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To cite this article: B A Belyaev *et al* 2020 *J. Phys.: Conf. Ser.* **1488** 012012

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Investigation of microstrip ultra-wideband bandpass filters

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Abstract. Ultra-wideband microwave filters with high frequency-selective properties have been developed by means of electrodynamic numerical analysis of 3D models. Microstrip structures, which are studied theoretically and experimentally, use one multimode resonator and a pair of single-mode resonators. There is fairly good agreement between the calculated data and the data taken on the experimental sample. The relative bandwidth of the manufactured microstrip filter is 60%.

1. Introduction

Microwave bandpass filters [1, 2] are traditionally used in communication centres, including space and tropospheric ones. Developers of such structures are constantly improving their frequency-selective properties [3, 4] trying to reduce their dimensions [5]. Furthermore, recently, researchers have shown some interest in ultra-wideband filters with a relative bandwidth of more than 50% [6, 7]. Obviously, high demand for such filters is primarily explained by the development of technologies for significant amounts of electronic data transmission over certain distances. At the same time, combination of such basic parameters as: miniature size, reliability, manufacturability and production cost, make microstrip filters most optimal [8, 9].

The use of multimode resonators [10-16] in microstrip frequency-selective devices is already fixed design approach aimed at reducing the size of these structures while maintaining their selective properties. Thus, using original topology of strip conductors in such resonators, it is possible to get resonance frequencies of n lowest oscillation modes approach, which forms filter passband. Furthermore, due to strong interaction of resonators' electromagnetic fields, their frequencies are «pushed aside», while filter's passband can significantly expand.

Thus, the development of new constructions of microwave ultra-wideband bandpass filters based on multimode resonators and the study of their frequency-selective properties is an important and urgent task.



2. Theoretical studies of microstrip ultra-wideband filter

The design of microstrip ultra-wideband filter is shown in figure 1a. When conducting theoretical studies of frequency-selective properties of the device, substrates with dielectric permittivity $\varepsilon = 20$ and $\varepsilon = 40$, with fixed thickness $h = 1$ mm, were used as they are considered to be enough common in microwave technology. Calculations of amplitude-frequency characteristics of all the filters considered in the work were performed by means of numerical electrodynamic analysis of their 3D models. The filters were tuned by «manual» parametric synthesis.

As it can be seen from the figure 1, a pair of wide rectangular segments (1) of strip conductor are grounded to the base by their free ends and are joined to each other through rectangular segments (2) and the central segment (3). In addition, they (1) are connected to perpendicular segments (4), which are then joined to two long segments (5)-(6). Such conductor with eleven segments located on dielectric substrate makes multimode microstrip resonator. Four lowest oscillation modes from this resonator take part in constructing passband of ultra-wideband microwave filter (figure 2b). The considered central multimode resonator is electromagnetically coupled to a pair of extreme resonators with « Π » shape strip conductors. Parallel strip segments (7) and (8) of these resonators are grounded to the base with their free ends and are joined to each other from the opposite side through a wide segment (9). Moreover, each segment (7) is joined with orthogonally located segments (10), where there are 50- Ω input and output ports at free edges. The last resonators are single-mode ones, so microstrip filter is of the sixth order.

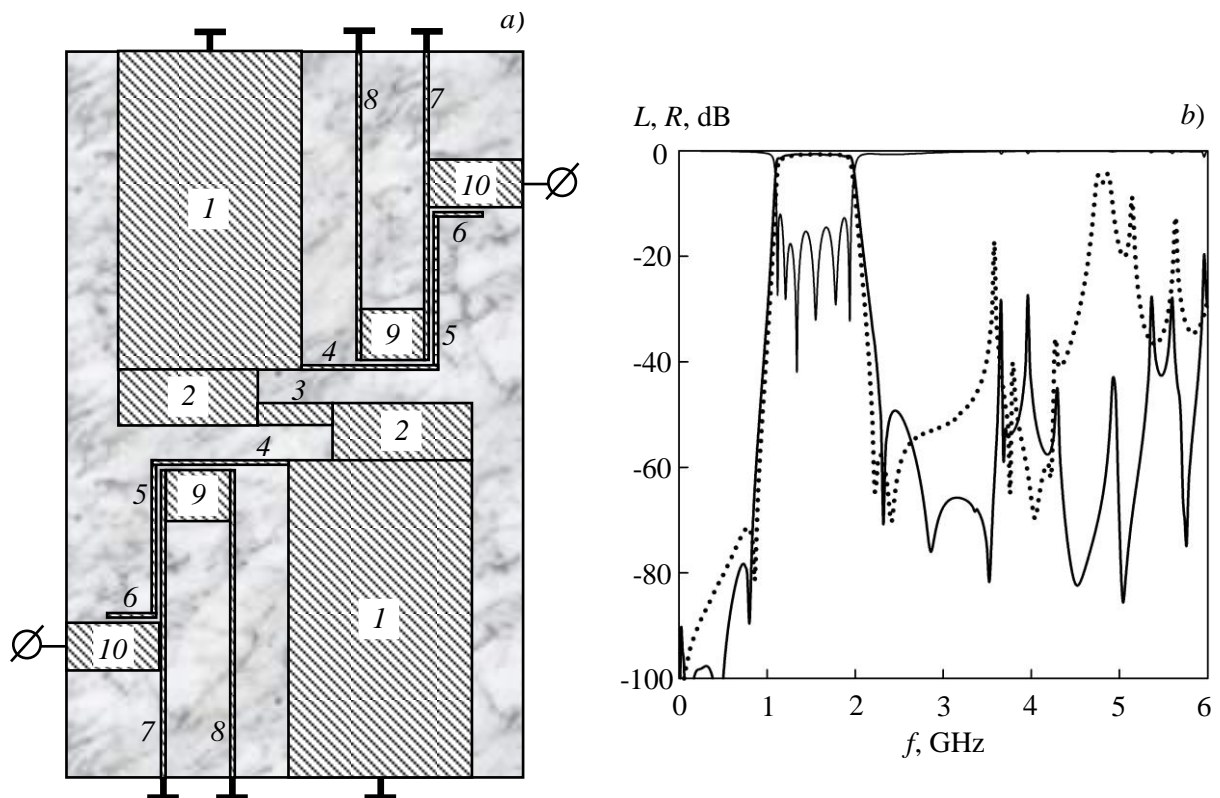


Figure 1. Topology of microstrip ultra-wideband filter strip conductors (a) and its amplitude-frequency characteristics (b) calculated with the use of substrates with $\varepsilon = 20$ (line) and $\varepsilon = 40$ (dots), respectively.

Structure amplitude-frequency characteristics are shown in figure 1b. High frequency-selective properties of such microwave filter with central passband frequency $f_0 \approx 1.55$ GHz are explained by the increased steepness of passband slopes realised due to attenuation poles observed at both amplitude-

frequency characteristics to the left and to the right from the passband. The filter also shows strong power suppression at low frequencies (more than 70 dB) and small power losses in passband with relative width of $\Delta f/f_0 \approx 60\%$. Boundary frequencies of passband were measured at level of -3 dB from the minimum losses ($L_{\min} \approx 0.6$ dB) at its frequencies. It is worth noting that in bandpass filter realized on a substrate with dielectric permittivity $\varepsilon = 20$, high-frequency stopband at the level of -25 dB extends to almost 6 GHz. Its length is caused by sufficient suppression of power at frequencies of spurious passbands, due to orthogonal arrangement of strip conductor segments (4) and (1) in four-mode resonator.

Table 1 shows the sizes of strip conductor segments in synthesized filters when using a substrate with dielectric permittivity $\varepsilon = 20$ and $\varepsilon = 40$.

Table 1. The sizes of strip conductor segments.

Number of the strip conductor segment	Substrate with dielectric permittivity $\varepsilon = 20$		Substrate with dielectric permittivity $\varepsilon = 40$	
	Segment length (mm)	Segment width (mm)	Segment length (mm)	Segment width (mm)
(1)	10.50	9.35	6.50	7.15
(2)	7.05	3.20	5.35	2.90
(3)	2.50	1.10	2.85	0.90
(4)	4.80	0.20	4.85	0.20
(5)	4.60	0.20	2.90	0.20
(6)	3.20	0.30	1.25	0.20
(7)	10.20	0.05	6.20	0.05
(8)	10.20	0.30	6.20	0.10
(9)	3.50	2.95	3.45	2.40
(10)	5.65	1.60	7.20	0.60

Let us indicate the clearance sizes between strip conductor segments in resonators (Table 2).

Table 2. The clearance sizes between strip conductor segments.

Numbers of the strip conductor segment	The clearance sizes between strip conductor segments (mm)	
	Substrate with dielectric permittivity $\varepsilon = 20$	Substrate with dielectric permittivity $\varepsilon = 40$
	(1) and (8)	1.25
(4) and (9)	0.10	0.10
(5) and (7)	0.05	0.10
(6) and (10)	0.20	0.10

Filters dimensions – 26.30×24.50 mm² ($\varepsilon = 20$) and 17.90×24.25 mm² ($\varepsilon = 40$).

3. Experimental studies of microstrip ultra-wideband filter

Amplitude-frequency characteristics recorded on microwave filter experimentally made by photolithography are shown in dots in figure 2b. Substrate material is polycor ($\varepsilon = 9.8$, $h = 1$ mm). To compare the obtained electrical characteristics of the developed microstrip construction (figure 2a) objectively, geometric dimensions of strip conductor segments were measured with the help of measuring microscope, then the values were used for calculating the characteristics of ultra-wideband filter 3D model shown in lines in figure 2b. The figure 2 shows that there is fairly good agreement

between the experimental data and the calculated ones. The bandwidth frequencies of the synthesized and experimental filter are the same. The number of resonances at the passband frequencies is also the same. The frequencies of high-frequency spurious passbands differ slightly. At the same time, the experimental filter has high frequency-selective properties.

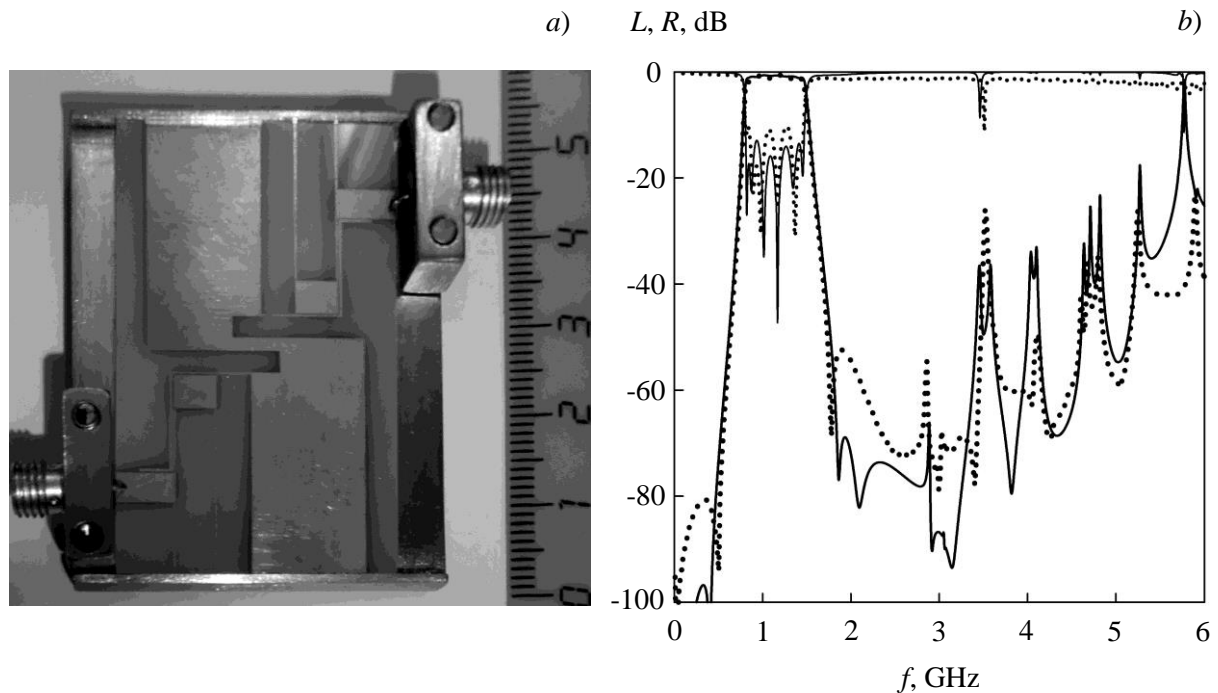


Figure 2. Photograph of microstrip ultra-wideband filter (a) and its amplitude-frequency characteristics (b). Dots – experimental data, lines – calculated data.

Relative bandwidth of the experimental microstrip filter was $\Delta f/f_0 \approx 60\%$. Boundary passband frequencies were also measured at the level of -3 dB from the minimum losses ($L_{\min} \approx 0.6$ dB) at its frequencies. The centre passband frequency of ultra-wideband microwave filter f_0 is approximately 1.2 GHz.

Let us also indicate the sizes of strip conductor segments in experimentally developed filter (Table 3).

Table 3. The sizes of strip conductor segments.

Number of the strip conductor segment	Segment length (mm)	Segment width (mm)
(1)	21.00	12.18
(2)	9.13	3.70
(3)	5.00	1.39
(4)	8.71	0.19
(5)	10.01	0.35
(6)	3.54	0.30
(7)	20.70	0.19
(8)	20.70	0.20
(9)	4.20	3.49
(10)	6.33	3.09

Table 4 shows the clearance sizes between strip conductor segments in resonators.

Table 4. The clearance sizes between strip conductor segments.

Numbers of the strip conductor segment	The clearance sizes between strip conductor segments (mm)
(1) and (8)	3.67
(4) and (9)	0.11
(5) and (7)	0.10
(6) and (10)	0.12

The dimensions of microstrip ultra-wideband bandpass filter are $48.01 \times 30.28 \text{ mm}^2$.

4. Conclusion

Thus, construction of ultra-wideband bandpass filters of the sixth order based on four-mode resonator are theoretically and experimentally investigated. High selective filter properties are caused by steep passband slopes and strong power suppression at the frequencies of low-frequency stopband. At the same time, microwave devices realised on substrate with dielectric permittivity of $\varepsilon = 9.8$ and $\varepsilon = 20$ have extended high-frequency stopband.

Acknowledgments

This study was supported by the Ministry of Education and Science of the Russian Federation, State assignment.

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