Suspended Stripline Bandpass Filters with Inductive and Mixed Coupling

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***Short Abstract*—As previous work has shown, the performance of capacitively coupled suspended stripline filters is asymmetric with higher out-of-band attenuation at low frequencies. As is demonstrated in this paper, this relation is inverted using inductively coupled filters. A symmetric behavior can be achieved using a mixed coupling. Based on the inductive coupling, together with modified shunt resonators, dual band filters (lowpass and bandpass) can be realized, too. A number of filter designs with simulated and experimental results are shown using different coupling elements.**

Keywords* — *suspended stripline, lumped-element filters, planar filters, bandpass filters, dual-band filters

I. INTRODUCTION

Suspended stripline (SSL) is an excellent transmission line medium for the realization of compact low-loss filters [1-4]. While previously mainly transmission line type filters were investigated, a wide variety of very compact, quasi-lumped filters have been demonstrated within the last years; a summary of this work in given in [5]. In this presentation, new results with respect to filters with inductive and mixed coupling are reported.

The ideal cross section of the SSL as considered throughout this work is shown in Fig. 1. RT Duroid 5880 is used as substrate material. Transmission line structures may be placed both on the top as well as on the bottom side of the substrate. The channel dimensions are selected wide enough to realize the necessary circuit elements, but small enough to suppress waveguide modes up to about 20 GHz. For the experimental realization, small groves are added to the sides of the mount to clamp the substrate. As long as no metallization is connected to the side of the mount, such groves have hardly any effect. With most of the filters presented in this contribution, however, narrow inductive strips to ground (at the side of the mount) are included. In such cases, the groves result in an increased inductance which may shift the filter response slightly. For the test filters shown here, a mount of 30 mm length with coaxial connectors is used, and measurements are performed with a coaxial calibration.

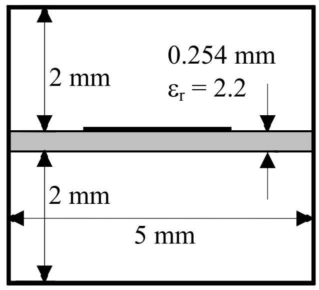

Fig. 1: Cross section of suspended stripline as used within this contribution.

A typical section of the equivalent circuit and the respective principal layout of a SSL bandpass filter as reported in [5] is displayed in Fig. 2. The SSL shunt resonators are formed by patches as capacitances and thin inductive strips to ground (at the edge of the substrate). An inset may increase the inductance. The inverter between the shunt resonators basically is formed by three capacitances in a Π-circuit with negative shunt capacitances (Fig. 3, [6]). In this configuration, the negative capacitances easily can be "realized" decreasing the values of the shunt resonator capacitances. At frequencies below the passband, both the shunt inductances and the series capacitances contribute to a high attenuation, while the reduced shunt capacitances result in a reduced high frequency attenuation. This asymmetric behavior of such a filter can be seen in the simulated [7] example given in Fig. 4.

By further increasing the coupling capacitors (with overlapping resonators on opposite substrate sides) and a suitable design of the resonators, even broadband highpass filter results can be achieved with such structure [5].

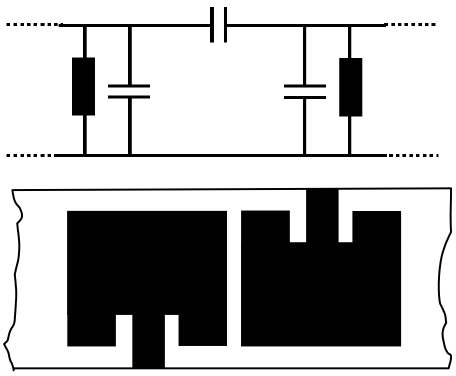

Fig. 2: Typical section of the equivalent circuit and the respective part of the layout of a SSL bandpass filter.

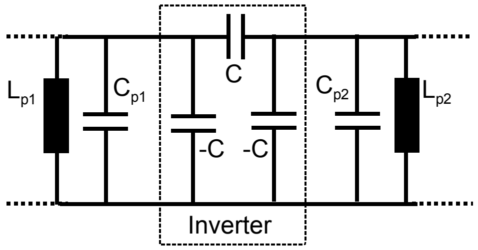

Fig. 3: Detail of the equivalent circuit pointing out the inverter structure of capacitive coupling.

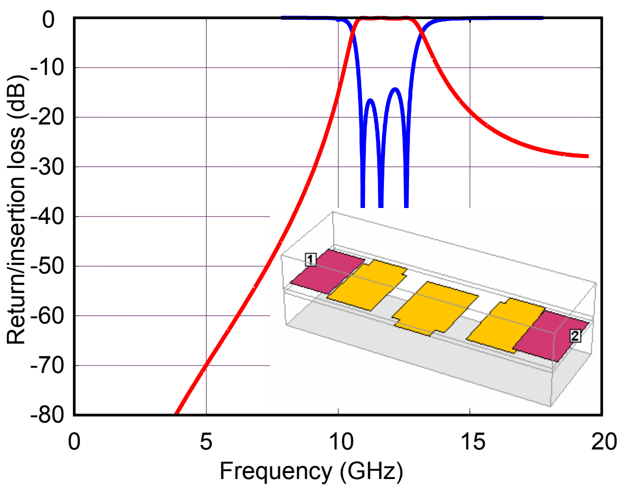

Fig. 4: Filter structure (inset figure) and simulated return and insertion loss of a capacitively coupled bandpass filter. Filter length is 10.6 mm.

II. Inductively Coupled Filters

An alternative to capacitive coupling is inductive coupling which can be realized in SSL using thin strips to connect the resonators. The equivalent circuit of such coupling is indicated in Fig. 5. The negative inductances associated with this type of inverter can be combined with the resonator inductances. Thus, in this case, the values of the resonator inductances are reduced. With respect to an inductively coupled bandpass filter as depicted in the inset of Fig. 7, the decrease of the shunt inductances results in an increased attenuation above the filter passband, while below the passband, due to the inductive coupling, attenuation is reduced. Once again, an asymmetric filter performance results, but in an inverse way as compared to the capacitively coupled filter.

A photograph of such an inductively coupled test filter is shown in Fig. 6. Simulated as well as measured performance of this filter are demonstrated in Fig. 7, showing the asymmetric behavior. Agreement between simulation and experiment is excellent; passband insertion loss is less than 0.5 dB including 14 mm excess transmission line length and the transitions to the coaxial measurement system.

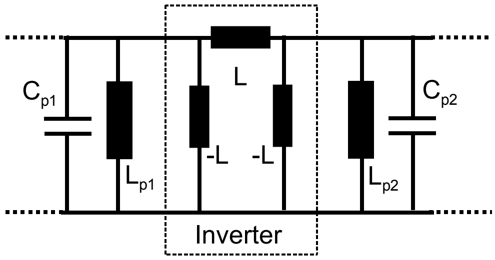

Fig. 5: Detail of the equivalent circuit pointing out the inverter structure of inductive coupling.

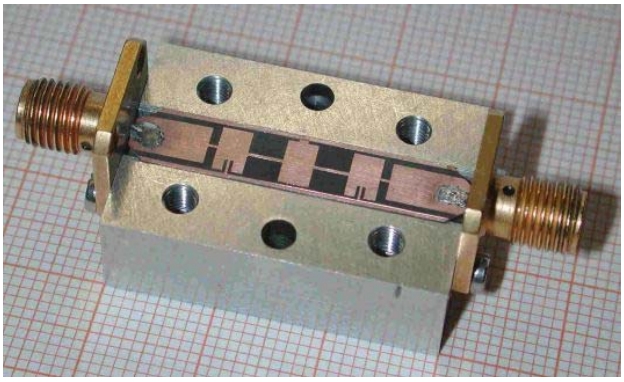

Fig. 6: Photograph of the opened bandpass filter with inductive coupling.

III. Filter with Mixed Coupling

As has been shown in the previous sections, the selection of the type of coupling results in different asymmetric behavior of SSL bandpass filters. This may be advantageous in some cases, but one might also want to achieve a more symmetric filter performance. To this end, a mixed coupling of the shunt resonators in a SSL filter is proposed. For example, input and output lines can be connected to the external resonators by thin strips, while the inner resonator is coupled capacitively. Such a filter is shown in Fig. 8, and Fig. 9 gives its return and insertion loss. The response of this filter is much more symmetric than that of the two filters presented before. As the shunt inductive strips of the filter were quite narrow (0.2 mm), insertion loss is slightly higher, and some tolerance problems occurred, leading to a lower attenuation at higher frequencies. The resonance slightly below 20 GHz is due to higher order mode excitation in the mount.

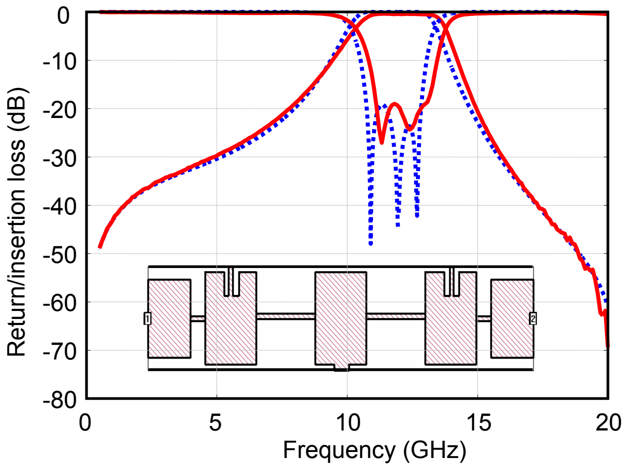

Fig. 7: Filter layout (inset figure) and simulated return and insertion loss of an inductively coupled bandpass filter. Filter length is 16 mm. Dotted lines: simulation, solid lines: experiment.

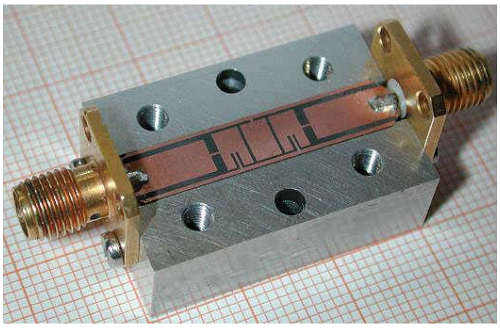

Fig. 8: Photograph of the bandpass filter with mixed coupling.

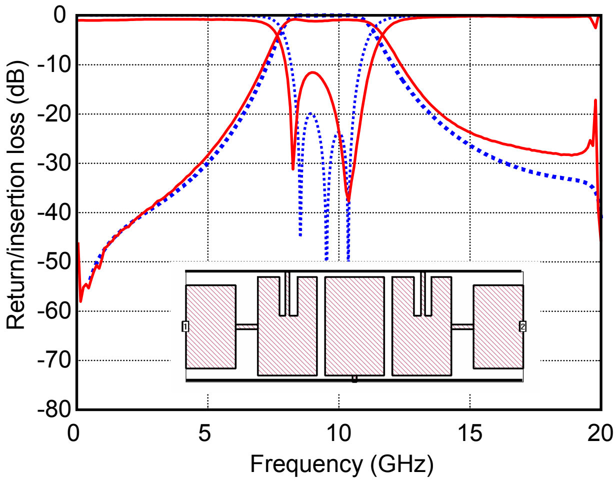

Fig. 9: Filter layout (inset figure) and simulated (dotted lines) and measured (solid lines) return and insertion loss of a bandpass filter with mixed coupling. Filter length is 10.8 mm.

IV. DUAL BAND FILTER

Regarding the filter layout of the inductively coupled filter in the inset of Fig. 7, except for the thin strips forming the shunt inductances, it looks very similar to a SSL lowpass filter with patches as shunt capacitances and narrow line elements as series inductances. If the shunt inductances of the inductively coupled bandpass filter now are replaced by a series resonator connected to ground (Fig. 10), such a structure exhibits both a lowpass as well as a bandpass performance. In a SSL configuration, this can be realized by removing the shunt strip of each resonator from the top layer and adding another patch to the opposite side together with an inductance to ground (Fig. 11), resulting in the detailed equivalent circuit of Fig. 10. By properly adjusting the circuit elements, a dual band filter results, e.g. [8, 9], here the combination of a lowpass and a bandpass filter. From a different point of view and with a wider bandwidth of the bandpass response, such a structure could equally be considered as a bandstop filter.

A photograph of the combined lowpass/bandpass filter and its results are plotted in Fig. 12 and 13, respectively. The cut-off frequency of the lowpass response is 4 GHz, the bandpass response is centered at 12.3 GHz. Bandwidth is 1.7 GHz. Lowpass and bandpass insertion loss are below 0.4 dB and 0.8 dB, respectively. Attenuation between 5.5 GHz and 8.5 GHz is higher than 50 dB resulting from three transmission zeroes generated by the specific form of the three resonators. Simulation and experiment agree well with some slight deviations in the return loss which partly is due to the transitions to the coaxial measurement system.

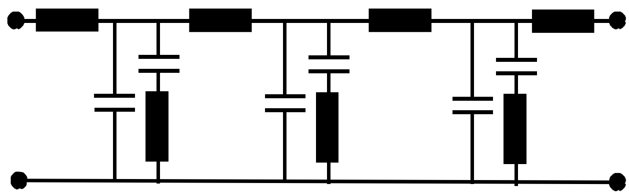

Fig. 10: Equivalent circuit of the dual SSL filter.

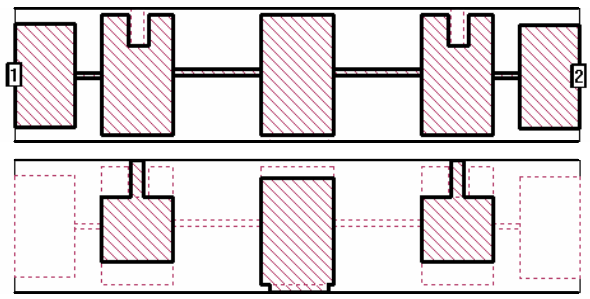

Fig. 11: Top and bottom layout of a dual band (lowpass and highpass) SSL filter.

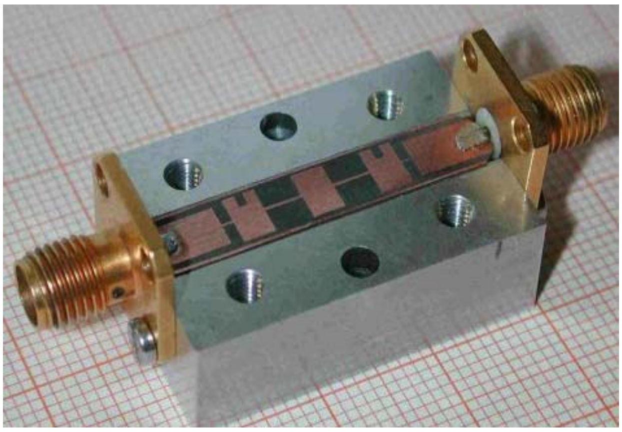

Fig. 12: Photograph of the opened dual-band filter with inductive coupling.

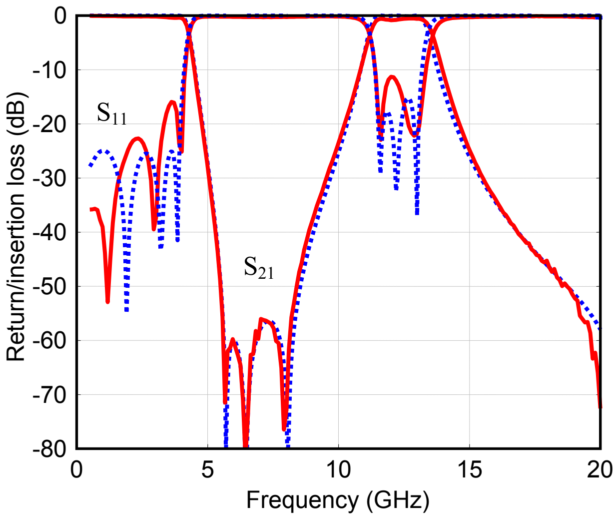

Fig. 13: Simulated (dotted lines) and experimental (solid lines) insertion and return loss of the dual SSL filter.

V. Conclusion

Quasi-lumped suspended stripline filters with different types of inverter or coupling, respectively, have been demonstrated. While both pure capacitive and inductive coupling lead to asymmetric bandpass responses, a mixed coupling allows to achieve a much more symmetric performance. In addition, by extending the principle of inductive coupling, the combination of lowpass and bandpass response in a single filter has been demonstrated. The realized and tested filters show an excellent agreement with the simulated response.

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