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A Miniature Filter on a Suspended Substrate with a Two-Sided Pattern of Strip Conductors

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Abstract—A miniature bandpass filter of new design with original stripline resonators on suspended substrate has been studied. The proposed filters of third to sixth order are distinguished for their high frequency-selective properties and mush smaller size in comparison to analogs. It is shown that a broad stopband extending above three-fold central bandpass frequency is determined by weak coupling of resonators at resonances of the second and third modes. A prototype sixth-order filter with a central frequency of 1 GHz, manufactured on a ceramic substrate with dielectric permittivity $\varepsilon = 80$, has contour dimensions of $36.6 \times 4.8 \times 0.5$ mm^3. Parametric synthesis of the filter, based on electrodynamic 3D model simulations, showed quite good agreement with the results of measurements.

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As is known, bandpass filters are among the most important elements of modern systems of communications, radiolocation, radio navigation, radioelectronic warfare, and measurement instrumentation. The filter quality and design frequently determine the dimensions and performance of radio engineering equipment. Designing new miniature filters possessing high frequency-selective characteristics is an important and topical task.

In designing new filters, developers devote most of their attention to increasing their selectivity, decreasing losses in the passband, reducing dimensions, improving fabrication technology, and reducing cost of production. On the whole, these requirements are met by the traditional stripline filters on substrates with high relative dielectric constant ($\varepsilon \geqslant 10$), which still find wide application in modern microwave electronics [1, 2]. However, solving the task of reducing filter dimensions without deterioration of its selectivity in the in the range of ultrahigh and, especially, very high frequencies encounters considerable difficulties. For example, the use of stripline resonator conductors of stepped width [3] and their transformation into hairpin [4], C-folded [5], or rectangular spiral [6] structures usually lead to decreasing unloaded Q-factor of filter resonators and, hence, to increasing losses in the passband. The selectivity of stripline filters can be significantly improved by using conductors made of high-temperature superconducting materials [7], but the high cost of these devices and their ability to work only at cryogenic temperatures restrict their wide practical use.

A recently proposed new design of miniature bandpass filters [8] based on stripline resonators [9] provided record high miniaturization for multistripline filters known in the previous art. However, the characteristics of filters based on suspended substrates with two-sided patterns of strip conductors [10, 11] and filters with resonators formed by three parallel conductors on two-layer hybrid substrates [12, 13] exceed those of simple stripline filters. This approach not only ensures a more than tenfold decrease in filter dimensions, but also significantly increases selectivity due to cross-coupling between nonneighboring resonators [14]. It should be noted that, although filters on suspended substrates are more difficult to manufacture than conventional stripline structures, they can also be fabricated as monolithic structures using low-temperature cofiring ceramic (LTCC) technology [15].

The present work was aimed at studying a stripline filter based on new resonators with two-sided pattern of conductors on a suspended substrate ($\varepsilon = 80$). This design allows miniature multipole bandpass filters with high frequency-selective performance characteristics to be created.

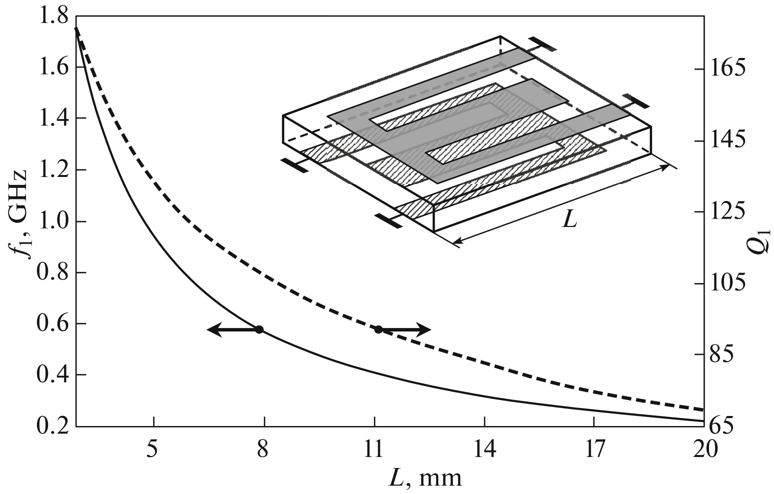

Fig. 1. Plots of the first-mode eigenfrequency (f_1) and unloaded Q (Q_1) vs. length L of a stripline resonator with a two-sided pattern of conductors on a suspended substrate. The inset shows the resonator design.

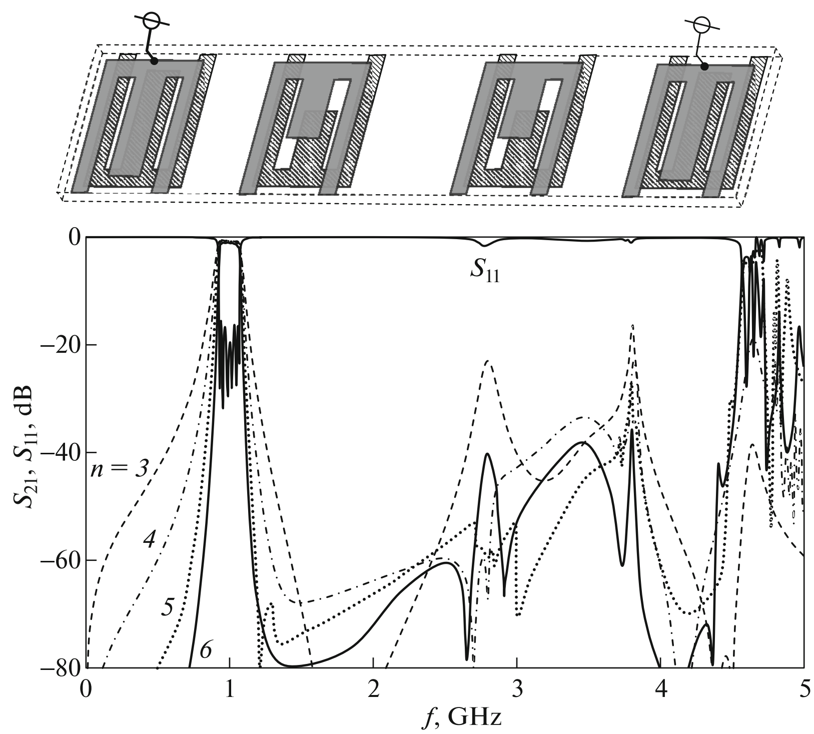

Fig. 2. Frequency responses of multipole filters (n = 3–6) with stripline resonators on a suspended substrate, determined from 3D model simulations. The inset shows a schematic diagram of the fourth-order filter.

The proposed resonator design is shown in the inset to Fig. 1. The resonator comprises a pair of mirror-symmetric E-shaped stripline structures arranged on the top and bottom sides of a substrate suspended inside a metal screen-case (not depicted in Fig. 1). The ends of the terminal conductors on both sides are connected to the screen so as to form inductances, while the free ends of middle conductors are open and form quasi-lumped capacitors. It is important to note that high-frequency potentials of the central conductors at the first-mode resonance frequency in this system have opposite signs, while the direction of current is the same in all conductors connected to the screen. Therefore, the mutual inductance of conductors increases their intrinsic inductances and thus reduces the first-mode resonance frequency of the resonator or decreases its dimensions at preset frequency.

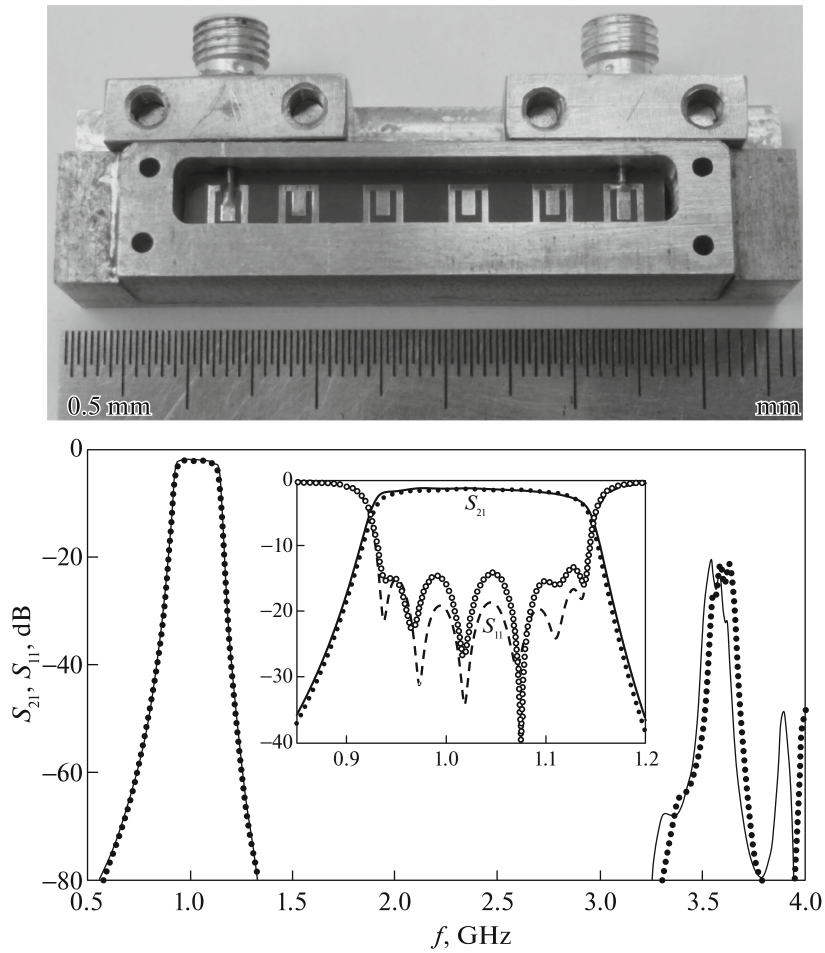

Fig. 3. Measured (points) and simulated (solid curves) frequency responses of the sixth-order filter. The inset shows a photograph of the prototype filter.

Figure 1 shows plots of the first-mode eigenfrequency (f_1) and unloaded $Q(Q_1)$ versus length L of the stripline resonator under consideration. The resonator substrate was made of a 0.5-mm-thick plate of TBNS high-frequency ceramics with relative permittivity $\varepsilon = 80$. The narrow terminal conductors of the stripline structures had a width of 0.5 mm, the central conductors had a width of 1 mm, and the gaps between conductors were 0.5 mm wide.

The properties of the proposed resonator structure were studied by electrodynamic simulations of a three-dimensional (3D) model. As can be seen from Fig. 1, the resonator with length L = 3 mm (equal to the stripline structure width) has a first-mode eigenfrequency of f_1 = 1.74 GHz and unloaded Q_1 = 177. As the resonator length is increased to L = 20 mm, the resonance frequency by drops almost eight times (to f_1 = 0.22 GHz), whereas the unloaded Q decreases only by a factor of about 2.6 (Q_1 = 69). As is known, second-mode eigenfrequency f_2 of any resonator usually determines the high-frequency boundary of the stopband of a bandpass filter based on this resonator. In the proposed resonator, this frequency is 2.65 times higher than first-mode eigenfrequency f_1 and the f_2/f_1 ratio is almost independent of resonator length L.

Figure 2 presents the frequency dependences of transmission (S_{21}) and reflection (S_{11}) losses of multipole bandpass filters of nth order (n = 3–6) consisting of three to six resonators arranged on a suspended 0.5-mm-thick substrate with ε = 80. In all resonators, the narrow terminal conductors of the stripline structures had a width of 0.5 mm, the central conductors had a width of 1 mm, and the gaps between conductors were 0.5 mm wide. To objectively compare their selective properties, all filters were tuned to the same bandpass central frequency of f_0 = 1 GHz and bandwidth Δf = 0.2 GHz at −3 dB from the minimum loss level). Resonator length L = 4.44 mm determined the substrate width, while the substrate length for filters of the third, fourth, fifth, and sixth order was 15.4, 23.3, 31.8, and 41.3 mm, respectively. The distances from the top and bottom screens to the substrate surfaces were 5 mm. It should be noted that the maximum reflection losses in the passband did not exceed −14 dB. The input and output ports of filters with 50 Ω impedance were connected to bases of the central conductors of end resonators on the top side of the substrate. As an example, the top inset to Fig. 2 shows a diagram of the filter with $n = 4$. The cross coupling of resonators (determining the passband width) was tuned by varying gap widths between stripline structures. It should be noted that, since the interaction of resonators decreases their resonance frequencies, it was necessary to adjust the inner resonators to the central frequency of passband, which was achieved by reducing the lengths of their central strip conductors.

An advantage of the proposed multipole filters based on resonators with two-sided pattern of strip conductors on a suspended substrate is a relatively wide high-frequency stopband that reaches ~$4f_0$, which is explained by the fact that the cross coupling of resonators at the second- and third-mode frequencies is much lower than that for the first mode. This circumstance is related to the fact that high-frequency currents in all conductors of each resonator are in-phase at the first-mode resonance frequency and counterphase at higher resonance frequencies. This is confirmed by the frequency dependences presented in Fig. 2. As was expected, an increase in the filter order led to an increasing slope of the frequency response and growing level of microwave power damping in the stopbands.

For experimental verification of the obtained results, we have synthesized and then manufactured a prototype sixth-order filter based on resonators with two-sided pattern of strip conductors on a suspended substrate. A photograph of this filter mounted in metal screen-case is shown in the inset to Fig. 3. The substrate with dimensions 36.6 × 4.8 × 0.5 mm was made of TBNS high-frequency ceramics ($\varepsilon = 80$). The width of the stripline structure of conductors forming the resonators was 3 mm, the narrow terminal conductors had a width of 0.5 mm, the central conductors had a width of 1 mm, and the gaps between conductors were 0.5 mm wide. The gaps between the outer pairs of resonators (first and second, fifth and sixth) were 2.3 mm, the next pairs (second and third, fourth and fifth) were spaced by 3.3 mm, and the central pair (third and fourth) were spaced by 3.4 mm. The lengths of central conductors in the second and fifth resonators were reduced by 0.37 mm, and those in the third and fourth resonators were reduced by 0.4 mm. The distances from the top and bottom screens to the substrate surfaces were 4 mm. The passband characteristics of the prototype agreed well with the calculated values: central frequency, $f_0 = 1.0$ GHz; relative width, $\Delta f = 20\%$; and transmission losses, not exceeding 1.4 dB. The high-frequency stopband width on a level of –40 dB extended up to $3.5f_0$.

Thus, we have studied a bandpass filter based on original stripline resonators with a two-sided pattern of strip conductors on a suspended substrate. A prototype sample of the sixth-order filter exhibited high frequency-selective properties and showed good agreement between the measured characteristics and those determined by 3D model electrodynamic simulation. The proposed filter has compact dimensions, wide stopband, and admits convenient manufacturing technology. The obtained results confirm that there are good prospects for using the proposed filter design in devices for modern systems of communications, radiolocation, radio navigation, and radioelectronic warfare.

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