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A Method of Stopband Widening in BPF Based on Two-Conductor Suspended-Substrate Resonators

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Abstract—A method aiming to widen the upper stopband in a microwave bandpass filter based on two-conductor suspended-substrate stripline resonators is described in this letter. Applicability of the method is illustrated by simulating and fabricating fourth-order filter that has a very wide upper stopband: $\Delta f_{\text{stop}}/f_0 = 7.92$ measured at a level $-50\,\text{dB}$, which is achieved because the widths of the inner resonators in the structure are 1.4 times greater than that of the outer ones.

1. INTRODUCTION

Resonator-based bandpass filters have spurious passbands originated from resonances of higher modes. These passbands limit the width of the upper stopband or weaken rejection in the latter. Microstrip bandpass filters (MBF) are widely used in various radio-systems. In order for MBF to be used as a preselector or harmonic filter, one has to expand its stopband. Several methods of stopband widening are suggested in literature. One of them is using stepped-impedance quarter-wavelength resonators [1]. In this method, frequency of the second mode moves away from the fundamental one due to the stepped impedance, and as a consequence, the stopband expands $(3\dots4) \times f_0$ (f_0 is a center frequency of the passband), and wide stopband with about 40 dB suppression may be achieved using this way.

Another approach is based on the usage of a filter structure rejecting spurs tuned at frequencies of spurious bands [2]. The approach allows widening a stopband up to $9.5f_0$ with 20 dB suppression.

In the next method, a filter structure consists of dissimilar resonators [3], whose fundamental frequencies are the same, but frequencies of the higher modes having equal numbers are different. In this case, $8.5f_0$ wide stopband is achieved, but at a level $-30\,\text{dB}$. Note, in all referred cases, the resonators are stepped-impedance. Unfortunately, such filters have some disadvantages. Firstly, any discontinuity of a resonator causes decrease in its Q_0-factor and, as a consequence, increases insertion loss of the filter. Besides, in the two last cases, the structure of a filter loses its symmetry, thus making it more complicated in tuning.

In [4], a method is described in which additional resonators placed in the vicinity of the filter's strip lines and tuned at frequencies of spurious bands play the role of the rejecters. The result appeared poorer than the previous ones. However, in this letter, the filter's resonators are half-wavelength, therefore it has two times more spurious bands.

At last, we mention a method based on coincidence frequencies of spurious bands and transmission zeros generated and properly located due to special configuration of the filter's structure [5]. Obviously, this method is rather complicated.

In the present work, we propose a method to widen the stopband of a filter based on suspended-substrate two-conductor resonators, which differ from the microstrip ones by higher Q_0-factor, less

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substrate area and larger ratio f_2/f_1, where f_1 is a frequency of the 1st (fundamental) mode and f_2 is that of the 2nd one. It means that filters having such a configuration have less insertion loss, are more diminutive and have better selectivity than microstrip ones designed for the same centre frequency.

2. TWO-CONDUCTOR RESONATOR ON SUSPENDED SUBSTRATE AND BANDPASS FILTER ON ITS BASE

A suspended substrate two-conductor resonator and a filter on its base were proposed in 2004 [6], and some details are described in [7, 8]. Such a resonator consists of a dielectric substrate suspended in metallic case; two strip conductors are placed on the substrate's faces: one on the upper face and the other on the bottom face. Each conductor is grounded by its one end at the opposite walls of the case. The resonator possesses a number of notable properties [7] that allow designing filters to have better performance than the microstrip ones. First, it has higher Q_0-factor, which grows when substrate becomes thinner. Secondly, f_2/f_1 ratio is higher too, and its dependence on the substrate thickness is the same. Besides, it occupies less area of the substrate. The f_2/f_1 ratio enlarges with increasing width of resonator's strip conductor. Additionally, this ratio enlarges to some extent when strip conductor overlapping decreases. The last two circumstances are the key moments in the wide-stopband filter design.

3. METHOD OF SUPPRESSING THE SECOND SPURIOUS BAND

Figure 1 shows the resonance curves obtained through a simulation for a set of two-conductor resonators. The resonators have different widths of strip conductors forming them: 2.0, 2.4, 2.8, 3.2 and 3.6 mm. The lengths l_r, equivalent to 9.5 mm, are the same and equal to the distance between the opposite walls to which resonator's strip conductors are connected. Suspended substrate of $\varepsilon_r = 80$ has 0.45 mm thickness. All resonators are tuned to the same fundamental frequency of 500 MHz by properly adjusting the lengths of strip conductors forming the resonators. Obviously, strip conductors overlapping decreases with their width increase. The distance between the substrate and the upper and the bottom covers of the metallic case is 3.0 mm.

As seen from the figure, while fundamental mode remains unchanged, the 2nd one shifts to higher frequencies. It means that a filter designed using this effect will have the magnitude of the second

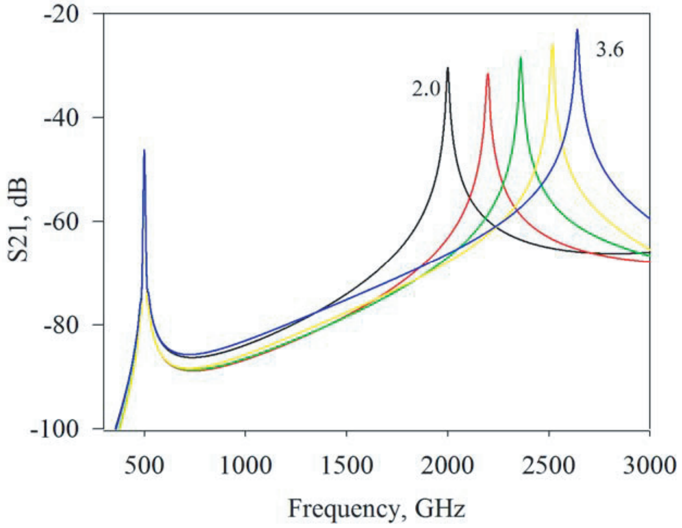

Figure 1. A set of responses simulated for the suspended-substrate two-conductor resonators tuned to the same fundamental frequency 500 MHz and differing by their conductors' width w: Black — $w = 2.0$ mm, red $w = 2.4$ mm, green — 2.8 mm, cyan — 3.2 mm and blue — 3.6 mm.

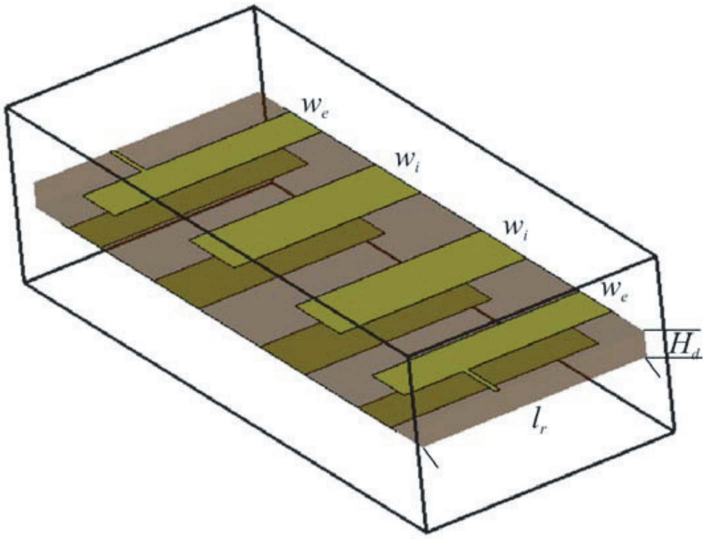

Figure 2. Structure of the filter.

(spurious) passband suppressed. To verify this assumption, we simulated and fabricated a 4-pole filter. Structure of the filter is shown in Fig. 2. In Fig. 3, frequency responses obtained by simulation for four 4-pole filters are shown. All filters have identical central frequency of 500 MHz and bandwidth of 50 MHz. Their structural parameters are as follows: substrate thickness $H_d = 0.45$ mm; dielectric constant $\varepsilon = 80$; resonators' lengths are equal to substrate width 9.5 mm; strip conductors forming the outer resonators have a length 8.4 mm and width 2.0 mm; space between the inner resonators is 3.8 mm, and between the inner and outer ones −3.3 mm. The tapping points are located on the strip conductors of the outer resonators at a 5.8 mm distance from their grounded ends. The filters differ by their widths and lengths of conductors forming inner resonators, and correspondingly by the substrates' length. The first filter has 2.0 mm conductor width of the inner resonators and 22.4 mm substrate length. The second one has 2.4 mm conductor width of the inner resonators and 23.2 mm substrate length. The third one has 2.8 mm conductor width of the inner resonators and 24.0 mm substrate length. And the fourth one has 3.2 mm conductor width of the inner resonators and 24.8 mm substrate length. In all the cases, distance between the substrate surfaces and upper and bottom covers is 3.0 mm.

Concerning the chosen values: central frequency of 500 MHz and bandwidth of 50 MHz are taken for concreteness, and these values are not attached to any task. Strip conductors' length, spaces between the resonators, substrate dimensions and tapping points were obtained as a result of optimization. Other parameters were unchangeable in the optimisation process and were determined with a help of an experience obtained in studying eigen properties of the resonator. E.g., the widths of inner resonators are taken from the results represented in Fig. 1.

It is seen from Fig. 3 that spurious bands formed by resonances of the second modes are located at frequencies 2–2.3 GHz. The first response has −30 dB peak, which deteriorates filter stopband performance. In the second response, spurious band splits because the second modes in the inner resonators shift to a higher frequency, and the peak magnitude drops to −60 dB. In the third response, it decreases more by the same reason down to −70 dB. Thus, we see that the assumption made in Section 3 is valid: using the proposed method, the stopband of a filter based on two-conductor resonators may be widened two times or more along with very high suppression in it.

Investigation carried out with a help of simulation has shown that further increase in inner resonators' width (3.2 mm) leads to raising the right-hand peak magnitude even if it moves far along the frequency axes. In order to spread the stopband more, one has to increase the width of the outer resonators and proportionally increase the width of the inner resonators too.

For the simulations we used well-known package AWR *Design Environment*. The designing method and algorithm that we used have been described in several papers, e.g., [9].

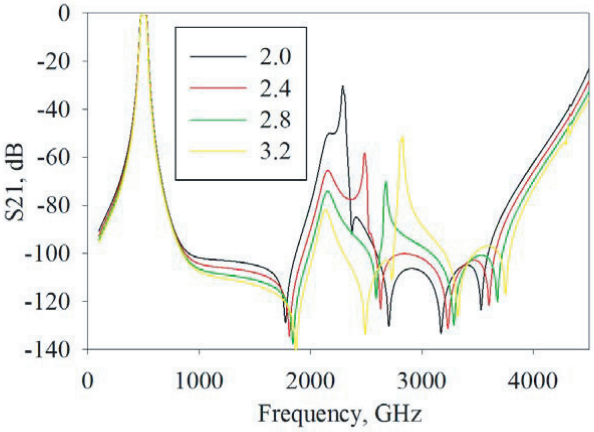

Figure 3. Simulated frequency responses for suspended-substrate filter having the same central frequency of 500 MHz and different inner resonators conductors' width.

4. EXPERIMENT AND DISCUSSION

In order to verify results of simulation, a suspended substrate filter based on two-conductor resonator was fabricated. The project having 2.8 mm width of the inner resonator was chosen, because it has the best stopband performance. The lengths of the resonators' strip conductors in a pair of inner resonators are 7.5 mm.

In Fig. 4, a photograph of the fabricated filter is shown, and its frequency responses of insertion and reflection loss measured in a range of the passband are also shown.

Mixed (Ba, Nb, Sr-titanates) ceramics were used as a material for substrates, $\varepsilon = 80$ and $\mathrm{tg}\delta = 0.0003$. Strip conductors of the experimental filter were fabricated by photolithography and chemical etching of cooper plated substrate. The filter's case was fabricated from brass.

In Fig. 5, frequency response measured in a wide band is represented. Stopband performance of the

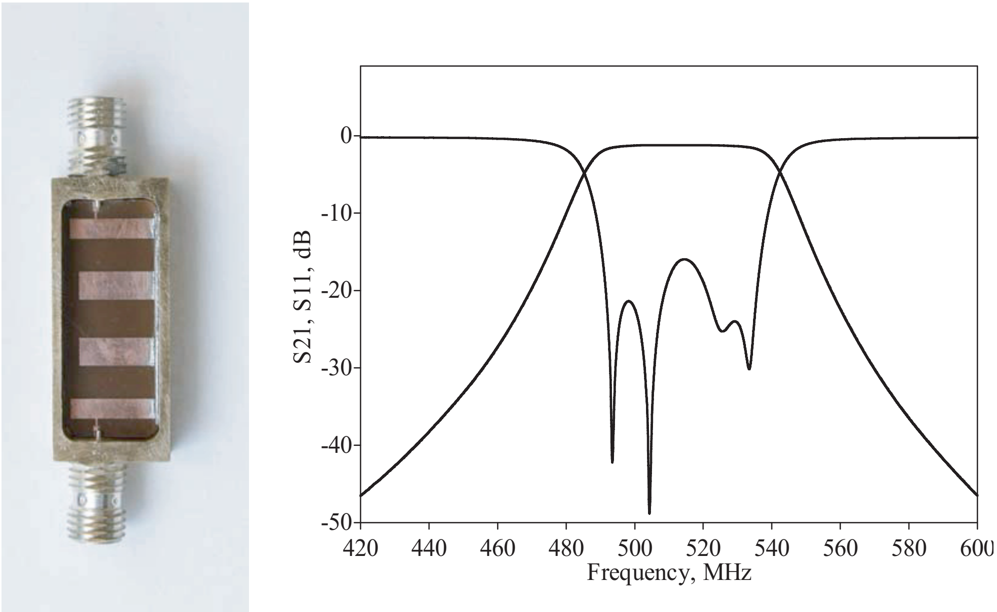

Figure 4. Photograph of the filter prototype without the cover and its frequency responses measured in a range of the passband.

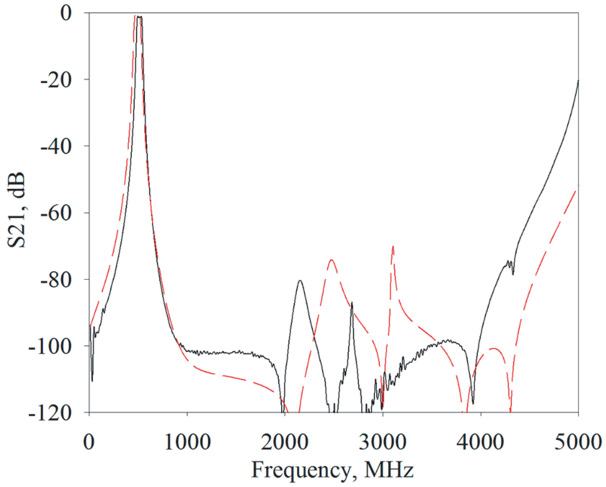

Figure 5. Comparison of frequency responses of designed (black) and fabricated (red) filters in a wide band.

experimental filter appears better than the simulated one: it is wider, and magnitude of the spurious band located in the stopband is 80 dB, i.e., 10 dB less than that of the simulated one.

For the convenience of comparison, the main parameters of simulated and experimental responses are summarized in Table 1. The bandwidth is determined at a level -3 dB, and stopband width is determined at a level -50 dB. A quite good agreement is observed.

Table 1. Summary of simulated and measured filter responses.

	f_0, MHz	Δf, MHz	L_0, dB	$\Delta f/f_0$, %	Δf_{stop}, GHz	$\Delta f_{\text{stop}}/f_0$
sim.	502	56	0.75	11.2	3.68	7.34
Exp.	514	55.6	1.2	10.8	4.07	7.92

Design of the filter allows further development of the stopband performance, because the ratio f_2/f_1 increases when substrate's thickness decreases [8]. It means that the thinner the substrate is, the wider the stopband is. Besides, the investigation carried out with the help of simulations shows that if one proportionally widens strip conductors of the resonators, the stopband becomes wider. For example, a filter fabricated on the same substrate and having widths 3.8 mm and 5.8 mm respectively for the outer and inner resonators will have the ratio $\Delta f_{\text{stop}}/f_0 = 8.84$, but its size will be 22% larger.

It should be noted that the basic idea of our method is similar to that of [3]. However, in our case a filter structure is symmetrical in contrast to the filter described in the cited paper. Filters having symmetrical structure are easier to design than asymmetrical ones. Also it should be noted that a similar strip conductors structure was used in [10], but for designing a filter using LTCC technology.

The sizes of the fabricated filter without coaxial connectors are $0.048\lambda_0 \times 0.020\lambda_0 \times 0.013\lambda_0$, i.e., very small.

5. CONCLUSION

A wide stopband bandpass filter implemented using suspended-substrate two-conductor resonator technology is proposed in this letter. The behavior of the second mode as a function of the resonators' width is investigated and applied. The proposed filter possesses several advantages including compactness, high performance and convenient design. It should be a competitive candidate for the development of RF or microwave circuits and systems.

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