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Multi-mode resonator for ultra-wide bandpass filter with good stopband performance

I V Podshivalov[1], M O Savishnikov[2], A A Leksikov[1], D D Dmitriev[3] and I N Kartsan[4]

[1]   Kirensky Institute of Physics SB RAS, Krasnoyarsk, Russia
[2]   Institute of Engineering Physics and Radio Electronics, Siberian Federal University, Krasnoyarsk, 660041, Russia
[3]   Scientific and Educational Laboratory "Systems of Navigation, Control and Communication", Siberian Federal University, Krasnoyarsk, 660041, Russia
[4] Reshetnev Siberian State University of Science and Technology, 31, Krasnoyarsky Rabochy Av., Krasnoyarsk, 660037, Russia

E-mail: a.a.leksikov@gmail.com

Abstract. A multimode resonator is proposed, containing five resonant modes that are incorporated in the passband forming. The structure is based on a dielectric substrate suspended in a metallic case that allows solving problem of electromagnetic compatibility. Due to features of the resonator's structure, several higher modes do not excite that significantly improve the performance of the filter's stopband. The resonator advantages are proved on the ultra-wide bandpass filter (101%) with small overall size ($0.11\lambda_0 \times 0.06\lambda_0 \times 0.03\lambda_0$) and good stopband performance (first spurious band locates at 8 GHz, suppression is 80 dB).

1. Introduction

The unlicensed use of ultra-wideband (UWB) devices, which was authorized in 2002 by the U.S. Federal Communications Commission, gave an impetus in the designing a new generation of ultra-wide bandpass filters. Despite that in 2005–2007 it were presented more than a thousand constructions of filters, nowadays this topic is still under great attention because of its potential usage in the indoor and outdoor radio systems.

Currently, three main approaches in UWB filters design can be marked:

- incorporation of short-circuited and open-circuited stubs in the filter structure [1, 2, 3];
- cascading high-pass and low-pass filters [4, 5];
- usage of multi-mode resonators (MMR) [6–10].

All recently presented structures can be assigned to one of the approaches or to several ones simultaneously. Simultaneous usage of several approaches allows one to achieve typical for bandpass filters goals: to increase selectivity of a passband, to wider the stopband and to reduce a filter size. For example, in [8] authors propose a filter, which contains MMR along with open stubs and electromagnetic bandgap structure. Such decisions allow authors obtain a limit of the upper stopband higher than 100 GHz at least in a simulation.

In [3] authors achieve very good performance of a filter in terms of stopband for a very small structure $0.24\lambda_0 \times 0.19\lambda_0$ by using open stubs and only one single-stage parallel-coupled line. Another miniaturized design $0.26\lambda_0 \times 0.26\lambda_0$ was presented in [7] were a single 3-mode resonator had been used to design a filter.
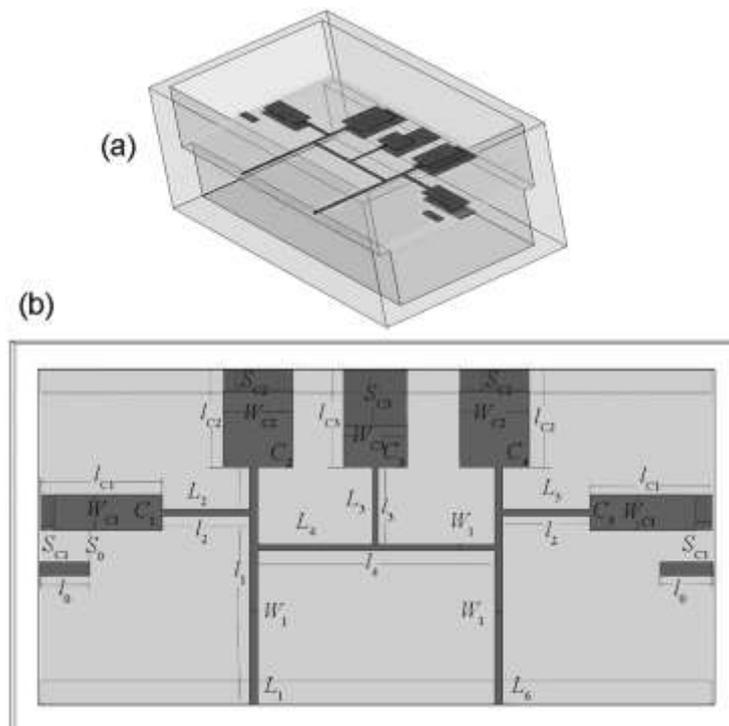

Figure 1. General view (a) and topology of the resonator (b).

At the same time, most of the currently presented filters are not installed in a metallic housing for shielding. In terms of a filter performance, such solution prevents it from an excitation of box resonances, which reduces an upper stopband of a filter. Currently only few filters are proposed having metallic housing and they do not present good out-band performance [8]. On the other hand, an unpackaged filter operates as a receiving antenna causing potential electromagnetic compatibility problems in a system, where a filter is installed, even for a poor matching of resonators with open space.

In this letter, we present 5-mode quasi-lumped resonator, which allow designing and fabricating a bandpass filter in a shielding housing for wideband and ultra-wideband applications. The proposed resonator allows one to design bandpass filter with a value of fractional bandwidth (FBW) in wide limits (from 20% to more than 100%). Moreover, the value can be changed twice only by tuning one parameter of the resonator. A bandpass filter with fractional bandwidth 101% was designed and fabricated having an internal size $31.5 \times 17.5 \times 9.5$ mm ($0.11\lambda_0 \times 0.06\lambda_0 \times 0.03\lambda_0$) that is smaller the most of recently presented filters.

2. Resonator's theory

Previously it was presented a half-wavelength MMR [9], which is sufficiently flexible: in particularly, it allows realizing filters with a wide range of bandwidths, and various numbers of modes can be incorporated in bandwidth shaping, also it is easy in post-fabrication tuning. However, it has strong limitation in a stopband performance, especially, in the case when it is installed inside a metallic case. Otherwise, as it has been already mentioned, an electromagnetic compatibility problem may appear when such filter is incorporated in a radio system. Based on the abovementioned resonator a new MMR is proposed that has much better out-band performance, is significantly miniaturized, and

electromagnetic compatibility problem is solved as the resonator and filter are designed in the metallic housing. Figure 1 (a) and 1 (b) illustrate the structure of the proposed resonator. It contains a dielectric substrate suspended in the metallic case; a topology of the conductors is made on the both sides of the substrate. In figure1 (b) the topology is presented; it consists of five quasi-lumped capacitors ($C_1…C_5$) and six stripline segments ($L_1…L_6$) where segments L_1 and L_6 are grounded. The capacitors C_1 and C_5 are connected to the segments L_1 and L_6 through the segments L_2 and L_5, respectively. The position where the segments L_2 and L_3 are connected to segment the L_1 depends on resonator configuration, and, in some cases, the segments L_2, L_4 and L_5 can arrange a straight line. The resonator has mirror symmetry, so the segment L_3 divides the segment L_4 into two equal parts. The structure is connected to the feed lines in the position of capacitors C_1 and C_5, or segments L_2 and L_5, depending on the required coupling strength with feedlines. In the case of an ultra-wideband filter, only conductive connection can be used, while for resonator properties investigation the capacitive coupling of feedlines to capacitors C_1 and C_5 is more suitable.
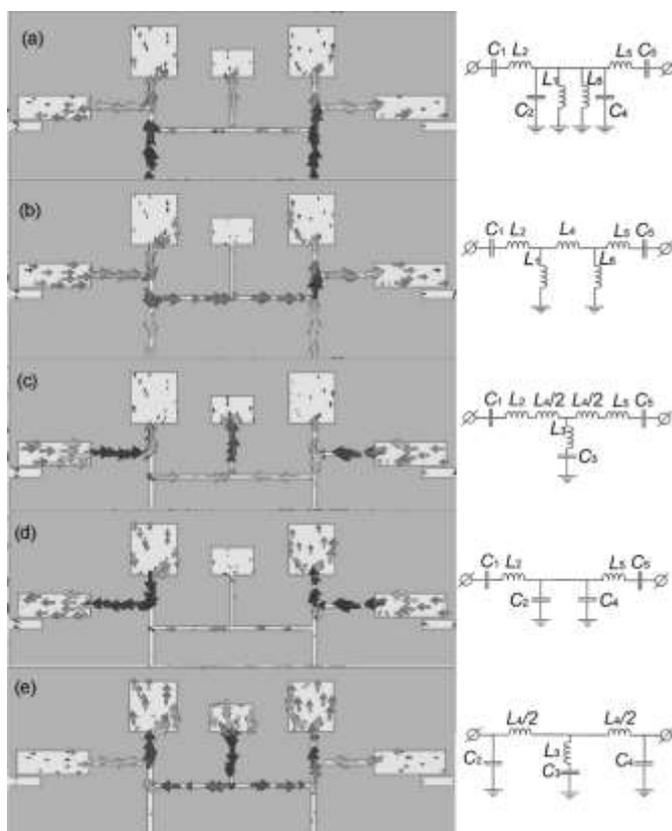

Figure 2. Microwave current distributions for 1st (a), 2nd (b), 3rd (c), 4th (d) and 5th (e) modes of the resonator and their equivalent circuits.

An investigation was performed to obtain current configuration of exited modes. Such information allows one designing bandpass filter with desirable configuration. In figure2 (a) – figure2 (e) all five modes are presented with corresponding equivalent circuits in the insets.

From figure 2 (a) one can see that at a frequency of the lowest oscillation mode the capacitors C_1, C_2, C_4 and C_5 have the same sign of electric charges resulting in the exciting of microwave current in the segments L_1, L_2 and symmetrically L_6, L_5, and only the capacitor C_3 is not incorporated in the mode excitation. This fact is depicted from the equivalent circuit for the mode.

At a frequency of the second mode (figure 2 (b)) the capacitors C_1, C_2 and C_4, C_5 have the opposite sign of electric charges. This leads to exciting the microwave current in the segments L_2, L_4 and L_5, and, in fact, it belongs to a half-wavelength resonance along the structure. At the same time, in the segments L_1 and L_6 small amount of microwave currents are still flowing in these segments, however, the directions of the currents are opposite to each other.

The capacitors C_1, C_3 and symmetrically C_5, C_3 are incorporated in the excitation of the third mode (figure 2 (c)). When the fourth (figure2 (d)) and fifth (figure2 (e)) modes excite, then charges localize in the capacitors C_1, C_2 and C_2, C_3, correspondingly, and the currents flow in the stripline segments connecting them.
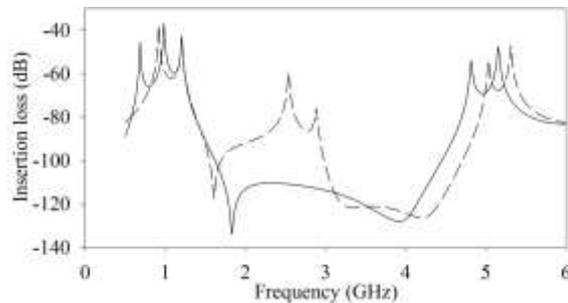

Figure 3. Comparison of frequency response of the structure with grounded segments L_1 and L_6 (solid line) and ungrounded (dash line). Capacitors C_2 and C_4 are removed in current configuration.
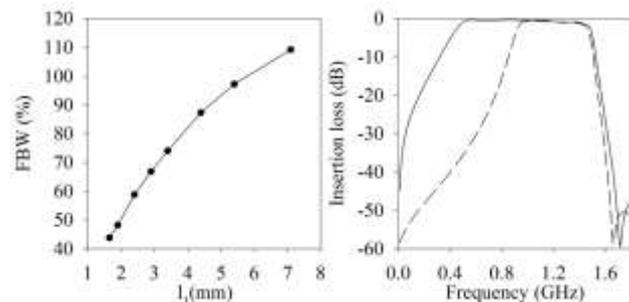

Figure 4. Dependence of FBW of the bandpass filter on segments length l_1 and frequency response of the filters for the extreme values of the l_1.

One can see the 1st mode is the only $\lambda/4$, and four other ones are $\lambda/2$, so it can be expected that higher-order modes of the same origin will excite and worsen a filter stopband performance. However, due to the segments L_1 and L_6 are grounded and connected to the points of the electric field antinode of these modes, they do not excite. The fact is proved in figure 3 where the responses are shown for the cases when the segments L_1 and L_6 are connected to (solid line) and disconnected (dashed line) to the ground. This feature of the resonator is one of the most important difference from the resonator presented earlier [9] that allows improving stopband performance of a UWB filter.

In addition, the resonator is a suspended stripline structure that is usually smaller then a microstrip structure for the same frequency range.

Next, the stripline segments L_1 and L_6, as it can be seen from the figures are mainly incorporated in the excitation of the 1st mode. At the same time, the capacitors C_1 and C_5 are incorporated in the excitation of the four first modes. Such configuration of the multi-mode resonator makes it very flexible and easy for tuning. Particularly, the resonator is suitable to design a bandpass filter with FBW in the range from at least 20% to more than 120%. Moreover, the width can be changed twice only by variation in the segments L_1 and L_6 length. A simulation was performed in CST Studio suite, were all the resonator parameters, except the length of L_1 and L_6, were fixed. A 0.25-mm substrate with dielectric constant $\varepsilon = 80$ and overall size 14.4×8.9 mm was suspended 3.5 mm from top and bottom covers of brass case. The maximum width value was found to be 110% at the segment's length l1 = 7.1 mm. Further increase of the bandwidth may be obtained only by narrowing the width of all segments in the structure; otherwise, the filter could not be properly matched. For the shortest segments (l1 = 1.65 mm) the corresponding bandwidth was found to be 43.8% only. In figure 4 (a) the dependencies of FBW on the segments length (l1) is represented, while in figure4 (b) the frequency responses of the filter are presented for the extreme values of l1.

As the capacitors C_1 and C_5 are incorporated in excitation 4 of 5 modes, the central frequency of the filter can be easily tuned only by changing of their capacitance.

Such design features and clearance of modes configuration allow one to design bandpass filter with required electrical characteristics.

3. UWB bandpass filter
A bandpass filter was designed and fabricated with a central frequency 1 GHz and fractional bandwidth 101% to prove the performance capability of the resonator. A 0.5-mm alumina substrate with lateral size 31.5×17.5 mm was suspended 4.5 mm from top and bottom covers of brass case. The

resonator parameters in millimeters were as follows: $W_1 = 0.375$, $l_1 = 8.75$, $l_2 = 5.0$, $l_3 = 1.1$, $l_4 = 10.0$, $l_0 = 1.0$, $S_0 = 3.25$, $W_{C1} = 4.375$, $W_{C2} = 4.63$, $W_{C3} = 4.5$, $l_{C1} = 4.875$, $l_{C2} = 6.25$, $l_{C3} = 6.25$, $S_{C1} = 1.0$, $S_{C2} = 1.4$, $S_{C3} = 1.225$ The fabricated filter is presented in figure 5.

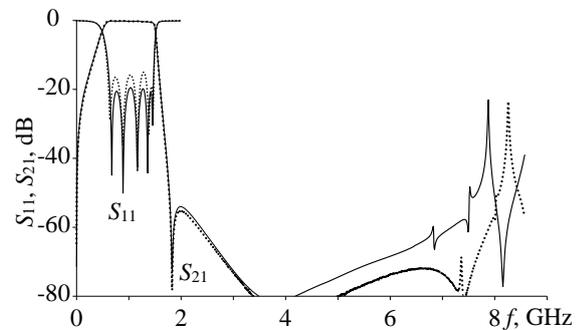
Figure 5. The fabricated filter.

Figure 6. Frequency responses of the simulated (solid line) and fabricated (dash line) filter.

The comparison of the frequency responses of the simulated and fabricated filters are presented in figure 6. One can see very good agreement between simulation and experiment. The minimum in-band loss is only 0.15 dB. The upper stopband is limited to 8 GHz at the level –55 dB, with overall suppression level around 80 dB.

Currently the only filter is known, which has smaller size [10]; however, it has significantly worse stopband performance, which suppression is at a level 25 dB

4. Summary
A novel multimode resonator is proposed, containing five resonant modes that are incorporated in the passband forming. The structure is based on a dielectric substrate suspended in a metallic case that allows solving problem of electromagnetic compatibility. Four of the modes are $\lambda/2$ and one is $\lambda/4$. Due to features of the resonator's structure, several higher modes do not excite that significantly improves the performance of the filter's stopband. The resonator structure allows designing bandpass filter with a wide bandwidth range (20–120%) and is flexible and easy in tune during the design procedure. The performance capabilities were proved on UWB filter (101%) with small overall size and good stopband performance (first spurious band at 8 GHz, suppression 80 dB).

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