ISSN 1063-7850, Technical Physics Letters, 2013, Vol. 39, No. 8, pp. 690–693. © Pleiades Publishing, Ltd., 2013.
Original Russian Text © B.A. Belyaev, A.M. Serzhantov, V.V. Tyurnev, A.A. Leksikov, Ya.F. Bal'va, 2013, published in Pis'ma v Zhurnal Tekhnicheskoi Fiziki, 2013, Vol. 39, No. 15, pp. 47–55.

# Miniature Bandpass Microwave Filter with Interference Suppression by More Than 100 dB in a Wide Rejection Band

**B. A. Belyaev, A. M. Serzhantov, V. V. Tyurnev, A. A. Leksikov, and Ya. F. Bal'va**

*Kirensky Institute of Physics, Siberian Branch, Russian Academy of Sciences, Krasnoyarsk, 660036 Russia*
*Siberian Federal University, Krasnoyarsk, 660041 Russia*
*Siberian State Aerospace University, Krasnoyarsk, 660014 Russia*
*e-mail: belyaev@iph.krasn.ru*

Received March 20, 2013

**Abstract**—A new planar resonator design in which a single conductor is replaced by three parallel stripe conductors located one above the other on a suspended two-layer substrate is proposed. It is shown that the resonator longitudinal sizes can be significantly reduced and, at the same time, the resonator intrinsic Q factor and frequencies of higher oscillation modes can be increased. A fourth-order bandpass filter with a central frequency of the transmission band (relative width 5%) of 1 GHz has been developed and fabricated. This filter has a –100-dB rejection band up to frequencies exceeding 10 GHz. The filter is enclosed in a metallic case with an internal size of 38 × 12 × 7.5 mm. It is shown that a similar filter fabricated in accordance with low-temperature cofired ceramic (LTCC) technology has a –40-dB rejection band up to 30 GHz, with sizes reduced to 5.0 × 4.25 × 1.24 mm.

**DOI:** 10.1134/S1063785013080026

Conventional microwave bandpass filters (BFs) have spurious transparency windows at resonant frequencies of higher oscillation modes; therefore, they have a relatively narrow high-frequency rejection band. However, modern communication systems and various designs of special radio equipment call for miniature, generally planar, BFs having not only a wide rejection band (RB), but also a high level of interference suppression therein. It is also known that simple addition of sections in widespread microstrip filters in order to increase the level of interference suppression in rejection bands leads to an unacceptably large loss of the desired-signal power because of the relatively low intrinsic Q factor of resonators. The Q factor of planar resonators can be increased using high-temperature superconducting films as conducting materials [1]; however, application of these devices is limited by their high cost and the necessity of maintaining cryogenic temperatures.

The rejection-band width in BFs can be increased several times using irregular microstrip resonators [2–4]; however, these irregularities generally reduce the intrinsic resonator Q factor and, correspondingly, increase the loss in the transmission band. One of the spurious bands can be suppressed by conductive connection of filter ports to the conductors of the outer resonators at points where the nodes of high-frequency voltage of the corresponding oscillation modes are located [5–7]. Several spurious passbands can be suppressed simultaneously using resonators with noncoinciding resonant frequencies of higher modes [8]; however, in this case, deep damping of microwave power in the filter RB cannot be obtained in principle. The RB width can be increased significantly by fitting the length of the coupling region of adjacent filter resonators [9, 10] so as to compensate for their inductive and capacitive interaction at the resonant frequencies of higher oscillation modes, as was shown previously [11]. However, this approach also cannot be used to satisfy the requirements to the RB characteristics of modern filters. Note that, in all the above-described filters, the high-frequency RB edge does not exceed $8f_0$ ($f_0$ is the central frequency of the filter transmission band) and the RB damping level is no more than 40 dB.

The rejection-band characteristics can be improved by fabricating planar filters on a suspended substrate with a two-side pattern of stripe conductors [12]. However, filters based on miniature coaxial resonators are characterized by unprecedentedly high RB characteristics [13]. For example, in the fourth-order filter based on these resonators the RB reaches $47f_0$ at a level of –90 dB [14, 15]. However, filters based on these resonators are technologically less efficient in comparison with planar designs.

In this paper, we report the results of studying an original miniature stripe resonator on a suspended substrate (Fig. 1a), which can be used to design BFs (Fig. 1b) with unprecedently high RB characteristics relative to all other planar configurations. The resonator is based on a two-layer dielectric substrate suspended in the middle of a metallic case in the form of

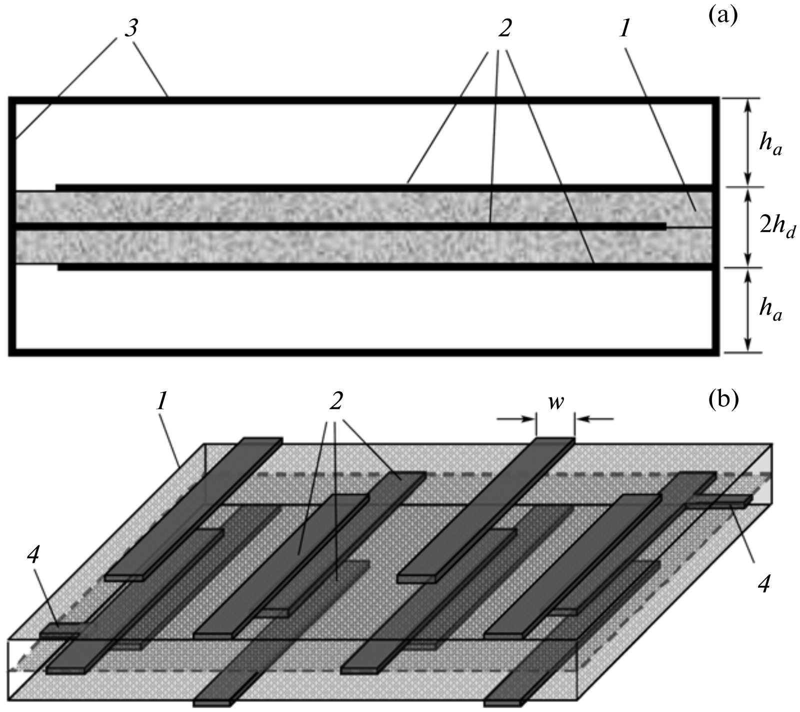


**Fig. 1.** (a) Longitudinal cross section of a stripe resonator and (b) a filter stripe board: (*1*) two-layer suspended dielectric substrate, (*2*) stripe conductors, (*3*) metallic-case walls, and (*4*) filter ports.

a parallelepiped. Its conductive part consists of three stripe conductors arranged one below the other on the surfaces of the layers of the combined dielectric substrate. Two external conductors located on the external substrate surfaces are connected to one of the lateral walls of the case with one end, whereas one end of the internal conductor located between the layers is connected to the opposite lateral wall. The other ends of the stripe conductors are opened and spaced by the same gaps from the corresponding lateral walls.

The first three oscillation modes in the resonator under consideration have maxima of high-frequency voltage only near the free conductor ends. For the first (main) oscillation mode with lowest frequency $f_1$, the currents in all three conductors flow in the same direction. For the second mode with higher frequency $f_2$, the currents in the upper and lower conductors flow in opposite directions, while the current in the internal conductor is zero. For the third mode with frequency $f_3 > f_2$, the currents in the upper and lower conductors flow in the same direction, while the current in the internal conductor flows in the opposite direction. It is noteworthy that the second oscillation mode, for which the currents in the upper and lower conductors are oppositely directed, is not excited when the resonator is connected to the port by the central conductor (as in the filter design shown in Fig. 1b). Therefore, the filter RB width is determined by the $f_3/f_1$ ratio.

As the investigations showed, frequency $f_1$ decreases with a decrease in layer thickness $h_d$ and the $f_3/f_1$ ratio, which characterizes the relative RB width of a bandpass filter based on these resonators, increases very rapidly. Note that the intrinsic Q factor of the first resonance monotonically increases with a decrease in $h_d$ and, the higher the Q factor of the insulator used, the more pronounced this effect is. For example, when RT/Duroid 5880 is used the Q factor increases by approximately 15%. It is noteworthy that, in our study, $h_d$ was reduced with the frequency of the first oscillation mode of the resonator maintained constant ($f_1$ = 1 GHz) by a corresponding decrease in resonator length $l_r$. Hence, the observed increase in $Q_1$ from 364 to 417 is obviously related to only the decrease in ohmic loss in the resonator due to the shortening of its stripe conductors.

Thus, to increase the relative RB width of a filter based on the resonator under study, one should use a combined dielectric substrate with layers that are as thin as possible. As a result, the upper RB boundary can be increased to a frequency that exceeds the central frequency by a factor of more than 40. In this case, the resonator length decreases with a simultaneous increase in the intrinsic Q factor. The analysis also showed that the RB width grows with an increase in stripe conductor width $w$ and distance $h_a$ from the surfaces of the combined dielectric substrate to the upper and lower surfaces of the metallic case (Fig. 1); however, this rise obviously leads to the corresponding increase in the filter sizes. The increase in the permit-

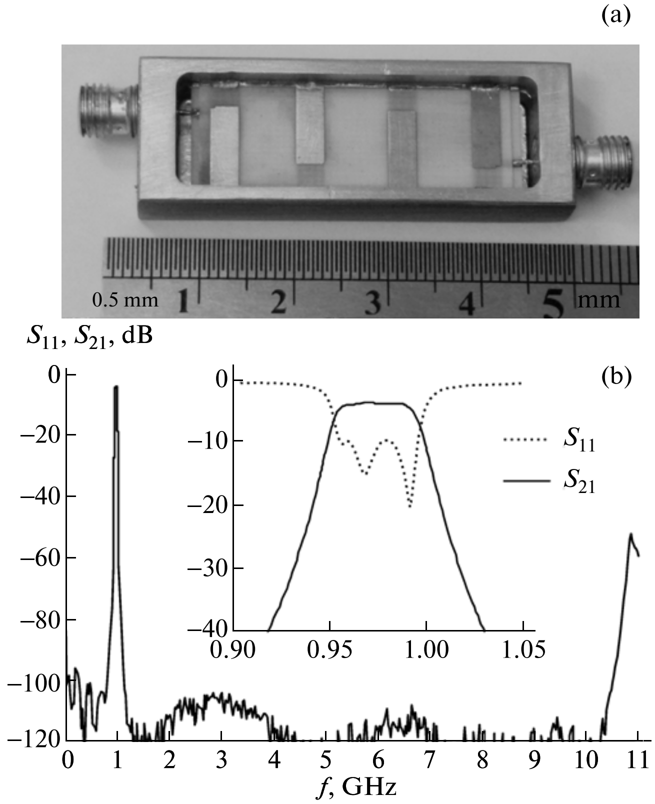


**Fig. 2.** (a) Operating filter breadboard and (b) measured frequency dependences of reflection ($S_{11}$) and transmission ($S_{21}$) loss.

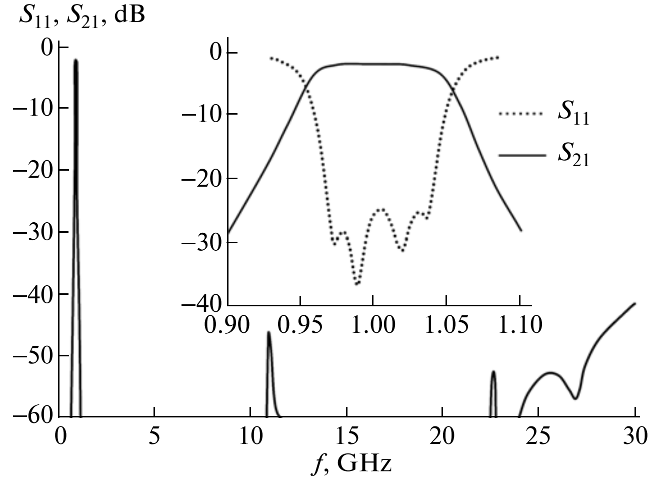


**Fig. 3.** Calculated frequency dependences of reflection ($S_{11}$) and transmission ($S_{21}$) loss of miniature monolithic filter, synthesized to be prepared according to LTCC technology.

tivity of the substrate layers slightly increases the RB width but, naturally, reduces the filter sizes.

To check experimentally the possibility of fabricating planar bandpass filters with unprecedently high RB parameters based on the resonator investigated, we synthesized a fourth-order filter using 3D electromagnetic design simulation (Fig. 1b). The measurement results and a photograph of the filter prototype are shown in Fig. 2. The two-layer substrate (12 × 4 × 38 mm in size) was made of Rogers R04003C™ with thickness $h_d = 0.2$ mm ($\varepsilon_r = 3.4$, $\tan\delta \approx 0.002$). The width of all stripe resonator conductors is $w = 3$ mm. Conductor lengths $l_s$ for the internal and outer resonators are 9 and 9.25 mm, respectively. The air gap between the dielectric substrate and metal case surfaces is $h_a = 3.5$ mm. The gaps between the stripe conductors are $S_1 = 6.5$ mm for the internal pair of resonators and $S_2 = 5.75$ mm for external pairs of resonators. The filter fractional bandwidth measured at −3 dB with respect to the minimum loss level is 5% and its central frequency $f_0 \approx 1.0$ GHz. The RB upper boundary at a level of −100 dB extends to $10.5f_0$. The minimum loss in the transmission band is about 3 dB.

The proposed bandpass-filter design can also be implemented using the technology of multilayer integrated circuits based on low-temperature cofired ceramics (LTCC) [16]. In this case, the filter is a monolithic structure in which the conductors are placed in a dielectric matrix without air gaps. The possibility of fabricating a monolithic filter based on a suspended substrate with a two-side pattern of stripe conductors [12] was demonstrated in [17].

Figure 3 shows the frequency response of a monolithic filter composed of the four above-considered resonators, which was synthesized by 3D electromagnetic simulation. The filter is based on LTCC materials [16] and has the following design parameters. The dielectric layers (ceramic sheets) filling the entire filter volume are made of Heratope CT2000 ($\varepsilon_r = 9.1$, $\tan\delta = 0.002$); the layer thicknesses are $h_d = 20$ μm (between stripe conductors) and $h_a = 600$ μm (between conductors and screens; three sheets per 200 μm). The stripe-conductor width is $w = 0.5$ mm; conductor lengths $l_s$ of the external and internal filter resonators are 4 and 3.95 mm, respectively. The total resonator length is $l_r = 4.25$ mm. The conductor material is a layer of Ag-based HF612 cofired conductive paste 10 μm thick with a surface resistance of 2 mΩ. The distances between conductors are 0.75 mm for internal pair of resonators and 0.625 mm for external pairs of resonators.

The filter developed has a central frequency of the transmission band $f_0 = 1.0$ GHz and a fractional bandwidth of 10%. The minimum loss in the filter transmission band is 1.7 dB. The RB width is $\sim 11f_0$ at the level −70 dB and $\sim 30f_0$ at the level −40 dB. The filter sizes are 1.24 × 4.25 × 5 mm.

Thus, we proposed a miniature design of an original stripe resonator based on a two-layer suspended substrate and analyzed its parameters. This design can be used to fabricate planar microwave bandpass filters with an unprecedently wide and deep rejection band. It was shown that devices based on these resonators can be implemented as monolithic structures using LTCC technology.

## ACKNOWLEDGMENTS

This study was supported by the Ministry of Education and Science of the Russian Federation (state contract no. 14.513.11.0010), the federal targeted program "Scientific and Pedagogical Personnel of Innovative Russia (2009–2013)" (state contract no. 16.740.11.0470), agreement nos. 14.V37.21.1103 and 14.V37.21.0070, and Integration Project no. 109 (Siberian Branch, Russian Academy of Sciences).

## REFERENCES

1. I. B. Vendik, O. G. Vendik, K. N. Zemlyakov, et al., Tech. Phys. Lett. **37** (5), 421 (2011).
2. B. A. Belyaev, S. V. Butakov, N. V. Laletin, A. A. Leksikov, V. V. Tyurnev, and O. N. Chesnokov, J. Commun. Technol. Electron. **49** (11), 1308 (2004).
3. B. A. Belyaev, S. V. Butakov, N. V. Laletin, A. A. Leksikov, V. V. Tyurnev, and O. N. Chesnokov, J. Commun. Technol. Electron. **51** (1), 20 (2006).
4. X. B. Wei, Y. Shi, P. Wang, J. X. Liao, Z. Q. Xu, and B. C. Yang, J. Electromagn. Waves Appl. **26**, 1095 (2012).
5. J.-T. Kuo and E. Shih, IEEE Trans. Microwave Theory Tech. **51** (5), 1554 (2003).
6. T.-N. Kuo, W.-C. Li, C.-H. Wang, and C. H. Chen, IEEE Microwave Wireless Compon. Lett. **18** (6), 389 (2008).
7. C.-Y. Hung, M.-H. Weng, S.-W. Lan, and C.-Y. Huang, J. Eletromagn. Waves Appl. **26**, 12 (2012).
8. S.-C. Lin, P.-H. Deng, Y.-S. Lin, C.-H. Wang, and C. H. Chen, IEEE Trans. Microwave Theory Tech. **54** (3), 1011 (2006).
9. J.-T. Kuo, S. P. Chen, and M. Jiang, IEEE Microwave Wireless Compon. Lett. **13** (10), 440 (2003).
10. M. A. Sanchez-Soriano, G. Torregrosa-Penalva, and E. Bronchalo, IET Microwaves Antennas Propag. **6** (11), 1269 (2012).
11. B. A. Belyaev, N. V. Laletin, A. A. Leksikov, and A. M. Serzhantov, J. Commun. Technol. Electron. **48** (1), 31 (2003).
12. B. A. Belyaev, A. A. Leksikov, V. V. Tyurnev, and A. V. Kazakov, in *Proceedings of the 15th International Crimean Conference "Microwave and Telecommunication Technology (CriMiCo)," Sevastopol, Ukraine, 2005*, p. 506.
13. B. A. Belyaev, A. M. Serzhantov, V. V. Tyurnev, and A. A. Leksikov, Microwave Opt. Technol. Lett. **54** (5), 1117 (2012).
14. B. A. Belyaev, A. M. Serzhantov, V. V. Tyurnev, A. A. Leksikov, and An. A. Leksikov, Tech. Phys. Lett. **38** (1), 47 (2012).
15. B. A. Belyaev, A. A. Leksikov, A. M. Serzhantov, V. V. Tyurnev, Ya. F. Bal'va, and An. A. Leksikov, J. Commun. Technol. Elektron. **58** (2), 110 (2013).
16. A. Simin, D. Kholodnyak, and I. Vendik, Kompon. Tekhnol. **5**, 190 (2005).
17. Y. Zhang, K. A. Zaki, A. J. Piloto, and J. Tallo, IEEE Trans. Microwave Theory Tech. **54** (8), 3370 (2006).

*Translated by A. Sin'kov*