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A Highly Selective Stripline Lowpass Filter with More Than 100-dB Wide Stopband Attenuation

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Abstract—A new miniature design of a highly selective lowpass filter based on a suspended substrate with a two-sided stripline pattern has been developed. The filter frequency response slope (cutoff attenuation rate) and stopband attenuation depth are determined by transmission zeros, the number of which is equal to the filter order. An experimental prototype of a fifth-order lowpass filter on 0.5-mm-thick alumina substrate with dielectric permittivity $\varepsilon = 9.8$ has been synthesized with the aid of numerical electrodynamic analysis of a three-dimensional model. The cutoff frequency of the filter passband at a –1-dB level is $f_c = 1.75$ GHz. The stopband width at a –100-dB attenuation level reaches $4.4f_c$.

Keywords: lowpass filter, substrate, stripline resonator, stopband.

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Microwave frequency filters are among the most important elements in modern systems of communications, radiolocation, radio navigation, and special measurement instrumentation [1, 2]. Wide bandpass filters are particularly requested in radio engineering, but lowpass filters are also frequently employed, which ensure low-loss transmission of electromagnetic waves in a frequency band from zero to preset cutoff frequency f_c and reject interferences in the high-frequency range. At present, ultra-wideband (UWB) bandpass filters [3, 4] are in demand for communication systems operating at high data transmission speeds. These UWB bandpass filters can readily be obtained by cascade-connected lowpass and highpass filers [5]. The characteristics of filters frequently determine their performance, while their sizes determine the overall dimensions of the whole microwave device. Therefore, the development of new lowpass filters with miniature design possessing high selectivity and low losses in the passband is an important topical task.

Microwave systems widely employs compact lowpass filters manufactured in the form of monolithic devices by multilayer integrated circuit technology using low-temperature co-fired ceramics (LTCCs) [6]. These filters are based on resonance structures consisting of quasi-lumped capacitive and inductive elements [7] known to possess relatively low unloaded Q value, which is manifested in the rather low frequency response parameters of these devices. Good frequency response parameters are achieved in two-dimensional (2D) lowpass filters based on microstrip resonators [8], but only by means of large sizes. Moreover, another disadvantage of most microstrip lowpass filters is the rather low level of interference attenuation in the stopband.

These disadvantages are eliminated in the proposed design of miniature highly selective lowpass filter based on a dielectric substrate with two-sided stripline pattern suspended in a metal case, an experimental prototype of which has been studied in the present work.

Figure 1a shows the design of a fifth-order lowpass filter based on a dielectric substrate of thickness h_d suspended in a metal case at air gap width h_a from the covers. The filter comprises a stripline (on the top side of substrate) connecting its 50-Ω input and output ports to five interdigital strips with free end pads. The bottom side of substrate bears hairpin stripe conductor segments arranged strictly under the pads and having the same width. One end of these conductors is free, while the other end is connected to the metal case. The metal pads with stripe conductor segments form resonators, which are represented by serial circuits $L_{\mathrm{S}i}C_i$ ($i = 1–3$) (Fig. 1b). The proposed filter design is symmetric with respect to the input and output ports, as is

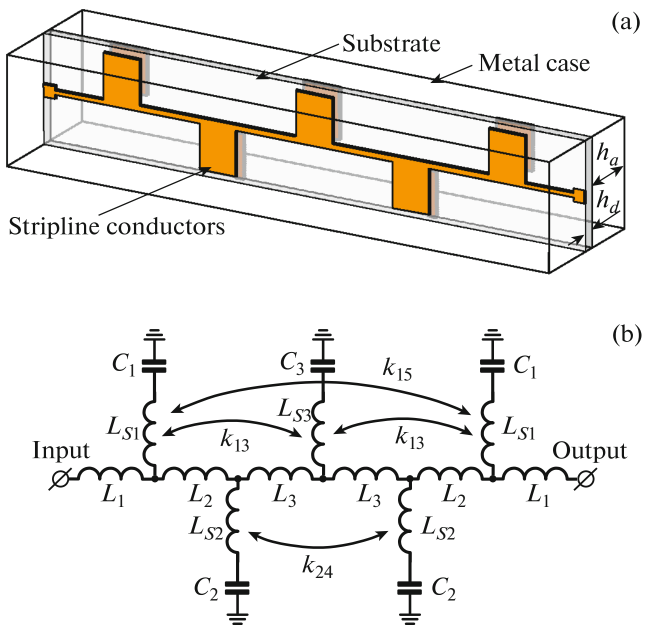

Fig. 1. (a) Design and (b) equivalent circuit of a highly selective fifth-order lowpass filter.

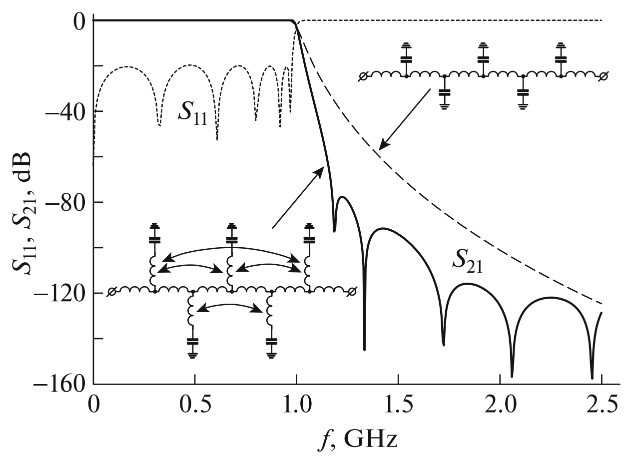

Fig. 2. Frequency responce of insertion losses of the fifth-order lowpass filter tuned using equivalent circuits of the proposed (solid line) and classical (dashed line) filter. The dotted line shows the frequency dependence of losses for reflection.

reflected by the notation of inductors and capacitors on the equivalent scheme.

The proposed filter design differs from the classical scheme by that the resonators are electromagnetically mutually coupled. As a result, by controlling the coupling of resonators via parameters of stripe conductor topography, it is possible to tune the filter so as to obtain the stopband frequency response with a number of transmission zeroes equal to the filter order. This was confirmed by simulations of the frequency response based on the equivalent circuit of a five-resonator filter model, which was tuned (for certainty) so that the cutoff frequency was $f_c = 1$ GHz. Figure 2 (solid line) shows the frequency responce of insertion loss of the tuned lowpass filter. The nominal parameters of elements of the equivalent circuit (Fig. 1b) and coupling coefficients k_{ij} of resonators are listed in Table 1.

For comparison, Fig. 2 (dashed line) also shows the frequency response of a classical fifth-order lowpass filter with the same cutoff frequency $f_c = 1$ GHz. As can be seen, the selectivity properties of the classical lowpass filter are significantly inferior to those of the proposed filter. Nominal parameters of elements of the equivalent circuit of the classical filter (in accordance with Fig. 1b) are also listed in Table 1. It should be noted that the frequencies of transmission zeros occurring in the stopband of the proposed filter can be varied within broad limits by changing the parameters of elements of the equivalent circuit, which makes it possible to increase not only the frequency response slope (cutoff attenuation rate), but also the stopband attenuation depth, and set especially strong suppression of high-frequency interferences at certain frequencies.

The frequency-selective properties of the proposed and classical filters can be objectively compared in terms of the frequency response slope calculated by the following formula [8]:

$$K = \frac{\Delta f_3}{\Delta f_{30} - \Delta f_3}, \quad (1)$$

where Δf_3 is the filter passband width at −3 dB relative to the level of minimum losses and Δf_{30} is the filter passband width at −30 dB relative to the same level. As a result, the frequency response slope calculated for the classical filter is $K \approx 6.7$, while that for the proposed filter is more than twice as large, $K \approx 14.3$.

For the experimental verification of performance of the proposed stripline lowpass filter design (Fig. 1a), parametric synthesis of a 3D model of the lowpass filter was performed by selecting proper dimensions of the stripe conductor topology based on the numerical

Table 1. Nominal parameters of equivalent circuit elements and coupling coefficients of lowpass filters

Filter design	L_1, nH	L_2, nH	L_3, nH	L_{S1}, nH	L_{S2}, nH	L_{S3}, nH	C_1, pF	C_2, pF	C_3, pF	$k_{13} \times 10^{-3}$	$k_{24} \times 10^{-3}$	$k_{15} \times 10^{-6}$
This work	5.90	11.28	13.58	2.37	4.80	0.308	3.63	3.33	5.55	3.544	17.0	5.0
Classical	8.4	16.48	17.32	–	–	–	4.88	5.61	5.72	–	–	–

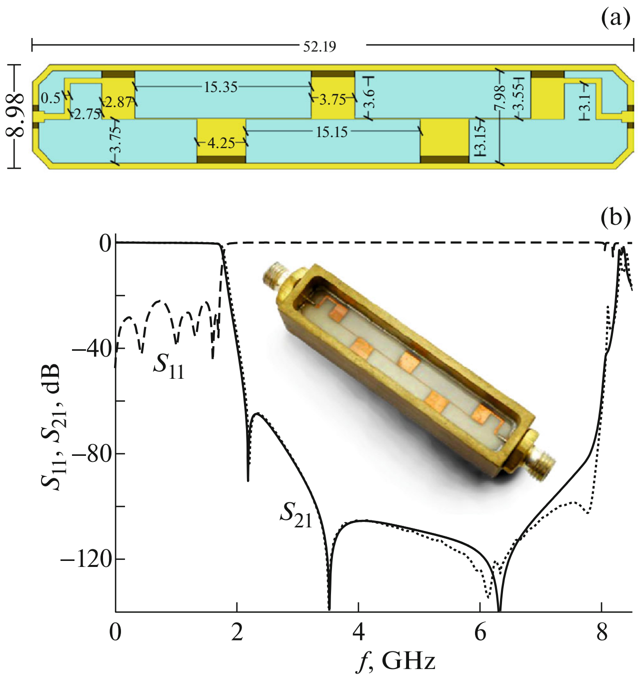

Fig. 3. (a) Topology and dimensions (in millimeters) of stripe conductors in prototype stripline lowpass filter and (b) measured frequency responces of (dotted line) insertion losses S_{21} and (dashed line) return losses S_{11} for the prototype stripline lowpass filter and (solid line) simulation S_{21} curve. The inset presents a photograph of the experimental prototype.

electrodynamic analysis using CST Microwave Studio program package. A 0.5-mm-thick substrate for the stripline filter structure was made of alumina—a material with dielectric permittivity $\varepsilon = 9.8$ that is traditionally used in microwave technology. The distance from the substrate surface to the metal case covers was $h_a = 5$ mm. Note that the only restriction in the synthesis of a prototype filter was imposed on the stripline structure length, which could not exceed the maximum size of standard alumina substrates (60 mm). The cutoff frequency of the filter passband at the −1-dB level was $f_c = 1.75$ GHz. The substrate length was additionally reduced by bending of the external segments of stripe conductors to which the input and output ports were connected. The topology of stripe conductors in the numerically synthesized filter with the given dimensions of elements (expressed in millimeters) is presented in Fig. 3a. The width of the narrowest internal conductors in the stripline filter structure was 0.1 mm (not indicated in Fig. 3a).

Figure 3b shows the frequency dependences of insertion losses S_{21} (dotted line) and return losses S_{11} (dashed line) for the experimental prototype of stripline lowpass filter manufactured using photolithographic techniques and measured on an R&S ZVA 40 vector network analyzer with a dynamic range exceeding 150 dB. In addition, the solid line has the form of a simulated $S_{21}(f)$ curve that well coincides with the measured frequency response. The manufactured prototype has a passband cutoff frequency of $f_c = 1.75$ GHz with a level of return losses in this band not exceeding −20 dB and exhibits a broad stopband extending up to frequencies about $4.4f_c$ at a −100-dB level. The level of attenuation in the middle of passband of the prototype filter is as low as 0.15 dB.

It is important to note that the stopband width of the proposed lowpass filter can be significantly increased by using dielectric substrates with smaller thickness or greater relative dielectric permittivity. This would also naturally reduce the length of resonators and, hence, the overall filter size. The width of high-frequency stopband also increases (but to a lower degree) with increasing distance from the suspended substrate surfaces to screens.

In concluding, we have studied a lowpass filter of new miniature design based on a suspended substrate with two-sided stripline pattern, which possesses high frequency selective properties. The filter frequency response slope (cutoff attenuation rate) and stopband attenuation depth are determined by transmission zeroes, the number of which is equal to the filter order. The compact design is related, in particular, to the fact that the resonators involved in formation of the passband employ quasi-lumped capacitive and inductive elements. The wide stopband of the proposed lowpass filter is determined by high resonance frequencies of parasitic large-mode oscillations of the stripline structure. Efficiency of the proposed design has been proved by high performance characteristics of the manufactured experimental fifth-order filter synthesized with the aid of numerical electrodynamic analysis of a three-dimensional model. It is important to note good agreement of the simulated lowpass filter characteristic with the results of their measurements for the experimental prototype.

The experimental prototype of a fifth-order lowpass filter based on a 0.5-mm-thick alumina substrate with dielectric permittivity $\varepsilon = 9.8$ had dimensions of about 52 × 11 × 9 mm, cutoff frequency $f_c = 1.75$ GHz of the filter passband at the −1-dB level, and a stopband width at the −100-dB attenuation level reaching $4.4f_c$. The proposed lowpass filter, owing to its compact dimensions and high characteristics, also has good prospects for use in UWB bandpass filters created using the traditional approach [5] as cascade-connected lowpass and highpass filters. Evidently, this bandpass filter would not only a high cutoff attenuation rate, but also provide strong suppression of high-frequency interferences in the stopband.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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