

## DUAL-MODE SPLIT MICROSTRIP RESONATOR FOR COMPACT NARROWBAND BANDPASS FILTERS

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**Abstract**—A straight split dual-mode microstrip resonator is proposed. The frequencies of the two first oscillation modes in the resonator may be brought closer together by adjusting a split parameter whereas the frequency of the third mode remains approximately equal to the doubled average frequency of the first and the second modes. It is shown that formulas derived within 1D model give qualitatively true relations between the resonant frequencies and the structure parameters of the resonator. Examples of narrowband bandpass filters of the fourth and the sixth order are described. Transmission zeros below and above the passband substantially improve the filter's performance. The simulated frequency response of the three-resonator dual-mode filter is compared with the measured response of the fabricated filter.

### 1. INTRODUCTION

Bandpass filters using dual-mode microstrip resonators differ by high selectivity because every dual-mode resonator is equivalent to a pair of coupled single-mode resonators, i.e., the filter order characterizing selectivity is twice more for a dual-mode filter than for a single-mode filter when they have an equal number of resonators. Loop dual-mode microstrip resonators are most popular [1–4]. However, they are bulky because their width is commensurable with the length.

Straight and folded stepped-impedance microstrip resonators are more compact [5]. A compact ultra-wideband bandpass filter using a triple-mode stepped-impedance microstrip resonator is described in [6].

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*Received 21 June 2011, Accepted 12 July 2011, Scheduled 15 August 2011*

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However, the step-impedance mechanism of the resonant frequency convergence alone is not enough to realize a narrowband dual-mode bandpass filter. In this case, the impedance step would be extremely large and not acceptable.

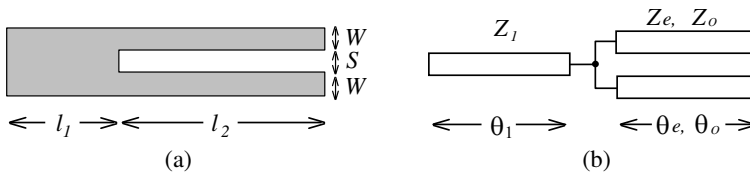
Another mechanism of resonant frequency convergence is proposed in [7,8]. It is inductive coupling between two parallel-coupled microstrip line sections being a component of a dual-mode resonator.

Thus, there is a problem of designing a compact narrowband dual-mode microstrip bandpass filter.

In this paper, we propose a simple dual-mode straight microstrip resonator resembling a single-mode hairpin microstrip resonator. The resonator layout is degenerated case for the layout of a multi-mode loop microstrip resonator whose properties have been superficially reported in [9]. The split microstrip resonator is good for design of compact highly selective narrowband filters. Examples of one-resonator and two-resonator filters are considered. Measured frequency performance of a fabricated three-resonator filter is presented.

## 2. DUAL-MODE RESONATOR

The strip conductor of the dual-mode split microstrip resonator has a form of a narrow rectangular that is partially split by a longitudinal slot at one of its ends. The layout and the equivalent circuit of the resonator are shown in Fig. 1.



**Figure 1.** The layout (a) and the equivalent circuit (b) of the dual-mode split microstrip resonator.

The resonant frequencies of the even oscillation modes are roots of the equation

$$Z_e \tan \theta_1 + 2Z_1 \tan \theta_e = 0 \quad (1)$$

and the resonant frequencies of the odd modes are roots of the equation

$$\cos \theta_o = 0. \quad (2)$$

The currents in the split conductors run in the same direction for even modes and in the opposite directions for odd modes. It is seen from (2) that the frequencies of odd modes do not depend on  $l_1$ .

It follows from (1) and (2) that the ratio  $f_e/f_o$  for the lowest resonant frequencies of the even and the odd modes is correlated with the length ratio  $l_1/l_2$  by the equation

$$Z_e \tan \left( \frac{\pi f_e}{2 f_o} \sqrt{\frac{\varepsilon_1 l_1}{\varepsilon_o l_2}} \right) + 2Z_1 \tan \left( \frac{\pi f_e}{2 f_o} \sqrt{\frac{\varepsilon_e}{\varepsilon_o}} \right) = 0. \quad (3)$$

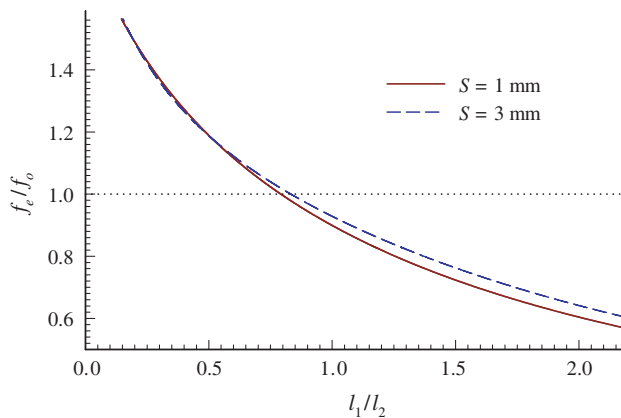
Figure 2 shows the frequency ratio dependence on the length ratio computed for the resonator having the substrate thickness  $h = 1$  mm, strip width  $W = 1$  mm, and dielectric constant  $\varepsilon_r = 9.8$ .

The symmetrical dual-mode resonator is equivalent to the symmetrical pair of coupled single-mode resonators with the coupling coefficient

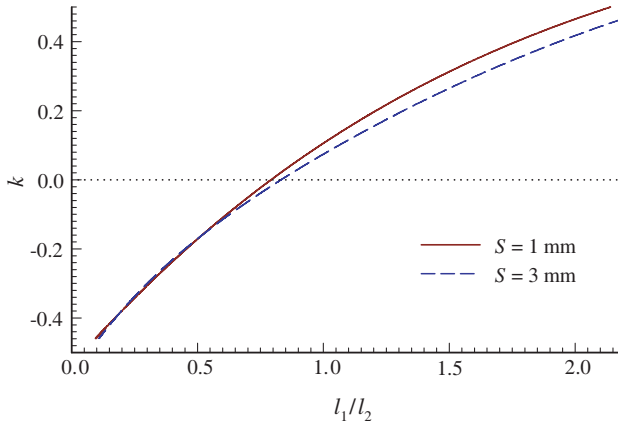
$$k = (f_o^2 - f_e^2)/(f_o^2 + f_e^2). \quad (4)$$

Here the positive value of  $k$  means that the inductive component  $k_L$  in the coupling mechanism prevails over the capacitive component  $k_C$  and vice versa. The inductive component  $k_L(f)$  has a decreasing frequency dispersion while the capacitive component  $k_C(f)$  has an increasing one. In the filter design, the sign of  $k$  does not matter. Only the absolute value of  $k$  is important [10].

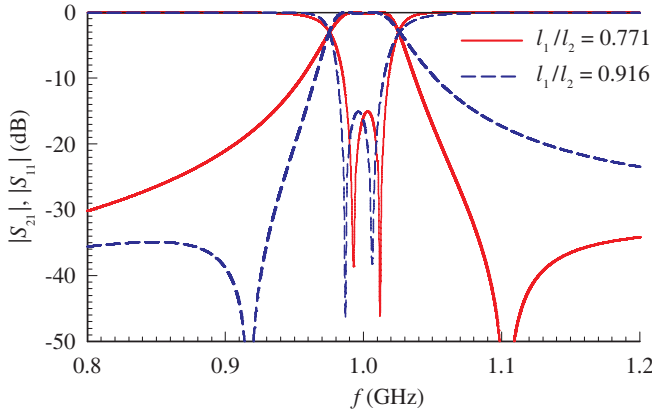
Figure 3 shows the dependence of the coupling coefficient on the length ratio computed for the same resonator parameters that are used for Fig. 2. It is seen that  $k$  is the increasing function of  $l_1/l_2$  and it can be both negative and positive. That means that the filter synthesis problem has two solutions. One solution answers to the negative  $k$  and another solution answers to the positive  $k$ . These two solutions having the same passband will have different stopbands and different transmission zeros.



**Figure 2.** The resonant frequency ratio versus the section length ratio.



**Figure 3.** The coupling coefficient versus the section length ratio.



**Figure 4.** Computed frequency responses of the resonator for the two values of  $l_1/l_2$ .

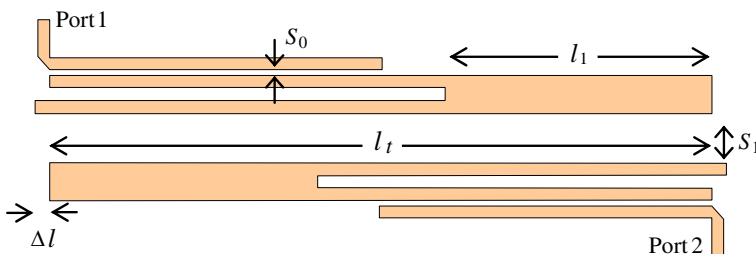
In Fig. 4, two computed frequency responses having a 3-dB fractional passband of 10% are plotted for different values of  $l_1/l_2$ . Here the resonator in both cases has  $h = 1$  mm,  $W = 1$  mm,  $S = 1$  mm, and  $\varepsilon_r = 9.8$ . Resonator coupling with input and output ports was realized with lumped capacitors on the ends of the split section. Their values  $C$  were tuned so that the reflection maximum in the passband was equal to  $-15$  dB. They are found to be about  $0.60$  pF in both cases. The ratio  $l_1/l_2$  was adjusted so that the 3-dB fractional bandwidth was 10%. The total resonator length  $l_1 + l_2$  was found to be  $50.64$  mm at  $l_1/l_2 = 0.771$  and  $52.99$  mm at  $l_1/l_2 = 0.916$ .

It is seen from Fig. 4 that the transmission zero arises above the

passband when the ratio  $l_1/l_2$  is smaller than the critical value and below the passband when the ratio  $l_1/l_2$  is greater than that value.

### 3. TWO-RESONATOR FILTER

The two-resonator dual-mode filter is a filter of the fourth order. That means its frequency response has four reflection minimums and three maximums in the passband. The layout of the filter is shown in Fig. 5. Here the notations of the adjustable structure parameters are given too.



**Figure 5.** The layout of the two-resonator filter.

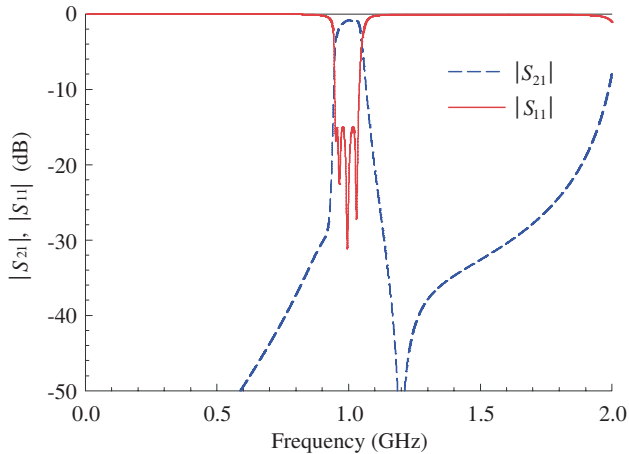
The filter has been designed using the rules of intelligence optimization [11]. The adjustment of the total resonator length  $l_t$  was used for tuning the center frequency  $f_0$ .

The adjustment of the parameters  $l_1$  and  $S_1$  was used for tuning two internal couplings that were responsible for both the bandwidth  $\Delta f$  and the even type deflection of three reflection maximums from the specified value in the passband.

The adjustment of the parameter  $\Delta l$  was used to tune the mistuning of the resonant frequencies of coupled single-mode resonators that are equivalent to the dual-mode resonator. This mistuning is responsible for the odd type deflection of three reflection maximums. The symmetrical dual-mode resonator in the two-resonator filter is initially mistuned because its upper and down parts are differently affected by their entourage.

The adjustment of the spacing  $S_0$  was used to tune the external couplings of the resonators with the ports. These couplings are responsible for average value of the reflection maximums in the passband.

The frequency response of the two-resonator dual-mode filter was computed within a 1D model that contains sections of single and coupled microstrip lines with up to six strip conductors connected



**Figure 6.** Computed frequency response of the two-resonator dual-mode filter.

likewise in Fig. 1(b). The parameters of the microstrip lines were calculated using TEM approximation.

Figure 6 shows the computed frequency response of the two-resonator dual-mode filter. The substrate with  $h = 1$  mm and  $\epsilon_r = 9.8$  was chosen for the simulation. All narrow strip conductors of the filter have the width of 1 mm. The slot in the split section of the resonator has the same width.

The passband of the two-resonator filter has the 3-dB fractional bandwidth of 10%, the center frequency of 1 GHz, and three reflection maximums at the level of  $-15$  dB. The transmission zero is above the passband because the length  $l_1$  is less than the critical value.

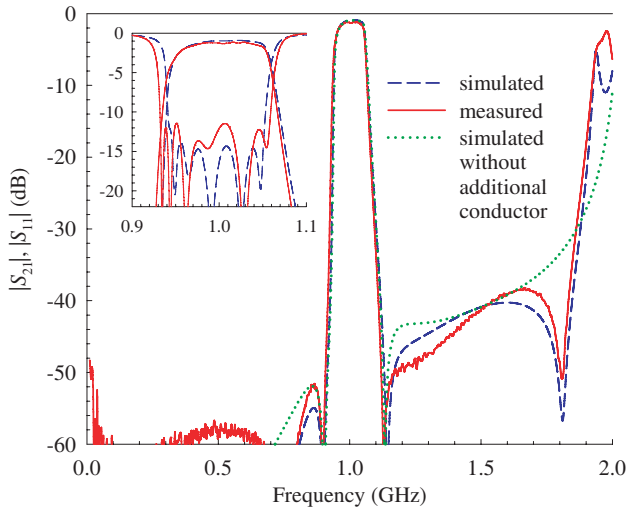
The filter optimization has given the following values for the adjustable parameters:  $l_t = 53.69$  mm,  $l_1 = 21.68$  mm,  $\Delta l = 1.21$  mm,  $S_1 = 3.02$  mm,  $S_0 = 0.30$  mm.

Surely, a full-wave electromagnetic simulation of the two-resonator filter may give more exact values to the structure parameters. However, such the model would give similar frequency response if the filter is optimized.

#### 4. THREE-RESONATOR FILTER

The layout of the designed and fabricated three-resonator dual-mode filter is shown in Fig. 7. The filter has an interdigital configuration. The dimensions of the internal resonator differ from the dimensions of the external resonators. That is caused by their different interaction





**Figure 9.** The frequency response of the three-resonator filter.

The adjustment of the spacing  $S_0$  was used to tune the external couplings of the resonators with filter ports. These couplings are responsible for average value of the reflection maximums in the passband.

In Fig. 8, the photograph of the fabricated three-resonator dual-mode filter is shown.

The frequency response of the three-resonator filter is presented in Fig. 9. The dotted curve shows the computed transmission function when the additional conductor between the ports is absent. In this case, there is only one transmission zero in the upper stopband and the rejection function considerably decreases above the transmission zero.

The dash curve shows the computed transmission function when the additional conductor is present. It is seen that the additional conductor generates one more transmission zero at its resonant frequency near the spurious passband but does not disturb the frequency response in the main passband. That improves the filter performance in the upper stopband.

The solid curve shows the measured transmission function when the additional conductor is present as well.

The inset in Fig. 9 shows the simulated and measured frequency responses near the passband in presence of the additional conductor. The fabricated filter of the sixth order has the center frequency of 1.00 GHz, the 3-dB fractional bandwidth of 11.4%, the maximum



reflection in the passband of  $-11.43$  dB, and the minimum insertion loss of  $1.15$  dB.

## 5. CONCLUSION

A simple compact dual-mode microstrip resonator having a longitudinal slot in the one end of its straight strip conductor is proposed. Two first modes of the resonator have close resonant frequencies. Their difference can be easily tuned by adjusting the slot length. The frequency of the third mode remains approximately equal to doubled average frequency of two first modes. The resonant frequencies of the resonator can be estimated with formulas that have been derived within 1D model.

The resonator is good for compact narrowband bandpass filters. Two-resonator and three-resonator filters are considered. They have transmission zeros in stopbands. The filters provide high selectivity and small size compared to filter designs using single-mode resonators. Filter adjustment is fulfilled using the rules of intelligence optimization. The simulated frequency response of the designed three-resonator filter is in good agreement with the measured response of the manufactured filter.

## ACKNOWLEDGMENT

This work was supported in part by the Siberian Branch of the Russian Academy of Sciences under the Interdisciplinary integration project No. 5 and the Federal Target Program "Research and Research-Pedagogical Personnel of Innovation Russia 2009–2013."

## REFERENCES

1. Wang, Y. X., B.-Z. Wang, and J. Wang, "A compact square loop dual-mode bandpass filter with wide stop-band," *Progress In Electromagnetics Research*, Vol. 77, 67–73, 2007.
2. Chen, H.-J., T.-H. Huang, L.-S. Chen, J.-H. Horng, and M.-P. Hwang, "New design concept of dual-mode bandpass filter by using nonorthogonal input and output ports for wireless application," *Microwave and Optical Technology Letters*, Vol. 48, 639–641, Apr. 2006.
3. Wang, H. and L. Zhu, "Microstrip dual-mode filters with miniaturized size and broadened stopband using meander-shaped

- stepped-impedance ring resonator,” *IEICE Electronics Express*, Vol. 2, 159–164, Mar. 2005.
4. Helvacı, A. K., C. Karpuz, and A. Görür, “Compact dual-mode microstrip resonator for 900 MHz bandpass filter applications,” *Microwave and Optical Technology Letters*, Vol. 45, 376–377, Jun. 2005.
  5. Makimoto, M. and S. Yamashita, “Bandpass filters using parallel coupled stripline stepped impedance resonators,” *IEEE Trans. Microw. Theory Tech.*, Vol. 28, 1413–1417, Dec. 1980.
  6. Zhu, L., S. Sun, and W. Menzel, “Ultra-wideband (UWB) bandpass filters using multiple-mode resonator,” *IEEE Microwave and Wireless Components Letters*, Vol. 15, 796–798, Nov. 2005.
  7. Hua, C., C. Miao, B. Li, H. Wang, and W. Wu, “Dual-mode bandpass filter using internally coupled stub-loaded resonators,” *Microwave and Optical Technology Letters*, Vol. 53, 643–646, March 2011.
  8. Hua, C., C. Miao, B. Li, H. Wang, and W. Wu, “Microstrip bandpass filters using dual-mode resonators with internal coupled lines,” *Progress In Electromagnetics Research C*, Vol. 21, 99–111, 2011.
  9. Belyaev, B. A., Yu. G. Shikhov, and P. N. Sergienko, “Spektr of own oscillations of an irregular microstrip resonator,” *Proc. 1998 4th International Conference on Actual Problems of Electronic Instrument Engineering, APEIE-98*, Vol. 2, 105–106, Novosibirsk, Sep. 1998.
  10. Tyurnev, V. V., “Coupling coefficients of resonators in microwave filter theory,” *Progress In Electromagnetics Research B*, Vol. 21, 47–67, 2010.
  11. Dovbysh, I. A. and V. V. Tyurnev, “Synthesis and investigation of three-section microstrip filter on folded dual-mode stepped-impedance resonators,” *Progress In Electromagnetics Research M*, Vol. 12, 17–28, 2010.