The Investigation of Microstrip Diplexer Based on 2D Electromagnetic Crystal

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***Abstract* – The structure of microwave diplexers based on two-dimensional (2D) electromagnetic crystals of various size has been theoretically and experimentally investigated. In the proposed devices with high-frequency selective properties two rows of microstrip quarter-wave resonators electromagnetically connected with each other and with the input of the strip conductor are used. This allows splitting the signal into two channels.**

***Index Terms* – microstrip diplexer, bandwidth.**

I. INTRODUCTION

THE periodic structure having the ability to inhibit the spread of electromagnetic radiation in certain frequency bands through them called forbidden zones are generally electromagnetic crystals [1]. The devices based on such structures are already well established [2-4] and now are of great interest for the microwave (MW) equipment developers. They are miniature, easy for manufacturing and have high frequency selective properties.

However, matching of interacting resonators in two coordinates of the space is a difficult task, so the implementation on the basis of electromagnetic crystal of bandpass filters [5] structures, filter with two bandwidths [6] and diplexers require the developers to have particular experience and knowledge about the features of electromagnetic waves propagation in recurrent multi-dimensional structures.

It is often impossible to achieve the required precision using the one-dimensional model of the analysis in a quasi-static approximation while using the device synthesis with specified amplitude-frequency characteristics (AFCs) on the basis of two-dimensional microstrip structures. In such cases, it is necessary to use numerical electrodynamic analysis of 3D devices models that allows getting electrical characteristics matching the actual characteristics of experimental devices. However, it is well known that relatively high capacity computers are required for such calculations.

This paper presents the results of studies of microstrip diplexers based on the two-dimensional electromagnetic crystal held theoretically by numerical electrodynamic analysis of their 3D models, also the comparison of the obtained results with the ones of measurements on the experimental samples is given.

II. PROBLEM DEFINITION

In this paper it is suggested to explore the microstrip diplexers, built on the basis of 2D electromagnetic crystal consisting of two rows of quarter-wave resonators.

In order to do this, it is required to solve the following tasks:

- to develop 3D models of studying microstrip diplexers based on the 2D electromagnetic crystal for further electrodynamic numerical analysis and «manual» parametric synthesis of diplexers with specified electrical characteristics;
- to compare the frequency-selective properties of diplexers using different strip conductors at the input of structure;
- to examine the frequency-selective properties of diplexers based on electromagnetic crystal with the dimension of 2×2 to 4×2;
- to assess the accuracy of the electrodynamic numerical analysis of 3D model of the microstrip structure, comparing the calculated characteristics of diplexer with the measured ones of the experimental sample.

III. THEORY

To get specific and objective comparison of frequency-selective properties of investigated diplexers the same substrate with a high dielectric permeability $\varepsilon = 80$ and thickness $h = 1$ mm (material is ceramics TBNS) were used. Parametric synthesis of all the constructions was carried out with the help of numerical electrodynamic analysis of 3D models in which one input and two output ports had a characteristic resistance of 50 Ω and were conductively connected to the connection conductors.

Construction with strip conductors' topologies given in Fig.1 is a microstrip diplexers based on the 2D electromagnetic crystal dimension of 2×2.

In order to miniaturize microwave devices in both elongated strip conductors *2-3* are grounded on the base from substrate edge sides, so they represent a quarter-wave resonators. In fact, there are two rows of resonators on the substrate in which the interaction of adjacent resonators of one row with another prevails over interaction between resonators of different rows. At the input of the proposed devices there is an input strip conductor *1*, which is electromagnetically connected both with resonators of the first and the second rows. This makes it possible to transmit the input signal through two channels.

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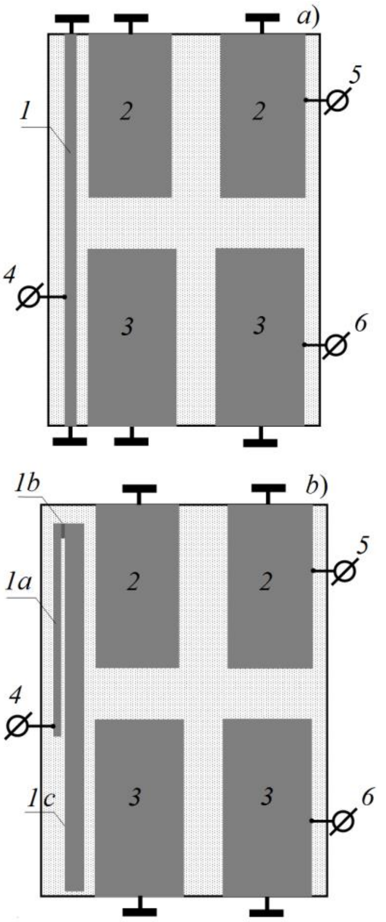

Fig. 1. Topologies of strip conductors of diplexers based on electromagnetic crystal with the dimension of 2×2. *a*) - using a regular input strip conductor, *b*) - using irregular compressed conductor.

Taking into consideration the fact that while the formation of bandwidth only the lowest longitudinal oscillation modes of quarter-wave resonators of the two rows (one from each of the resonator) are involved, the principle of diplexers work is the following: the signal coming to the input *4*, due to the input conductor *1* is divided in two channels, while shorter strip conductors -resonators of the first row *2* form bandwidth *I* (Fig.2, the frequency dependence of S_{21}, S_{11}) by two resonances, the processed signal is removed from the output *5*. Longer resonators of the second row *3*, likewise, form bandwidth *II*, the signal is removed from the output *6* (Fig. *2*, the frequency dependence of S_{31}, S_{11}).

At the same time frequency-selective properties of diplexers with the use of regular input and compressed strip conductors in the structure differ. The first MW structure (Fig.1) allows realizing stronger suppression of power at high-frequency stop band. But at the same time, conductor *1* has greater connection with the adjacent resonator of the second row *3* than with the adjacent resonator of the first row *2*, so at the AFCs (Fig.2*a*) there is inequality in the power passage at frequencies of one of the bandwidths.

The use of extreme compressed strip conductor allows realization of selective devices bandwidth with regular transmission of microwave power (Fig.2*b*). Therefore, this connection conductor was used in further studies of diplexers based on 2D crystals of larger dimension.

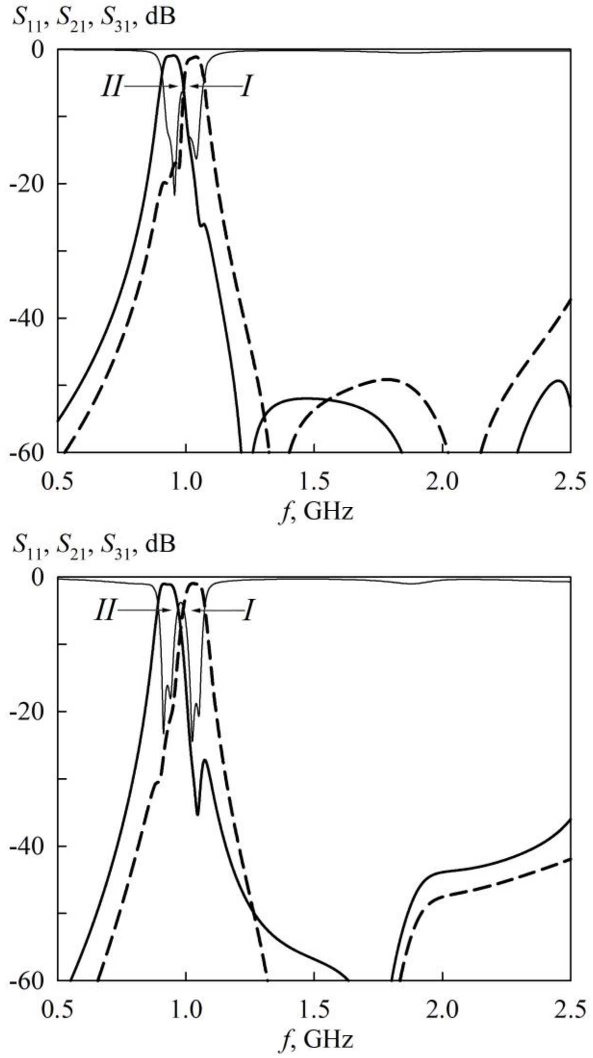

Fig. 2. AFCs of diplexers based on electromagnetic crystal with the dimension of 2×2. *a*) - using a regular input strip conductor, *b*) - using irregular compressed conductor.

Therefore Fig.3 shows the topology of the diplexer strip conductors with six quarter-wave resonators in two parallel rows.

High frequency-selective properties (Fig.4) of this structure are caused by steep slopes of bandwidths *I* and *II*, as well as a significant suppression of microwave power at low-frequency (more than 100dB) and an extended high-frequency ($1.5f_0$ the level of -50 dB) stop bands. In this connection the observed attenuation poles of power at AFCs stimulates the improvement of its frequency selective properties.

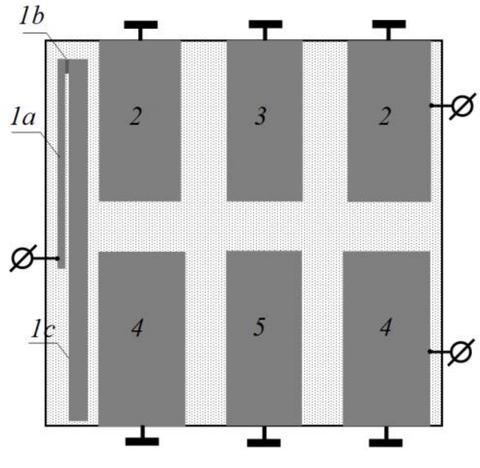

Fig. 3. Topologies of strip conductors of diplexer based on electromagnetic crystal with the dimension of 3×2.

The relative width *I* and *II* of diplexer bandwidth was $\Delta f/f_0 \approx 10\%$, measured at the level of -3 dB from the minimum loss ($L_{min} \approx$-1.4 dB) at center frequency of the low-frequency bandwidth $f_0 \approx 0.93$ GHz and high – $f_0 \approx$ 1.03 GHz.

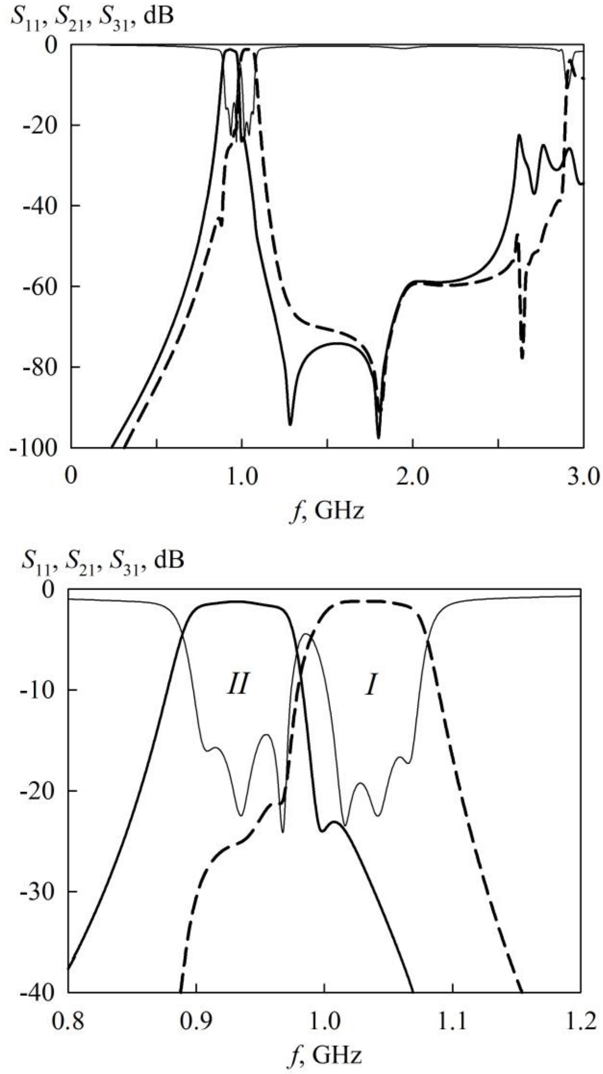

Fig. 4. AFCs (in the wide and narrow band) of diplexer based on electromagnetic crystal with the dimension of 3×2.

As one could expect each bandwidth is formed by three resonances.

It is worth noting that the easy setup of such dual microwave devices is caused by the fact that the setting of bandwidth *I* and *II* due to the frequency and the relative width is carried out almost independently, i.e. varying of strip conductors sizes of one row leads to a slight change in bandwidth formed by resonances of adjacent row resonators.

Therefore, increasing the number of resonators in a microwave structure is not accompanied by a significant complication of the configuration of its bandwidth. For example, diplexer based on 2D electromagnetic crystal with the dimensions 4×2 (Fig.5 and Fig.6), i.e. with eight interacting resonators along two spatial coordinates.

It is worth noting that the selection of the parameters of the microstrip structure was made in such a way to observe adjacent bandwidth *I* and *II* (Fig.6) that are maximum brought together at AFC, the each bandwidth, as one might expect, is formed by four resonances, one from each quarter-wave resonator *2-5*.

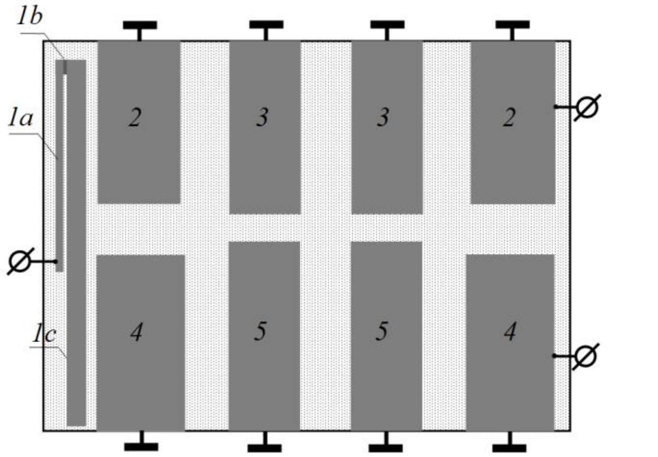

Fig. 5. Topologies of strip conductors of diplexer based on electromagnetic crystal with the dimension of 4×2.

The relative diplexer bandwidth *I* and *II* was $\Delta f/f_0 \approx 12\%$, measured at the level of -3 dB from the minimum loss ($L_{min} \approx$-1.4 dB and $L_{min} \approx$-1.2 dB) at central frequency of the low bandwidth $f_0 \approx 0.96$ GHz and high frequency – $f_0 \approx 1.07$ GHz, respectively. As one could expect, at the synthesized AFC the increase of bandwidth slopes steepness and increasing of power suppression at stop bands frequencies are observed.

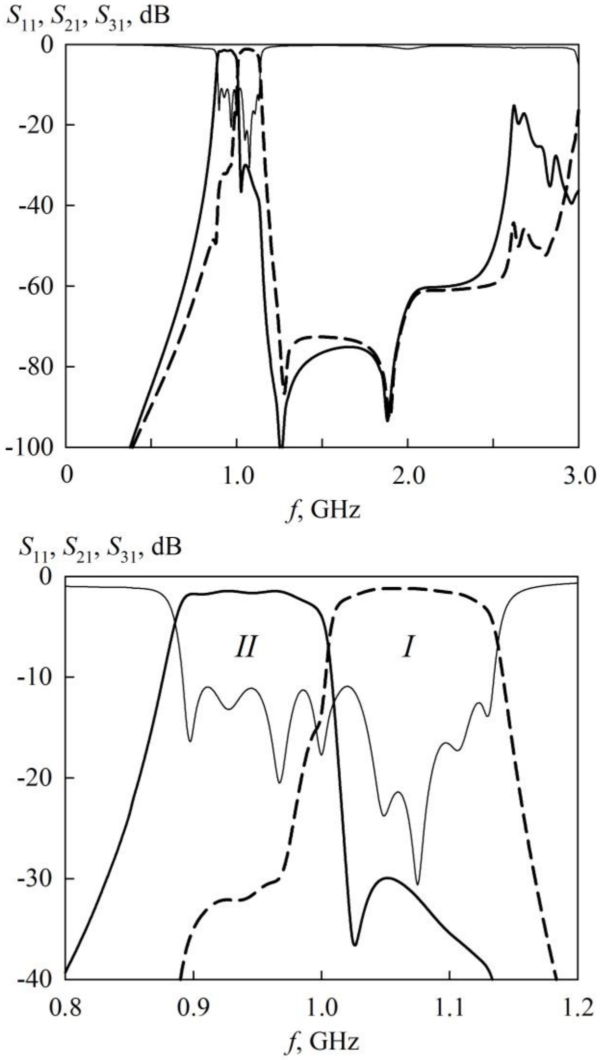

Fig. 6. AFCs (in the wide and narrow band) of diplexer based on electromagnetic crystal with the dimension of 4×2.

The structure parameters of all above mentioned microstrip diplexers based on the two-dimensional electromagnetic crystal with the dimension of 2×2 to 2×4 are shown in Tab. I.

TABLE I
THE STRUCTURE PARAMETERS OF DIPLEXERS

Diplexer	Conductor (segment) position in Fig.	Conductor (segment) sizes, mm	Conductor (segment) positions and gaps between them, mm
Fig.1*a*	*1*	21.50×0.50	*1* and *2* are 0.40; *2* and *2* – 2.35; *1* and *3* – 0.40; *3* and *3* – 2.15; *2* and *3* – 2.90
	2	8.90×4.75	
	3	9.70×4.85	
Fig.1*b*	*1a*	11.30×0.20	*1c* and *2* are 0.80; *2* and *2* – 2.65; *1c* and *3* – 0.80; *3* and *3* – 2.35; *2* and *3* – 2.90
	1b	0.50×0.10	
	1c	20.10×0.95	
	2	8.80×4.60	
	3	9.80×4.75	
	Note. Displacement of lower edge of the conductor *1* from the lower edge of substrate is 0.20 mm.		
Fig.3	*1a*	11.50×0.20;	*1c* and *2* are 0.65; *1c* and *4* – 0.65; *2* and *3* – 2.55; *4* and *5* – 2.35; *2* and *4* – 2.90; *3* and *5* – 2.90
	1b	0.50×0.10;	
	1c	20.10×0.95;	
	2	8.80×4.55;	
	3	8.80×4.20;	
	4	9.80×4.75;	
	5	9.80×4.20	
	Note. Displacement of lower edge of the conductor *1* from the lower edge of substrate is 0.20 mm.		
Fig.5	*1a*	11.50×0.25;	*1c* and *2* are 0.55; *1c* and *4* – 0.55; *2* and *3* – 2.00; *3* and *3* – 2.45; *4* and *5* – 1.75; *5* and *5* – 2.45; *2* and *4* – 2.30; *3* and *5* – 1.65
	1b	0.40×0.10;	
	1c	19.15×1.10;	
	2	8.50×4.35;	
	3	8.85×2.50;	
	4	9.70×4.50;	
	5	10.00×2.60	
	Note. Displacement of lower edge of the conductor *1* from the lower edge of substrate is 0.15 mm.		

IV. EXPERIMENTAL RESULTS

For verifying the serviceability of the developed selective structures and estimating the accuracy of the electrodynamic calculation of their electrical characteristics, we fabricated by engraving method on a varnish the experimental sample of microstrip diplexer based on 2D electromagnetic crystal with the dimension of 3×2 (Fig.7 and Fig.8.).

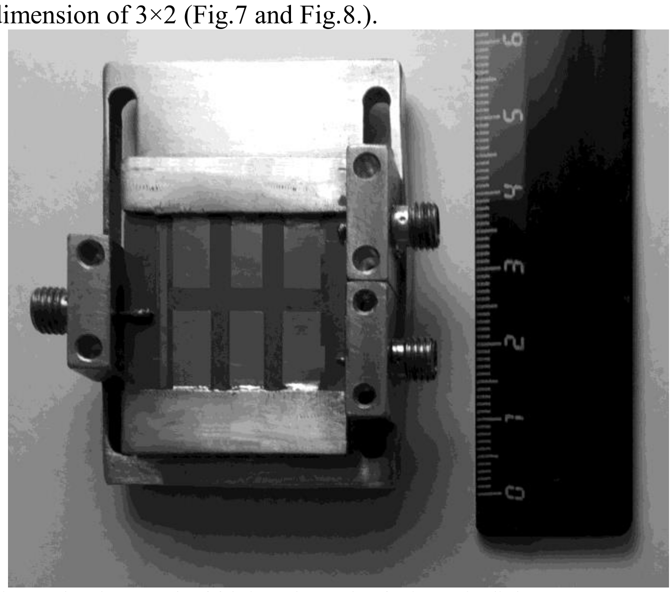

Fig. 7. The photograph of fabricated sample of microstrip diplexer.

In this case, it was «TBNS» of 1 mm thick with the permittivity ε = 80 that was used as a substrate material. The topology of the strip conductors of two-dimensional structure (Fig.8) was obtained by the parametrical synthesis using 3D models.

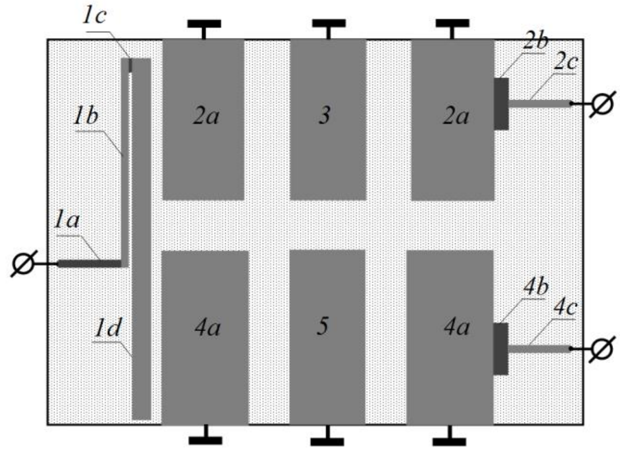

Fig. 8. Topologies of strip conductors of experimental diplexer based on electromagnetic crystal with the dimension of 3×2.

AFCs of the microstrip diplexer with adjacent bandwidths are shown in Fig. 9.

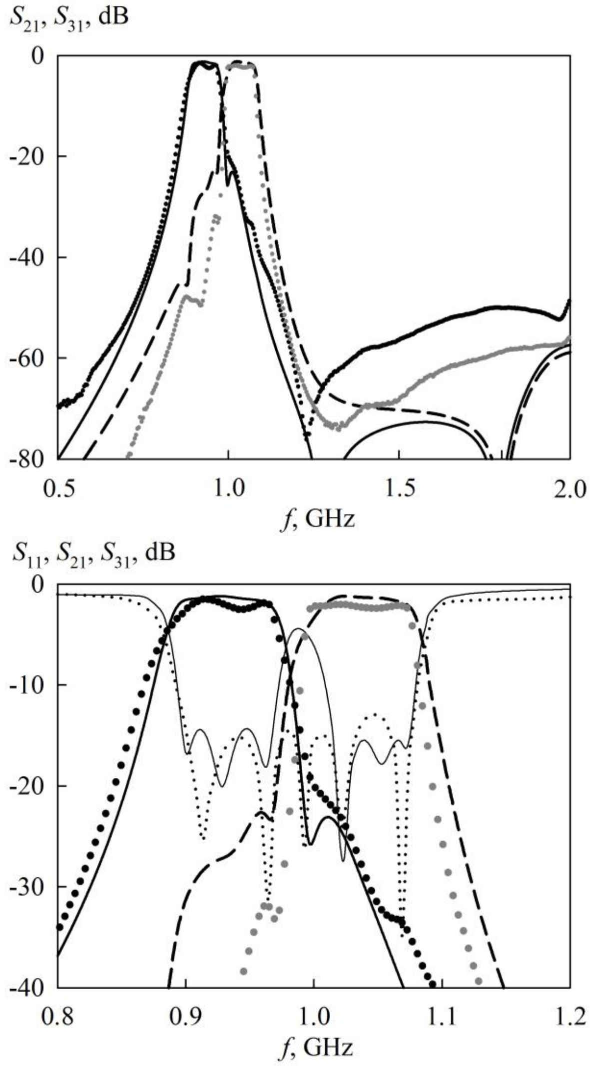

Fig. 9. AFCs of diplexer in the wide and narrow band. Lines are the calculation, and points are the measurements.

The lines show the results of calculation, and the points show the results of measurements. It is visible that the two-channel device shows a sufficient agreement of the calculated AFCs of diplexer with the measured ones. One should note that the low frequency spike of the inverse loss in bandwidth contains two resonances at the depicted amplitude-frequency characteristic.

The constructional data of the diplexer received by means of a measuring microscope are given in the Tab. II.

TABLE II
THE CONSTRUCTIONAL DATA OF EXPERIMENTAL DIPLEXER

Diplexer	Position in Fig.	Conductor (segment) sizes, mm	Conductor (segment) positions and gaps between them, mm
Fig.7 and Fig.8	*1a*	3.84×0.16	*1d* and *2a* are 0.70; *2a* and *3* – 2.67; *1d* and *4a* – 0.69; *4a* and *5* – 2.36; *2a* and *4a* – 2.86; *3* and *5* – 2.86
	1b	11.56×0.16	
	1c	0.46×0.14	
	1d	20.03×0.92	
	2a	8.78×4.57	
	2b	3.16×0.61	
	2c	3.23×0.16	
	3	8.77×3.83	
	4a	9.77×4.70	
	4b	3.15×0.62	
	4c	3.23×0.17	
	5	9.77×4.23	
	Note. Displacement of lower edge of the conductor *1d* from the lower edge of substrate is 0.26 mm.		

The relative width of low (high) frequency diplexer bandwidth has $f/f_0 \approx 9\%$ ($\Delta f/f_0 \approx 8\%$), measured at the level of -3 dB from the minimum loss $L_{min} \approx$-1.5 dB ($L_{min} \approx$-1.8 dB) at central frequency of the bandwidth $f_0 \approx 0.96$ GHz ($f_0 \approx 1.03$ GHz).

V. DISCUSSION OF RESULTS

In the paper the results of theoretical and experimental studies of microstrip diplexers based on the two-dimensional electromagnetic crystal dimension of 2 × 2 to 4 × 2 are presented.

In MW structures regular quarter-wave resonators are arranged orderly in two rows, the topology of their strip conductors is selected in such a way that the electromagnetic interaction of adjacent resonators of one row with another predominates over the interaction between the resonators of different rows. At the input of the proposed devices the input strip conductor electromagnetically connected both with the resonators of the first and the second rows is situated. This allows separating the signal into two channels, meanwhile the longitudinal oscillation mode of resonators of the first row forms bandwidth *I*, likewise, oscillation longitudinal mode of resonators of the second row forms bandwidth *II*. The lowest oscillation mode of each quarter-wave resonator with strip conductors, grounded on the base at one end, is involved in the formation of the bandwidth *I* or *II*.

The use of input compressed strip conductor instead of the regular one allows realizing more steady transmission of microwave power at the frequencies of both bandwidths.

Significant advantage of the constructed diplexer is easy tuning of bandwidths, so the choice of the strip conductors' size within one row does not lead to significant changes in the bandwidth, formed by oscillation modes resonator of adjacent row. It allows almost independently adjusting bandwidths including adjacent ones.

It is not difficult to improve the properties of frequency selective devices increasing the number of resonators in rows. It is accompanied by the addition of an equal number of resonances both in low frequency and in high frequency bandwidth.

At the same time the advantage of developed microstrip diplexers is caused not only by their electrical characteristics, but by the possibility of their production; as well as by photolithography, and by the method of engraving on lacquer, and by sufficient consent of electrodynamic analysis of 3D frequency-selective devices models with the experiment.

VI. CONCLUSION

Thereby, microstrip diplexers interacting along two spatial coordinates of quarter-wave resonators are proposed and investigated.

In selective devices the use of input compressed strip conductor, electromagnetically connected with resonators of the first and the second rows allows them to realize a high frequency-selective characteristics: steep slopes of bandwidths and strong power suppression at frequencies of low-frequency (more than 100 dB) and extended high-frequency stop bands.

The increase of resonators number in the rows is accompanied by improvement of frequency-selective properties of diplexers.

Measurement of the electrical characteristics of the experimental microstrip diplexer with a relative width of the first bandwidth $\Delta f/f_0 \approx 8\%$ and second – $\Delta f/f_0 \approx 9\%$, showed sufficient agreement with the results of numerical electrodynamic analysis of devices using 3D models.

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REFERENCES

[1] Vetluzhsky A.Yu. The effective electrophysical properties of metal electromagnetic crystal // Magazine of radioelectronics. 2015. No 1. pp. 18-19. (in Russian).

[2] Belyaev B.A., Tyurnev V.V., Shabanov V.F. Investigation of the Q-factor of optical resonators in photonic crystals and principles of designing highly selective filters on their basis // Russian Physics Journal. 2014. V. 56. No 12. pp. 1378-1386.

[3] Isaac C. A. Dispersion in One-Dimensional Photonic Band Gap Periodic Transmission Lines// Submitted to Microwave and Optical Technology Letters. 2008. No 11. pp. 689-692.

[4] Mollah M.N., Karmakar N.C., Fu J.S. A Binomially Distributed Photonic Bandgap Structure (PBGS) and Its Application to Bandpass Filter // International Journal of RF and Microwave Computer – Aided Engineering. 2006. No 16. pp. 355-366.

[5] Belyaev B.A., Borisenkov D.V., Khodenkov S.A., Butikov A.S. Microstrip Filters Based on 2-D Photonic Crystal // 24th International Crimean Conference Microwave and Telecommunication Technology Conference Proceedings. 2014. pp. 572-573.

[6] Belyaev B.A., Khodenkov S.A., Shabanov V.F. Investigation of Frequency Selective Devices Based on a Microstrip 2D Photonic Crystal // Doklady Physics. 2016. V. 61. No. 4. pp. 155-159.

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