0.70 ÷ 1.50	0.80	72.07	- 35.0
2	1.15	0.69 ÷ 1.60	0.91	79.13	- 38.5

5. Discussion of Results

The approach of FEL was developed in MATLAB. There is a perfect agreement between the results obtained by the FEL approach and measurements of [9] and those of [10].

Indeed, the rejection bands of the two structures studied of [9] measured and simulated by the approach of FEL overlap perfectly for center frequencies which are respectively 5.6 GHz and 2.7 GHz and for their relative widths at -20 dB that are 63.39% and 44.44% respectively. The obtained simulated and measured depths of the structures also overlap and they are equal to -50 dB and -51 dB.

For the structure of [10], a perfect agreement between the center frequency of the measured first rejection band and the simulated by the FEL model which is equal to 8.5 GHz is obtained. The measured and simulated depth is - 22 dB.

For both proposed hybrid periodic structures, the results are shown on the table 1. The second structure having a higher contrast in width of the microstrip has rejection band wider and deeper.

6. Conclusion

Two types of periodic structures selected from the literature were studied using the approach of FEL. The first has a relatively low dielectric constant (10.2) and the second with a high dielectric constant (13). In the two structures of equal size, increasing the contrast of the sine amplitude of the microstrip increases width and depth of the rejection band. The obtained results were compared with those published and good agreement is observed. The differences between the results of the FEL approach and the measurements of Dusant Nesic and Aleksandar Nesic are approximately 1.8% for the center frequency of rejection, 0.4% for the depth and 0.0% for the width of the rejection band. The peculiarity of the FEL approach lies in its simple implementation, its speed of calculation and the relatively low resource requirement, which allows concrete facility in the analysis and synthesis of structures. Two periodic hybrid structures of the same physical size have been proposed for two different rejection bandwidths. This FEL approach allows the design of filters for specific applications in a remarkably short time.

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