Compact Suspended Stripline Quasi-Elliptic Low-Pass Filters

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Abstract **— The design of very compact suspended stripline low-pass filters with additional transmission zeroes is presented. The transmission zeroes are achieved by additional capacitive coupling between different elements of the low-pass filter. Both interdigital as well as broadside coupling is investigated, and single, twofold, and threefold coupling is demonstrated for test filters with edge frequencies between 5 GHz and 6 GHz and order 5. Excellent agreement is achieved between theory and experiment.**

I. Introduction

Suspended stripline (SSL) has proven to be an excellent transmission line system to realize different types of filters with moderate or even low loss. Using both sides of the substrate, very versatile transmission line structures can be realized, e.g. improved end-coupling by overlapping of strips on different sides of the substrate [1, 2]. Using an additional ground metallization on one side of the substrate, microstrip lines can be designed with very low impedance compared to the quite high impedance of a narrow normal SSL line. This enables the realization of very compact low-pass filters with, at the same time, wide stopband [2]. The basic cross section of the SSL as used in this work is shown in Fig. 1.

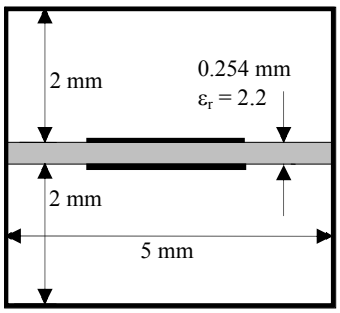

Fig. 1: Cross section of the suspended stripline as used in this work.

Quasi-elliptic low-pass responses can be achieved either by using parallel resonators instead of the series inductances or by series resonators instead of the shunt capacitances (Fig. 2). The first solution may be realized using stub-type elements [3, 4], the second one by placing the capacitive patches close to each other and using narrow folded lines as inductances [5, 6].

This paper describes a similar approach. As the SSL low-pass filters can be made much more compact, however, some kind of "inline" coupling between the capacitive patches can be achieved.

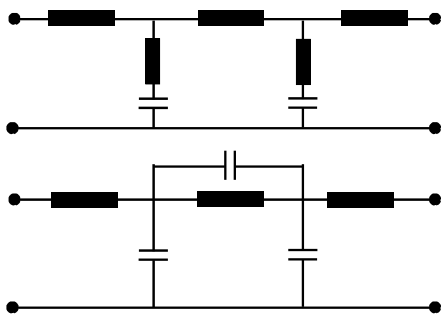

Fig. 2: Equivalent circuits of possible quasi-elliptic low-pass filters.

II. Low-Pass Filter with Interdigital Coupling

As both the inductive and capacitive transmission line segments in a SSL filter are quite short, two neighboring capacitive elements each can be modified in such a way that they, while keeping their capacitance, are made shorter in the center but lengthened at the edges to couple in the form of an interdigital capacitor (Fig. 3). At the same time, the narrow inductive line length has to be increased slightly to maintain the passband filter performance. Details of the design were done using a 2.5D simulator [7]. Modifying the amount of coupling, the position and distance of the transmission zeroes can be adjusted to some extent.

The layout of such a filter of order 5 for a corner frequency of about 6 GHz is displayed in Fig. 3. The capacitive elements consist of wide lines (the same width as the 50 Ω SSL connecting lines) with partly backside metallization. They are coupled to input and output lines by two interdigital structures arranged at the side of the narrow inductive lines.

Together with the inductances for the outer filter elements, this forms two parallel resonators at the input and output of the filter.

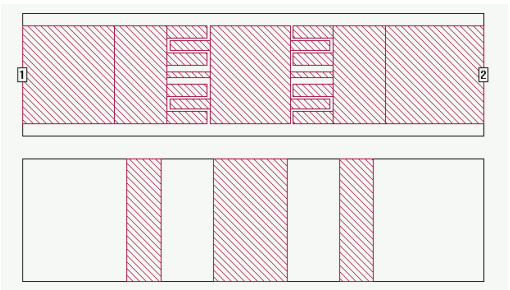

Fig. 3: Front side (top) and back side (bottom) layout of a quasi-elliptic low-pass filter using interdigital coupling.

The substrate is placed in a mount as shown in Fig. 1 (this mount is used for all other filters presented here, too); it is clamped by two 0.5 mm deep grooves at the edges. The low-pass filter itself (without connecting lines) is only 8 mm long. Fig. 4 shows theoretical and experimental results of this filter. Two transmission zeroes can clearly be recognized; however, some frequency shift can be stated. On the one hand, the width of the coupling slots of the interdigital capacitors was 90 µm in reality compared to 100 µm as designed, and the metallization thickness of 17 µm was not taken into account for the design. Therefore, the structure was recalculated using a slot width of only 50 µm to account for both the smaller slot width as well as approximately the effect of the finite metallization thickness (reduction of the slot widths by twice the metallization thickness). This result is included in Fig. 4 with the dash-dotted line, now showing a very close agreement with experiment.

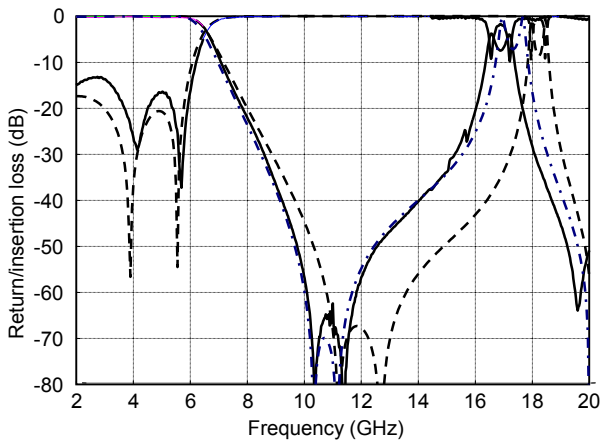

Fig. 4: Return and insertion loss of the low-pass filter according to Fig. 2. (Dashed lines: theory, solid lines: experiment, dash dotted line: theoretical S_{21} with coupling slots reduced to 50 µm).

III. Low-pass filters with additional broadside coupling

The use of metallization patterns on both sides of the structure allows the realization of broadside capacitive coupling. In the configuration as used here, the lines are on the same side of the structure. Therefore, neighboring low-pass shunt capacitances are brought close together (but not as close as with the previous example), and some small metal patches are placed on the backside of the substrate overlapping with both, resulting in the series connection of two capacitances. This provides an additional coupling between the two capacitive elements (see Fig. 2, bottom). The overlapping areas result in increased coupling without critical narrow slot widths as in the first example. Design examples and experiment were done for single as well as multiple couplings, as shown in the Figs. 5 to 8. In all figures, layout of front and back side is given on top of the figures, and theoretical and experimental results are compared at the bottom.

As expected, a single additional coupling leads to one transmission zero. For a coupling capacitance in the center (Fig. 5), the transmission coefficient shows a zero at about 11 GHz, and a narrow spurious passband at 18 GHz. This is caused by the bigger lengths of both capacitive and inductive elements. With the broadside capacitive coupling as used here, a very good agreement between theory and experiment can be stated.

An interesting effect occurs if a single additional coupling is introduced at one of the edges of the filter, i.e. between one of the capacitive elements and one of the input lines (Fig. 6). A very wide stopband can be observed with a rejection of better than 40 dB up to nearly 25 GHz. Some resonances around 20 GHz and 24 GHz are probably due to some clamping problems of the mount. In addition, in that frequency range, the first waveguide mode may be excited in the channel. An excellent agreement between theory and measurement is found, only the passband return loss is slightly deteriorated by reflections of the transition from the coaxial connector to the SSL.

In the low-pass filter examples of 5th order as investigated here, also a twofold coupling at the two edges and a threefold coupling at the edges and in the center were investigated (Fig. 7 and 8). Different amounts of coupling were adjusted to control the positions of the transmission zeroes. In both cases, a high stopband rejection over a wide frequency range could be realized, and once again, an excellent agreement with experiments can be stated down to -60 dB and even below.

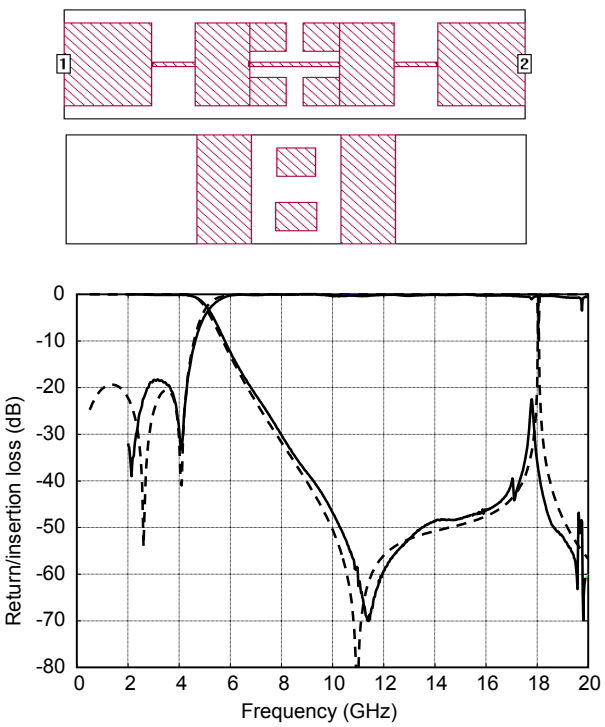

Fig. 5: Front and backside layout and transmission performance of a low-pass filter with a single central capacitive coupling. (Dashed lines: theory, solid lines: experiment).

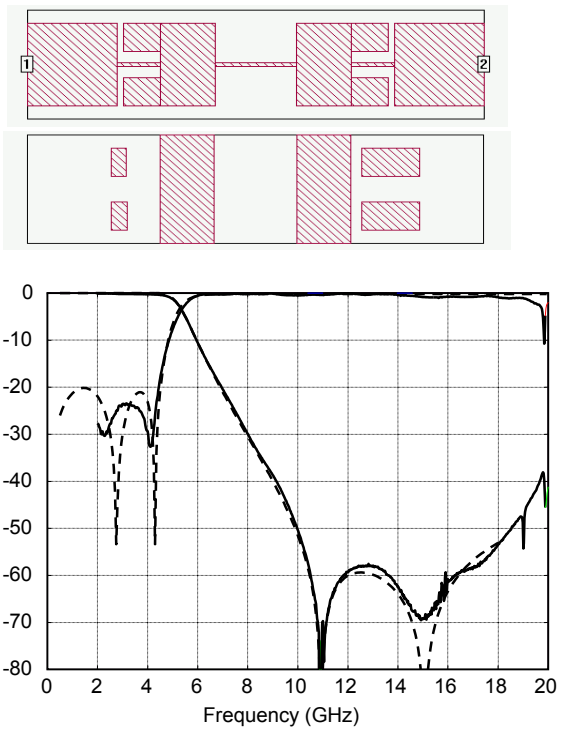

Fig. 7: Front and backside layout and transmission performance of a low-pass filter with a twofold edge capacitive coupling. (Dashed lines: theory, solid lines: experiment).

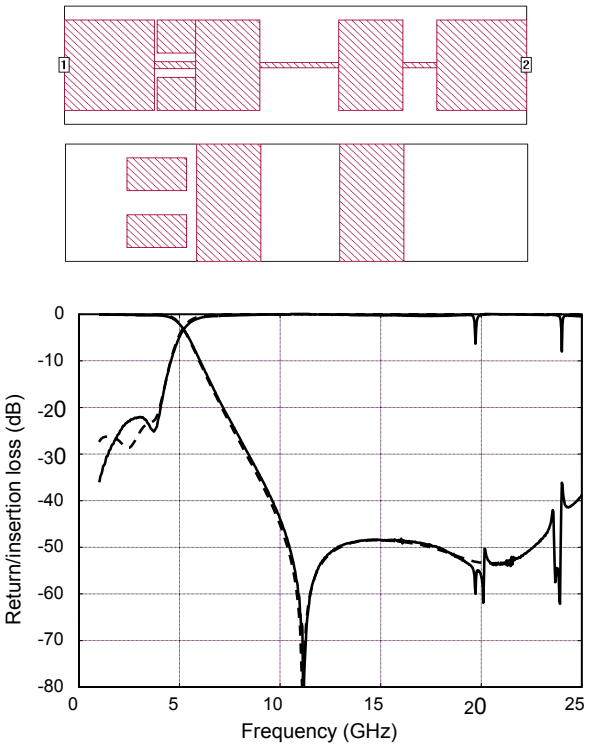

Fig. 6: Front and backside layout and transmission performance of a low-pass filter with a single edge capacitive coupling. (Dashed lines: theory, solid lines: experiment).

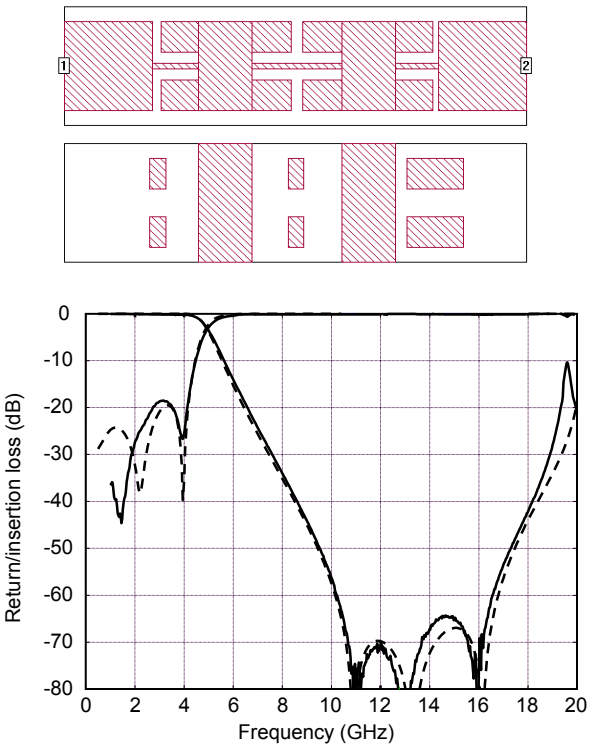

Fig. 8: Front and backside layout and transmission performance of a low-pass filter with a threefold capacitive coupling. (Dashed lines: theory, solid lines: experiment)

IV. Low-pass filterwith a modified capacitive element

Transmission zeroes can be implemented, too, in a way similar to Fig. 1, top. In the example given here, the ground plane metallizations below one of the capacitive elements is replaced by a shunt resonator similar to that used in [8] for bandpass filters (Fig. 9, top). In an approximate equivalent circuit (Fig. 9, bottom), this results in the series connection of this shunt resonator and the capacitive low-pass filter element. This configuration again leads to transmission zeroes of the low-pass filter as shown in Fig. 10.

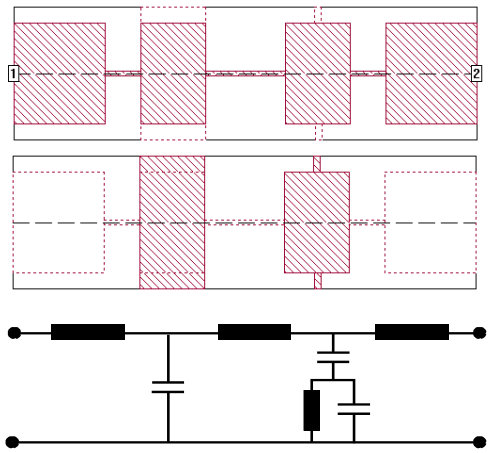

Fig. 9: Layout and equivalent circuit of a low-pass filter with modified capacitance element.

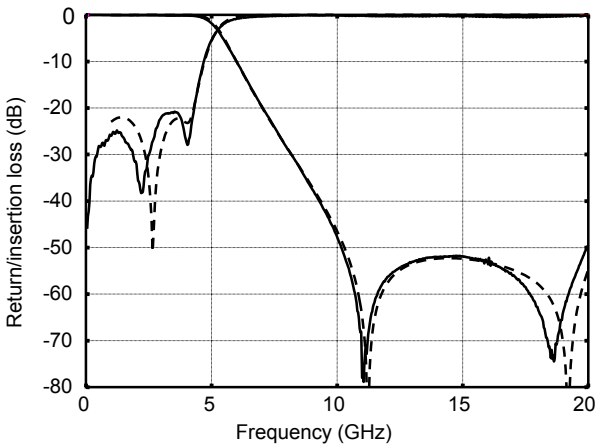

Fig. 10: Transmission performance of a low-pass filter with modified capacitance element. (Dashed lines: theory, solid lines: experiment).

V. Conclusion

This contribution has shown that transmission zeroes can easily be added to suspended stripline low-pass filters without major increase in complexity and size. This is simply done by introducing coupling between the shunt capacitances of the low-pass filters which can be achieved on the same substrate side as well as well as by structures on the backside of the substrate. An additional way to introduce transmission zeroes is demonstrated adding a parallel resonator to one (or more) of the shunt capacitive elements. Simulation and optimization with a commercial 2.5D simulator give results which show an excellent agreement with experiment, and computation time even including optimization is kept reasonably short. The design principle as used here can easily be scaled to other frequencies.

References

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