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MINIATURE SUSPENDED-SUBSTRATE BANDPASS FILTER

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Abstract—A new quasi-lumped suspended-substrate stripline structure admitting implementation of miniature highly selective narrow-band filters is studied. Appreciable improvement of the device selectivity is achieved with supplementary strip conductors introduced between the resonators, which induce attenuation poles near both passband edges. Furthermore, these supplementary conductors reducing the coupling between the resonators allow diminishing the inter-resonator spacing and the total size. A four-resonator filter is synthesized using the intelligence optimization method. Experimental results of the manufactured filter are presented.

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1. INTRODUCTION

Microstrip filters are widely used in microwave engineering due to their small size. However, they do not have high selectivity at frequencies below 1 GHz because of the resonator's Q-factor decays with frequency lowering when the substrate thickness is fixed. One of the ways to improve filter performance is use of a quasi-lumped suspended-substrate strip structure where resonator conductors are formed on both substrate surfaces [1–6]. Resonators in such structures are distinguished by small size and high Q-factor. Their second (spurious) resonant frequency may exceed the first resonant frequency more than 3 times. This ensures that the filters have broad upper stop band and low insertion loss.

In this paper, an original modification of quasi-lumped suspended-substrate strip structure is proposed. It differs in supplementary pairs of grounded strip conductors on both substrate surfaces between adjacent resonators. The supplementary conductors generate attenuation poles on lower and upper passband sides, if input and output taps are placed on different surfaces of the substrate. Furthermore, the supplementary conductors, diminishing coupling between resonators, allow to push them closer and to reduce size of narrow-band filter.

An influence of variation in structure parameters on frequency response for two-resonator filter is investigated theoretically. A four-resonator bandpass filter has been designed and manufactured. Experimental data are compared to the data computed within the 1D model.

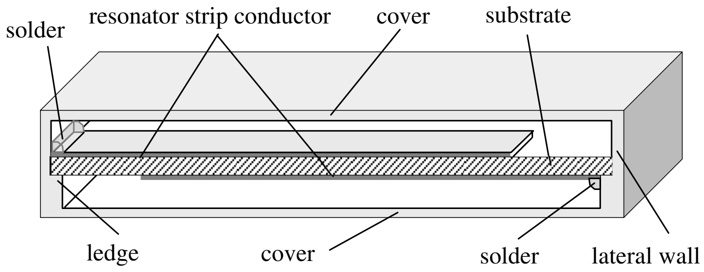

Figure 1. Cross section of the structure along the resonator conductors.

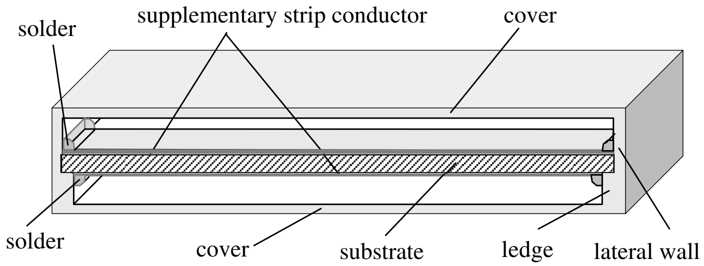

Figure 2. Cross section of the structure along the supplementary conductors.

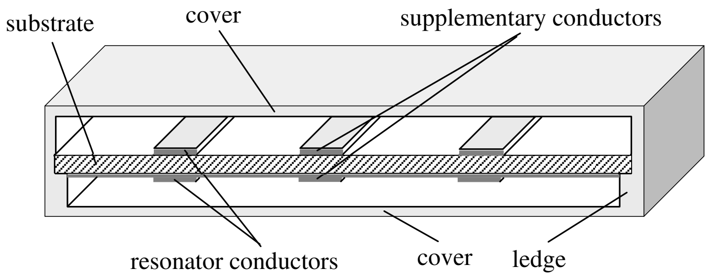

Figure 3. Cross section of the structure across the strip conductors.

2. FILTER STRUCTURE AND ITS MODEL

The cross sections of the filter structure are shown in Figs. 1, 2, and 3. Every quasi-lumped resonator of the filter structure consists of two parallel strip conductors, positioned oppositely on both substrate surfaces (Fig. 1). The substrate is suspended on ledges formed at the lateral walls of a metallic enclosure. Each conductor in the resonator is grounded by its one end to the wall of the enclosure by soldering, where the ends are grounded to the opposite walls. Every adjacent pair of resonators is separated by two parallel supplementary strip conductors on both substrate surfaces. All their ends are grounded to the walls (Fig. 2).

The structure admits two configurations, which we following to [5] call combline and interdigital ones. They are presented in Fig. 4 and Fig. 5 where the enclosure is not shown.

Notations of geometrical parameters for the interdigital configuration are shown in Fig. 6. Other structure parameters are substrate dielectric constant ε_r, substrate thickness h_d, and cover height h_a. Notations for the combline configuration are similar.

Input and output taps are located at the equal distance l_t from the opposite lateral walls. In the combline configuration, taps are on different substrate surfaces, and in the interdigital configuration, they are on the same surface. Thus, input and output ports have "diagonal" symmetry for both configurations.

For theoretical investigation of the filter structure, we use a one-dimensional model. It consists of connected sections of multi-conductor strip lines. We only take into account running fundamental waves and compute their parameters in quasi-TEM approximation. Losses in transmission lines are specified phenomenologically by the Q-factor. The running waves' amplitudes are solutions of the Kirchhoff's equations for all junction nodes of the 1D model.

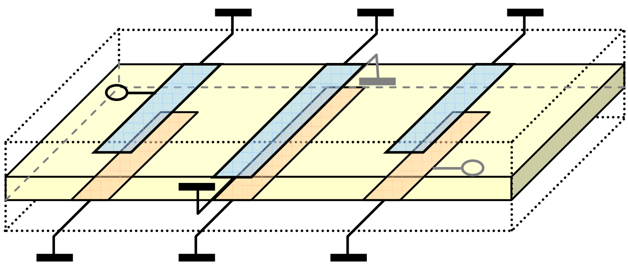

Figure 4. Two-resonator combline structure with "diagonal" ports.

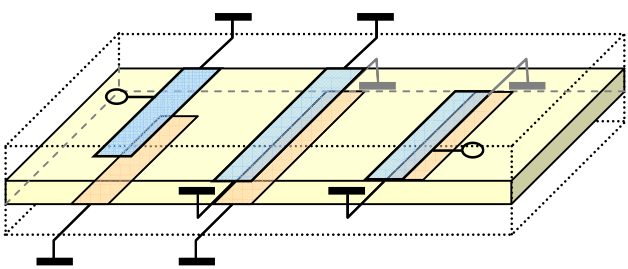

Figure 5. Two-resonator interdigital structure with "diagonal" ports.

3. INVESTIGATION OF THE TWO-RESONATOR STRUCTURE

Amplitude-frequency response of the two-resonator filter structure is presented in Fig. 7. Computations were carried out at $\varepsilon_r = 80$, $w_s = 2\,\mathrm{mm}$, $w_r = 2\,\mathrm{mm}$, $S_r = 6.6\,\mathrm{mm}$, $S_h = 5\,\mathrm{mm}$, $h_d = 0.5\,\mathrm{mm}$, $h_a = 5\,\mathrm{mm}$, $l_s = 23\,\mathrm{mm}$, $l_r = 22.05\,\mathrm{mm}$, $l_t = 4.55\,\mathrm{mm}$.

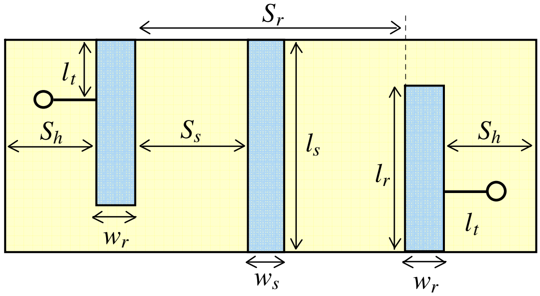

Figure 6. Structure layout and parameters.

Solid line refers to combline and interdigital configurations with "diagonal" ports. It has one attenuation pole below the pass band and one pole above it. The fractional bandwidth measured at level -3 dB is 2%.

Dashed line refers to combline and interdigital configurations with opposite ports where l_t for two ports is measured from the same lateral wall. It has no attenuation pole. The fractional bandwidth is 2% as well.

Dotted line refers to the structure with "diagonal" ports and without supplementary conductors separating the resonators. It has one attenuation pole situated above the pass band. The fractional bandwidth is 9%. It will be 2% if we increase S_r up to 9.5 mm. In the case of the opposite ports and absence of supplementary conductors, frequency response has no attenuation pole at all.

The results below are obtained for combline and interdigital configurations with the supplementary strip conductors and "diagonal" ports. It is supposed that $\varepsilon_r = 80$, $h_d = 0.5$ mm, $h_a = 5$ mm, $w_r = 2$ mm, and $w_s = 2$ mm if there are no diverse data. Lengths l_r and l_t are adjusted to keep the midband frequency of 0.2 GHz and maximum passband return loss of -14 dB.

Figure 8 shows dependence of the fractional bandwidth on the width of the supplementary strip conductors at $S_r = 3.4$ mm.

Figure 9 shows dependences of the attenuation-pole frequencies on the cover height. The fractional bandwidth of 2% is fixed with adjusting of S_r. Both the frequencies are normalized to the midband frequency.

Figure 10 shows dependences of the attenuation-pole frequencies on the width of the supplementary strip conductors for the structure with fractional bandwidth of 2% and $h_a = 5$ mm. It is seen that variation of the width w_s allows efficient controlling the attenuation

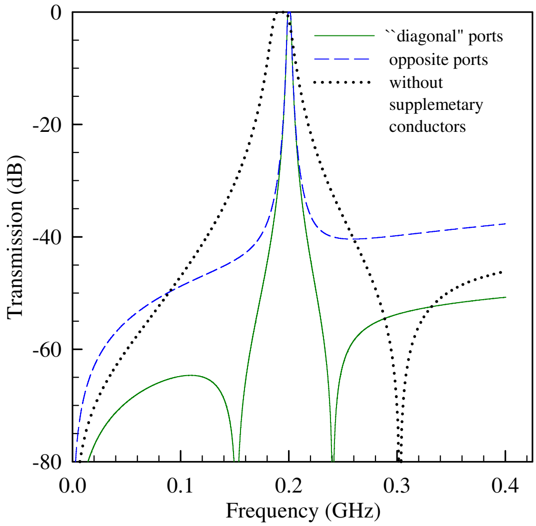

Figure 7. Amplitude-frequency response of the two-resonator structure.

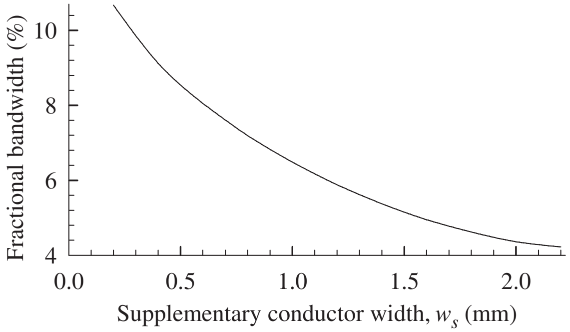

Figure 8. Fractional bandwidth versus the width of supplementary conductors.

poles frequencies.

It was found that the influence of the resonator width w_r variation on the attenuation-pole frequencies is not so significant.

Similar investigation has been carried out for the filter structure on the substrate with $\varepsilon_r = 9.8$. It has shown the variation of dielectric constant does not affect the dependences presented in Figs. 8, 9, and 10, that is accounted for by weak capacitive coupling between conductors of the structure in comparison to the inductive one.

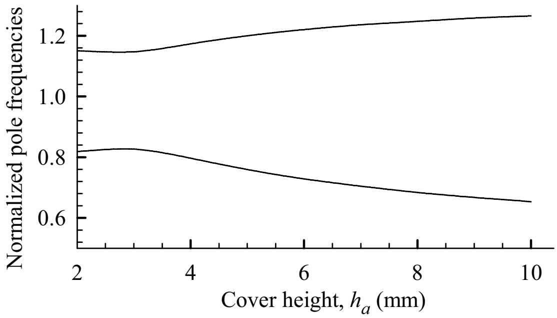

Figure 9. Attenuation-pole frequencies versus the cover height.

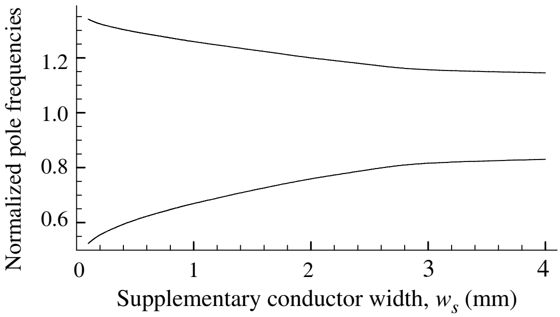

Figure 10. Attenuation-pole frequencies versus the width of the supplementary conductors.

It has also been found that the interaction between the supplementary strip conductors and the resonator slightly heightens its resonant frequencies. The effect becomes drastic when the spacing S_s is compared to the substrate thickness h_d.

4. DESIGN OF FOUR-RESONATOR FILTER

The layout of the designed four-resonator filter is shown in Fig. 11. It has combline configuration with "diagonal" ports on both substrate surfaces. Strip conductors and a port on the back surface are not shown.

The pass band was specified by the midband frequency $f_0 = 0.183\,\text{GHz}$, maximum passband return loss $R_{\max} = -14\,\text{dB}$ and fractional bandwidth $\Delta f/f_0 = 4\%$ measured at the level of $-3\,\text{dB}$ relative to minimum insertion loss. The substrate was specified by thickness $h_d = 0.5\,\text{mm}$ and dielectric constant $\varepsilon_r = 80$. We used l_r, l_t, S_1, S_2, and S_3 as adjustable parameters. Other parameters were fixed.

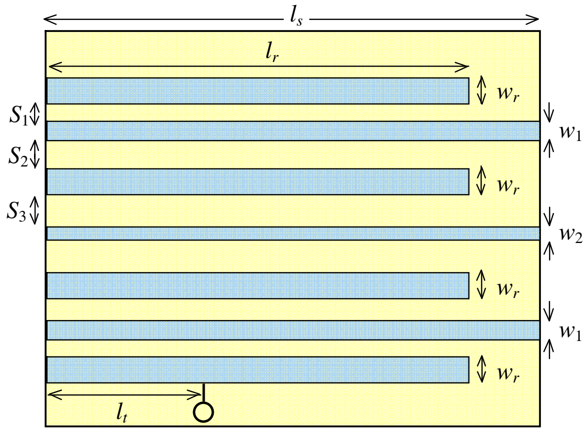

Figure 11. The layout of the four-resonator filter.

They had values: $h_a = 5\,\mathrm{mm}$, $l_s = 30\,\mathrm{mm}$, $w_r = 2\,\mathrm{mm}$, $w_1 = 1.5\,\mathrm{mm}$, and $w_2 = 1\,\mathrm{mm}$.

The filter synthesis was fulfilled using the intelligence optimization method. The use of a priori universal knowledge about resonator bandpass filters underlies this method [7, 8]. The single goal of optimization method is to form the frequency response with the specified passband parameters using minimum quantity of adjustable parameters. Other structure parameters are reserved for any posterior optimization if the latter is required. Peculiarities of intelligence optimization of dual-mode filters are described in [9–11]. The method is successfully used in the expert system Filtex32 for automated design and investigation of microstrip and stripline filters [12, 13].

The intelligence optimization method is based on the use of a vector goal function $\mathbf{D}$ called the distortion vector and correction operators C_i corresponding to D_i. The vector's components in a four-resonator filter are defined by the formulas

$$D_1 = (f_c - f_0)/f_0, \tag{1}$$
$$D_2 = (\Delta f_c - \Delta f)/\Delta f, \tag{2}$$
$$D_3 = (R_1 + R_2 + R_3)/3 - R_{\max}, \tag{3}$$
$$D_4 = R_1 - R_3, \tag{4}$$
$$D_5 = R_2 - (R_1 + R_3)/2. \tag{5}$$

Here f_c and Δf_c are the current midband frequency and the bandwidth, R_i is ith maximum of return loss in the pass band.

The operator C_1 corresponding to D_1 simultaneously lowers the resonant frequencies of all the resonators if $D_1 > 0$. That is achieved by the increase of l_r.

The operator C_2 corresponding to D_2 simultaneously weakens all inter-resonator couplings if $D_2 > 0$. That is achieved by proportional increase of S_1, S_2, and S_3.

The operator C_3 strengthens input and output coupling of the terminal resonators if $D_3 > 0$. That is achieved by the increase of l_t.

The operator C_4 heightens the resonant frequency of the terminal resonators and simultaneously lowers the resonant frequency of the internal resonators if $D_4 > 0$. That is achieved by the increase of S_1 and the simultaneous decrease of S_2.

The operator C_5 strengthens the coupling between a terminal resonator and its neighbor resonator and simultaneously weakens the coupling between internal resonators if $D_5 > 0$. That is achieved by the simultaneous decrease of S_1 and S_2 and increase of S_3.

In the case of opposite sign of D_i, the operator C_i makes the opposite action.

The correction operators corresponding to the components of the distortion vector are quasi-orthogonal which means that operator C_i eliminating the distortion D_i does not generate other distortions commensurable with D_i in absolute value.

The optimization process is the successive eliminating of an ith frequency-response distortion in the pass band whose current component D_i has maximum absolute value. The process terminates when the absolute values of all components of the current distortion vector are less than the specified value. The intelligence optimization process is stable and highly effective because the correction operators are quasi-orthogonal.

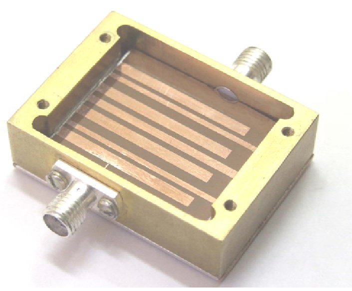

Figure 12. Fabricated four-resonator filter.

5. EXPERIMENTAL RESULTS

The synthesized filter has internal dimensions 30 mm × 26 mm × 11 mm. It was fabricated on a ceramic substrate with $\varepsilon_r = 80$. A photograph of the fabricated filter is shown in Fig. 12. The measured amplitude-frequency response is presented in Fig. 13.

The fabricated filter has a broad higher stopband where attenuation is better than −60 dB. The measured minimum insertion loss is 3.8 dB at the fractional bandwidth of 4% and the center frequency of 183 MHz.

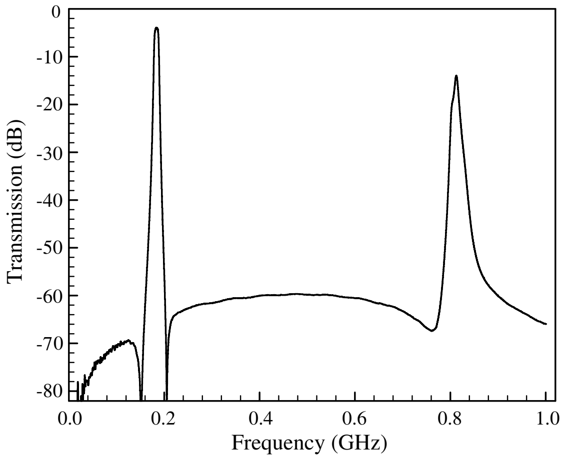

Figure 13. Measured performance of the fabricated filter.

The midband frequency of the first spurious passband is 4.45 times higher than the midband frequency of the main passband. This spurious passband is due to the second oscillation mode of the resonators. This mode has one voltage antinode on the open end of the resonator conductor and one current antinode on the conductor middle. The spurious passband cannot be suppressed, but its midband frequency may be shifted farther from the main passband. It may be achieved by means of increasing the cover height h_a, optimizing the length difference $l_s - l_r$, or forming step impedance in the resonators [2].

Comparison of the simulated and measured performances of the filter is shown in Fig. 14. The good agreement between the simulated and measured results demonstrates that the 1D model may be used for design and investigation of the suspended-substrate stripline filter.

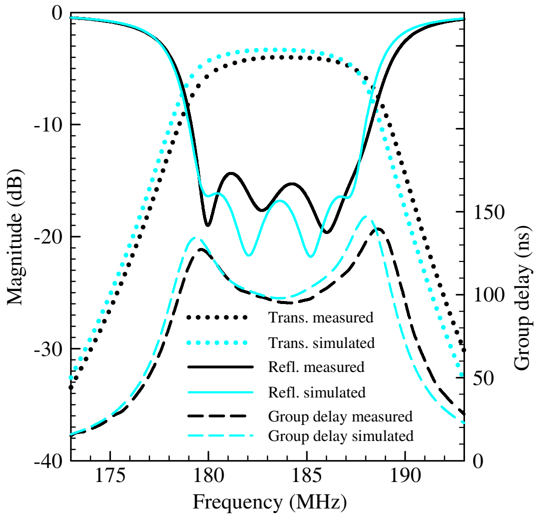

Figure 14. Simulated and measured performances near the passband.

6. CONCLUSION

A new construction of quasi-lumped suspended-substrate stripline bandpass filter is described. It differs in supplementary strip conductors with grounded ends introduced between the resonators. They induce attenuation poles near both passband edges and thereby improve the filter selectivity. Authors think that physical nature of the poles is nulls of the frequency dependent coupling coefficient near the passband [14]. Properties of the filter are studied theoretically within a one-dimensional model. Synthesis of the four-resonator filter is fulfilled automatically using the intelligence optimization method. Simulated performance is compared with experimental one.

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