Investigation of Microstrip Band-pass Filters Based on 2D Electromagnetic Crystal

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***Abstract*—Electrodynamic numerical analysis of 3D models was used in order to study microstrip filters of 4-th and 6-th order. When constructing 2D microwave structures, irregular resonators with Π-shaped slit in a grounded strip conductor were used. The band-pass filters tuned by manual parametric synthesis have high frequency-selective properties, including extended high frequency stopband.**

Keywords— microstrip filter, 2D electromagnetic crystal, strip conductor, amplitude–frequency characteristics, irregular resonator

I. INTRODUCTION

Electromagnetic crystals are known [1] as periodic structures, which usually have the ability to suppress the propagation of electromagnetic radiation in certain frequency ranges through them, that are called stopbands. At present, various frequency-selective devices have been developed on the basis of such one-dimensional (1D) and two-dimensional (2D) crystals, both optical [2-6] and microwave [7-10] ranges, including band-pass filters [2, 8-10], low-pass filters [3, 7], rejecting filters, etc.

It is obvious that microstrip structures, developed on the basis on traditional approaches only, are out of date, therefore, when designing competitive devices, microwave designers are using new approaches to an increasing extend [10-12]. One of such promising approaches, that allows to improve frequency-selective properties of microstrip filters significantly, is two-dimensional arrangement of strip conductors' resonators on dielectric substrate [12]. In this case, additional electromagnetic coupling appear between adjacent resonators, which can not be realized in one-dimensional construction of microstrip structure. In a number of cases, this allows the development of microwave designs with the improved characteristics.

Therefore, the present paper gives the results of the study of frequency-selective properties of band-pass filters based on 2D electromagnetic crystal.

In order to compare the characteristics of four devices, calculated with the help of electrodynamic numerical analysis of their 3D models, which, as it is well known [11], is in good agreement with the experiment, identical dielectric substrates of thickness $h = 1$ mm (polycor is the material) were used. Additionally, central frequency of the passband of $f_0 \approx 1.0$ GHz was recorded, while the relative bandwidth was $\Delta f/f_0 \approx 20\%$. The tune of the fourth and the sixth order microstrip filters was done by means of «manual» parametric synthesis, in which the geometric dimensions of strip conductors' topology were selected, i.e. their length and width, the dimensions of the slits in them and the size of the gaps between them.

II. BAND-PASS FILTERS OF THE FOURTH ORDER

The topology of strip conductors of the four-resonator microstrip filter is shown in Fig. 1. The strip conductor of each resonator in 2D structure has Π-shaped cut, which consists of one horizontal slit and two identical vertical slits. Besides, the central narrow extended segment of the strip conductor is grounded by means of round-form perforation (*1*) with the height *h* in a dielectric substrate filled with a conductive material. Such design features of the band-pass filter allow one to observe in its amplitude-frequency characteristics (Fig. 2) an extended high-frequency stopband, realized due to high jump in wave impedances of line segments. It is necessary to note, that while forming the passband of the filter, only the lowest mode of oscillations is used from each irregular resonator.

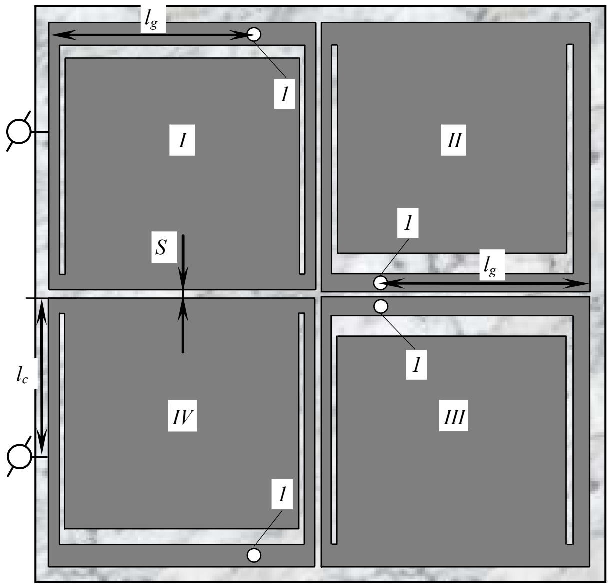

Fig. 1. The topology of band-pass filters of the 4-th order.

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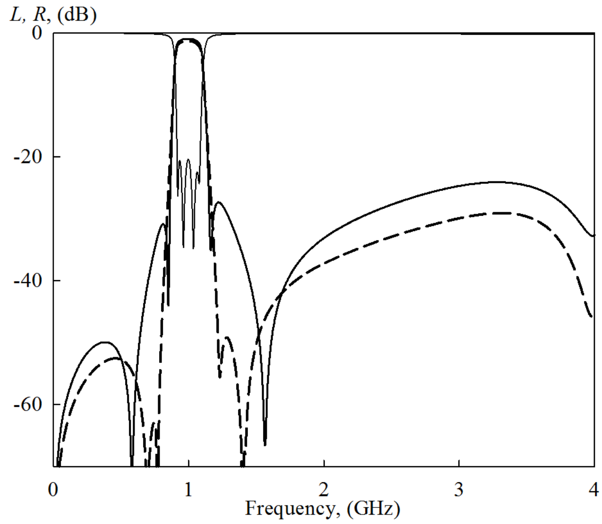

Fig. 2. Amplitude-frequency characteristics of the 4-th order band-pass filters, calculated at a strong capacitive coupling between the input and the output resonators (lines) and their weak coupling (dashed line). *L*(*f*) – frequency dependence of direct losses, *R*(*f*) – frequency dependence of losses in reflection.

It is also important to note that in such microwave designs, the amplitude of high-frequency currents on narrow extended segments of strip conductors exceeds the amplitude of the currents on wide rectangular segments significantly. As a result, the inductive interaction in all of four resonators is much stronger than the capacitive one, due to this fact, the signal from the input resonator (*I*) is transferred to the adjacent resonator (*II*) of the horizontal row, then to the adjacent resonator (*III*) of the vertical row, and only then to the output resonator (*IV*).

It is obvious that such filter of the 4-th order can be realized with different capacitive interaction between the input (*I*) and the output (*IV*) resonators, that is constructively easy to realize by means of vertical extending of the conductors in these two resonators (see Fig. 1, gap *S*). Such additional electromagnetic coupling between the above-mentioned resonators, explained by 2D design of microstrip structure, contributes to the emergence of two pairs attenuation poles located on the amplitude-frequency characteristics of the filter, both to the left and to the right from its passband, which leads to a significant increase in its steepness slopes.

Let us study the influence of such a link between a pair of adjacent resonators of the device on its frequency-selective properties.

In the first microstrip filter with a strong capacitive coupling between the input and the output resonators, the separation value $S = 0.40$ mm is selected in such a way, that the power suppression near the passband is to be near -30 dB on the amplitude-frequency characteristics of the device (Fig. 2, lines).

In the second band-pass filter, in order to reduce the capacitive coupling between (*I*) and (*IV*) resonators, the separation value became more than doubled – $S = 0.90$ mm, while on the amplitude-frequency characteristics of the device, power suppression near the passband is not less than 50 dB (Fig. 2, dashed line).

Further reduction of capacitive link between the input and the output resonators leads to the disappearance of all four attenuation poles on the amplitude-frequency characteristics of the filter and, accordingly, to the degradation of its frequency-selective properties.

Let us give the constructive parameters in mm of the above described frequency-selective devices.

In the first filter, the length and width of the strip conductors (*I*) and (*IV*) of the resonators – 9.60×9.60, (*II*) and (*III*) – 9.70×9.75, respectively. The length and width of the horizontal (vertical) slit in the strip conductor (*I*) and (*IV*) of the resonators are 8.80×0.50 (8.30×0.20), (*II*) and (*III*) are 8.70×0.90 (8.30×0.20), respectively. The width of the segment of the strip conductor with a round-form perforation (*1*) is 0.45 mm in diameter of resonators (*I*) and (*IV*) – 0.80, (*II*) and (*III*) – 0.70, respectively. The displacement of l_g centre of round-form perforation (*1*) from the edge of the conductor (*I*) and (*IV*) of the resonators (see Fig. 1) – 7.40, (*II*) and (*III*) – 7.50, respectively. The displacement of the conductive connection point l_c from the edge of the conductor is 5.65. The gaps between the conductors (*I*) and (*II*) of the resonators are 0.20, (*II*) and (*III*) – 0.10, (*III*) and (*IV*) – 0.20, (*IV*) and (*I*) – S = 0.40, respectively.

In the second filter, the length and width of the strip conductors (*I*) and (*IV*) of the resonators – 9.70×9.60, (*II*) and (*III*) – 9.55×9.75, respectively. The length and width of the horizontal (vertical) slit in the strip conductor (*I*) and (*IV*) of the resonators are 8.90×0.25 (8.25×0.20), (*II*) and (*III*) are 8.70×0.85 (8.30×0.20), respectively. The width of the segment of the strip conductor with a round-form perforation (*1*) is 0.45 mm in diameter of resonators (*I*) and (*IV*) – 0.80, (*II*) and (*III*) – 0.70, respectively. The displacement of l_g centre of round-form perforation (*1*) from the edge of the conductor (*I*) and (*IV*) of the resonators (see Fig. 1) – 7.70, (*II*) and (*III*) – 7.75, respectively. The displacement of the conductive connection point l_c from the edge of the conductor is 6.25. The gaps between the conductors (*I*) and (*II*) of the resonators are 0.25, (*II*) and (*III*) – 0.10, (*III*) and (*IV*) – 0.25, (*IV*) and (*I*) – S = 0.90, respectively.

III. BAND-PASS FILTERS OF THE SIXTH ORDER

As it is known, while studying frequency-selective properties of new microstrip band-pass filters, the increase of their resonators number is the simplest way to improve the characteristics of the structures.

Let us consider the feasibility of the realization of such sixth-order microstrip filters based on 2D electromagnetic crystal.

The third band-pass filter, presented in this paper, has one resonator in the upper and the lower horizontal rows (Fig. 3), it is designed for the case of the input and the output 50 Ω ports on one edge of the dielectric substrate location, that is sometimes necessary while designing units of modern radio equipment.

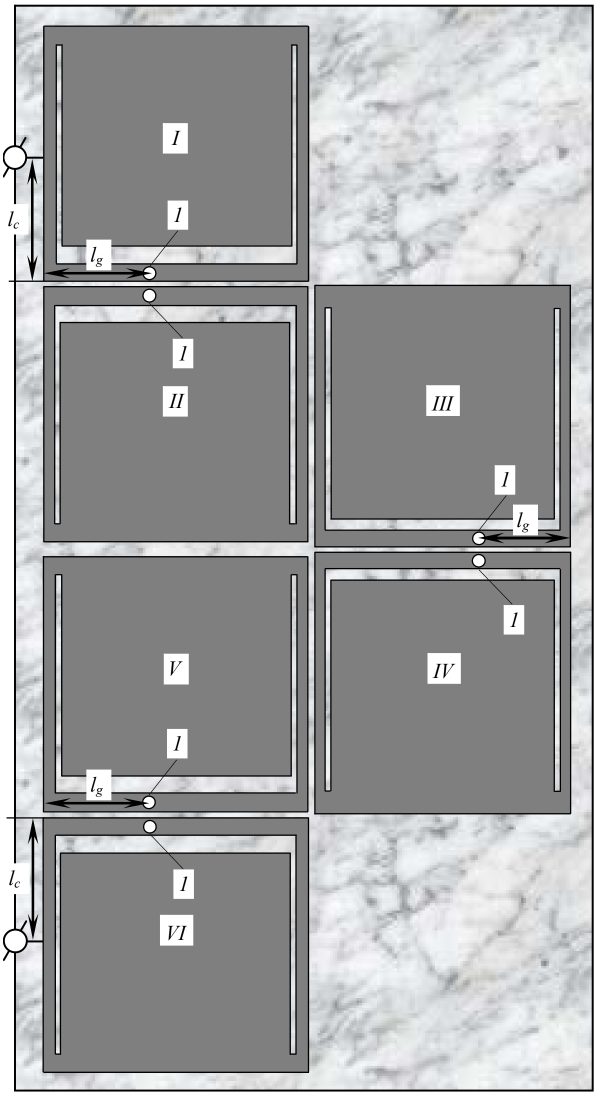

Fig. 3. The topology of the strip conductors of the 6-th order filter with the location of the input and the output ports on one edge of the substrate.

The fourth microstrip filter, realized on the basis of a crystal with the dimension of [2×3], the input and the output 50 Ω ports are located on the opposite edges of the dielectric substrate (Fig. 4).

In such two-dimensional microstrip structures, the signal is transmitted similarly to the fourth-order filters consequently from one resonator to another: (*I*) → (*II*) → (*III*) → (*IV*) → (*V*) → (*VI*).

The amplitude-frequency characteristics of the synthesized structures are shown in Fig. 5. As it was supposed to expect, the increase of filters' orders up to six, is accompanied by the amplification of power suppression at the frequencies of the stopbands and the increase in the steepness of the passband slopes. It should be noted that the frequency-selective properties of the fourth band-pass filter are significantly higher than the ones of the third order filter. So, in particular, it has an extended high-frequency stopband that reaches the value of $3f_0$, measured at -30 dB.

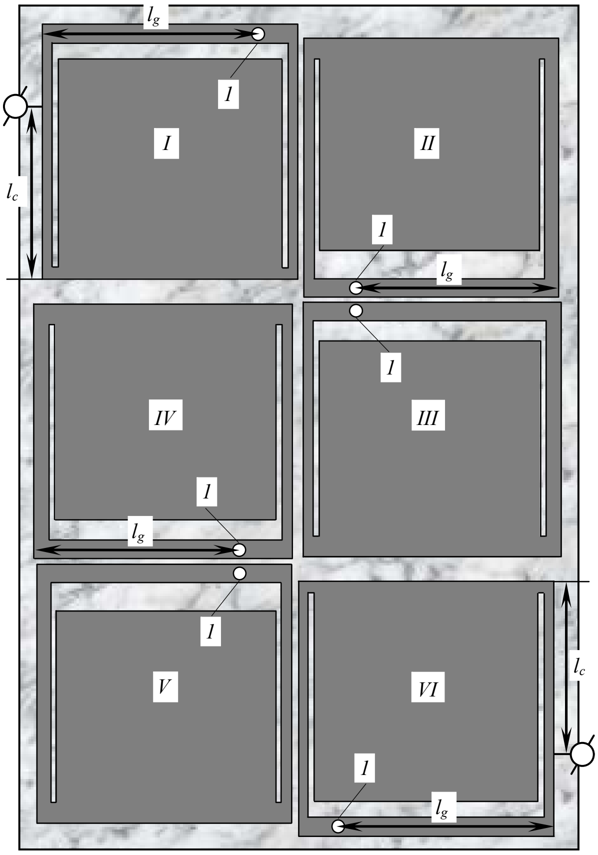

Fig. 4. The topology of the strip conductors of the 6-th order filter with the location of the input and the output ports on opposite edges of the substrate.

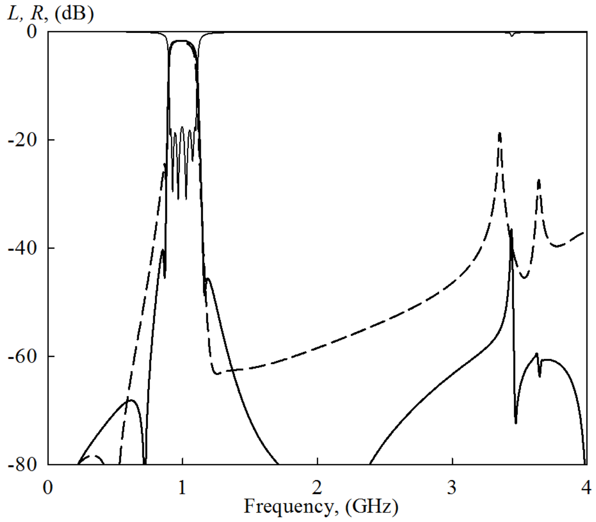

Fig. 5. Amplitude-frequency characteristics of filters of the sixth order. Dashed lines show calculated data for the filter with the input and the output 50 Ω ports location on the one edge of the dielectric substrate; lines show the ports located on opposite edges of the substrate, respectively. *L*(*f*) – frequency dependence of direct losses, *R*(*f*) – frequency dependence of losses in reflection.

Similarly, the constructive parameters in mm of the above described two filters of the sixth order are given as well as it was done for the filters of the fourth order.

In the third design (see Fig. 3), the length and width of the strip conductors (*I*) and (*IV*) of the resonators – 9.60×9.40, (*II*) and (*V*) – 9.60×9.35, (*III*) and (*IV*) – 9.30×9.60, respectively. The length and width of the horizontal (vertical) slit in the strip conductor (*I*), (*II*), (*V*) and (*VI*) of the resonators are 8.80×0.70 (8.05×0.20), (*III*) and (*IV*) are 8.50×0.40 (8.10×0.20), respectively. The width of the segment of the strip conductor with a round-form perforation (*1*) is 0.45 mm in diameter of all six resonators – 0.65. The displacement of l_g centre of round-form perforation (*1*) from the edge of the conductor (*I*), (*II*), (*V*) and (*VI*) of the resonators – 3.80, (*III*) and (*IV*) – 3.30, respectively. The displacement of the conductive connection point l_c from the edge of the conductor is 4.55. The gaps between the conductors (*I*) and (*II*) of the resonators are 0.05, (*II*) and (*III*) – 0.20, (*III*) and (*IV*) – 0.05, (*IV*) and (*V*) – 0.20, (*V*) and (*VI*) – 0.05, (*II*) and (*V*) – 0.45, respectively.

In the fourth design (see Fig. 4), the length and width of the strip conductors (*I*) and (*IV*) of the resonators – 9.60×9.60, (*II*) and (*V*) – 9.60×9.75, (*III*) and (*IV*) – 9.70×9.65, respectively. The length and width of the horizontal (vertical) slit in the strip conductor (*I*) and (*VI*) of the resonators are 8.80×0.60 (8.45×0.20), (*II*) and (*V*) – 8.70×1.05 (8.30×0.20), (*III*) and (*IV*) – 8.70×0.80 (8.20×0.20), respectively. The width of the segment of the strip conductor with a round-form perforation (*1*) is 0.45 mm in diameter of resonators (*I*) and (*IV*) – 0.75, (*II-V*) – 0.70, respectively. The displacement of l_g centre of round-form perforation (*1*) from the edge of the conductor (*I*) and (*VI*) of the resonators – 8.10, (*II*) and (*V*) – 7.60, (*III*) and (*IV*) – 7.70, respectively. The displacement of the conductive connection point l_c from the edge of the conductor is 6.50. The gaps between the conductors (*I*) and (*II*) of the resonators are 0.20, (*II*) and (*III*) – 0.10, (*III*) and (*IV*) – 0.40, (*IV*) and (*V*) – 0.10, (*V*) and (*VI*) – 0.20, (*I*) and (*IV*) – 0.45, (*III*) and (*VI*) – 0.90, respectively.

IV. CONCLUSION

Consequently, we suggested new designs of microstrip band-pass filters based on an electromagnetic crystal with a two-dimensional arrangement of irregular resonators with Π-shaped slit in a grounded strip conductor. It is shown that the serial transmission of the microwave signal from one resonator to the other, as well as crossed links between them [13, 14], allows the construction of band-pass filters with high frequency-selective properties, including the ones with an extended high-frequency stopband, which can reach the value of $3f_0$, measured at -30 dB.

In this case, due to two-dimensional arrangement of the original microstrip resonators in the space, additional capacitive coupling appears between certain pairs of resonators, as a result up to two pairs of attenuation poles are observed on the amplitude-frequency characteristic of the filters. They are located near passband, a pair on the left and a pair on the right of it, which leads to a significant increase in the steepness of its slopes. Besides, in the proposed designs, it is not difficult to select the capacitive link between certain adjacent resonators in such a way, as to amplify power suppression near the passband frequencies or to increase the slope of its slopes substantially.

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