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RESEARCH ARTICLE

Quasi-lumped multimode stripline resonator and filter with good stopband performance

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Abstract

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 the problem of electromagnetic compatibility. 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 advantages are proved on the bandpass filter (3.1…10.6 GHz) with a small overall size ($0.19\lambda_0 \times 0.11\lambda_0 \times 0.11\lambda_0$) and a good stopband performance (first spurious band locates at 29 GHz and suppression is 70 dB).

KEYWORDS

bandpass filter, multimode resonator, quasi-lumped resonator, stripline resonator, wide stopband

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 designing a new generation of ultra-wide bandpass filters. Despite that in 2005-2007, it was presented more than 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: (a) incorporation of short-circuited and open-circuited stubs in the filter structure[1-3]; (b) cascading high-pass and low-pass filters[4,5]; and (c) usage of multimode resonators (MMR).[6] 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 bandpass filter goals: to increase selectivity of a passband, to widen the stopband, and to reduce a filter size. For example, in Ref. 8, authors propose a filter, which contains MMR along with open stubs and electromagnetic bandgap structure. Such decisions allow authors to obtain a limit of the upper stopband higher than 100 GHz at least in a simulation.

In Ref. 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 Ref. 7 where a single three-mode resonator had been used to design a filter.

At the same time, most of the currently presented filters are not installed in a metallic housing for shielding. In terms of filter performance, such a solution prevents it from an excitation of box resonances, which reduces an upper stopband of a filter. Currently, only a 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 a five-mode quasi-lumped resonator, which allows designing and fabricating a bandpass filter in a shielding housing for wideband and UWB applications. The proposed resonator allows one to design a bandpass filter with a value of fractional bandwidth 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 for well-known UWB range (3.1–10.6 GHz) was designed and fabricated having an internal size $7.5 \times 4.2 \times 4.25$ mm^3 $(0.19\lambda_0 \times 0.11\lambda_0 \times 0.11\lambda_0)$ that is smaller than most of the recently presented filters.

2 | RESONATOR'S THEORY

Previously it was presented a half-wavelength MMR,[9] which is sufficiently flexible: in particular, 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 a 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 a filter is incorporated in a radio system. Based on the above-mentioned resonator, a new MMR is proposed, which allows us to design a bandpass filter 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 1A,B illustrates the structure of the proposed resonator. It contains a dielectric substrate suspended in the metallic case; topology of the conductors is made on both sides of the substrate. In Figure 1B, the topology is presented; it has mirror symmetry and consists of five quasi-lumped capacitors and stripline segments (inductor) they connecting. The capacitors C_1 are connected to the segments L_0 through the segments L_1. Segments L_0 are connected to the ground. The position where the segments L_1 and L_2 are connected to the segment L_0 depends on resonator and filter configuration, and, in some cases, both segments L_1 and L_4 can arrange in a straight line. The structure is connected to the feed lines in the position of capacitors C_1, or segments L_1, depending on the required coupling strength with feedlines. In the case of an UWB filter, only conductive connection can be used, while for resonator properties investigation, the capacitive coupling of feedlines to capacitors C_1 is more suitable.

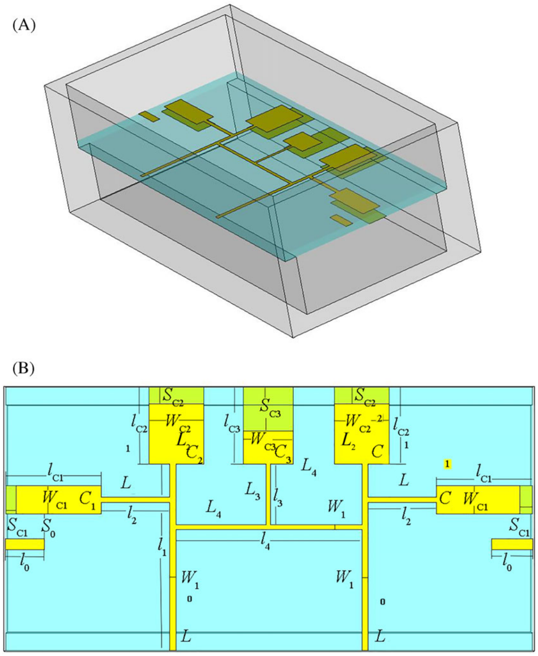

FIGURE 1 General view (A) and topology of the resonator (B). Substrate—blue, upper metal layer—yellow, lower metal layer—green [Color figure can be viewed at wileyonlinelibrary.com]

An investigation was performed to obtain the current configuration of excited modes. Such information allows one to design bandpass filter with a desirable configuration. In Figure 2A–E, all five modes are presented with corresponding equivalent circuits in the insets.

The origin of the two lowest modes can be explained in terms of odd-mode and even-mode configuration. From Figure 2A one can see that at a frequency of the lowest oscillation mode all the capacitors have the same sign of electric charges on the plates resulting in the exciting of microwave current flowing to the ground points (segments L_0) or back. This fact is depicted from the equivalent circuit for the mode.

At a frequency of the second mode (Figure 2B) the capacitors C_1 and C_2 have the opposite sign of electric charges, while capacitor C_3 is zero charged. This leads to exciting the microwave current flowing from one part of the structure to the opposite part, and, in fact, it is corresponding to the odd mode in the resonator and a half-wavelength resonance along the structure.

Three higher oscillation modes (Figure 2C–E) are localized only in capacitors and strip lines connecting them. Therefore, for the third oscillation mode, all the internal capacitors are charged identically; for the fourth one—capacitor C_3 is zero charged, while capacitors C_2 have opposite charge signs; for fifth oscillation mode capacitors, C_2 have opposite charge sign to the C_1 and C_3 capacitors. This distribution of capacitor charges determines the direction of microwave currents flowing in the segments of the transmission lines.

For UWB filters, a problem exists to obtain a wide and deep high-frequency stopband since spurious resonances are excited rather close to the passband of the structure.[9] In the case of the presented resonator, rarefaction of the spectrum of eigenfrequencies is achieved in two ways. First of all, in the presented quasi-lumped construction of the resonator a great step exists in the width between high impedance part (inductor) and low impedance part (capacitor) brining to the repulsion of the spurious modes, for example, for the first mode the closest spurious resonance is shifted to $4.3f_1$ (where f_1 is frequency of the first mode). Next, capacitors C_1 and inductors L_1 are involved in generation of all five modes and by proper choosing feed points, particularly, connection in the point of antinode at the frequency of the first spurious resonance, the resonance can be suppressed for all the

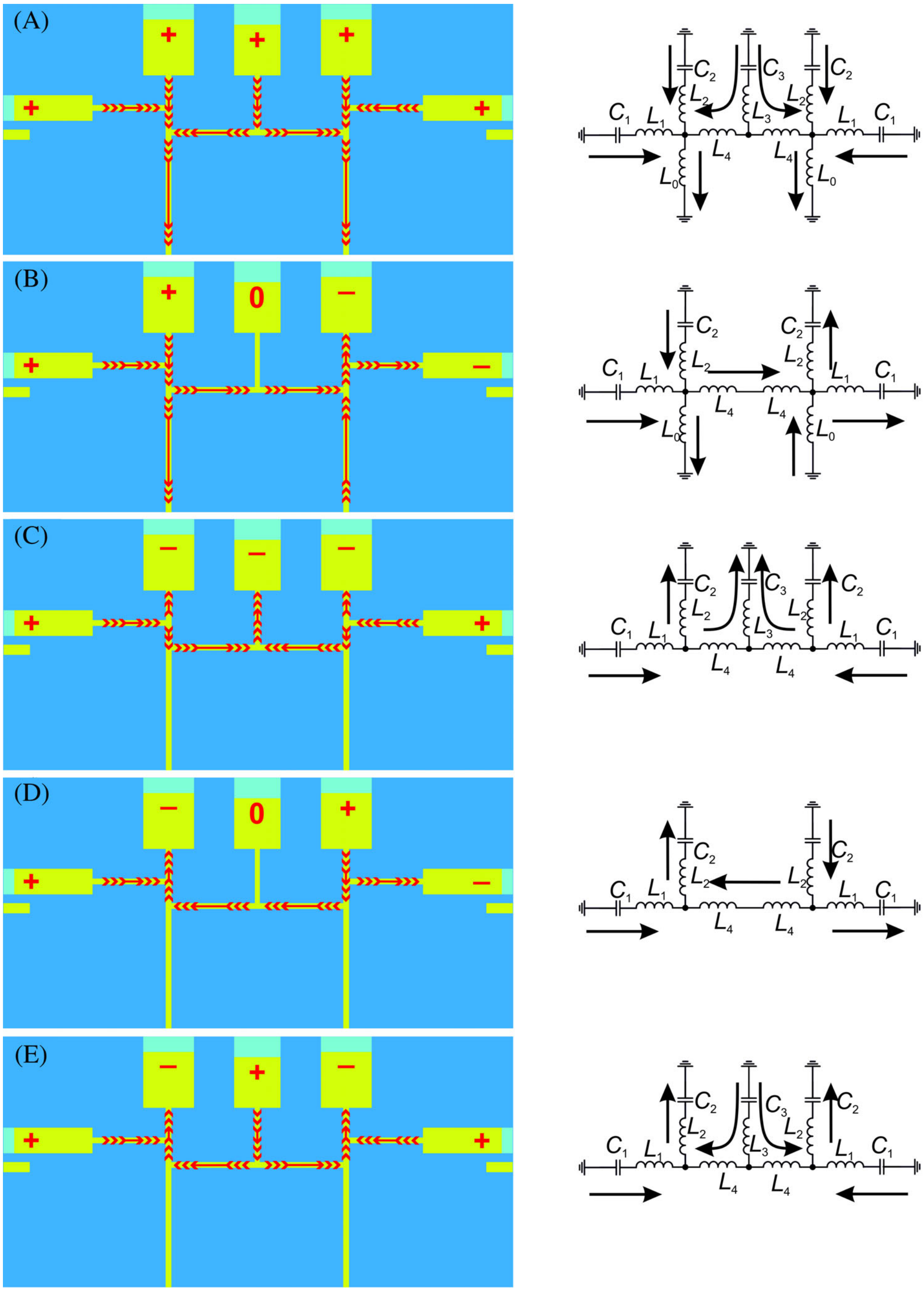

FIGURE 2 Microwave current distributions for first (A), second (B), third (C), fourth (D), and fifth (E) modes of the resonator and their equivalent circuits [Color figure can be viewed at wileyonlinelibrary.com]

modes, bringing to a broadening of a stopband. These facts are illustrated in Figure 3 for the part of the resonator consisting segments L_0, L_1, and capacitor C_1 presented in the inset. One can see that by changing the position of feedlines the first spurious resonance can be suppressed. In addition, some of the spurious modes are suppressed because of resonator construction. For example, the first spurious resonance of the second mode is suppressed in the presence of capacitance C_3.

As can be seen from Figure 2, the stripline segments L_0 are only incorporated in the excitation of the first and second modes. These two modes are much less interacting with other modes than the other three modes in the structure that are strongly coupled. A simulation was performed in the CST Studio suite to investigate how the length (l_1) of segments L_0 will influence the frequency of all five modes. It was chosen 0.25-mm substrate with dielectric constant $\varepsilon = 9.8$ suspended 3.5 mm from top and bottom covers of the brass case. The coupling with feedlines was chosen in such a way that all the modes had a weak coupling with external lines. The parameters of the resonator were chosen close to the one that was further used to design a bandpass filter for the unlicensed band (3.1-10.6 GHz). During the simulation, all the parameters of the resonator, except l_1, were fixed. The result of the simulation is presented in Figure 4A. It was found that with a change of l_1 value from 6.25 to 1.35 mm it was observed 86% shift of the frequency of the first oscillation mode, 23% shift of the second oscillation mode, and only 2% shift of the third and fourth oscillation modes. Such a design feature allows one an easy redesign of a bandwidth of a filter based on the proposed resonator by changing the length l_1 and the position of feed point. In the best case, it was found that only by a change of these parameters the bandwidth can be regulated in the range 44-110% for a bandpass filter designed on dielectric substrate with a higher dielectric constant. Further narrowing or widening of the bandwidth may be obtained only by changing the width of all the inductive segments in the structure. In Figure 4B the frequency responses of the filter are presented for the extreme values of l_1.

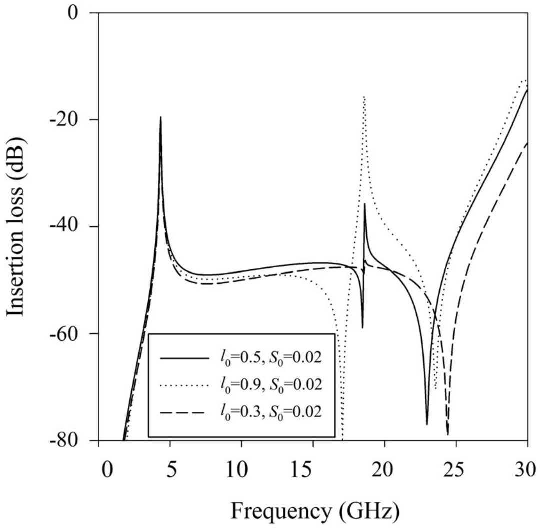

FIGURE 3 Frequency response of first oscillation mode for different tapping points

Such design features and clearness of modes configuration allow one to design a bandpass filter with required electrical characteristics. For example, the lower limit of the

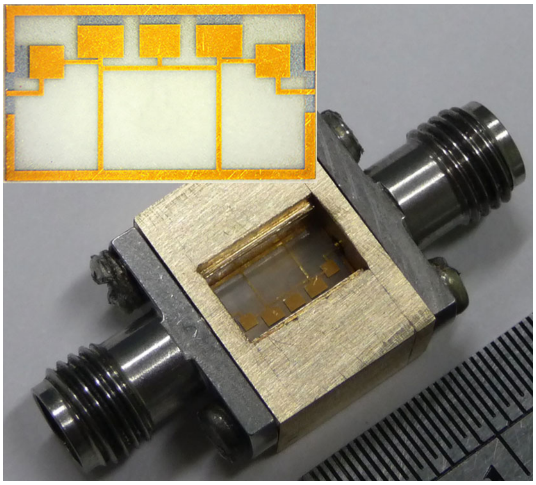

FIGURE 5 The fabricated filter and its topology in the inset [Color figure can be viewed at wileyonlinelibrary.com]

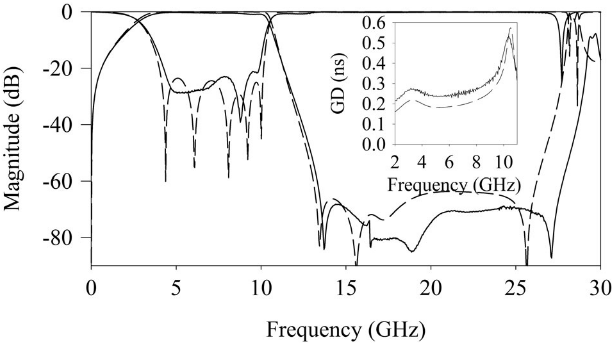

FIGURE 6 Frequency responses of the simulated (dash line) and fabricated (solid line) filter and group delay response in the inset

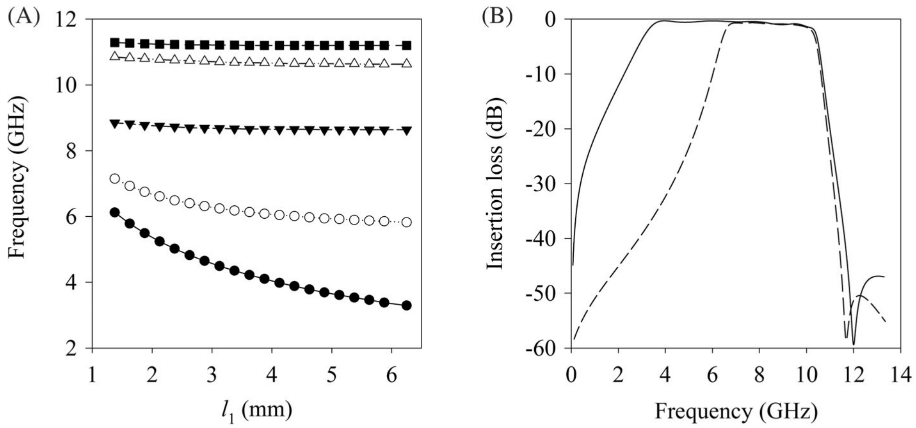

FIGURE 4 Dependence of mode's frequency (first mode—black dots, second mode—white dots, third mode—black triangle, fourth mode—white triangle, fifth mode—black square) vs segments length l_1 (A) and the frequency response of the filters for the extreme values of l_1 with a fixed other parameter of a structure (B)

passband, as it was previously mentioned, is controlled by the value of the parameter l_1, the higher limit of the passband is controlled by means of parameters of the capacitance C_3, particularly, its width W_{C3} and length l_{C3}. A degree of mutual coupling between three higher modes is determined by the value of the parameter l_3, in other words, by the value of the inductances L_2 and L_3. An overall matching level with an external line is determined by the values l_0 and S_0, and for the most of the wideband and UWB filters, a galvanic coupling is required, when the feedlines are connected to the capacitors C_1.

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

3 | UWB BANDPASS FILTER

A bandpass filter was designed and fabricated for frequency range 3.1-10.6 GHz to prove the performance capability of the resonator. A 0.25-mm alumina substrate with lateral size $7.5\times 4.2\ \text{mm}^2$ was suspended 2 mm from top and bottom covers of brass case. The resonator parameters in millimeters were as follows: $W_1 = 0.12$, $l_1 = 2.68$, $l_2 = 0.81$, $l_3 = 0.18$, $l_4 = 2.74$, $l_0 = 0.23$, $S_0 = 0.27$, $W_{C1} = 0.8$, $W_{C2} = 1.13$, $W_{C3} = 1$, $l_{C1} = 0.85$, $l_{C2} = 0.78$, $l_{C3} = 0.8$, $S_{C1} = 0.35$, $S_{C2} = 0.24$, and $S_{C3} = 0.22$. The fabricated filter is presented in Figure 5.

The comparison of the frequency responses of the simulated and fabricated filters is presented in Figure 6. One can see very good agreement between simulation and experiment. The minimum in-band loss is only 0.2 dB, while the maximum is less than 1.5 dB. The upper stopband is limited to 29 GHz at the level −30 dB, with an overall suppression level of around 70 dB.

Currently the only filter is known, which has a smaller size[10]; however, it has significantly worse stopband performance, which extends only to 20 GHz and has suppression level 25 dB.

4 | SUMMARY

A novel MMR 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 the 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 a bandpass filter with a wide bandwidth range (20-120%) and is flexible and easy in tuning during the design procedure. The performance capabilities were proved on the UWB filter (3.1…10.6 GHz) with a small overall size and good stopband performance (first spurious band at 29 GHz, suppression 70 dB).

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