ISSN 1028-3358, Doklady Physics, 2019, Vol. 64, No. 3, pp. 85–89. © Pleiades Publishing, Ltd., 2019.
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PHYSICS

A Lowpass Filter Based on a 2D Microstrip Electromagnetic Crystal

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Received October 19, 2018

Abstract—A new construction of a lowpass filter was developed based on a two-dimensional microstrip electromagnetic crystal, which had a steeper slope of the frequency response as compared to a filter consisting of a one-dimensional microstrip electromagnetic crystal. The investigated lowpass filter construction is characterized by a high workability and ease of manufacturing. Electrodynamic numerical simulation of the 3D model of the considered microstrip structure agrees well with the experiment, which allows conducting parametric synthesis of devices with the required properties using a personal computer.

DOI: 10.1134/S1028335819030017

INTRODUCTION

It is well known that microwave frequency-selective devices, in particular, filters, are very important in communication systems, radiolocation, radio navigation, and in different measuring and specialized radio equipment [1, 2]. The most needed are bandpass filters; however, optimal solution of radiotechnical problems often requires the use of lowpass (LP) filters that transmit electromagnetic waves almost without loss in the frequency range from zero to the given cutoff frequency and thus block high-frequency noises. It is also known that the characteristics and sizes of the filters determine the quality and sizes of microwave devices. Thus, development of new miniaturized LP filters having high selectivity, low loss in the passband, ease of manufacturing, and inexpensiveness is an important and urgent task.

Today, miniature LP filters are used in the microwave technique and are made as a monolithic structure using the multilayer integrated circuits technology and are based on low-temperature cofired ceramics (LTCC) [3]. The main elements of such filters are resonance structures consisting of a quasi-lumped capacitive and inductive elements [4] with relatively low unloaded Q-factors; this results to relatively poor parameters of the frequency response of these devices.

LP filter constructions based on microstrip resonators are bigger but easier to produce; moreover, they may possess superior characteristics. That is why novel constructions of microstrip LP filters have been widely developed and studied lately [5–8]. To improve their properties, a large set of various resonators is typically used in devices of this kind; some of them provide the required passband, while the others are responsible for rejection and thus allow increasing the frequency response steepness and widening the stopband. Splitted resonators in the plane of microstrip constructions are made with the same purpose [9].

This paper presents the results of investigation of a novel LP filter design based on a two-dimensional microstrip electromagnetic crystal, which differs from other known constructions by a high slope value of the frequency response.

EXPERIMENTAL

Construction of the 2D Microstrip Electromagnetic Crystal

One-dimensional microstrip electromagnetic crystals, which are often called analogues of photonic crystals, are a chain of resonators made of segments of a transmission line with high and low wave impedances. The segments of microstrip lines manufactured on a monolithic dielectric substrate usually differ by the width of the strip conductors and thus form an irregular periodic structure. These microstrip structures serve as a basis for bandpass [10, 11] and lowpass [12] filters. However, the frequency selectivity of devices based on 1D electromagnetic crystals is relatively poor due to the small slope of the frequency response, which can be increased only by increasing the number of resonators in the structure. This problem is successfully solved when an LP filter is made as a two-dimensional microstrip electromagnetic crystal

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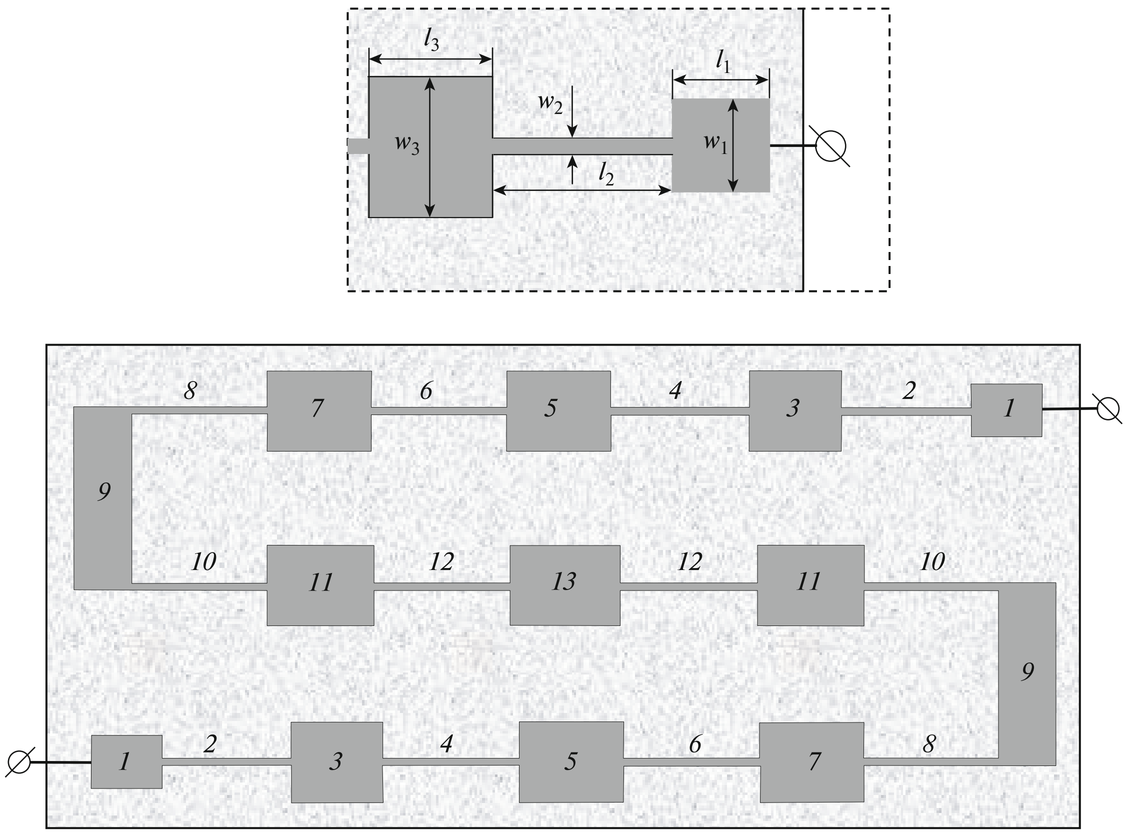

Fig. 1. Design of the lowpass filter based on the two-dimensional microstrip electromagnetic crystal.

(Fig. 1), in which an additional electromagnetic coupling between nonneighbor resonators is present. This cross-coupling is known to increase the frequency response steepness significantly [13].

The filter is a triple chain of microstrip resonators with a direct (galvanic) coupling, differing by the width w_i and length l_i of their strip conductors (i is the resonator number). The ends of the strip conductors of extreme resonators are connected to the input and output ports having the standard impedance of 50 Ω, which defines the symmetry of the construction. The substrate of the microstrip structure has a permittivity of ε and a thickness of d. It is worth noting that the dielectric substrate material should possess a high enough Q-factor so that it does not increase microwave loss in the passband of the filter; in microstrip constructions they are mainly due to ohmic loss in conductors.

Parametric synthesis of the LP filter was carried out by numerical electrodynamic analysis of a 3D model of the considered structure with the aid of the AWR Microwave-Office software by adjusting the construction parameters w_i and l_i. As can be seen from Fig. 1, the length of resonator no. 9 defines the distance between the parallel chains of resonators. For the sake of definiteness, polycor ($\varepsilon = 9.8$) was chosen as a material for the 1-mm-thick dielectric substrate for the microstrip structure; it is a traditional ceramic material in the microwave technique. The only limitation in the synthesis of the studied construction was the length of the microstrip structure, because the maximal standard size of polycor substrates is 60 mm. Allowing for the necessary margins around the outer conductors, which should be at least equal to the substrate thickness, the length of the microstrip structure cannot exceed 58 mm.

A prototype LP filter was created using the construction parameters obtained in the parametric synthesis (see photograph in Fig. 2). The substrate sizes are 60.0 × 24.4 mm; the sizes of the segments of the strips forming the resonators in the irregular microstrip structure are listed in the Table 1 according to labels shown in Fig. 1. The dots in Fig. 2 present the measured frequency response of insertion loss S_{21} and return loss S_{11}; solid lines show the frequency response obtained in the numerical analysis of the 3D model of the designed LP filter. Note that electrodynamic calculation of the frequency response shown in the figure was based on the real sizes of the construction (measured after its creation) to make the comparison impartial.

The dependences in Fig. 2, first of all, show a good agreement of the measured and calculated characteristics of the LP filter; second, they show a very steep frequency response due to the attenuation pole close to the passband. Note that the cutoff frequency measured at the level of 3 dB from the minimal loss level (which is only 0.2 dB) is f_3 = 2.11 GHz. At the frequency of 2.18 GHz (i.e., when the offset from the cutoff frequency is only 0.07 GHz), the filter provides an attenuation larger than 40 dB. An important remark is that a filter made as a 1D microstrip electromagnetic crystal and having the same number of resonators and the same cutoff, provides attenuation at 2.18 GHz that is about 10 dB smaller, which is due to the absence of attenuation poles in its frequency response.

Investigation of the Designed Lowpass Filter Construction

The high frequency selectivity of the LP filter developed on the basis on the 2D microstrip electromagnetic crystal, its workability, and the ease of creating show that employment of this filter in radiotechnical circuits is quite promising. Therefore, it is of interest to investigate the possibility of increasing the cutoff frequency of the proposed LP filter construction and also the possibility of using substrates with a higher permittivity, which would obviously allow further decreasing the device sizes. Since the electrodynamic simulation shows a good agreement with the experiment, we studied the designed construction by numerical analysis of its 3D model.

The results of this study are presented in Fig. 3, which shows frequency responses of the synthesized filters with the cutoff frequencies of 2, 3, and 4 GHz (Figs. 3a–3c). They are built on a polycor substrate with a thickness of 1 mm and sizes of 57.7 × 32.6, 38.7 × 25.8, and 29.85 × 19.4 mm^2, respectively. It is convenient to compare the frequency-selective properties of the obtained devices by the frequency response slope [14], which is calculated as follows:

$$k = \frac{\Delta f_3}{\Delta f_{30} - \Delta f_3}, \qquad (1)$$

where Δf_3 is the passband width at the level of –3 dB from the level of minimal loss and Δf_{30} is the passband width at the level of –30 dB measured from the same level of minimal loss.

For the studied filters with the cutoffs at 2, 3, and 4 GHz, the values of k are 24, 26, and 28; that is, the frequency response slope grows monotonically as the cutoff frequency increases. Figure 3d shows the frequency response of a filter built on a substrate with the permittivity of $\varepsilon = 20$ and the thickness of $d = 1$ mm. The filter has the cutoff frequency of 2 GHz, and its frequency response steepness is $k = 22$. The substrate sizes of this LP filter are 54.1 × 22.9 mm, so its area is nearly 1.5 times smaller than that of a similar filter made on the polycor substrate ($\varepsilon = 9.8$).

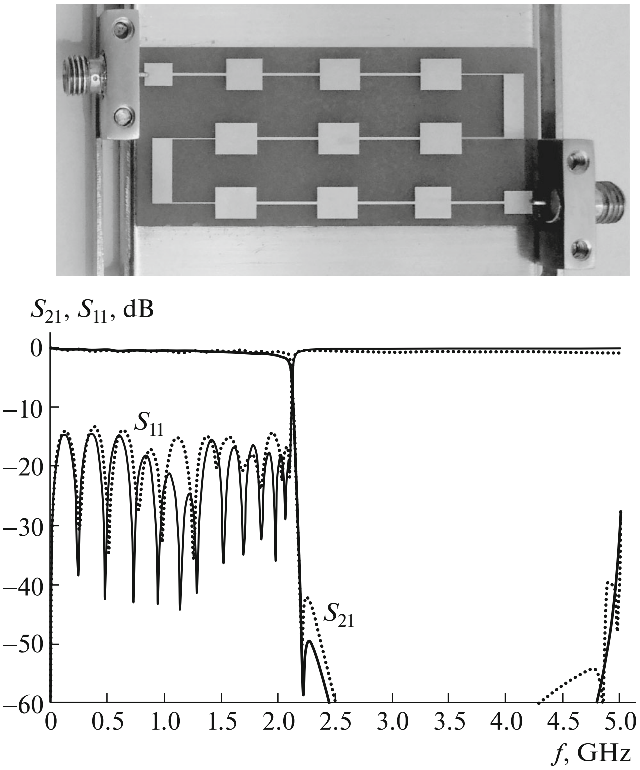

Fig. 2. Frequency response of the LP filter based on the 2D microstrip electromagnetic crystal. Dots: measurements; lines: simulations. The photograph of the prototype sample of the filter is shown on top.

RESULTS AND DISCUSSION

The proposed LP filter based on the 2D microstrip electromagnetic crystal has a steeper frequency response slope than LP filters based on 1D microstrip

Table 1. Topological sizes of strip conductors of the lowpass filter based on the 2D microstrip electromagnetic crystal

Resonator number, i	Conductor length l_i, mm	Conductor width w_i, mm
1	4.20	3.21
2	8.01	0.40
3	5.40	4.39
4	8.60	0.40
5	6.01	4.41
6	9.10	0.39
7	6.10	4.41
8	6.40	0.20
9	9.21	3.00
10	6.40	0.20
11	6.19	4.40
12	9.15	0.40
13	6.09	4.40

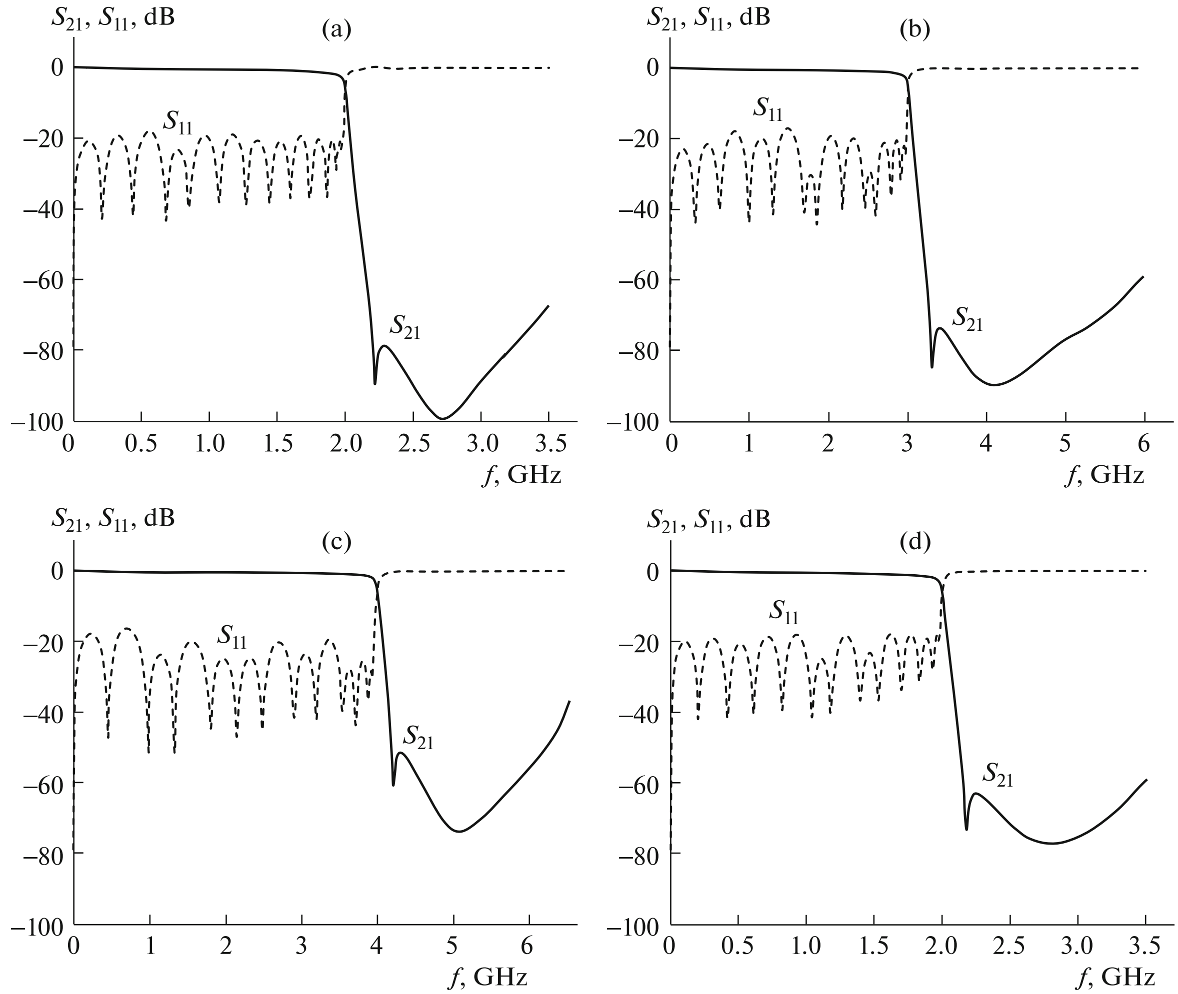

Fig. 3. Frequency response of the LP filter based on the 2D microstrip electromagnetic crystal. Filters are built on the polycor substrates (ε = 9.8) with the cutoff frequencies of (a) 2, (b) 3, and (c) 4 GHz; (d) the filter on the B-20 substrate (ε = 20) and the cutoff frequency of 2 GHz.

electromagnetic crystal, which is caused by the presence of an attenuation pole near the edge of the passband on the 2D crystal. At the frequency of the attenuation pole, two electromagnetic waves cancel out each other: one of them comes from the input to the output of the device through all resonators in three chains, and the second comes from the input to the output due to the coupling between the resonator chains. Obviously, at the attenuation pole frequency, these two waves have the same amplitudes but opposite phases. Note that, as the gap between the resonator chains decreases, the attenuation pole comes closer to the passband, and vice versa.

CONCLUSIONS

The investigated construction of LP filter is noted for its high workability and ease of manufacturing. Numerical electrodynamic simulation of the 3D model of the considered microstrip structure shows good enough agreement with the experiment, and hence, parametric synthesis of devices with given characteristics can be performed on a personal computer. These results prove that use of the developed LP filter construction in communication systems, radiolocation, measuring, and specialized radio technical devices is quite promising.

ACKNOWLEDGMENTS

This study was supported by the Ministry of Education and Science of the Russian Federation, project no. RFMEFI60417X0179.

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Translated by S. Efimov