A Novel Miniature Suspended Stripline Filter

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ABSTRACT — **Concept, design, and results of a novel miniature suspended stripline (SSL) filter type based on an interdigital filter structure with quasi-lumped elements are presented. The filter is realized in a metal channel of 4.25 mm × 5 mm. Compared to a standard SSL resonator, length is reduced by about 75%. A three resonator filter at 7 GHz with a 450 MHz bandwidth is demonstrated, having a filter length of only 12 mm and losses of about 1.4 dB, including 18 mm of excess transmission line and the transitions to coaxial line. Further examples are a three-resonator filter at 11 GHz and a 8 GHz five-resonator filter.**

I. Introduction

Suspended stripline has proven to be a suitable transmission line medium with moderate loss and a wide range of possible circuit configurations, especially for filters [1]. Although some size reduction of the filter circuits has been demonstrated earlier, filter length mostly is large due to the one-dimensional extension of the circuit in a channel, combined with a low effective dielectric constant of the transmission line structures. On the other hand, due to a narrow channel, coupling within a circuit can be kept low, and waveguide modes can propagated only at frequencies much higher than the design frequency of the respective circuit. In this paper, a novel approach for the design of very compact filters based on a mixture of quasi-lumped and transmission line elements is presented.

II. Filter Concept and Design

The filter as described in this contribution is placed on either side of a substrate suspended in a metal channel (Fig. 1 a). The filter resonators consist of a narrow strip connected to the side wall of the metal housing and some kind of patch at the other end (Fig. 1 b). An inset is used to increase the length of the narrow strip – or to control its inductance, while the patch can be regarded as a shunt capacitance, resulting in a shunt resonator circuit (Fig. 1 c). An alternative description could be that of a short-circuited, branched, and folded quarter-wave resonator. To characterize the resonator properties, a gap source is introduced at the ground contact point of the narrow line (Fig. 1 b), and the input reactance X_{in} is calculated using a MoM software [2]. This reactance and its derivative with respect to frequency are compared to the respective quantities of the equivalent circuit (Fig. 1 c). In this way, inductance and capacitance can be extracted.

For the selected configuration, the inductance mainly depends on the inset depth (Fig. 2), while the capacitance remains nearly constant. The capacitance, on the other hand, mostly depends on the patch width (Fig. 3) with approximately constant inductance.

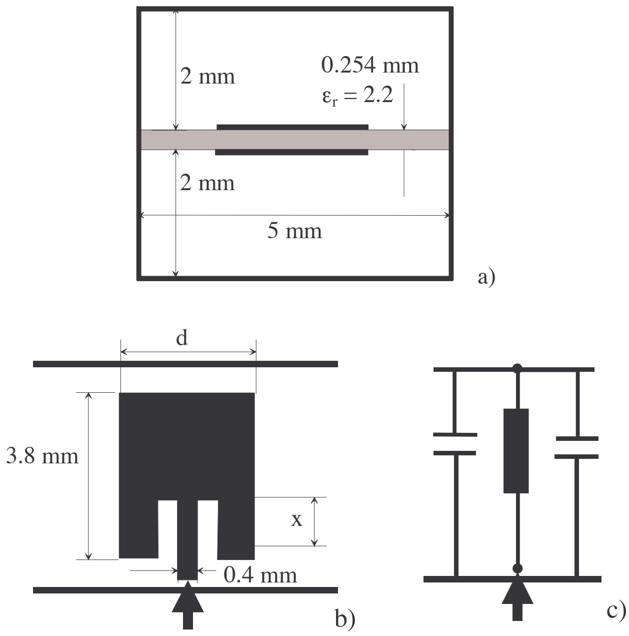

Fig. 1: Cross section of suspended stripline (a), novel resonator (b), and equivalent circuit of resonator (c).

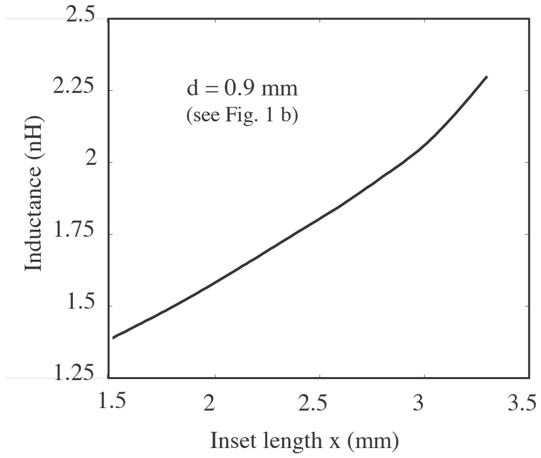

Fig. 2: Dependence of resonator inductance on the inset depth (capacitance of the resonator does hardly depend on this quantity).

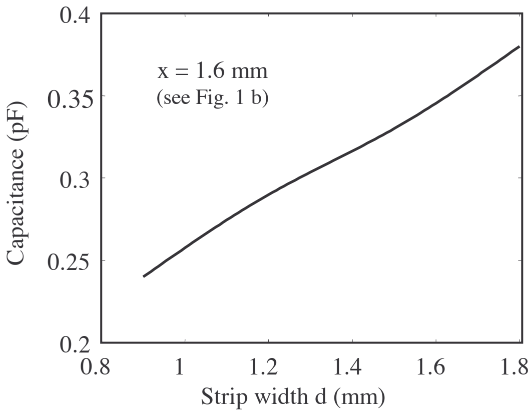

Fig. 3: Dependence of capacitance on overall strip width (the inductance depends on the width only in a minor way).

The filter is designed according to the equivalent circuit of Fig 4 and [3]. The coupling capacitances are realized by the stray fields between the resonators and the connecting lines and the outer resonators, respectively, calculated approximately by gaps between transmission lines [2]. The connecting lines (width w = 3.8 mm) preferably are placed on the opposite side of the substrate, thus enabling stronger coupling (with overlapping) and less critical tolerances. In principle, the resonators themselves may be arranged on alternating sides of the substrate, too. The final filter then is optimized based on a full-wave simulator [2].

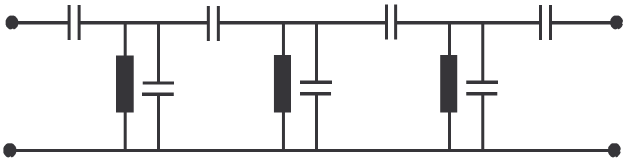

Fig. 4: Equivalent circuit of the suspended stripline filter.

III. Filter Examples

A. Three-resonator filter at 7 GHz

A first filter with three resonators was designed for a center frequency of 7 GHz. The substrate with two of these filters and, for comparison, a standard SSL resonator bandpass filter (with the same filter specifications) are shown in Fig. 5. The novel filter has a length of only 12 mm, compared to more than 50 mm of the standard one. Based on the alternative interpretation of the resonators as quarter-wave folded resonators as mentioned above, the novel filter resembles a very compact "folded" interdigital filter [4].

Fig. 6 shows theoretical and experimental results of the first test filter. Bandwidth is about 450 MHz. Insertion loss, due to the small size and the narrow inductive strips, is slightly higher than for a standard filter and amounts to 1.3 … 1.5 dB, including 18 mm of excess transmission line and the transitions to the coaxial measurement system. Fig. 7 shows a comparison of experimental results for the novel filter and the standard filter [1] as shown, too, in Fig. 5. Around the passband, performance is very similar. The novel filter, however, exhibits a considerably wider stopband behavior due to the reduced size and quasi-lumped nature of the resonators. The spurious passband of the novel filter in the 16 GHz to 18 GHz region is due to a $\lambda/2$-resonance of the patches acting as bent resonators (without the ground connection).

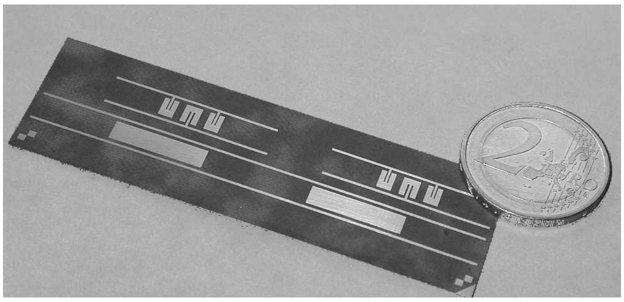

Fig. 5: Photograph of two of the novel three-resonator filters designed for 7 GHz compared to a standard suspended stripline filter (connecting lines for all filters and central resonator of the standard filter are on the backside of the substrate).

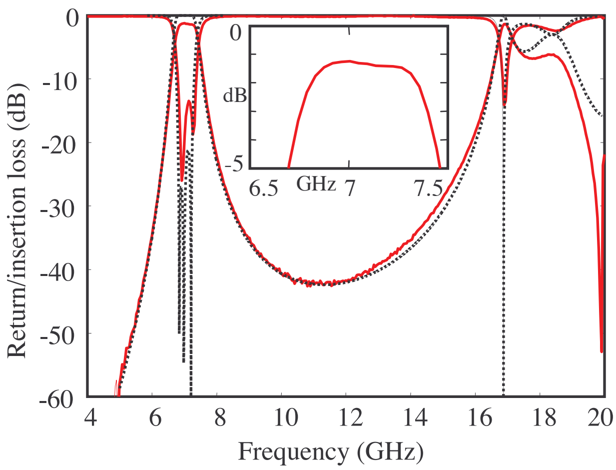

Fig. 6: Theoretical (dotted lines) and experimental (solid lines) results of the 7 GHz filter. Experimental passband insertion loss is enlarged in the inset figure.

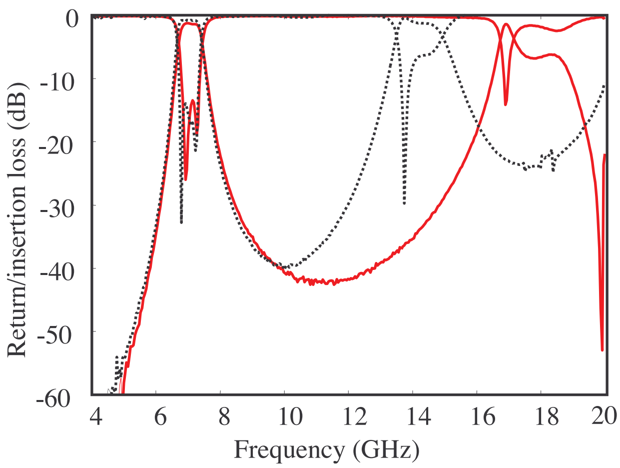

Fig. 7: Experimental results of the novel filter (solid lines) compared to a standard suspended stripline filter with the same passband specifications (dotted lines).

B. Possible Frequency Range of the Filter Design

In a next step, an investigation was made about the possible range of center frequencies for filters realized in the specific waveguide channel used here. Therefore, the inset depths of all resonators were changed equally step by step – starting with a maximum inset depths (0.1 mm metal left for the central resonator) until the insets completely disappeared for the outer resonators. The return loss for a number of such filters is plotted in Fig. 8; the inset depth decreases from lower to higher frequencies in steps of 0.8 mm (0.9 mm for the last step). As can be seen, the filter performance approximately is kept the same, mainly bandwidth is increasing with decreasing inset depth.

Once the inset had disappeared, the strip width of the ground connection was successively increased until the outer resonators consisted of homogeneous stubs only (width of the strips: 0.4 mm, 1.2 mm, 2 mm, 2.6 mm). For these modifications, the return loss curves are plotted in Fig. 9. Once again, the basic filter characteristic is maintained with bandwidth increasing with increasing strip width.

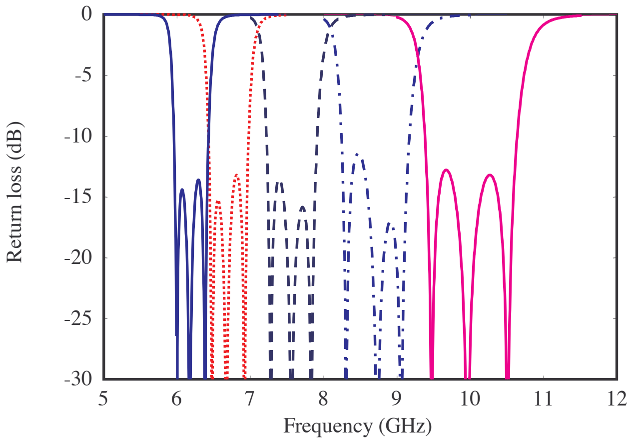

Fig. 8: Return loss of filters with increasingly reduced inset depth. All other dimensions were kept constant. Inset depth varies between maximum and minimum from left to right.

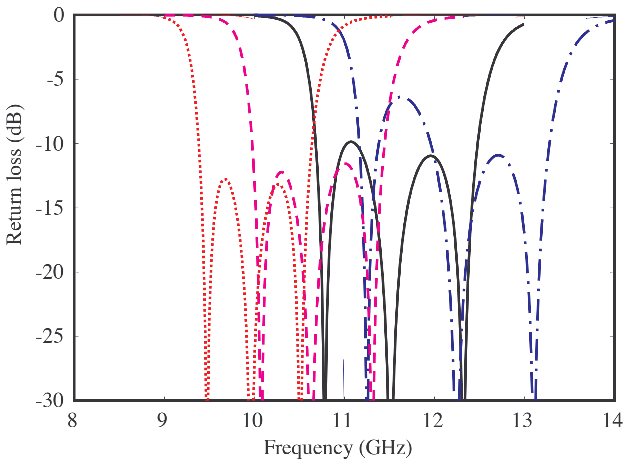

Fig. 9: Return loss of filters with increasing width of the ground connection of the patches. All other dimensions were kept constant. Strip width varies between 0.4 mm and 2.6 mm from left to right.

C. Three-resonator filter at 11.5 GHz

To verify filter performance at higher frequencies, a filter with a center frequency of 11.5 GHz (equivalent to the filter version plotted with a solid line in Fig. 9) was redesigned with reduced bandwidth and improved return loss, fabricated and tested. The basic layout of this filter is shown in Fig. 10.

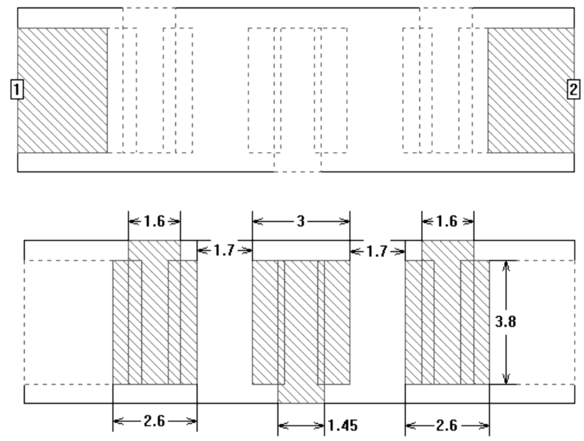

Fig. 10: Layout of back side (top, connecting lines) and front side (bottom, resonators) of the 11.5 GHz filter. Dimensions are given in mm.

Theoretical and experimental results of this filter are plotted in Fig. 11. Bandwidth is 1 GHz, experimental insertion loss amounts to 0.4 dB … 0.5 dB only, including the transitions to coaxial line. Compared to the results of the first example, this is considerably lower, resulting from the greatly increased widths of the ground strips (0.4 mm compared to 1.45 mm and 1.6 mm, respec-tively, see Fig. 10). Center frequency is slightly shifted compared to theory. This is partly due to tolerances in mounting the filter, partly due to some increased resonator inductance provided by the clamping area in the circuit mount (this influence is bigger here as the overall strip inductance is much smaller than in the first example). Furthermore, the spurious-free stopband is even much wider than that of the first filter (up to more than 25 GHz).

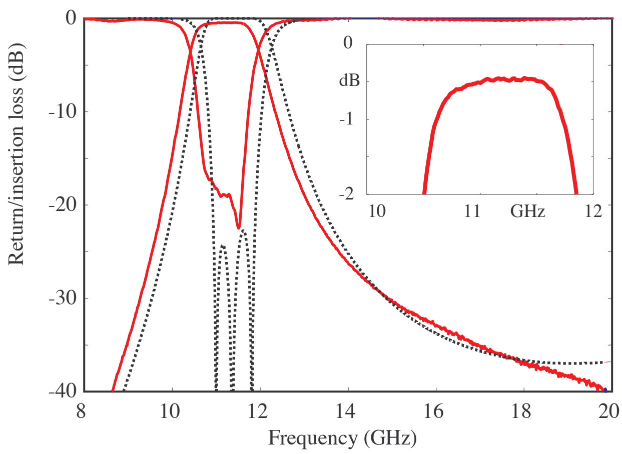

Fig. 11: Theoretical (dotted lines) and experimental (solid lines) results of the 11.5 GHz filter. Experimental passband insertion loss is enlarged in the inset figure.

D. Five-resonator filter at 8.3 GHz

Finally, another filter was designed having five resonators (Fig. 12). Center frequency is 8.3 GHz, bandwidth about 800 MHz. Preliminary theoretical results of this filter are demonstrated in Fig. 13; a further optimization, however, still has to be done.

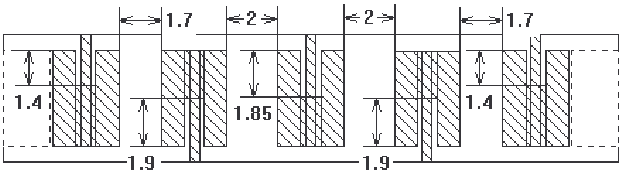

Fig. 12: Layout of the resonator side of the five-resonator filter.

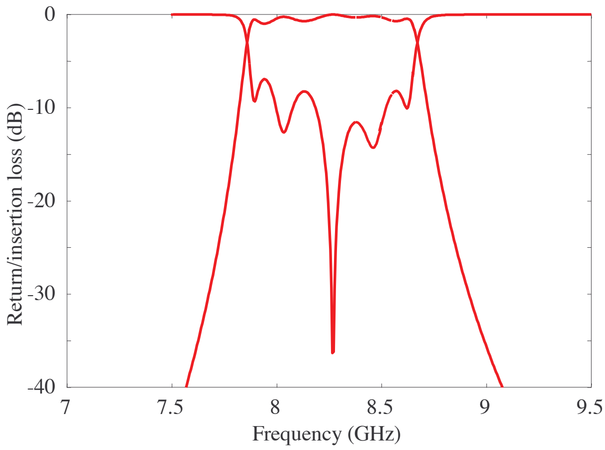

Fig 13: Preliminary theoretical results of a five-resonator filter according to Fig. 12.

IV. Conclusion

A novel concept for a miniaturized suspended stripline filter has been demonstrated and verified experimentally. The proposed filter exhibits only about 25 % of the size of a standard SSL filter, and, at the same time, shows a considerably wider stopband. Due to the reduced size of the filter, insertion loss is slightly increased. Design and performance of two filters with three resonators have been reported, and first theoretical results of a five-resonator filter have been presented.

References

[1] W. Schwab, F. Bögelsack, W. Menzel. "Multilayer Suspended Stripline and Coplanar Line Filters." IEEE Trans. on MTT, Vol. MTT- 42 (July 1994), pp. 1403-1407.

[2] SONNET, Version 8, Sonnet Software Inc.

[3] G. Matthaei, L. Young, E.M.T. Jones. "Microwave filters, impedance matching networks, and coupling structures". Reprint by Artech House, 1980.

[4] J.H. Cloete. "The Resonant Frequency of Rectangular Interdigital Filter Elements." IEEE Transactions on Microwave Theory and Techniques, Vol. MTT-31 (Sept. 1983), pp. 772-774.