Investigation of Microstrip High-Pass Filters Based on Multimode Resonator

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***Abstract*— Microstrip high-pass filters were investigated by means of electrodynamic numerical analysis of 3D models. In the microwave constructions a new multimode resonator with a strip conductor of "E" shape was used, the central segment of which is grounded at its base. Synthesized filters with fixed cutoff frequency $f_c = 3$ GHz have high frequency-selective properties.**

Keywords—high-pass filter, multimode resonator, strip conductor, amplitude–frequency characteristics, microwave, microstrip

I. Introduction

It is known that frequency-selective microwave devices are essential elements in communication, radar and radio navigation systems [1, 2]. Traditionally, bandpass filters are the most popular of them [3, 4], but in many cases for optimal solution of radio engineering tasks, there is a need in high-pass filters (HPF), which pass electromagnetic waves in a given frequency band almost without any losses, providing required suppression of interference power less than cutoff frequency f_c.

At present, when designing communication centers and special radio equipment, HPF on concentrated elements [5], waveguide HPF as well as microstrip HPF [6] are used.

At the same time, it is well known that constructions on microstrip resonators possess not only high frequency-selective properties [1, 3, 7, 8], but also manufacturability, miniaturization and low cost in mass production. Such constructions function in microwave frequency ranges from *L* to *K*.

Moreover, in such frequency-selective devices, it is possible to implement multimode operation mode of microstrip resonators using certain form of their strip conductors. This allows bringing natural frequencies of the lowest *n* oscillation modes of resonators together and significantly miniaturize microwave structures implemented on their basis [7, 9-11].

The present paper gives the results of studying high-pass filters constructions on five-mode microstrip resonator.

II. Multimode Resonator

Topology of strip conductor of a new multimode microstrip resonator shown in Fig. 1.

Located on substrate (*1*) with high dielectric permittivity ε = 80 and thickness h = 1 mm, rectangular segments (*2*)-(*3*) of strip conductor are connected to each other in the form of a "hairpin". There is also a segment of strip conductor (*4*) on this substrate, grounded by its free end to the base and connected to the segment (*3*) by the opposite end. Thus, strip conductor of a multimode resonator has "E" shape.

Calculations of amplitude-frequency characteristics (AFC) of this microstrip resonator (Fig. 2), as well as AFC calculations of high-pass filters based on it, were made using electrodynamic numerical analysis of their 3D models, which, as it is known [1, 7, 8], is in good agreement with the experiment.

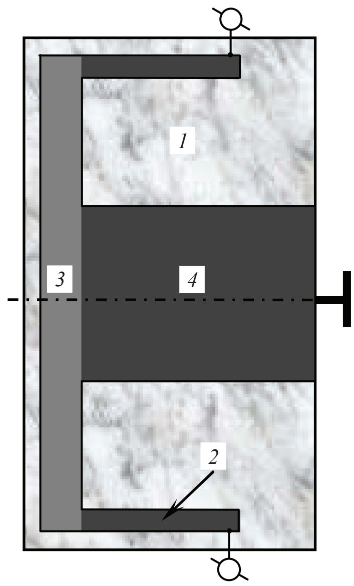

Fig. 1. Topology of strip conductor (*2*)-(*4*) of microstrip resonator on the substrate (*1*).

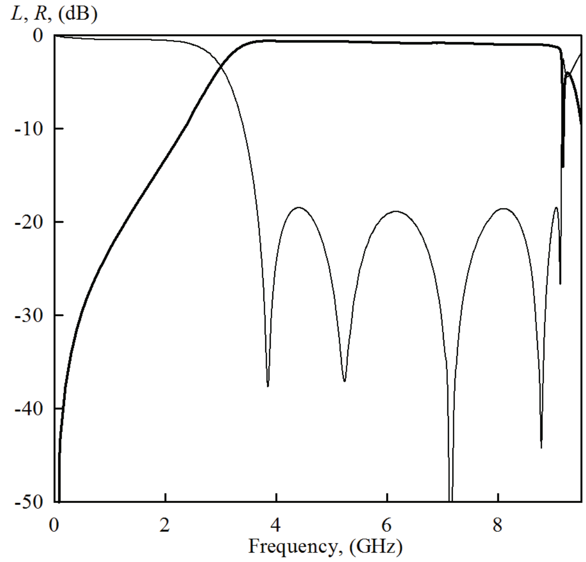

Fig. 2. AFC of microstrip five-mode resonator. *L*(*f*) – frequency dependence of direct losses, *R*(*f*) – frequency dependence of losses in reflection.

Their adjustment was carried out by "manual" parametric synthesis while fixing cutoff frequency of the constructions $f_c = 3.0$ GHz.

On amplitude-frequency characteristic of microstrip resonator, there are resonances of its five lowest oscillation modes, which form passband (Fig. 2), minimum power losses at its frequencies are $L_{\min} = 0.6$ dB. Higher in frequency ($f = 9.17$ GHz) is the attenuation pole of microwave power, which limits frequency passband.

It is worth noting, the passband of filters based on the "hairpin" microstrip resonators, is known from publicly available sources [12-14], to form only a couple of resonances from each of such resonators. In the proposed five-mode resonator it is possible to bring together natural frequencies of three more oscillation modes that form its passband changing the geometry of the strip conductor segments.

Here are the constructive dimensions of the resonator described above, in particular length and width of the strip conductor segments: (*2*) – 1.04×0.15 mm^2, (*3*) – 3.19×0.29 mm^2, (*4*) – 1.53×1.19 mm^2. Thus, the area of the miniature resonator, without taking into account the indents from the strip conductor to the edges of the substrate, is only $S = 5.81$ mm^2.

III. High-Pass Filters Based on Multimode Resonator

The first high-pass filter is shown in Fig. 3. The construction used three resonators – central five-mode resonator with a strip conductor consisting of segments (*3*)-(*6*) and a pair of last regular quarter-wave resonators with strip conductors (*2*) grounded from one end to the base.

The proposed arrangement of the resonators in the selective construction allows not only to increase significantly power suppression at frequencies below filter cutoff frequency, but it also leads to a significant increase in the passband slope – power passing at -30 dB is at $f_{-30} = 2.71$ GHz (Fig. 4). It is important to note that high frequency-selective properties of HPF are observed due to the presence of attenuation pole on AFC that is located near the decay of filter amplitude-frequency characteristic.

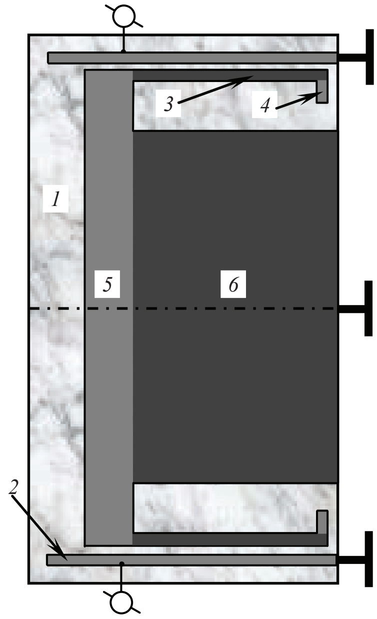

Fig. 3. Topology of strip conductors (*2*) - (*6*) of HPF based on multimode resonator. (*1*) – dielectric substrate.

It is worth mentioning that the use of different types of microstrip resonators at the same time in the construction of high-pass filter, multimode and single-mode, narrows its passband compared to the passband of five-mode resonator. Thus, high-frequency limit of HPF passband is ~ 8.4 GHz. The minimum power loss at the passband frequencies is $L_{\min} = 0.8$ dB.

In synthesis of this frequency-selective device, substrate with dielectric permittivity $\varepsilon = 80$ and thickness $h = 1$ mm was also used; segment dimensions of strip conductors were: (*2*) – 2.22×0.04 mm^2, (*3*) – 1.49×0.05 mm^2, (*4*) – 0.20×0.04 mm^2, (*5*) – 3.66×0.35 mm^2, (*6*) – 2.72×1.58 mm^2. The gaps between the strip conductors (*2*) and (*3*) are 0.03 mm.

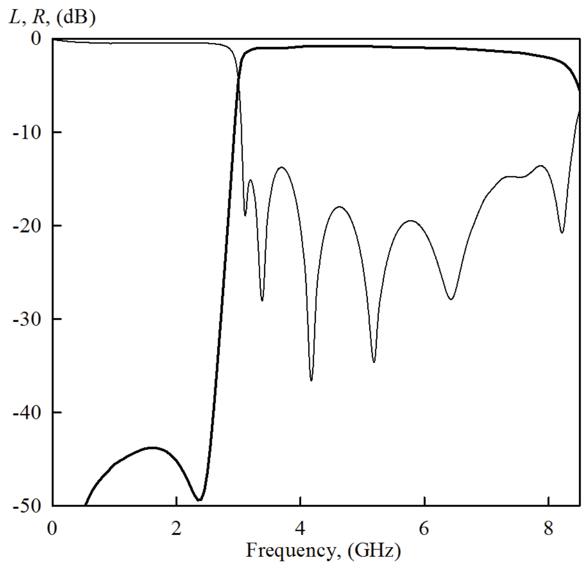

Fig. 4. AFC of high-pass filter based on multimode resonator. *L*(*f*) – frequency dependence of direct losses, *R*(*f*) – frequency dependence of losses in reflection.

In the second construction of high-pass filter, only two microstrip resonators were used, but both were five-mode ones. The studies have shown that HPF implemented based on opposite-directional multimode resonators has rather flat slope of filter frequency characteristic, since near the cutoff frequency there is no attenuation pole. When designing high-pass filters based on co-directional multimode resonators, the adjacent segments of their strip conductors were further folded, as shown in Fig. 5, it allows choosing optimal electromagnetic coupling of resonators with each other. By varying the length and width of rectangular pieces of strip conductors (*2*)-(*7*), it is possible to adjust the natural frequencies of such microstrip resonators, which allows adjusting filter passband with maximum allowable level of reflection losses in them R ⩽ – 14 dB.

The passband of such HPF should be formed by ten resonances – five from each resonator. However, additional folding of strip conductors in the construction leads to the appearance of parasitic attenuation pole (Fig. 6) at the frequencies of the passband (at 8.94 GHz), furthermore, it makes high-frequency resonances located next to it degenerated in frequency.

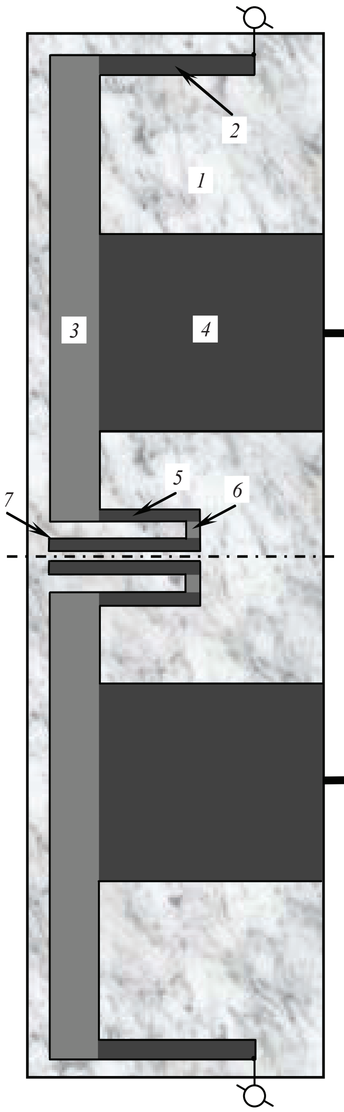

Fig. 5. Topology of strip conductors (*2*) - (*7*) of HPF based on co-directional multimode resonators. (*1*) – dielectric substrate.

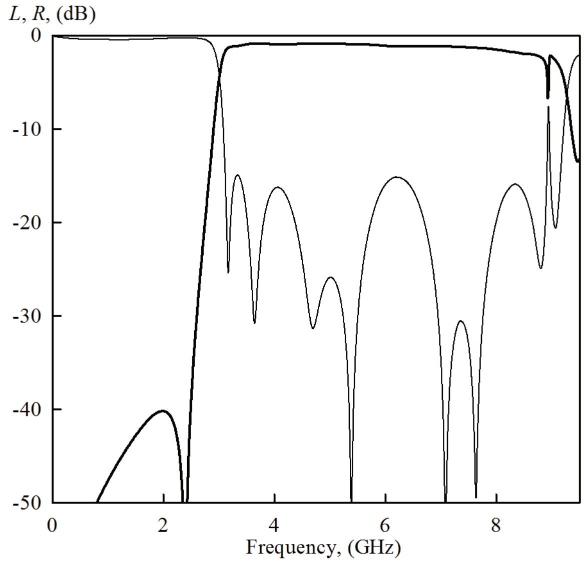

Fig. 6. AFC of high-pass filter based on co-directional multimode resonators. *L*(*f*) – frequency dependence of direct losses, *R*(*f*) – frequency dependence of losses in reflection.

As a result, the passband of second high-pass filter is narrower than the passband of multimode resonator, but it is wider than the passband of the first HPF by more than 500 MHz. The decline of its amplitude-frequency characteristic, on the contrary, is lower – power pass at the level of -30 dB goes on at the frequency f_{-30} = 2.6 GHz. The minimum power loss at the frequencies of second HPF passband is L_{min} = 0.6 dB.

In this case, calculations also included substrate with dielectric permittivity ε = 80 and thickness *h* = 1 mm, similarly, dimensions of strip conductors, as well as their segments: (*2*) – 1.12×0.13 mm^2, (*3*) – 3.10×0.30 mm^2, (*4*) – 1.55×1.43 mm^2, (*5*) – 0.64×0.04 mm^2, (*6*) – 0.07×0.05 mm^2, (*7*) – 0.95×0.05 mm^2. The distance between segments (*2*) and (*4*) is 1.03 mm. The gaps between segments of adjacent strip conductors (*7*) and (*7*) are 0.02 mm.

IV. Conclusion

Consequently, constructions of high-pass filters based on new multimode resonator are investigated. The proposed high-pass filters are implemented with the use of various types of microstrip resonators – five-mode and quarter-wave single-mode, as well as single-type – a pair of five-mode ones. Filters have high frequency-selective properties, and in particular have steep slope of AFC due to the presence of attenuation pole near the cutoff frequency on the amplitude-frequency characteristic of each microwave construction.

At the same time, the construction with last quarter-wave resonators has a steeper slope of amplitude-frequency characteristic, while the constructions based on five-mode resonators have wider passband.

Availability of the proposed constructions is determined not only by their high frequency-selective properties, but by the possibility of increasing the number of resonators in filters, if there is a necessity to increase the steepness of its slope.

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