Microstrip filters based on 2D electromagnetic crystal

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Microstrip filters based on 2D electromagnetic crystal

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Abstract. Construction of microstrip bandpass filters is suggested on the basis of 2D electromagnetic crystal consisting of *P* horizontal and *K* vertical rows of resonators. Adjacent vertical rows of resonators are connected by additional m_{K-1} resonators arranged above and below the outside 2D crystal. Parametric synthesis of six bandpass filters based on crystals with the dimension of 1×2, 2×2, 2×3, 3×1, 3×2 and 3×3 was conducted with use of electrodynamic numerical analysis of 3D models in studied constructions. While calculating substrates with relative permittivity ε=80, *h*=1 mm thick were used, in this connection, center frequency of bandwidth was registered as follows - f_0≈1.0 GHz, as well as their relative bandwidth $\Delta f/f_0$≈20%. High frequency-selective properties of the filters are connected not only with the increase of their *N* order, but also with the presence of amplitude-frequency characteristics of power attenuation poles located near the bandwidth.

1. Introduction

Electromagnetic crystals are usually periodic structures having the ability to inhibit the spread of electromagnetic radiation going through them in certain frequency bands, called forbidden zones [1, 2]. The devices based on these structures [3-6] proved themselves and are of specific interest for microwave technology developers nowadays. They are manufacturable, miniature, and besides have high-frequency selective properties [7].

In the present paper a new model of 2D arrangement of strip conductors on dielectric substrate, which allows constructing microstrip bandpass filters with high frequency-selective properties is proposed.

2. Model

Let us consider the structure which is periodic on two coordinates, consisting of half-wave microstrip resonators. The number of horizontal rows of resonators is marked as *P*, while vertical ones - as *K* (figure 1). Strip conductors of single-mode resonator have rectangular shape elongated along the *x* axis. It is well known [8] that the interaction between the resonators in one row is much stronger than the interaction between the resonators of different rows in such two-dimensional structures. Therefore, signal propagates sequentially from one resonator to another in vertical rows of resonators. Due to additional m_{K-1} microstrip resonators located below and above outside the crystal, the signal is sent to the next vertical row.

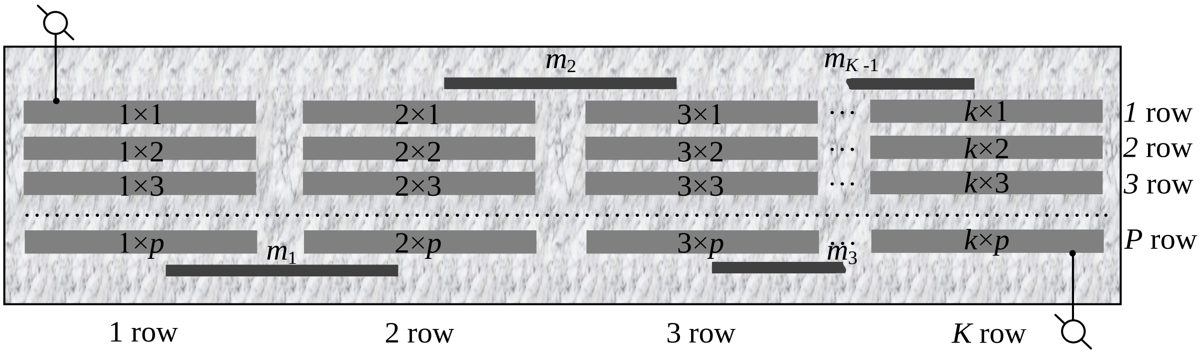

Figure 1. Model of two-dimensional location of strip conductors on dielectric substrate.

The input 50 Ω port is conductively connected with the strip conductors of the first resonator within the first row in the proposed structure. When constructing structures with even number of vertical rows of resonators K = 2, 4, 6, ..., the output filter port is connected with the strip conductors of the first resonator of the last vertical row. Both ports are located on the same edge of the substrate. When being placed on a substrate of an odd number of vertical rows of resonators K = 3, 5, 7 ... output 50 Ω port is conductively connected with the strip conductors of the last resonator within the last row. Accordingly, the ports are located relative one to another, on the opposite sides of the microstrip substrate.

Consequently, in the proposed two-dimensional microstrip crystal, the signal propagates on odd vertical rows of resonators in one direction (from top to bottom), and in even ones - in the opposite direction (from bottom to top).

Taking into consideration the fact that only one resonance is involved in the formation of microstrip filter passband, the increase of the number of horizontal P rows and vertical K rows, as well as the increase of the N filter order, is connected by the following relation

$$N = K(P+1)-1. \quad (1)$$

It is obvious in this connection that the use of the dimension $k \times p$ of multimode resonators [9] instead of single-mode in such structure, allows not only to improve the frequency-selective properties of developing filter, but also to miniaturize them significatly.

3. Numerical filters' analysis

In order to test the proposed model six microstrip bandpass filters, based on electromagnetic crystal dimension 2×1, 2×2, 2×3, 3×1, 3×2 and 3×3 (figure 1), have been developed. Parametric synthesis of these structures was carried out with the help of electrodynamic numerical analysis of 3D models, which, as it is known [8, 9], is in good agreement with measurements made on the fabricated structures.

For objective comparison of their amplitude-frequency characteristics (figure 2) the same substrates with dielectric penetrability ε=80 and thickness h=1 mm (material - TBNS ceramics) were used in calculations. Also center frequency of the filter passband f_0≈1.0 GHz and their relative bandwidth $\Delta f/f_0$≈20% was registered. For this purpose, the length and width of strip conductor resonators as well as the gaps between them were selected, when needed separation between strip conductors was used.

It is necessary to note that high frequency-selective properties of the proposed microwave constructions arise not only because of the increase of filter N order, but also because of power attenuation poles observed in amplitude-frequency characteristics. In this connection, bandpass filter, based on the two-dimensional crystal with the dimension of only 3×3, has power suppression at low frequencies of around 150 dB, near bandwidth - approximately 110 dB, at minimum loss in the passband - 1.9 dB.

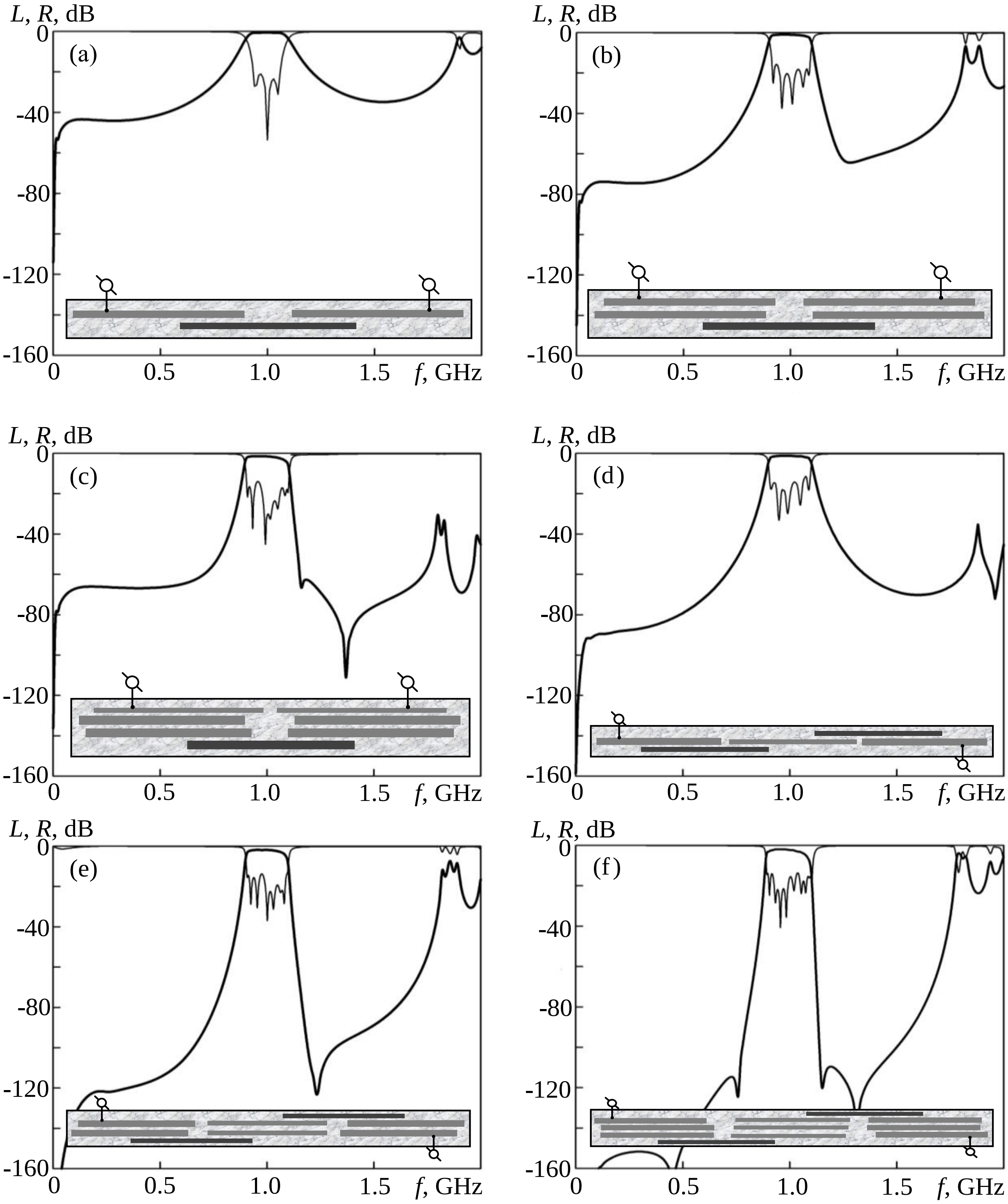

Figure 2. Comparison of amplitude-frequency characteristics of filters based on 2D electromagnetic crystal dimensions 2×1 (a), 2×2 (b), 2×3 (c), 3×1 (d), 3×2 (e) and 3×3 (f). On inserts relevant amplitude-frequency characteristics of the topology of strip conductor filters.

Dimensions of strip conductors' resonator and the gaps between them for all six investigated structures are presented in table 1.

Table 1. Dimensions of microstrip filter conductors' topology.

The dimension of the crystal on the basis of which the filter is implemented	Figure with appropriate for filter amplitude-frequency characteristics	Position of strip conductor in figure 1	The area of strip conductor (mm^2)	The gaps between strip conductors (mm)
2×1	figure 2a	1×1	20.00×1.00	1×1 and 2×1 – 5.40
2×1		2×1	20.00×1.00	1×1 and m_1 – 0.40
2×1		m_1	20.80×0.70	2×1 and m_1 – 0.40
2×2	figure 2b	1×1	20.50×0.80	1×1 and 2×1 – 3.20
2×2		2×1	20.50×0.80	1×2 and 2×2 – 5.40
2×2		1×2	20.50×1.00	1×1 and 1×2 – 0.50
2×2		2×2	20.50×1.00	2×1 and 2×2 – 0.50
2×2		m_1	20.80×0.80	1×2 and m_1 – 0.50
2×2				2×2 and m_1 – 0.50
2×3	figure 2c	1×1	20.90×0.45	1×1 and 2×1 – 1.80
2×3		2×1	20.90×0.45	1×2 and 2×2 – 6.20
2×3		1×2	20.50×0.85	1×3 and 2×3 – 4.00
2×3		2×2	20.50×0.85	1×1 and 1×2 – 0.45
2×3		1×3	20.80×0.90	2×1 and 2×2 – 0.45
2×3		2×3	20.80×0.90	1×2 and 1×3 – 0.90
2×3		m_1	21.00×0.90	2×2 and 2×3 – 0.90
2×3				1×3 and m_1 – 0.55
2×3				2×3 and m_1 – 0.55
3×1	figure 2d	1×1	20.60×0.65	1×1 and 2×1 – 2.60
3×1		2×1	20.80×0.70	2×1 and 3×1 – 2.60
3×1		3×1	20.60×0.65	1×1 and m_1 – 0.60
3×1		m_1	21.00×0.75	2×1 and m_1 – 0.50
3×1		m_2	21.00×0.75	2×1 and m_2 – 0.50
3×1				3×1 and m_2 – 0.60
3×2	figure 2e	1×1	20.40×0.85	1×1 and 2×1 – 2.20
3×2		2×1	20.80×0.70	2×1 and 3×1 – 3.70
3×2		3×1	20.60×0.95	1×2 and 2×2 – 3.70
3×2		1×2	20.60×0.95	2×2 and 3×2 – 2.20
3×2		2×2	20.80×0.70	1×1 and 1×2 – 0.50
3×2		3×2	20.40×0.85	2×1 and 2×2 – 1.00
3×2		m_1	21.20×0.60	3×1 and 3×2 – 0.50
3×2		m_2	21.20×0.60	1×2 and m_1 – 0.65
3×2				2×2 and m_1 – 0.60
3×2				2×1 and m_2 –0.60
3×2				3×1 and m_2 – 0.65
3×3	figure 2*f*	1×1	20.40×0.95	1×1 and 2×1 – 5.20
3×3		2×1	20.90×0.75	2×1 and 3×1 – 3.10
3×3		3×1	20.60×1.05	1×2 and 2×2 – 3.60
3×3		1×2	20.50×0.90	2×2 and 3×2 – 3.60
3×3		2×2	20.60×0.60	1×3 and 2×3 – 3.10
3×3		3×2	20.50×0.90	2×3 and 3×3 – 5.20
3×3		1×3	20.60×1.05	1×1 and 1×2 – 0.30
3×3		2×3	20.90×0.75	1×2 and 1×3 – 0.75
3×3		3×3	20.40×0.95	2×1 and 2×2 – 1.05
3×3		m_1	21.20×0.75	2×2 and 2×3 – 1.05
3×3		m_2	21.20×0.75	3×1 and 3×2 – 0.75
3×3				3×2 and 3×3 – 0.30
3×3				1×3 and m_1 – 0.60
3×3				2×3 and m_1 – 0.55
3×3				2×1 and m_2 – 0.55
3×3				3×1 and m_2 – 0.60

4. Conclusions

Consequently, a model of constructing microstrip bandpass filters based on 2D electromagnetic crystal with the dimension of $k \times p$ is suggested. In vertical rows of resonators, the signal transmits sequentially from one resonator to another, and due to additional $m_{K\text{-}1}$ microstrip resonators located at the top and bottom beyond the crystal, the signal is directed towards the next vertical row. The increase of number of horizontal P rows and vertical K rows and the increase of N filter order while using single-mode resonator is connected with the following relation $N=K(P+1)-1$. Significant improvement of frequency-selective properties in the constructed filters based on 2D electromagnetic crystal filters is connected not only with the increase of their N order, but also with the appearance of power attenuation poles on the amplitude-frequency characteristic near the passband. So, bandpass filter on the basis of crystal with the dimension of 3×3 has power suppression at low frequencies of around 150 dB, near the bandwidth - approximately 110 dB.

Acknowledgments

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