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A Monolithic Miniature Multi-Conductor Strip-Resonator Bandpass Filter

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Abstract—A new monolithic design of a miniature bandpass filter for manufacture by means of multilayer printed-circuit-board technology has been developed. It is demonstrated using a fourth-order filter that multi-conductor strip resonators used in the design ensure both miniaturization and high selectivity of the device. The passband center frequency of the manufactured filter is $f_0 = 546$ MHz, the fractional bandwidth is $\Delta f/f_0 = 25\%$, and the insertion loss is 0.8 dB. The filter has a wide high-frequency stopband, which extends up to a frequency of $10f_0$ at a level of –30 dB. The filter dimensions are 15.0 × 12.0 × 4.3 mm ($0.027\lambda_0 \times 0.021\lambda_0 \times 0.007\lambda_0$, where λ_0 is the wavelength in vacuum at frequency f_0) and the mass is only 1.8 g. The performances of the filter and the accessibility of its design for surface mounting show that the device has great potential.

Keywords: bandpass filter, multi-conductor strip resonator, multilayer printed-circuit-board technology.

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The most important devices of modern radio engineering systems of signals transmitting, receiving, and processing are bandpass filters, which determine not only the quality of radio equipment, but often its dimensions and even price as well. Therefore, it is important to develop new miniature filter designs with high selectivity and low cost in mass production. To accomplish this, various designs based on strip resonators, including multi-conductor ones [1, 2], which not only have the smallest dimensions among electrodynamic resonators, but also a relatively high unloaded Q-factor, are being actively investigated. Importantly, the Q-factor of a multilayer resonator increases and its dimensions decrease with an increase in the number of conductors and a decrease in the thickness of dielectric substrates [2]. However, as the number of conductors increase, the resonances of the higher oscillation modes monotonically decrease and approach the resonance of the first operating oscillation mode. This reduces both the filter high-frequency stopband and the attenuation in it, which obviously degrades the frequency selectivity of the filters, especially those with the wide passbands.

In this Letter, the above-mentioned problem of a multi-conductor resonator is solved by means of a special connection of its even or odd conductors near their free ends. Filters based on such resonators are manufactured using multilayer printed-circuit-board (PCB) technology widely used in production of various microelectronic devices, including filters, as a rule, of conventional designs [3, 4]. A positive aspect of using the PCB technology for producing multi-conductor resonators is the ability to reduce the insertion loss in the filter passband as compared with the attenuation in smaller low-temperature cofired ceramic (LTCC) devices [5–7] with the use of thin dielectric layers and copper conductors [8]. In addition, the development of PCB technology has achieved a high accuracy in positioning of conductors in multilayer structures with the possibility of simultaneous fabrication of many devices on a large area of the structure. This significantly reduces the filter cost in mass PCB production as compared with other technologies for manufacturing miniature devices.

Figure 1 shows the design of the investigated monolithic filter based on multi-conductor strip resonators. Each filter resonator is formed by six strip conductors located one above the other and separated by thin dielectric layers. The conductors are connected to a ground at one end (the next but one on opposite shielding housing sides). The role of shielding housing is played by multilayer-structure outer surfaces metalized by electrodepositionof copper with final gilding. The fundamental difference of the investigated structure from the available designs is the connections of even or odd conductors of the edge filter resonators by

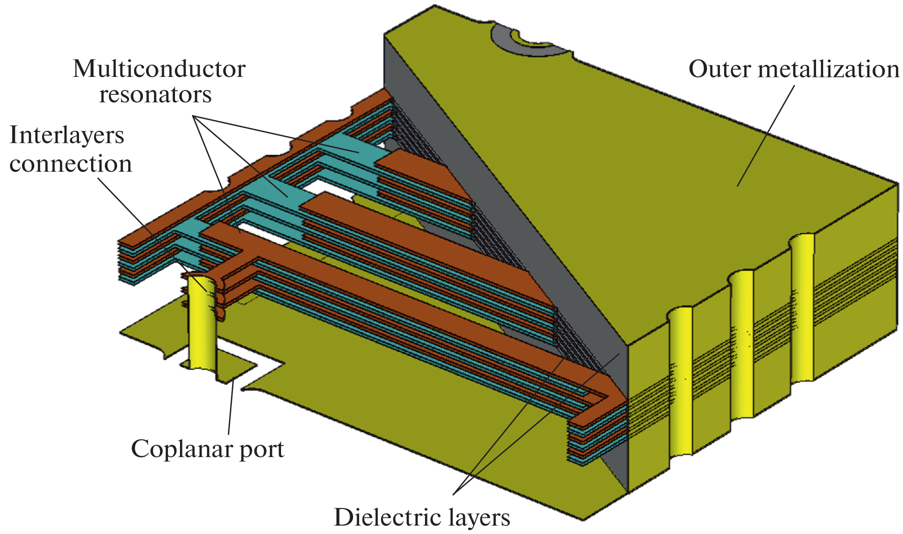

Fig. 1. Design of a monolithic multi-conductor strip resonator filter.

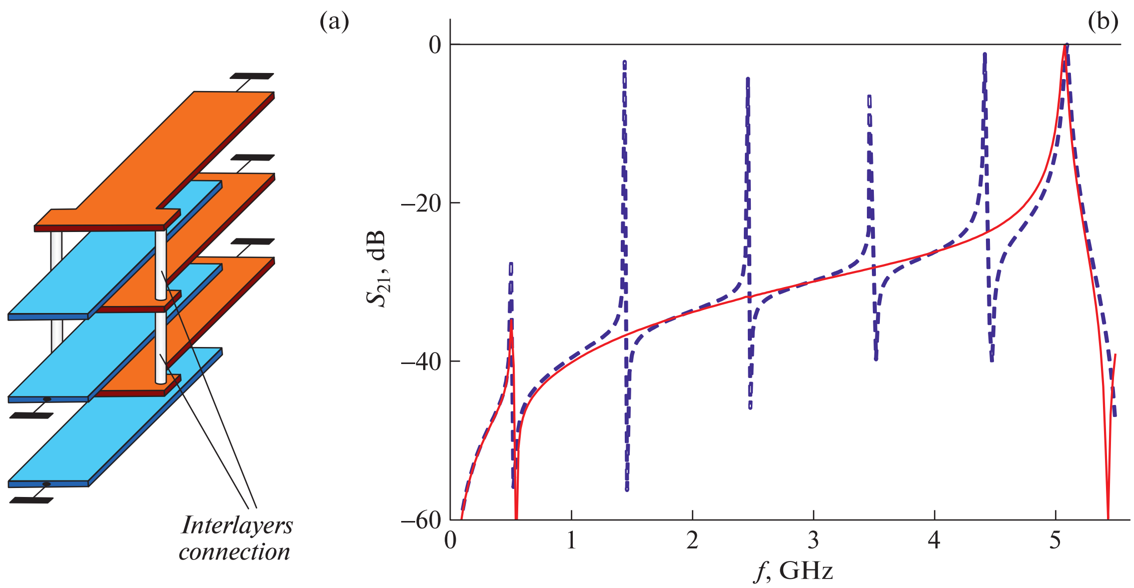

Fig. 2. (a) Design of a six-conductor resonator with jumpers between nonadjacent conductors, (b) its eigenfrequency spectrum (solid line), and frequency spectrum of this resonator without jumpers (dashed line).

through metallized cylindrical holes cut along the diameter axis (see Fig. 1). The hole metallization serves as a central conductor of the coplanar line segments that represent the input and output filter ports available for surface mounting of the device.

Let us demonstrate that an advantage is possessed by a multi-conductor resonator consisting, for example, of six strip conductors (Fig. 2a) at free ends of nonadjacent conductors (the next but one) connected by wire jumpers. So as not to overburden the figure, the dielectric layers are not shown. The solid line in Fig. 2b shows the calculated frequency response of the investigated resonator connected to the transmission lines with the weak coupling and the dashed line shows the frequency response of this resonator without jumpers (with disconnected strip conductor ends). The calculation was made using the electrodynamic analysis of the resonator 3D models in the CST Studio Suite software package under the assumption that five dielectric spacers between conductors made of an RO4350B™ material with permittivity $\varepsilon = 3.48$ had thickness $h_1 = 0.102$ mm and two outer layers of the same material had thickness $h_2 = 1.524$ mm. The width of all the strip conductors in the structure is

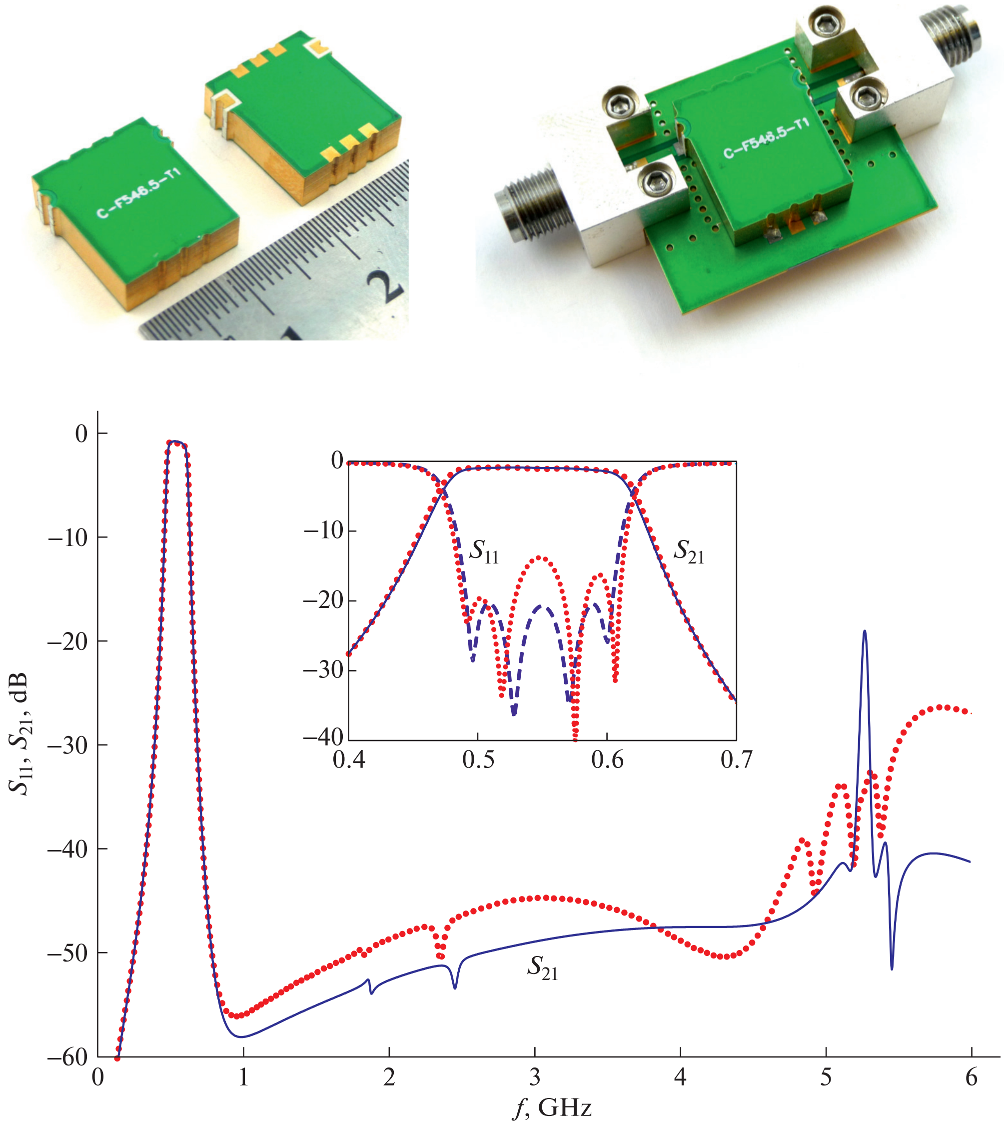

Fig. 3. Photographs of the monolithic filter (top and bottom views and in the evaluation board) and its frequency response. The solid and dashed lines show the calculation; the dashed line shows the experiment.

1 mm, their length is 13.1 mm, and the total resonator length is 15 mm.

The frequency response of the resonator without jumpers (the dashed line in Fig. 2b) has six resonances corresponding to six oscillation modes of a system of six strongly coupled quarter-wave resonators. The lowest resonance corresponds to the oscillation mode for which the currents in all the conductors are codirected and the charges at free ends of neighboring conductors have opposite signs, as in the case of strongly coupled quarter-wave microstrip resonators forming an interdigital structure [9, 10]. The inclusion of jumpers between nonadjacent strip conductors almost does not affect the resonant frequencies of the first and sixth oscillation modes, since the charges on all the closed conductors have the same sign for these modes. However, these jumpers prevent the excitation of resonances of the rest four oscillation modes, since for them, depending on the mode number, on all the conductors closed by jumpers or some of them, the charges have opposite signs. Thus, in the design of a multi-conductor resonator with jumpers, the difference between frequencies of the first two resonances corresponding to the first and sixth oscillation modes of the resonator without jumpers increases by many times. As a result, in the filter based on such resonators, not only does the high-frequency stopband broaden, but the attenuation level in it increases. Obviously, rarefication of the spectrum of resonances of oscillation eigenmodes in the multi-conductor resonators with jumpers between nonadjacent conductors will be observed in the resonators with more than three conductors.

To experimentally test the performance of the proposed fourth-order filter design (Fig. 1) with each resonator formed by six strip conductors, a parametric synthesis of the device was previously performed by the electrodynamic analysis of its 3D model in the CST Studio Suite software package. The parameters of the dielectric layers of the filter were as mentioned above for the investigated resonator (Fig. 2a). For certainty, the conductor width was 1 mm in the internal resonators and 0.8 mm in the external ones. In the synthesis, the filter passband center frequency was set to be f_0 = 545 MHz and the relative bandwidth was at a level of –3 dB $\Delta f/f_0$ = 25%.

Synthesis yielded the remaining design parameters of the device, including the gap between a pair of internal resonators (1.64 mm) and a pair of external resonators (1.93 mm). Basing on the obtained parameters, a monolithic filter was fabricated by the multilayer PCB technology using photolithography (see photographs in Fig. 3). The filter dimensions are 15.0 × 12.0 × 4.3 mm or $0.027\lambda_0 \times 0.021\lambda_0 \times 0.007\lambda_0$ in units of wavelengths in vacuum at the passband center frequency, while the filter mass is only 1.8 g. The measured frequency dependences of insertion loss $S_{21}(f)$ and return loss $S_{11}(f)$ of the experimental filter are shown by dotted lines in Fig. 3a; solid and dashed lines show the calculated dependences obtained by the parametric synthesis of the device. The dependences shown in Fig. 3 demonstrate good agreement between the calculation and experiment.

The passband center frequency of the fabricated filter is f_0 = 546 MHz and the fractional bandwidth measured at a level of –3 dB is $\Delta f/f_0$ = 25%. The minimum insertion loss in the filter passband was only 0.8 dB, and the maximum level of return loss in the passband was –15 dB. The stopband high-frequency edge at –30 dB extends to $10f_0$. It should be noted that the similar filter without interlayer connections has a stopband width of only $2.2f_0$ at the same level.

Thus, a new miniature monolithic design of the bandpass strip filter manufactured using the multilayer PCB technology was investigated.

The filter housing is formed by the outer surfaces of the multilayer structure, which are metallized by electrodeposition of copper with final gilding. The miniature dimensions and high selectivity of the filter are obtained by using multi-conductor strip resonators, in which nonadjacent conductors are connected by through metallized cylindrical holes. The hole metallization serves as a central conductor of the coplanar line segments, which are the input and output filter ports accessible for surface mounting of the device. The measured characteristics of the fabricated fourth-order filter are in good agreement with the characteristics obtained during the parametric synthesis of the device. The aforesaid demonstrates the prospects of the developed filter design for use in various radio engineering systems.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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